SOUTHERN PACIFIC COMPANY

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# PROGRAM OF RESEARCH

# ON

# OIL BURNING STEAM LOCOMOTIVES

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## OIL BURNER TESTS

Office of General Supt. Motive Power
San Francisco, California
September 5th, 1951.

Report No. ST-5

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* For convenience of reference, following are bound separately on back of front cover in order listed:

## FOREWORD

This report primarily covers the study of oil burners for steam locomotives made at standing test plant at Sacramento, California, designated as ST-5 Tests, as one phase of a comprehensive research program on oil burning steam locomotives authorized by GMO-35006, and also includes the final recommendations developed by standing test portion of program.

The purpose of the ST-5 Test was to investigate the existing designs and types of oil burners, as well as new developments to determine whether an improvement could be obtained over the Von Boden burner which has been the standard on Southern Pacific Lines for many years. A total of 43 designs and arrangements were considered during this study.

Two methods were employed in these investigations of oil burners:

The first method consisted of a photographically recorded study of the atomizing characteristics of individual burners by means of a "cold" test in which oil and steam passed through burner at actual rates of flow encountered in operation but oil was not ignited. This investigation was conducted by auxiliary tests outside of the standing test plant.

The second method, reserved for burners which showed promise on the "cold" test or merited further investigation, consisted of actual installation in standing test locomotive and full scale combustion trial.

The "cold" test procedure was developed to expedite the research program by reducing the number of actual burner installations in test locomotive. The "cold" test readily eliminated from consideration those burners which had markedly poor oil atomizing characteristics or other obvious deficiencies which would render them undesirable for locomotive application. On experimental burner designs the "cold" test also provided an economical and rapid means of establishing capacities and the effects of changes in steam jet angles, apertures and other components of burner design.

This report contains final recommendations on oil burner, firepan, drafting arrangement and front end design based on results of tests and observations during the conduct of standing test program.

## RECOMMENDATIONS AND CONCLUSIONS

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 oil burner design. These recommendations also incorporate firepan design, air admission, front end arrangement and other details and will serve as a culmination for standing test program as covered by the following progress reports, namely -

ST-1, Spark Arrester Tests, Nov. 12, 1947,

ST-2, Exhaust Nozzle and Stack Height Test, April 28, 1949,

ST-2 (a) Maximum Exhaust Nozzle Pressure Determination, July 15, 1948,

ST-3, Recommendations for Interim Improvements, December 8, 1948,

ST-4, Firepan Tests, July 12, 1949.

1. Burner Design:

Gyrojet oil burner shown by drawing BL-101850 dated June 27, 1951 and Figure 1 of this report, should be adopted as the standard oil burner for steam locomotives. The gyrojet design tubular oil burner demonstrated superior characteristics during test and provides an improved atomization of oil due to the size and location of steam jets and the whirling conical flame produced. The atomizing steam surrounds a central oil tube inside the burner barrel, thereby preheating the incoming oil and reducing its viscosity to a certain extent before reaching burner tip, similar to burners used in stationary boiler practice. These improved characteristics reduce the necessity for high velocity air to provide sufficient turbulence and mixing of oil spray and air for combustion as is necessary with the present Von Boden drooling type burner. Inadequate air velocity with the drooling type burner results in poor mixing of oil and air stream and adversely affects the efficiency of combustion with this type of burner.

On the other hand, with the gyrojet burner, as the oil flows past the steam orifices near the end of the burner, the steam jets issuing from these orifices are directed to impart a rotational velocity to the resulting spray of oil mixture. The oil is broken up into a finely divided spray as this mixture emerges from the burner tip in the form of a cone. The ease with which the conical spray of oil can be supplied with air minimizes the quantity of excess air required to complete combustion. The rapid atomization and soft flame issuing from the gyrojet burner are conducive to more thorough combustion which is essential to high efficiency. In comparison, the drooling type outside mixing burner, such as the Von Boden design, discharges the oil through a flat horizontal orifice superimposed above the steam jet which likewise consists of a horizontal orifice. Oil is picked up by steam jet and thrown into firebox in relatively large particles making it difficult to obtain maximum combustion efficiency. The shape of the oil spray issuing from the drooling type burner is not so conducive to ready mixture with air as the conical spray from the gyrojet burner. The inefficient atomization and resulting large particles issuing from the drooling type burner also create the problem of carbon formation on the flash wall and brick work in the firepan.

2. Firepan Design:

Improved design of firepan shown by Figure 2 of this report should be adopted in place of present round bottom firepan for

Pacific Lines and firepan used by T&NO Lines. This improved design firepan provides a tapered trough which eliminates dead spaces in front corners of pan and reduces the tendency for drumming. With the recommended gyrojet burner the tapered trough conforms to the expanding characteristic of the conical flame and prevents short circuiting of under-burner air directly to back tube sheet. The recommended tapered firepan incorporates the best characteristics of present T&NO design firepan such as the cross-bracing for rigidity and resistance to distortion and eliminates curved surfaces, which simplifies maintenance and repairs.

3. Drafting Arrangement:

Improved drafting arrangement also shown by Figure 2 of this report should be adopted in place of present "modified" drafting arrangement used on Pacific Lines and drafting arrangement used by T&NO Lines. The improved arrangement provides for a Venturi-shaped port, shown by drawing CL-101826 and Figure 3, around gyrojet burner so that primary air for combustion enters firepan with a streamlined flow in order that air entrainment of conical oil spray will be uniform and complete. Burner is centered in Venturi-shaped fixed air opening by means of an adjustable outboard support and locating lugs in burner port.

Additional primary air is admitted underneath burner port air opening on front wall of pan and is varied by an adjustable damper. Secondary air is admitted through floor of firepan near flash wall and is also controlled by adjustable damper. Both adjustable dampers are linked together for simplicity and are operated by one control. Firepan has been shortened because of the flame characteristics with the gyrojet burner which does not produce the long flame travel. While Figure 2 pertains to firepan and drafting arrangement for GS class locomotives, similar design can be developed for other classes. The improved drafting arrangement eliminates entirely the use of flapper type side dampers which are employed with modified drafting arrangement and which have been continual source of trouble.

4. Spark Arrester:

Cylindrical basket type spark arrester developed by standing test has been adopted in place of Master Mechanic's front end arrangement which created undue restrictions to gas flow in the smokebox and required higher back pressure to move air and gas through combustion system. Adoption of basket type spark arrester has markedly decreased material and labor costs for both construction and maintenance because of simplicity of design and increased accessibility of flues and superheater units. Development of basket type spark arrester is discussed in detail in Report ST-1 "Spark Arrester Tests."

5. Stack Size:

For GS class locomotives size of stack should be increased from 20" inside diameter to 24" inside diameter, an increase of 44%. This recommendation is based on model tests conducted by Battelle Memorial Institute as a part of the research program and their recommendations for stack size on other classes of superheated locomotives are tabulated on page 34 of Report S-1100, dated October 1949 entitled "Report to The Southern Pacific Company on the Performance of Locomotive Front Ends Based on an Experimental Study of a Quarter-Scale Model." All piping and obstructions should be removed from interior of stack, such as booster exhaust piping, sand ejectors and feedwater exhaust pipes.

6. Exhaust Nozzle Size:

For GS class locomotives, exhaust nozzle should be increased to 9-1/2" diameter with 1" split in place of 8" nozzle with 3/4" split which was standard at start of Research Program. This increase of about 34% in effective exhaust nozzle area is made possible through the improvements in burner and drafting arrangement and will permit operation of locomotives at greatly reduced back pressure, which in turn will result in increased cylinder horsepower, or the attainment of the same cylinder horsepower with reduced fuel consumption.

7. Firing Valve:

An improved firing valve has been adopted as result of standing test to provide more accurate adjustment of rate of flow particularly at low firing rates and spot fires. This valve, shown by drawing BL-101516B and Figure 4 of this report, is serving as a further improvement in the oil burning arrangement by permitting more precision in firing under low load and spot fires. This is discussed in greater detail in Report ST-3, "Recommendations for Interim Improvements."

8. Firebrick Application:

Method of bricking locomotives has been standardized in order to provide improved distribution of heat on firebox sheets and to obtain additional heat transfer through surfaces previously covered by brick work. The recommended tapered design firepan will simplify bricking of locomotives and consideration should be given to the purchase of brick in pre-formed shapes when applying improved firepan, rather than to continue use of small firebrick. In this way, standardization of bricking can be obtained with the improved pan, thereby reducing labor of installation and maintenance costs. Expansion joints should be applied at corners of firepan to permit movement of brick without buckling of brick setting. Thickness of brick on floor of pan should be minimum necessary so that weight of brick supported by firepan can be reduced and proper clearance for flame can be obtained. This subject is further discussed in Report ST-3 "Recommendations for Interim Improvements."

9. Heat Loss From Non-Insulated Sheets:

Where considered practicable, lagging and jacketing should be applied to the bottom of boiler shell under combustion chamber and to the outside wrapper sheets below running board on locomotives where large non-insulated areas exist in these locations. When properly insulated, heat now lost by dissipation to atmosphere will be retained in the boiler. This subject is also further discussed in Report ST-3 "Recommendations for Interim Improvements."

10. Boiler Feedwater Injection:

Consideration should be given to the installation of top boiler checks on injector and feedwater hot pump delivery lines in order to obtain benefits from improved temperature distribution throughout the boiler shell as discussed in Report ST-3 "Recommendations for Interim Improvements."

11. Smokebox Door Gasket:

In order to prevent possibility of air leaking in the smokebox, door gaskets should be applied to all locomotives and maintained in proper condition at all times. When operating on reduced back pressure such as is possible with improved combustion system, it is essential that smokebox be tight and all sources of leakage eliminated.

12. Oil Tank Heater:

Enclosed type oil tank heater installed in tender tanks should be revised as shown by Figure 5 of this report, to provide higher temperature to oil leaving the tank outlet, without the necessity of heating body of oil in tank to high temperature, thereby conserving steam necessary to bring oil up to proper operating temperatures and minimizing trouble with cold oil.

13. Circulator Units:

During the course of standing tests, Locomotive SP-4401 was equipped with Security circulator units as illustrated by Figure 6 to determine what effects, if any, these circulators had on fuel economy or combustion efficiency. Tests indicated that water temperature distribution during firing up was improved by these units, and that this was the principal benefit derived from their application. However, on the basis of any indicated fuel economy, further installation of circulator units on oil burning steam locomotives is not recommended since the use of these units restricts the free drafting of locomotive because of the obstruction to flow of gases through firebox which would undoubtedly necessitate reduction of nozzle size in service to counteract the effect of the circulators.

## GENERAL DISCUSSION OF OIL BURNER DESIGNS

Oil burners are generally classified according to the medium used for accomplishing atomization, namely -

A. Air-atomizing burners

B. Steam-atomizing burners

C. Mechanical-atomizing burners

The essential characteristics of oil burners designed for locomotive service are, principally, complete atomization of oil without drooling, fouling or clogging, maintenance of proper atomization over the wide capacity range encountered, spray pattern which will secure intimate mixing of atomized oil with incoming air to insure complete combusion with minimum excess air over the operating range, simplicity and ruggedness of design to withstand service conditions, and minimum maintenance costs.

### Air-Atomizing Burners

Applications of burners utilizing air as the medium for producing atomization are very limited. The principal reason for this is the cost of producing compressed air necessary for atomization as balanced against any possible benefits that could be realized. For locomotive service use of compressed air for atomization would entail complications and additional equipment which would not be justified.

### Mechanical-Atomizing Burners

Mechanical-atomizing burners are used extensively in certain stationary installations where this type of burner is well suited. The mechanical-atomizing burner consists of a precision made atomizer which breaks up the oil mechanically into a fine uniform spray that will burn with minimum amount of excess air when injected into the firebox. This atomization is accomplished by using mechanical pressure produced by suitable pump to force the oil at high velocity through the small openings in the atomizer head. The mechanical burner produces a thin layered mist-like hollow conical spray which is capable of burning with high efficiency.

After serious consideration of straight mechanical pressure type burners it was decided that this design would not be adaptable to steam locomotive service and that consideration should not be given to this type of burner during the research program. Among the reasons why the mechanical-atomizing burner would not be adaptable to locomotive service is that this type of burner is best suited to a steady load and high capacity rather than the variable loads required under locomotive operating conditions. Secondly, frequent cleaning of the burner tip is necessary to maintain an efficient spray and because of the small openings in the atomizer, plugging could be expected in locomotive service.

Thirdly, additional equipment, such as fuel pump to produce oil pressures from 200 to 250 pounds per square inch is required for this type of burner and oil temperature must be maintained at a higher level, approximately 220°F. to reduce viscosity low enough to produce satisfactory atomization.

## Steam-Atomizing Burners

All oil burning steam locomotives to the best knowledge are employing steam-atomizing burners at the present time. Steam-atomizing burners are, as the name implies, those that use steam as the medium for atomizing the oil ejected from the burner. The oil can be supplied to the burner either by gravity or pressure from a suitable pump. While several types of steam-atomizing burners employing pressurized oil were tried out during the research program, the simplest and most generally used locomotive type oil burner employs gravity flow of oil. Steam-atomizing burners are well suited to locomotive application because they can handle variable loads readily with a wide capacity range. Inasmuch as the openings in the burner tips are relatively large as compared with the mechanical burners, they can be easily blown out with steam, thereby minimizing necessity for frequent cleaning. Oil temperatures for proper atomization are lower than those necessary with mechanical burners and while it is true that the steam used for atomization is lost up the stack, proper burner design can keep the steam consumption for atomization to a minimum.

Steam-atomizing burners are generally sub-divided into two classifications, namely outside-mixing and inside-mixing, depending on whether the oil and steam are mixed inside or outside the burner tip. The Von Boden burner used on Southern Pacific Lines is classified as an outside-mixing, drooling type burner.

Steam-atomizing burners are further classified into the shape of flame produced; namely, flat flame burners and conical flame burners. At high capacities, the flat flame burners generally produce poor atomization. Under such conditions even with appreciable amount of excess air, it is difficult to secure complete combustion and trouble is encountered with carbon formation and smoking, with resultant loss of efficiency.

Conical flame steam-atomizing burners are quite generally used where load variations are appreciable. The steam-oil mixture issues from burner tip in the shape of a cone, the surface of which is at an angle to the entering, primary, air stream. By proper design of air port around burner, intimate mixing can be obtained and combustion completed with a short flame and minimum of excess air.

## Variations in Conventional Burner Location & Design

In addition to the conventional types of locomotive steam - atomizing oil burners, several variations in design and location were tried out during the standing test program. In locomotive service, a single unit, steam-atomizing burner is usually located on vertical center line of the front wall of the firepan with oil spray directed toward the door sheet. During course of tests the following deviations in conventional burner location and design were tried out:

1. Coen precision burners installed in multiple at front wall of firepan, see photographs

2. Coen precision burners installed in multiple on each side of firepan, see photographs

3. Nagel Oil Economizers installed in multiple on rear wall of firepan, see photographs

Also included in test was the Alexander rotating cup type burner which consists of a steam turbine driven cup for producing atomization of oil spray in conjunction with steam used for regular atomization.

## DISCUSSION OF OIL BURNERS FOR STEAM LOCOMOTIVE USE

Oil burners for steam locomotives are subjected to conditions of operation not encountered in stationary boiler service and special consideration must be given to these conditions when evaluating oil burner designs for railroad locomotive use.

In the first place the locomotive oil burners must be rugged in construction to withstand the shocks and vibration to which they are subjected in normal usage. This requirement would preclude consideration of burners which are too delicate or complex in construction and which can be thrown out of adjustment by such vibrations or shocks.

Locomotive oil burners must be simple in construction requiring minimum maintenance. This requirement would discourage the use of complicated burners or burners with small orifices such as mechanical-atomizing burners which would require frequent maintenance and cleaning.

In addition, the locomotive oil burning system must be as simple as possible. This requirement would favor the use of the single unit steam-atomizing burners rather than multiple burner designs and those involving rotating cups, fuel pumps, pressure regulators, etc. Oil burning systems operating by gravity flow of oil from tender tank are of course the simplest for locomotive service.

Locomotive oil burners also must be capable of atomizing oil effectively over the wide range of flow rates between the spot fires while locomotive is standing and the maximum firing rate under full load. Some designs of oil burners are well adapted to steady loads and high capacities but are not efficient over a wide range of flow rates, which makes such designs undesirable for locomotive use.

Flame shape from burner must conform to the design of firepan made possible by clearance restrictions on locomotives.

During this study the major oil burning railroads were contacted to determine the type of burner currently used in their locomotives. With one exception, it was found that the type of burner in general use is the outside-mixing steam-atomizing burner producing a flat flame.

This type of burner, numerous variations of which are illustrated in this report, generally consists of an elongated rectangular oil slot located above the atomizing steam slot, or jets. The oil flows from the tender by gravity, and as it passes through the opening at the end of the burner, the oil is picked up by the steam jet, or jets, directly beneath. The mixing of oil and steam takes place outside the burner, which is therefore classified as outside-mixing. This type of burner also is referred to, at times, as the "drooling" type, in that the oil merely slavers or drools from the oil slot onto the steam jet.

From photographic evidence presented in this report it is readily apparent that the atomization characteristics of this type of burner leave much to be desired. The action of the steam jet in picking up the oil is such that it slings the oil into the firebox instead of breaking it up into an intimate mixture with the steam. The large particles of oil produced by this type of atomization are not so readily combusted and have a tendency to form carbon on refractory surfaces where they impinge before burning. Also, due to the dimensions of oil slot necessary to accommodate maximum flow rates, this type of burner does not operate too satisfactorily at lower rates as the oil emitted from the burner has a tendency to wander across slot, causing irregularity in fire.

With this type burner, it was found that a high velocity of the air for combustion is necessary to overcome the deficiencies in atomization produced by burner design. This burner design has the advantage of simplicity but efficiency of atomization is sacrificed thereby. Some attempts have been made on individual railroads to improve atomization by modifying the basic design with such details as corrugated lips under steam jet to produce more turbulence, and presumably obtain better mixing of oil and steam; by use of multiple circular orifices, in place of one slot for the steam in order to obtain better mixing and atomization, and some other minor changes as can be noted by referring to illustrations in report.

The trend of the investigation therefore, was to determine a design of burner which, though simple, would not have the undesirable features of the drooling type and yet would approach the effective atomization of stationary boiler type burners. While several stationary boiler type burners were tried out during the investigation, there was serious doubt as to whether this type, even though approaching the optimum in atomization characteristics, would be practicable for locomotive service because the refinement in design and construction would require additional maintenance and operating equipment.

As the result of tests and consideration of the numerous burner designs during the investigation, the type of burner illustrated by Figure 1 was found to be the most adaptable to locomotive use. This burner, designated as the gyrojet burner, because of the whirling, conical spray produced, is of tubular, inside-mixing design, with an oil tube centered inside the burner barrel. The steam for atomization surrounds the oil tube, and assists in heating the oil. It is then emitted through jets in burner tip directed so as to impart a rotational velocity to the resulting steam-oil mixture, which is projected in a conical shape. A vortex breaker is provided to improve performance of the burner, particularly at the lower rates of flow. Tests conducted indicated that this type of burner approaches the efficiency of atomization of the more precise stationary boiler type burners and it is a compromise between efficiency of atomization and simplicity of design. The context of this report demonstrates that the gyrojet burner is a step forward in railroad locomotive burner design and will permit more effective utilization of fuel in steam locomotive operation.

# INDEX OF BURNER TESTS

| ITEM NO. | BURNER | DESIGN* GROUP | TEST DESIG'N | PHOTO PAGE NO. | COLD TEST PHOTO NO. |
|---|---|---|---|---|---|
| | FLAT FLAME, OUTSIDE MIX<br>BOOTH TYPE | | | | |
| 1 : | 2½" Texas & Pacific Ry. | I-A-1 | None | 5-1 | 5-22 |
| 2 : | 3" St.LSW, (no lip) | " | " | 5-2 | 5-23 |
| : | VON BODEN, STD | | | | |
| 3 : | 2½" Size (Reduced from 3") | | | | 5-24 |
| 4 : | 3" " | " | " | SP,5-3 | 5-25 |
| 5 : | 3½" " | " | B-2 | T&NO | 5-26-A,B,C,D |
| 6 : | 4½" " | " | B-5 | 5-4 | |
| : | VON BODEN TYPE | | | | |
| 7 : | 3" St.LSW,(corr.lip) | " | None | 5-2 | 5-27-A,B |
| 8 : | 3" " (smooth lip) | " | " | | |
| 9 : | Shallow Vee oil passage | " | " | 5-4 | 5-28 |
| 10 : | Walled exit | " | " | | 5-29 |
| 11 : | Strapped exit | " | " | | 5-30 |
| 12 : | Divided oil passage | " | " | 5-5 | 5-31 |
| 13 : | Double, ** ., Position A | " | " | 5-6 | 5-32 |
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| 16 : | " ,Spl ., C | " | " | - | 5-35 |
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| | MULTIPLE STEAM JETS | | | | |
| 18 : | Great Northern | " | B-3 | 5-8 | 5-37 |
| 19 : | CRI&P | " | B-4 | 5-9 | 5-38 |
| 20 : | Mltple Diamond channel, J.C.*** | " | B-8 | 5-10 | 5-39 |
| 21 : | " " JDC**** | " | None | | 5-40 |
| 22 : | Jets in rectangle | " | " | 5-11 | 5-41 |
| 23 : | Multiple Vee jets | " | " | 5-12 | 5-42 |
| | FLAT FLAME, INSIDE MIX | | | | |
| 24 : | Sheedy, Atm. steam slot | I-A-2 | " | 5-13 | 5-43 |
| 25 : | " Mtpl. " jets | " | " | | 5-44 |
| 26 : | Brittain (steam slot) | " | " | 5-14 | 5-45 |
| | CONICAL FLAME, OUTSIDE MIX | | | | |
| 27 : | Clark (FEC Ry.) | I-B-1 | B-6 | 5-15 | 5-46 |
| 28 : | Alexander, rotary cup | " | B-9 | 5-16 | - |
| 29 : | Battelle, slag blower | " | None | 5-17 | - |
| 30 : | Models of Clark type | " | " | - | - |
| | CONICAL FLAME, INSIDE MIX | | | | |
| 31 : | Gyrojet ST-323 | I-B-2 | B-11 | 5-18 | - |
| 32 : | " ST-366 | " | B-12 | | 5-47 |
| 33 : | " ST-366-A | " | B-13 | | - |
| 34 : | Chamber Type Tubular,Orig. | " | None | - | - |
| 35 : | " " " ,Final | " | B-7 | 5-19 | 5-48 |
| 36 : | Tubular, cone end | " | None | - | - |
| 37 : | Nagel | II-B-2 | B-10 | 5-20 | - |
| 38 : | Coen,16 burner, orig. | " | None | - | - |
| 39 : | " ,16 " ,mdfid.plate | " | " | - | - |
| 40 : | " ,11 " ,(new tips) | " | " | - | - |
| 41 : | Coen, side burners, 16 jets | " | B-1 | 5-21 | - |
| : | COMB. INSIDE-OUTSIDE MIX | | | | |
| 42 : | Coen,side burners, trial | II-B-3 | None | - | |
| 43 : | " , " " , jets | " | " | - | |

* Design grouping on the following basis:

| TYPE OF OIL SUPPLY | FLAME SHAPE | MIXING TYPE |
|---|---|---|
| I. Gravity oil supply | A. Flat | 1. Outside |
| II. Pressure oil supply | B Conical | 2. Inside |
| | | 3. Combination inside-outside |

*** Steam jets centered under Vee's of oil outlet
**** " " " " crests, or ridges, of oil outlet

** The double Von Boden, consisted or two burners, one on top the other; the lower a 3½" size with shallow "V" oil passage Item No. 9 and the upper a standard 2½".

The double Von Boden, special, was the same except that the lower burner was a standard 3½" Von Boden, Item 5.

In position "A", the tips of the two burners were even; in "B", the tip of top burner was even with face of oil outlet of bottom burner, and in position "C", the tip of upper burner was set back 1" behind face of oil outlet of lower burner.

## COMPARISON OF BURNER DESIGNS STUDIED

Burners for use on oil burning steam locomotives are best separated into two general classifications, those requiring only the usual gravity oil feed or the nominally low air pressure in tender tank to overcome flow resistance of the unusually long feed line on AC-class (cab in front) locomotives, and those requiring a substantial pressure in the burner to assist in atomization or to overcome a pressure developed in the mixing chamber by the atomizing steam.

For convenience the gravity type burners were designated group "I" and those requiring pressure, group "II". For use on locomotives this is an important distinction because of the extra mechanical equipment and controls that would be required to provide pressures of the order of more than 5 or 6 pounds per square inch.

A second classification that is of importance in applying oil burners to locomotives is the shape of the oil spray or flame. There are in general, but two basic flame shapes that need be considered; flat and conical. Although it may be said that none are truly flat, nor conical either, the flame patterns are, in effect, one or the other and such differences as between hollow and solid conical shapes were neglected since no problems of application appeared between these two.

The flame shape must be considered in selecting a burner's position or location in the firepan and in general, but with some few exceptions, the flat flame burners, herein called group "A" can be placed lower and closer to the firepan floor than those producing a conical flame. The conical flame burners were designated group "B".

A third classification, more generally used and applicable to burners for any purpose, is the segregation as to whether the atomizing steam and oil mix inside the burner or after each leaves the burner; that is, outside the burner. Those burners employing the outside mixing principle, being in the majority, were designated as group "1"; the burners where mixing occurred entirely on the inside, as group "2" and those where the two methods were combined, as group "3".

In considering the individual burners, it will be noted from the photographs that the Texas and Pacific (Photograph 5-1) burner and the St. Louis-Southwestern burner (Photograph 5-2) with no lip under the steam slot were the simplest of all, consisting merely of a thin slot for the atomizing steam above which is a wider slot from which the oil flows out on to the flat stream of atomizing steam.

This type of burner is commonly referred to as the "Booth" and plainly, is very elementary, embodying only the barest essentials for breaking up and distributing the oil.

In the design grouping employed herein, these burners are classified as I-A-1, as gravity oil flow is adequate; the flame shape would be essentially flat, and the mixing of oil and steam occurs entirely outside the confines of the burner.

The Von Boden burner as used on both the Pacific Lines (Photograph 5-3) and those in Texas and Louisiana (Photograph 5-4) is also a group I-A-1 burner and while having some features not included in the Booth type, is also a very simple type of burner. The burner with the corrugated lip used by the St. Louis Southwestern may be seen from the photographs to be a Von Boden style burner also, the removable lip feature being merely to facilitate manufacture and maintenance of the desired thickness of atomizer slot.

In this connection, machining the 1/32" atomizing slot accurately on the Von Boden burner is difficult because it is so thin but this problem is overcome in the St. Louis Southwestern design by use of the removable lip. With the standard Von Boden the slot is first milled with a 1/16" thick milling cutter, the thinnest practical, following which, the slot is driven closed on a 1/32" thick shim. The slot is then finished with a 1/32" thick hacksaw blade.

The lip area and oil outlet are finished as well as possible by filing to remove burrs and rough projections, but the design of the burner tip makes precision machining impractical hence reproducibility in manufacture is poor.

The shallow Vee oil passage modification of the Von Boden (Photograph 5-4) was an attempt to center the oil at low rates and reduce the tendency for the oil to flow from one side or the other on curves in road service. Better results might have been obtained had the shallow Vee been cored full length of the oil passage and had been less pronounced.

The walled exit modification (Photograph 5-4) was tried, to reduce the side splatter of the Von Boden standard burner.

The Von Boden burner with the strap over the center area of the atomizing portion (Photograph 5-4) was proposed to spread the flame and prevent the heavy concentration of oil spray normally obtained with the standard Von Boden.

The divided oil passage burner (Photograph 5-5) was considered as a possible improvement for low fires and to serve also to maintain more uniformly distributed oil flow in service on curves.

The double Von Boden (Photograph 5-6) was composed of two burners; a 2-1/2" size on top for low fires and a 3-1/2" size burner underneath to be used together with the top burner at high rates. The use of two burners at high rates reduced the amount of oil each had to atomize and the steam jet from the top burner was thought to be useful for reducing the upward scatter from the lower burner.

The steam aspirating modification (Photograph 5-7) was intended to improve atomization from the Von Boden burner but some features of the modification were not suitable and results may have been better had the modification been the conventional design for aspirating burners.

Although of the so-called "drooling" type, the Great Northern burner (Photograph 5-8) had several features that improved its performance far above others of this type. The most important of these was the use of multiple steam jets in place of the flat, solid jet of the Von Boden style burners.

These steam jets were arranged along an arc and radiated from a point on the centerline of the burner to provide a fan shaped, flat flame which spread the oil over a wide area and eliminated the usual heavy concentration in line with the burner.

The atomizing steam holes traversed a segment of a circle hence with a straight hole, those near the center would be longest; those at the ends shortest, and the others would be of intermediate length. To avoid this unequal length of steam nozzles, each hole was counter-drilled larger at the back to the depth necessary to make each of the smaller, nozzle portions of the hole identical in length. This counter drilling also acted as a flow approach to the nozzles and improved their performance.

The lip for this burner was removable, facilitating the machine work, and being without wings, such as on the Von Boden, the operating surface which had three concentric grooves cast in, could be machined readily. With this lip portion machineable, the atomizing jets could always be precisely spaced above the operating surface and the reproducibility possible on this important part of the burner, was excellent.

An objection to the removable lip feature was that in production, care is not always taken to assure that entry ends of the steam ports are completly unrestricted when fitted to the burner body.

The oil outlet could be finished to some extent and had the overhanging, or curved, upper edge, similar to the Von Boden, for deflecting the oil at full flows into the atomizing jets, a feature some other burners lacked. Performance of the outlet could perhaps be improved by a slight change in shape at ends to eliminate "curling" or "rolling" of the oil stream at edges.

In operation, the multiple steam jets on this and other burners, were visibly much more effective than the flat sheet-like jets from slots due, obviously, to the fact that entrainment of the oil can occur around the entire periphery of each jet as compared with the single flat sheet-like jet which the oil appears not to penetrate, hence the jet is but partially effective.

During the tests in the engine the abrupt shape change at end of burner, particularly of the lip, caused some eddies and low pressure areas which drew down some of the fine mist of oil, causing an accumulation which the air stream through the burner port blew off in blobs from time to time.

The Chicago, Rock Island and Pacific burner (Photograph 5-9) was essentially the same as the Great Northern but lacked two features of that burner. The oil outlet was straight and did not have the deflecting upper edge for full flows and the lip operating surface was flat without the recesses for better entrainment of the oil. In this burner the outlet of the atomizing jets was recessed under the oil outlet instead of being slightly beyond the outlet as in the Great Northern.

The Multiple Diamond Channel burner (Photograph 5-10) was an attempt to eliminate the upward scatter of oil, which was common to practically all of the drooling type burners, by the use of steam jets above the oil outlet; secondly, to increase the effectiveness of the atomizing steam, by the use of multiple jets and the controlled delivery of oil to the jets through the toothed openings, and thirdly, by the use of a weir type approach or oil entry into the oil passage in conjunction with the continuous Vee channels of the passage, to provide a uniform distribution of oil across the width of the burner. For trial, two lower, removable plates with different tooth and steam jet relations were provided. In one of the lower plates the steam jets were centered under the crests of the teeth and in the other, the jets were centered under the V's of the teeth.

The steam jets above the oil were quite effective in reducing the upward scatter but the atomization could probably have been improved if the oil were directed more into the jets, or the outlet size increased, so as to reduce the forward velocity of the oil at high flows. A different lip would also have improved the performance.

The burner with numerous steam jets arranged in a rectangle around the oil outlet (Photograph 5-11) was designed to eliminate stray oil spray and scatter by wholly enclosing the oil stream with steam jets. However, the jets were not proportioned in size or number around the oil stream in relation to their share of the work of atomization but were uniform as to size and spacing on both top and bottom, and on the sides.

The Multiple Vee Jet burner (Photograph 5-12) as may be seen from the photograph was in effect three burners, to be operated simultaneously. The "Vee" shaped oil outlet released the oil over the center of each Vee shaped steam jet. Since the atomizing Vee slots were out in a thin plate which at its inner face was not at right angles to the center line of the burner, the steam jets issued at an angle, upward, instead of directly forward in line with the burner.

The Sheedy, inside mixing burner (Photograph 5-13) under this classification method was in the I-A-2 group, being gravity feed, flat flame, and inside mixing. This style burner was at one time in the past, used in regular service but was displaced by extending the use of the Von Boden to all Districts.

The Sheedy, standard, had a steam slot inside the outer shell of the burner, the jet being directed to the outside through a converging shell with a relatively wide outer opening.

The Sheedy, as modified during these tests, was the same as the standard burner except for the atomizing orifice. Instead of a slot for the atomizing steam orifice, multiple, diverging nozzles were provided to impart a higher velocity to the steam, and to improve entrainment of the oil.

In both burners the oil entered the atomizing jet from above and air was entrained from a similar passage below.

The Brittain burner (Photograph 5-14) was developed and patented by a locomotive engineer and was an inside mixing burner that also entrained air in the jet. The oil, upon entering the weir box was supposed to receive additional heating through radiation from the firebox.

The weir chamber outlet to the flat steam jet had several Vee shaped weirs at different levels to control the oil flow, the lowest, for small flows being centered over the steam jet. At increasingly larger rates, the oil would flow through additional "Vee" weirs and for the highest rates, oil could flow over the entire upper edge of the oil riser. Actually, at the maximum rate required in these tests, the capacity was so exceeded that oil also flowed out of and over the burner past the loose cover of the weir chamber.

The Clark burner (Photograph 5-15) as used by the Florida East Coast Ry. was a group I-B-1 type requiring only gravity flow and producing a conical flame by outside mixing atomization.

The present design, illustrated, employs a different atomizing jet than was in use in the year 1913, at which time the steam issued from a 1/32" wide, continuous annular orifice surrounding the circular oil outlet. The approach to the orifice was designed to produce a converging conical jet of steam having a total included angle of 46°. Beyond the apex, the jet would, of course, expand.

In the present design, the principle of the wholly surrounded oil outlet was retained but the steam jet, formerly continuous, was changed to multiple jets, and in addition, the jets were given a tangential component which so shortened the converging portion as to make the spray effectively diverging at the start. The tangential component of the jets also gave a rotational motion to the spray and spread the oil more uniformly around the jet.

The Alexander rotary cup burner (Photograph 5-16) was an adaptation of a commonly used stationary type. The practice in stationary service of using air as the atomizing medium for this type burner was undesirable for locomotive service because of the large amounts of oil to be atomized, so steam was used, its available energy being higher, in addition to the other advantages.

In this type burner the oil flowed by gravity onto the inner face of the rotating cup from a central oil passage with a radially directed outlet. The inner surface of the rotating cup was flared outwardly, which in conjunction with the rotation, caused the oil flowing onto it at the smaller inner end, to move forward toward the larger outer end of the cup which was surrounded by a thin, annular, atomizing steam outlet. The path of any part of the oil in traversing the cup was then helical, and because of the high rotational speed of the cup, the oil was deposited uniformly on and around the inner surface. This was the primary function of the rotating cup. It did however serve a second important purpose.

As the oil left the end of the rotating cup it did so tangentially because of the speed of rotation, and in so doing, encountered the axially directed steam jet at right angles, and with appreciable velocity. The resulting abrupt change in direction of the oil, together with the forced entry of the oil into the jet did much toward causing the excellent atomization obtained with this burner.

Primarily the advantage of this design of burner was the extensive entraining or atomizing area of steam jet available to the oil, the rotating cup features being merely an assurance of optimum use of this large area. With the particular burner tested, the slightly greater than 4" diameter atomizing annulus provided a steam jet but little less than four times the width of jet available with the 3-1/2" size Von Boden.

Mechanically, some needed changes in the design were indicated during the tests, such as provision of an outward taper to the outer surface of the rotating cup to throw off any fuel oil on this surface, which on the design tested, adhered and carbonized, preventing rotation of the cup. The lubrication of the bearing could perhaps also have been improved.

A burner of novel design was proposed by Battelle Memorial Institute and was constructed in a small experimental size. This was the burner designated as the "Slag blowing" type (Photograph 5-17) since its basis was the process or method commonly used to produce the insulating material known as "rock wool" from molten slag.

The oil flowed by gravity from a small pipe vertically down into the steam trough formed by the Vee shaped atomizer slot. For this experimental burner adjustable features were incorporated in the design to permit study of the effects of variations in height of oil outlet above steam jet and distance of impingement point of the oil from face of steam nozzle.

The oil outlet pipe was encased in a larger open ended pipe to act as a wind or air shield to protect the free fall length of the oil stream from undue deflection by air currents.

The Vee jet blowhead portion of this burner was designed so as to eliminate low pressure areas on the surface of the head. In blowing slag wool, the molten material does not strike the blowhead because air entrained by the jet flows down the recession, carrying the molten slag directly into the steam trough. Also with slag, improvement in atomization occurs when the slag stream is moved slightly off center from the apex of the Vee slot since the slag is thrown back and forth between the legs of the Vee.

With fuel oil, being of different viscosity, the height of the outlet above jet was found to be less important than in slag blowing and the air flow into the jet was insufficient to deflect the stream away from the head and out into the jet, as with slag.

The best performance was obtained with the parts in the relation shown in the photograph and drawing, and in this position the maximum oil rate for good atomization was found to be but four gallons a minute. Consequently for full flow in service four such burners would be required.

Although the number of burners necessary to provide adequate capacity might be arranged to result in a flat flame, the shape of the spray from but one was such as to best classify the burner in the "B" or conical flame class.

In comparing this burner with the previously mentioned multiple Vee jet burner it should be noted that the inner face of this blowhead is at right angles to the burner axis and the steam consequently issued from the orifice in the desired direction, that is, in line with the burner. Also, in this burner, the oil flow was directed into the steam jet at right angles as compared with the parallel flow from outlet of the multiple Vee burner from which the oil issued practically in line with the jet. The width or thickness of the atomizing slot on this burner was four times that of the multiple Vee burner.

The Gyrojet burners (Photograph 5-18) were in group I-B-2, being gravity feed, conical flame, and inside mixing. The steam jets surrounded the oil outlet and had an angularity to the burner axis such that the jet cuts across, but slightly out from the oil outlet, being tangential to a cylinder of slightly smaller diameter than the outlet.

Burners of this style but with different designs of atomizing jets were tried. In one design, the jets were milled, and were semi-circular, with the outer side flat. In the other, the jet nozzles were first drilled and then reamed at entry and exit ends to a total taper of $6^{\circ}$. The entry end was also chamfered appropriately to assure proper entry conditions and hence full flow.

The burner with drilled nozzles had a slightly less angle of flare to the spray than the burner with the milled nozzles and the length of the mixing chamber was increased correspondingly to maintain the same relation between jets and exit of chamber.

This style burner had considerable aspirating effect on the oil which, in conjunction with the rotational effect of the jets, caused the oil to form a vortex in the oil tube at least in the low range of flows. At rates below a certain minimum, of the order of one half gallon per minute, all oil in the burner would be drawn into this vortex and sprayed from the burner at a rate greater than the incoming flow. Consequently the vortex and spray would periodically cease and not recur until a certain amount of oil had accumulated in the tube.

The oil would then form a vortex; be sprayed from the burner, and the cycle would start over.

To eliminate this, a number of means were tried and as a result, the vortex breaker or preventer illustrated, was incorporated in the burner design. This device consisted merely of a short length of small diameter tubing held central in the oil tube at the exit. The small tube extended a short distance into the oil tube and from there, out into the mixing chamber about one half the length of the chamber. The small tube was conveniently held securely in the oil tube by three thin vanes or webs attached in a short length of thin wall tubing of proper size to be a light press fit in the end of the main oil passage.

This modification eliminated the periodic fluctuation in the spray and flame, apparently by allowing air to enter the oil tube and reduce or eliminate the vacum caused by the aspirating effect of the atomizing jets. The location of the supporting webs in the oil tube and their number proved to have neglible, if any, effect on performance, but if the small tube extended into mixing chamber less than half the chamber length, performance at low rates was adversely affected. If tube extended much more than half the distance into the chamber, then atomization at high rates was affected because the oil issuing from the small tube would not be thoroughly mixed in the chamber.

The drilled nozzles with reamed expanding section appeared to give somewhat better results than the milled, half round style but the burner was exceptionally noisy. Furthermore, milling the atomizer nozzles facilitated the manufacture, so no further work was done with the drilled style although a change in design of the nozzle may have reduced the noise level.

A tubular burner of this style has a major advantage over the flat types because of the ease, and particularly the precision with which the burner may be machined. Dimensions and shape of oil outlet, atomizer slots, combining chamber and the other features important to reproducibility of atomization can all be closely controlled, assuring consistent performance from mass production burners.

Another tubular, inside mixing, chamber type, burner was tried (Photograph 5-19). In this burner the outlet of the mixing chamber was of smaller diameter than the chamber itself and the oil flowed into the jets from their outer perimeter, that is the oil surrounded the steam jets as compared with the gyrojet type where the jets surround the oil.

While this burner was intended for gravity oil feed and is classified as such in group I-B-2, actually, the capacity of the burner was limited account not using pressure feed. This occurred because the restricted outlet caused a pressure to develop in the chamber sufficient to restrict and diminish the flow at high rates and high atomizer pressures.

The original model of this style burner, not illustrated, had a less constricting outlet and the steam jets did not have the tangential component to cause whirling.

In both burners the distance between the atomizing head and the chamber outlet could be varied for study of the effect, and the relative location as shown in the illustrations was found to produce best results.

A somewhat similar burner, not illustrated, of the inside mixing type was constructed from the parts of the above burner by changing the constricting end to a deep cone of approximately 60° total angle, the conical portion being $2\frac{1}{2}$" in length. The atomizing cap had ten atomizing holes drilled to correspond with the angle of the cone so that the jets would issue parallel with the combining surface of the chamber.

The position of the atomizing head was variable longitudinally in the burner, so that cone formed by jets could be moved in or out of conical combining chamber for study of effect on performance.

In this burner, oil leaving the annular oil passage entered the combining chamber between the jets and the cone of the chamber, and best performance was obtained with atomizing head set so centerline of jets cleared the surface of cone by approximately 1/4".

Atomization appeared good with this burner but the overall spray pattern was larger than was deemed suitable for the limited size of locomotive firepans and no work beyond the preliminary trials was done with this style.

The Nagel burner (Photograph 5-20) was a group II-B-2, requiring a pressure on oil supply of the order of 75 pounds per square inch gage and producing a conical shaped flame by the use of steam which mixed with the oil inside the burner.

This burner was a stationary boiler type and as is common with such types, the burner proper was held in a mount to which the steam and oil connections were made. The oil and steam then entered the burner proper through matching holes in mount and burner, the burner being held tight in the mount by means of a stirrup and hand screw.

The atomizing portion of the burner was very simple and the oil and steam orifices were comparatively large, being of the order of 1/8", so little or no trouble could be expected from plugging. Atomization was accomplished by centrifugal action in an annular mixing chamber, into which numerous steam jets were directed tangentially. The oil entered the steam jets from an annular chamber and the mixture then proceeded into the annular mixing or swirl chamber from which it issued in a conical spray.

The burner was used in conjunction with a large 24" diameter conical cast iron shield, having slots for admission of primary air to maintain initial combustion in the shield. These air slots were designed with blades to deflect the air around the interior of the cone, causing a swirl to the stream.

Secondary air for combustion was admitted through an annular space around the shield.

To obtain the full range of flow in the tests, three burner assemblies were used and applied at the rear or a special firepan, as shown in firepan sketches and installation photographs, herein.

The initial design of the Coen Multiple burner, not illustrated, consisted of 16 individual burners appropriately spaced in two mounting blocks which contained the connecting oil and steam passages. One block contained eleven burners, the connections to alternate tips being in parallel to provide two operating groups, one of six tips and one of five. The second block contained five burner tips also connected to provide two independent operating groups. The center burner was separately piped for use as a pilot and the four outer tips, two on each side of center, were connected to function as one unit.

As shown in photographs of installation on test engine the two burner blocks were mounted on a long "L" shape plate provided with suitable holes for the burners to fire through. The "L" portion of the plate overhung the fire side and when applied to the engine acted to prevent entry of air from above the oil spray.

The burner tips were an inside mixing type requiring high oil pressure and employing the centrifugal principle. The oil entered a swirl chamber tangentially through two 1/8" diameter holes. The oil then passed into a smaller diameter cylindrical chamber into which four 1/16" diameter holes for the atomizing steam were drilled, also tangentially. From there, the mixture issued from the burner tip through a 5/32" orifice in a conical spray.

Because of the design, the output of the burner was particularly sensitive to changes in the atomizer pressure and for this reason firing rates were set with difficulty during the trials on the locomotive where oil and atomizing steam was adjusted manually and without the advantage of coordinated valves.

This multiple burner arrangement then provided four groups of burners to cover the range of firing rates up to 15-16 gallons of oil per minute. In the trial installation, individual control valves were provided for the steam and for the oil to each group of burners. For more extended use, a multi-purpose valve with single operating lever could have been designed to control both oil and atomizer and to cut in the groups of burners successively at appropriate increments of the firing rate.

For several reasons disclosed by the tests the burner mounting plate was changed from the original "L" shape to a perforated one that enclosed the entire assembly on four sides. This change reduced and slowed the flow of air into the jets from the sides but permitted free flow from the rear toward the flame.

Among other things, trials in the locomotive showed that a very considerable amount of oil spray accumulated on the burner block as a result of eddy currents formed because the burner tip, in this design, was flush with the relatively wide burner block.

A second design of multiple burner, also not illustrated, was constructed using the original eleven tip burner block with a different design of tip which having greater capacity reduced the total required to the eleven applicable to the one block.

The oil swirl chamber and inlet was not changed but new tips were applied having slightly larger mixing chambers; steam inlets relocated to be equally spaced around the chamber, and 3/16" diameter outlets. These tips were also made longer than the originals and protruded 1" beyond the burner block so that the air flow would sweep them and prevent the drooling effect occurring with the flush tips.

These burners were connected to provide groups of one, four, and six, symetrically arranged with the single burner centered for use as pilot and at low fires. While the output of these burners was not quite so sensitive to atomizer pressure changes, great care was still required in adjustments.

A third style of Coen burner was developed for an entirely new application in multiple on the sides of the firepan, in order to improve turbulence and mixing with combustion air. These burners, which are not illustrated, were for application in pairs to opposite sides of the firepan in the slope, or trough sheets, so that the flames would meet about in the center of the firebox and create a desirable disturbance.

To investigate the feasibility of this application, two trial burners were constructed on the outside mixing principle to provide a relatively short bushy, conical flame. These burners were for trial only and each had a nominal capacity of about 2 gallons of oil per minute.

The oil and steam entered the atomizing head through separate 1/4" iron pipes. From there the oil entered a swirl chamber through a single tangentially drilled hole. This swirl chamber also had a very small tangentially drilled entry for the inside mixing steam. The oil then left the burner through a 3/16" diameter outlet nozzle which extended a short ways out from the center of the shallow, conically recessed end of the burner.

There, six, 1/16" diameter, outside atomizing steam jets were drilled on a 7/8" diameter circle in the recess around the oil nozzle and at an angle so that the axes of the jets were approximately tangential to the oil stream at exit. The jets would thus wipe the end of the oil nozzle and create a whirling oil spray.

Although not a part of the burner, the air port casting and vaned primary air inlet should be mentioned, being necessary to the proper operation of the burner. A burner port casting with 8" outer diameter and an inner smaller throat of 6-1/2" was provided, together with an air spreading casting for mounting on the burner barrel as an aid in holding the flame at the burner. Surrounding the port entry, and holding the burner centered, was a cylindrical, vaned cage with outer end closed except for hole for insertion of burner. This cage was constructed with 16 vanes 1-1/4" wide arranged to whirl the air counterclockwise. For the trial, a movable disk was also provided in the cage so that flow of primary air could be controlled.

Following the experiments and studies with the trial installation a full set of eight burners was constructed on the same design except for minor deviations necessary to produce the desired capacity. The full set included six main burners and two of smaller capacity for the pilot and for very low fires.

The main burners had an oil outlet of 1/4" diameter and had eight outside atomizing jets instead of the six on the trial burners. The pilot burners had 1/8" diameter oil outlets.

These burners were superior to the several previous designs and since the main steam jets were outside the burner, variations in atomizing steam pressure had negligible effect on oil flow, thus making these burners much more adaptable to locomotive service than the other styles. However, improved performance was obtained from the next and final, design.

The final style of Coen burners was as illustrated in Photograph 5-21 and several improvements were incorporated in their design. These burners have been classed as wholly inside mixing, since the oil entered the main atomizing jets at the inner end of the conically recessed burner tip and hence was incorporated in the jets before passing the end of the burner.

These burners had a central steam passage and the oil flowed to the atomizing head through an annular space between the steam tube and the outer shell of the burner barrel. This construction provided a heating area for the oil that considerably reduced the external oil temperature necessary.

At the inlet to the steam passage a removable basket strainer was built in to the burner assembly. The strainer was of monel and had perforations of 0.2" diameter. This steam strainer served effectively to eliminate plugging of the atomizing tip with pipe scale, etc.

In these burners the fuel oil entered an annular swirl chamber tangentially through two 1/8" diameter holes where it was mixed with steam from four 1/32" diameter holes entering radially. The oil then passed through a thin, 5/128", annulus around the 3/8" diameter main steam tip.

A circle of 16, No. 67 drill size, atomizing steam holes radiated from the central atomizing tip to form a diverging cone with a total included angle of 100° at burner axis. The steam from these holes, in flaring outwardly, impinged on the recessed conical face of the burner end, thus trapping the oil between the jets and tje metal surface.

To control the flame flare to that desired the included central angle of this conical surface was made 90° on the main burner tips to provide a wide flame and but 60° on the pilot burners to better suit the smaller diameter air port.

These burners also, were used with the special constricting port castings previously described, an air diffuser or deflector mounted on the burner casing near the tip, and a vaned cage around port entry to impart a whirl to the entering air.

With this design and arrangement of burners, the pilot burners were controlled independent of the main group of six which operated from one firing and one atomizer valve. In practice a single firing controller would have been used which would not only have regulated both oil and steam in proper proportion, but would have cut-in and cut-out the main burners at a predetermined firing rate. In addition, this single controller could readily have been designed to adjust properly the single damper required.

## DISCUSSION OF "COLD" TESTS

The apparatus for studying the operating characteristics of the oil burners by means of atomization patterns and photographs was as diagrammed in Figure 6.

The arrangement for supplying the oil to the burner also permitted the oil to be circulated through a meter, bypassing the burner, so that the flow rate might be set to that desired. This method is open to some criticism because the oil did not flow thru the burner outlet which conceivably could restrict the flow beyond the setting of the flow valve.

Actually, if the precision were warranted, the oil rate would have to be set with the oil issuing from the burner under the exact atomizer pressure, since some burners had an aspirating action which would tend to increase the flow, while in others the atomizer pressure opposed the oil flow. Under such circumstances a very considerable amount of oil would have been discharged from the burners during the course of these tests. This oil would have contained an undesirable amount of moisture from the atomizing steam which could not readily be extracted by settling because of the practically identical densities. Reuse of the oil to reduce the disposal problem would again introduce question in the results because of the rapid build up of moisture.

Consequently, the method employed in setting the flow rate, that is, free discharge of the oil, but not from the burner, was considered of ample accuracy in view of the observations being subject only to a somewhat arbitrary, visual interpretation and evaluation.

The procedure was to set desired flow rate after sufficient oil had been passed through to warm piping, meter, etc. and temperature had become stable. Circulating valve was then closed and atomizer steam turned on and pressure adjusted as necessary. Then with all other preparations made, the valve allowing oil to flow to burner was opened, spray pattern or camera shutter tripped, and oil valve closed.

Because of blow back, and splatter from the spray shutter plates it was not possible to obtain both the spray pattern and the photograph of spray appearance at the same time. When obtaining the spray appearance photos, the shutter plates were slipped out of the guides and removed, allowing unobstructed flow of the jet from the burner.

For obtaining the spray pattern, a suitable supporting panel was provided to which was affixed clean new sheets of kraft wrapping paper each time a pattern was obtained. Immediately after the pattern was made by tripping the shutter trigger which caused the shutter slot to rapidly traverse the spray thus permitting a portion of the oil to reach the paper and in effect create a cross sectional effect, a photo was taken of the oil spotted paper for the record.

With some burners producing a heavy concentration, the oil would run on the sheet before the picture could be taken but this, effectually, merely emphasized the condition existing.

The spray patterns did show the nature of the oil spray at a distance from the burner but with some burners much of the oil would not reach the pattern target after passing through the shutter slot. With other burners, large amounts would fall before reaching the shutter. Since these conditions are not disclosed by the pattern photos an evaluation of a burner by that means alone would therefore be controversial.

It also should not be overlooked when considering these spray pattern photos that little or none of the finely atomized oil would reach the pattern target because of the light weight and small size of those particles.

The chief value of the spray patterns, as taken, then was that they showed clearly, tendencies toward concentrations. They also provided a means of observing relative size of the droplets in the main stream.

To serve a similar purpose but with some advantages, the apparatus was arranged to permit photographing the spray under the motion-stopping, high speed exposure conditions provided by electronic flash lighting equipment. With suitable procedure and the electronic speed light, the exposures are of the order of one five-thousandths of a second which was quite effective in photographically stopping the motion of a preponderance of the oil particles.

It was found that lighting the oil spray from the back produced the most informative photos. A black background and a roof or cover, also painted black, was provided. These, together with the shield for the camera excluded direct sunlight and assured sufficiently uniform lighting regardless of the weather.

During cold weather, the greater cloud of steam vapor added some difficulties to the photograph but ordinarily the visibility of the atomizing steam proved an advantage. In effective or doubtful value portions of the atomizing jet, which otherwise would escape detection except by elaborate survey, were readily apparent with the steam visible.

In order to reduce the variables involved in comparing the performance of the burners by the cold test, two oil rates were selected which were representative of the low and high rates of actual service, and for these oil rates fixed values of atomizer steam pressure were adopted after experiment.

In the photographs, some of the burners may have appeared to better advantage when operated at a different atomizer pressure but determining optimum values for the atomizer would entail laborious repetitions of cold test procedure until a better pressure was found. In development work with some of the burners, atomizer pressures were changed from the usual fixed values, while visual observations were made but for the report the photos taken at the standardized pressure amply illustrate the characteristic performance.

The suitability of pressure as the standard for the atomizer is somewhat debatable for reasons similar to those in the discussions on method of setting the oil rate, that is, the burners would probably emit considerably different quantities of steam for the same pressure head because of the difference in orifice or nozzle shapes and sizes.

Whether the quantity of the steam or the pressure at the burner would provide the better condition was not of particular importance considering the purposes of the cold tests and the pressure was selected because of the relative ease and accuracy of setting. Actually, other work during the test program, on steam consumption of some similar type burners, indicated that any differences in the observations would have been inconsequential.

As a matter of record the low rate for the cold tests was established at 5 gallons per minute for the oil with atomizer steam pressure set at 10 pounds per square inch; the high rate was 15 gallons of oil per minute and 40 pounds per square inch atomizer pressure at the connection to the burner. These values are not shown on the photographs as for their purpose, the pictures are best identified as at "low rate" and at "high rate."

## DISCUSSION OF FIRING TESTS

The firing tests were the determining factor in the burner studies because they represented conditions of actual service and exposed many features and characteristics of burner performance that would have been difficult if not impossible to find by any other means.

The prior test work on firepan designs revealed that an important criterion for judging burner performance during the firing tests would be the reduction possible in pressure of exhaust steam from the main cylinders accomplished through enlargement of the exhaust nozzle.

The reduction in exhaust pressure may appear unrelated to burner performance but in a steam locomotive, both front end and firepan must be considered along with the burner because together they control the supply of air for combustion which is inspirated by the jet action of the exhaust steam from the front end nozzle, the size of which controls the exhaust pressure. The exhaust pressure on a locomotive is important because it affects the power output of the cylinders. Therefore for a steam locomotive, the performance of a burner not only affects the combustion efficiency as is usual in any installation but also has a direct effect on the power available to haul trains.

Observations during tests of numerous designs of firepan showed that the performance of many of the locomotive type burners depended largely on characteristics of the air flow into the firepan. With the Von Boden burner, for example, high velocities and turbulence in the entering air would prevent heavy accumulations of hard carbon and unburned oil in the firebox by creating good combustion conditions, resulting in high efficiencies with low excess air. The high velocities and turbulence were usually obtained through use of firepans with high resistance to air flow. High resistance firepans require high induced drafts to provide sufficient combustion air and on steam locomotives this necessitates a restriction of the exhaust nozzle at the expense of cylinder power output. With such burners, low resistance firepans which permitted adequate air flow with reduced draft and consequently lower exhaust steam pressures, gave poor combustion results accompanied by smoke and carbon formations, even with very high excess air.

Therefore boiler efficiency alone does not adequately reflect the desirability of a burner for steam locomotive service because a high efficiency in a standing test, secured by manipulation of the drafting and firepan designs would indicate an ostensible improvement which through loss of power from the engine in service because of increased back pressures, might well be nullified in the overall performance of the locomotive.

The boiler efficiency cannot be neglected, however, in evaluating burners by standing tests for it still is a valuable criterion of performance when properly considered in connection with the changed air flow conditions and quantities resulting from alteration of front end and firepan.

The nature of the firing tests was such that the boiler efficiencies were influenced most by the changes in amount of excess air caused by modifications of the exhaust nozzle aperture and for a given combination of burner and firepan, the expected tendency would be for the boiler efficiency to increase progressively with enlargement of the exhaust nozzle. However, this could only hold true to the point where, for the particular burner, combustion became adversely affected by the decreased supply of air. Hence, the amount of combustion air available was a parameter for considering the boiler efficiency and in these tests both the exhaust nozzle combinations and the exhaust pressures were expressive of the available air as well as cylinder power potential.

There were of course other, but more obscure, factors influencing the boiler efficiencies obtained. One was the factor of utilization of combustion air through optimum placement and regulation of draft ports to prevent bypassing and stratification of entering air. Selection of air port location and proportion was a continuing problem, for air improperly brought in served mainly to raise the level of excess air, with little benefit to combustion ensuing. With some burners of poor atomizing and spray characteristics it was impossible to utilize effectively the majority of the entering air. Others, with different flame shape and good atomizing ability, could be operated with a minimum of excess air, indicating full utilization of the entering air.

This phase of the combustion process was studied by means of long, water cooled probes inserted through appropriately large hollow staybolts in side sheets and at other locations. By means of suitable probes, both gas samples and gas temperatures were obtained at numerous locations throughout the firebox. This study disclosed channeling and stratification of the gases and areas deficient in oxygen, as well as "hot spots" and other undesirable conditions.

In these firing tests the capabilities of the burners in locomotive service were therefore explored by making successive enlargements of the exhaust steam nozzle in conjunction with changes to firepan arrangements to best suit the burner. This permitted investigation of burner performance under decreasing drafts and air supplies; the attendant decreases in exhaust steam pressure being an indication of the advantage in increased power from the engine in service.

The designations used for the firing tests were composed of three symbols which indicate respectively the burner tested, the firepan arrangements, and the front end arrangement. The symbols for firepan and front end arrangements were a continuation of those used in prior reports and, throughout, similar symbols refer to similar arrangements. The numbers applying to the burners were based solely on sequence of test, hence no significance as to merit or performance is implied.

The results of the firing tests are illustrated graphically by Figures 8 to 29, inclusive, and the various smokebox and firepan arrangements and details are shown by Figures 30 through 48.

## COEN MULTIPLE BURNERS, PHOTO 5-21

**TEST SERIES:** B1-T10-D Figs., 8, 36, 30
B1-T10-AF " , 9, 36, 35

The firing tests of these Coen multiple burners were the culmination of numerous trials of different styles of Coen burners and considerable preliminary work with this particular design.

The B1-T10-D tests were made using one of the largest exhaust nozzle combinations tried up to that time, the 1/2" x 3" basket bridge cross split on an 8" dia. nozzle, and it may be noted from Fig. 8 that exhaust pressure at maximum rate reached only 11 lbs. pressure, a very creditable reduction from those necessary with the drooling type burner.

The smoke during the tests was negligible as may also be noted from Fig. 8. The boiler efficiency curves dip downward at the medium rates but from the curve of fire box draft it appears possible that some slight adjustment of the damper might have reduced this. The firebox drafts shown are well above the design figure of 4" but those values are the differential between inside the firebox and atmospheric pressure whereas the actual draft differential between firebox and plenum chamber housing the main burners was much less and of the desired order.

Since the damper was not open wide during any of the B1-T10-D tests, as may be observed from Fig. 9, it was evident that an enlargement of the exhaust nozzle beyond the "D", arrangement Fig. 30, would be possible with these burners.

Accordingly the exhaust nozzle tip was bored to 8-3/4" diameter, the largest size possible with the standard casting, and fitted with a 3" high basket bridge made from 1/2" square stock, as shown in Fig. 35. This nozzle combination was a very considerable enlargement over previous ones and it may be noted that at a firing rate of 5000 pounds of oil per hour the exhaust steam pressure was but 5 pounds per square inch.

With this arrangement the tests, Series B1-T10-AF, were started and data obtained for the two rates shown, however, difficulties from excessive leakage in the firebox prevented completion of the series due to extent of boiler repairs required.

The firebox drafts were more nearly of the order desired and the damper settings were more open than during the previous tests, as could be expected. The excess air was very low during the two runs of this series, being of the order of 7% to 8%, but had been lower, down to 6% during the previous series. There is then some basis for expecting that a further enlargement of the nozzle might have been possible but this possibility would have been more evident from the performance at the higher rates.

The performance of these burners was outstanding during the standing tests and their possibilities were not fully explored since for example, a service installation could be operated from a single control lever which would not only control the oil flow but also both the atomizing steam and the damper position. However, an installation suitable for service would require extensive development work to design the control valve and a firepan with plenum housing which would give adequate clearance for the movement of the trailing truck, protect the numerous oil connection lines from chilling in cold weather, and provide quick access to burners and piping. As the burners also required a relatively high oil feed pressure it also would have been necessary to develop a rugged and reliable oil pumping arrangement.

The expense of installation and the probable expense of maintenance of the extra equipment would therefore have to be considered as detracting from the advantage obtained from the excellent performance.

## 3-1/2" VON BODEN BURNER, PHOTO 5-4

### TEST SERIES: B2-T11-AB, Figs. 10, 37, 31

This series with the size Von Boden burner that was standard for the GS class locomotives, represented a basis for comparison during these burner tests which, with the exception of tests with the Coen multiple burners, were all made using a larger than standard stack and nozzle which otherwise would have made correlation difficult.

Many more than the usual four to five runs were available for this series because of the use of this combination as a basis of comparing various fuel oil additives and for other tests. Although normally not necessary the data from the larger number of runs with this burner serves to emphasize one of the main points disclosed by the various tests and trials of the Von Boden type burners, that is, the poor response in atomization to variations in steam supplied.

During each run, atomizer and damper were controlled as necessary to create optimum combustion results as determined from visual inspection of fire and stack, yet the graphs of atomizing steam, smoke, and damper opening show no consistent trend as should be expected. It is manifest from the erratic nature of the atomizing steam consumption curve that the steam did little toward atomization, serving mainly to carry the oil away from the burner, since nominally equal atomizer rates served equally well with oil flows up to more than double the minimum rate.

It will be noted that on two of the runs there was appreciable smoke and that exhaust steam pressures were around 11 pounds per square inch at a firing rate of 6000 pounds of oil per hour. Boiler efficiencies, including feedwater heater, were around 89% to 90%.

## GREAT NORTHERN BURNER, PHOTO 5-8

| | | | |
|---|---|---|---|
| TEST SERIES: | B3-T11-AB, | Figs. | 11, 37, 31 |
| | B3-T12-AB, | " | 12, 38, 31 |
| | B3-T13-AB, | " | 13, 39, 31 |
| | B3-T13-AC, | " | 14, 39, 32 |
| | B3-T14-AD, | " | 15, 40, 33 |

The various series with this burner represent a development of a more suitable firepan arrangement for the burner than that provided by the T11 firepan used to permit direct comparison with the Von Boden, Series B2-T11-AB, Fig. 10.

As brought out in other sections of this report, the Great Northern burner was sufficiently different from the Von Boden in design to cause a considerably different flame shape, obviously requiring changes to the firepan. However, even with that handicap the burner performed as well or better than the standard Von Boden with the same firepan and front end arrangement, as may be noted from Fig. 11 which shows there was negligible smoke and that boiler efficiencies were slightly higher.

Since with this burner the preponderance of oil was not discharged at an upward angle it was necessary first to raise the burner higher in the firepan than was found best for the Von Boden and the results of this change alone are shown by Series B3-T12-AB, Fig. 12. It will be noted that considerable improvement was effected, particularly in eliminating much of the former dispersion of results.

For the series B3-T13-AB, Fig. 13, an additional airport was added in the floor of the firepan to supply air to a section found deficient. This change had little effect on the results plotted although the boiler efficiency fell off slightly, perhaps because of the increased amount of air supplied through the greater airport area.

For the next series, B3-T13-AC, Fig. 14, the amount of combustion air available was reduced by enlarging the front end exhaust nozzle aperture by changing the cross split size from the 1" square to the 7/8" square, size. This change raised the boiler efficiencies slightly but to little more than those obtained with the previous combinations.

For the final series, B3-T14-AD, Fig. 15, the exhaust nozzle aperture was further enlarged and the air ports were restricted to those as shown by Fig. 33. Both changes tended to reduce air available and a large increase in boiler efficiency resulted.

These tests disclosed that excellent performance was possible from this burner which was relatively simple, both in design and from an application standpoint, yet the burners could be produced with considerable accuracy assuring uniformity of results in service. However, for optimum results with this burner a firepan should be specially designed to eliminate the impingement of oil on the side walls occuring with the modified T&NO, narrow trough type pan employed during these tests.

## ROCK ISLAND BURNER, PHOTO 5-9

### TEST SERIES: B4-T11-AB, Figs. 16, 37, 31

Results of the series of runs with this burner disclose no particular advantages, and the boiler efficiencies are substantially the same as those obtained with the Von Boden burner. There was negligible smoke during the tests but the firebox sheet temperatures indicate a pronounced change in flame distribution between high and low rates. The atomizer steam consumption curve, being flat, would indicate an atomizing performance somewhat similar to the Von Boden yet the nearly constant boiler efficiencies obtained tend to show it to be adequate with the particular front end used. There was, however, considerable carbon formed on flash wall.

## 4-1/2" VON BODEN BURNER, PHOTO 5-3

TEST SERIES: B5-T11-AB, Figs. 17, 37, 31

These tests were made with a standard Von Boden burner but in the next larger size than normally used in the GS class locomotives.

With the Von Boden burner, low oil flows were usually better atomized than high oil flows and on that basis it might be expected that this larger size burner would show a better performance over the wide range of oil rates covered by this series. However, it may be noted from Fig. 17 that boiler efficiencies were even lower than with the smaller 3-1/2" size and no improvement was found in the other aspects of performance such as carbon formation.

## FLORIDA EAST COAST BURNER, PHOTO 5-15

| | | |
|---|---|---|
| TEST SERIES: | B6-T11-AB, | Figs. 18, 37, 31 |
| | B6-T12-AB, | " 19, 38, 31 |
| | B6-T13-AB, | " 20, 39, 31 |

This burner, producing a conical flame was not particularly suited for installation in the firepan T11, Fig. 37, as arranged for the flat flame Von Boden but series B6-T11-AB was made to permit direct comparison and disclose what changes might be necessary.

It may be noted, Fig. 18, that boiler efficiencies were slightly better than with the Von Boden, that smoke was negligible, and that firebox sheet temperatures were quite uniform throughout. Atomizer steam consumption curve rises smoothly as should be expected.

The next series with this burner was with the burner raised as shown by Fig. 38, this being the only change made. The boiler efficiencies were quite constant throughout the series.

Atomizer pressures (not shown) were maintained practically constant, but curve of steam consumption shows actual steam flow fell off with increase of oil rate. This, together with a nearly complete absence of carbon accumulation during the series would indicate that the atomization steam was effective but perhaps not controlled to the minimum necessary.

Between this Florida East Coast burner and the Great Northern burner, the results of trials with the T13-AB combination of firepan and front end arrangements, as shown by Figs. 13 and 20, indicate the Florida East Coast burner gave a slightly better performance.

## TUBULAR BURNER, PHOTO 5-19

**TEST SERIES:** B7-T12-AB, Figs. 21, 38, 31
B7-T13-AB, Figs. 22, 39, 31

Results with this burner in the tests, series B7-T12-AB, Fig. 21 were quite similar to those obtained with the Von Boden burner, however, the burner did not fire well at very low rates perhaps because it was slightly short for the thickness of burner wall.

As this was a tubular burner producing a bushy flame it was tried in the T13 firepan which had the higher location for the burner. In this series the usual run at a low rate was omitted because of difficulties with the feedwater pump. The firing tests at the high rate disclosed that the burner was sensitive to changes in atomizer pressure in that raising the atomizing steam rate reduced the oil flow and vice versa. This was a distinct disadvantage.

## MULTIPLE DIAMOND CHANNEL BURNER, PHOTO 5-10

**TEST SERIES: B8-T17-AB; Figs. 23, 43, 31**

The firepan T17 used with this burner was essentially the same as the T11 arrangement used for the series with the 3-1/2" Von Boden except that the bottom airports were placed a few inches further from the flash wall, hence the results of this series may be compared with the Von Boden on an equal basis.

No particular advantage was found for this burner and the carbon accumulation on the flash wall during the tests was undesirable.

## K. O. ALEXANDER BURNER, PHOTO 5-16

**TEST SERIES: B9-T15-AD; Figs. 24, 41, 33**
**B9-T15-AE; " 25, 41, 34**

The firing tests of this burner interposed several special problems because of the steam driven rotating cup and the nature of the oil spray. Some preliminary work was necessary to investigate effect of turbine speed on performance and to devise a firepan arrangement that would supply adequate combustion air in the right locations so as to prevent carbon formation and avoid blowing the flame from near burner.

Firepan arrangement T-15, Fig. 41, was evolved. In this arrangement the amount of air available to the flame near the burner is notable and is indicative that the spray particles were small, light, and easily ignited. The sloping bottom to the hoppers was necessary to avoid strong upward currents in the entering that would lift and turn back the light spray. The air through port under burner, entered longitudinally with the burner but because of the natural tendency to flow toward the tube steet, the wing walls indicated, were installed to confine this air to the flame as much as possible. The wing walls also re-radiated heat to the flame and spray near the burner and facilitated combustion there.

The burner performance shown by Fig. 24 was quite good; the boiler efficiency being high and nearly constant over the range of firing rates and the exhaust nozzle pressures low. Smoke was also of a low order.

The burner was then tried with a larger exhaust nozzle, the AE, Fig. 33, which lowered the exhaust pressures nearly one pound over the range of the tests. As shown by Fig. 25 the boiler efficiencies were then slightly higher but there was some tendency toward smoking.

In addition to the results shown, the firing tests disclosed one undesirable feature of the burner that probably could be corrected. It was found that fuel oil entered the burner between the atomizer steam housing and the rotating cup during some phase of operation and became carbonized and gummy preventing rotation of the cup. A change in the design of the cup from a cylindrical exterior to a tapered one, so it would be flared similarly on both inside and out, would perhaps correct this trouble. Although no difficulties were experienced with the rotor bearings during the rather extensive trials and tests, indications were that loss of lubricating oil was excessive and special care was taken to maintain the supply.

Within broad limits, variations in the rotational speed of the oil cup were found to have no noticeable effect on the fire and steam pressure to the turbine did not have to be changed with the oil rate. It was also found that it was possible to fire the engine with the turbine and cup stationary but firing was then more difficult and the atomization somewhat deficient as indicated by formation of carbon.

Several additional modifications were made in the firepan arrangement in an attempt to make firing easier and eliminate a tendency of the fire to drum but trials showed no improvement over the T15, Fig. 41, arrangement.

## NAGEL OIL BURNER, PHOTO 5-20

### TEST SERIES: B10-T18-AC; Figs. 26, 44, 32

The application of the three Nagel oil burners together with the Nagel Oil Economizer Process Shield assemblies in a special flat firepan, Fig. 44, represented a wide departure from customary locomotive design and considerable preliminary work was done to develop proper firing practice and best adjustment of size of primary and secondary air inlets.

The burners were each centered in a cast NOEP shield, 24" in diameter, which contained radial louvers through which the primary air entered. The air opening at these slots would normally be cast to the desired size but for the tests, adjustments were made by wedging the heat resistant air deflecting plates to provide the 1/8" air space used during this series of tests.

Normally all secondary air would enter through the annular openings around the shields but the preliminary firing tests showed that air supply was deficient below the flame path and that flame was lower than expected. This resulted in poor combustion in the lower portion of the firebox with considerable sooting of the lower boiler flues. In addition, the flame tended to overheat the firebox throat sheet. Use of the 1" wide air slot across the firepan in front of the burners as shown by Fig. 44, corrected the apparent deficiency of air in that area and together with additional fire brick protection for the throat sheet, to provide that shown by Fig. 44, eliminated the undesirable condition found during the preliminary trials.

With this application of three burners the design procedure was to use only the middle burner for spot fires and low rates. With higher firing rates all three would be used, the two outer ones being lit by the flame from the center burner. It was found that this interposed some problems of firing for if the draft was too high at the time the two outer burners were cut in, the flame at times would not penetrate into the NOEP shield because the air velocity exceeded the rate of flame propagation. In such instances it was necessary to hold a torch flame at the burner shield. This obviously would not be possible in road service.

The results of test shown by Fig. 26 indicate fairly good performance at low exhaust pressures. There was, however, more smoke than desirable at the high rate.

The reduction in atomizer steam consumption with increase in oil was a characteristic of the burner. The atomizing principle and design of the burner was such that an increase in oil flow decreased the steam flow because both issued through the same tangential passages. Atomizing steam, once adjusted, subsequently was not changed manually but varied inversely as the oil flow because of the burner design.

With these burners the main problem of use was the flame length, which varied with the velocity of the entering air. Reduction of width of annulus for secondary air increased the velocity and shortened the flame but at the same time the resistance of the firepan to air flow was increased, thereby reducing the available air.

The individual burners had sufficient capacity to permit subsequent trial of an arrangement employing only the two outside burners; the center shield being bricked over. This showed that the installation could be simplified by reducing the number of burners employed, but the wide separation of the burners proved awkward in firing up and each had to be lighted individually.

The firing tests showed that, due mainly to the length of the flame, the installation as used during the firing tests would not be entirely suitable for road service. However, some other position for the burners such as the front end of the firepan might be employed to extend the path available to the flame but at that location the restricted space on existing locomotives, due to slope of the mudring, would make application of the 24" diameter NOEP shield assemblies difficult.

## GYROJET BURNER, PHOTO 5-18

TEST SERIES: B11-T19-AC, Figs. 27, 45, 32
B12-T19-AD, " 28, 45, 33
B13-T20-AC, " 29, 46, 32

During the series with the Gyrojet burner, three slightly different designs were employed, the B11, the B12 and the B13 burners respectively.

Burner B11 had a slightly smaller angle of flare to the flame and the atomizing jets issued from tapered nozzles as compared with half-round slots in burners B12 and B13. Burner B13 was the same as B12 except for the addition of the small tubular insert in, and extending out from, the oil passage.

Although the primary characteristics of performance were negligibly affected, the modifications in the design, culminating in that of burner B13, did eliminate two objectionable features of performance that were disclosed by the firing tests. These were that burner B11 was excessively noisy which would be a potential source of complaint in many situations existing in railroad operation. The exact cause of the excessive noise was not determined but in the B12 design the level of noise was low and not objectionable. The B13 design eliminated the spasmodic spot fires produced at very low oil rates during the trials of the B12 design.

During these series an entirely different style of firepan was used, Figs. 45 and 46, which was specially designed for actual road service with the Gyrojet oil burner and embodied several special features particularly suited to produce optimum results with that burner.

As has been explained elsewhere in the report, the firepan arrangement has much to do with the performance of the burner and airport size and location must be suited to the atomization characteristics of the particular burner involved.

It is therefore consistent to review briefly the pertinent features of the performance of the Gyrojet burners as disclosed by the various investigations made during the Research Program and point out the accompanying feature incorporated in the firepan design.

As has been shown, the Gyrojet burner produces a whirling conically shaped flame. This required two things in the firepan; first that the burner be placed relatively high above firepan floor, and secondly, that adequate width be available for the wide spreading flame.

The Gyrojet burner in addition, produced a relatively light mist of finely atomized oil which was conducive to early combustion but also introduced the problem of bringing in the combustion air in a manner that would prevent turning of the soft, gaslike flame with consequent "short circuiting" and non-use of the air for combustion. This also required two things of the firepan arrangement; first, that there must be adequate primary air to maintain combustion at or very near the burner, but with appropriate controls to prevent chilling of the oil in that vicinity during low fires, and at the same time insure desired mingling of the air and oil spray without bypassing; and second, that the secondary air not turn the flame back from its path toward the flash wall.

The first requirement was satisfied in the firepan design by placing a horizontally opening airport in the burner walls, in the space between burner port and firepan floor and providing a regulating damper. Although air through this port could be considered as secondary air it actually serves as a primary source, for the tendency is for entering air to turn toward the tube sheet thus causing air from an under burner port to tend to encounter or to bypass the flame near the end of the burner. To prevent the bypassing of this air and assure its full use in initiating combustion near the burner, the side walls of the firepan were brought in close to the burner. This served several purposes, first to confine the entering air to the flame path and second, to assure a high temperature zone in the vicinity of initial combustion due to the reradiating effect of the closely adjacent sidewalls and also to reduce tendency for fire to "drum" or pulsate. The second requirement, as to entering secondary air, was satisfied by the design and proportioning of airport, hopper and hopper openings which were constructed to cause the air on entry in the firebox to be reasonably turbulent, of relatively low velocity, and not strongly counterdirectional to the flame path.

The resulting firepan was therefore deeply troughed to keep burner port in the troughed section with the trough flared widely from the burner wall, to provide the width required for the spread of the flame. The burner wall was made as high as possible above burner port, again with the view of reducing bypassing of air.

Two styles of burner port were tried, as indicated by the figures, one straight cylindrical and one of a venturi shape; the latter being included in the final design.

The dampers for both hoppers were interconnected and operated together by means of a lever-and-quadrant arrangement once standard on oil burning locomotives equipped with the round bottom, front drafted firepan arrangement that preceded the existing standard "modified draft" design. For the standing tests, the connecting levers were designed to permit ready adjustment of the relation of damper openings.

It is plainly evident from the graphs, Figs. 27, 28, 29 and the tabulated data on air supply, calculated from gas analysis, that the combination of burner and firepan was eminently successful. The boiler efficiencies in the three series are extremely high, due primarily to the ability of the combination to produce good combustion with low excess air. It is obvious from the low percentages of excess air that little, if any, air was bypassing the flame.

During these tests the boiler was equipped with Security Circulators. This of course had an effect on the temperatures of the firebox sheets that precludes any direct comparison with prior tests as to temperature difference. However, it may be noted from Figs. 27 and 28 that in general, the sheet temperature curves rise smoothly with firing rate and that the erratic variations found with some burner and firepan combinations did not occur. This should be a distinct advantage from the standpoint of boiler maintenance for it is an indication of the absence of local hot spots and the uniformity of flame distribution throughout the firing range. This tends to promote uniformity of expansion in the firebox with less working and straining of the staybolts.

In connection with boiler maintenance, the location of the air openings into the hoppers is important in road operation. On the taper firepan arrangements T18, T19 and T20 the openings were designed and so located as to prevent cross winds and other conditions of ambient air flow from influencing the flow into the hopper. This was done to prevent the occurrence of the situation found in service on engines equipped with the standard modified draft where the draft chutes, being located on the sides of the pan, allow crosswinds to cause greatly disproportionate flows of air through the two ports. Reportedly, this effect was at times sufficient to cause firebox to be visibly free of fire on the windward side which obviously would cause a mal-distribution of heat and consequently undesirable stresses in the firebox, increasing maintenance.

It was therefore manifest that Gyrojet oil burner used in conjunction with the taper type firepan approached an optimum combination for steam locomotive use. The burner produced good atomization over a sufficiently wide range of rates to eliminate need for its use in multiple and furthermore the burner required no attendant mechanical equipment such as pumps, special strainers, special heaters etc., the usual gravity fuel feed and other conventional arrangements being sufficient. There also should be no need for mechanical maintenance on the burner for both the oil and atomizing passages are sufficiently large to avoid stoppage under any normal conditions; the only operational maintenance necessary being the provision of a small amount of atomizing steam flow for a short length of time after fire is extinguished. This continuation of a small amount of atomizer after fire is put out assures that no oil, which might later harden or carbonize, enters the atomizing steam passages.

## DETAILED DISCUSSION OF INDIVIDUAL TESTS

This section has been included to cover the miscellaneous observation and data recorded during the individual tests, which were not readily shown by other means.

The tests of burners in the locomotive were designated by a symbol system which continued the method used for the firepans and front ends in previous test series and included an additional item to indicate the burner.

The burners, as well as the different firepan and front end arrangements were assigned numbers in sequence, as tested, consequently, the number assigned bears no relation to the style or design, nor to the performance. Furthermore, the numbering system was applied only to those burners on which full scale regular combustion tests were made in locomotive. Therefore, the reported data shows no gaps in the burner numbers although some other burners were tried in the locomotive, as for example the several preliminary designs of Coen burners which culminated in the final style that was given the regular full scale test and assigned number "B1" since its test marked the start of the burner series.

The second symbol in the designation, "T10" for example in the series "B1-T10-D", indicates the firepan arrangement and that it was the tenth modification of the T&NO style firepan.

The third portion of the designation, "D" in same sample, indicates the size of exhaust nozzle and cross split used in the locomotive front end during the tests. In this case, the "D" indicates that the exhaust nozzle was 8" diameter and the cross split was the 5/8" x 3" basket bridge. The two letter symbols, such as "AB", "AC", etc., were merely the result of having passed through the alphabet once in the designations and the letter "A" was used as a prefix in the subsequent designations.

The "wye pipe" pressures mentioned herein were the pressures existing in the wye shaped pipe connected to the steam chest heads through which the surplus steam resulting from the desuperheating spray water was bled off. These pressures were used in establishing the desired steaming rates for reasons as explained in report ST, entitled "Description of Sacramento Locomotive Standing Test Plant."

The firepan arrangements and the exhaust nozzles described are also shown diagramatically in the various sketches.

<u>Test B1-T10-D</u> (Coen Burners - side application, opposing jets.)

Tests were run at 4, 7, 10 and 13 pounds wye pipe pressure.

The engine was equipped with an 8" nozzle, 1/2" x 3" basket cross split and basket spark arrester. There was no sand ejector. The T&NO firepan had a bottom air duct with front damper for supplying air to the 6 main Coen burners. A Coen pilot burner was mounted on each side of the firepan 12" ahead of the flash wall. These two burners had no damper or chute, and were equipped with the hollow truncated cone type of shield. Shields were not used on the main burners.

At the 4 pound rate, atomizer steam pressure was 100 pounds. Fuel oil pressure was 90 pounds at pump. Oil temperature was 177$^{\circ}$ at burner. The front damper was 1-1/4" open and firebox draft was 5.7". Excess air as indicated by analysis of flue gas samples was 15.9%.

For the 7 pound rate, fuel oil pressure at the pump was 88 pounds; oil temperature at the burner was 172°. Pilot burner atomizer pressure was 80 pounds and main burner atomizer pressure was 140 pounds. The front damper was open 1-1/4" and firebox draft was 10.1". Excess air was 13.4%.

For the 10 pound rate, oil pressure at the pump was 86 pounds. Oil temperature at burner was 173°. Atomizer steam pressure was 98 pounds for pilot burners and 158 pounds for main burners. Front damper was open 1-1/4", and firebox draft was 14.2". Excess air was 5.8%.

For the 13 pound rate, oil pressure at the pump was 86 pounds; oil temperature at the burner was 174°. Atomizer steam pressure was 90 pounds for the pilot burners and 153 pounds for main burners. The front damper was open 2-1/8", and firebox draft was 15.6". Excess air was 6.3%.

The fire was quiet and smooth at all test rates. The stack was clear. Snoke was 0.25 Ringelmann at the high rate. Combustion was not sootless and when flues were sanded, No. 4 or 5 density smoke resulted until flues were well sanded. Some of the sand collected at the bottom of firepan near the front wall, particularly on the left side. No carbon was visible in firepan or on crown sheet when the tests were over. The brickwork was uniformly hot. It was noted that some of the firebox stays were leaking.

It was evident that a nozzle of larger effective area could be used with this oil burning arrangement.

Test B1-T10-AF (Coen Burners - side application, opposing jets.)

Tests were run at wye pipe pressure of 4 and 7 pounds.

The engine was equipped with an 8-3/4" nozzle, 1/2" x 3" basket cross split, and basket spark arrester. There was no sand ejector.

The T&NO firepan was equipped with 6 Coen main burners and 2 Coen pilot burners, arranged four on each side of firepan. Pilot burner centers were 12" from the flash wall, with the remaining burners spaced 13" apart between centers.

Air to the main oil burners was controlled by a damper at the front of the firepan. There was no damper or draft chute to the pilot burners, but air for the main burners was passed through a draft chute built around the outside of the firepan so that this air would scrub the firepan surface, utilizing waste heat transmitted through the firepan walls and bottom. There was a transverse draft slot in the bottom of the firepan below each transverse pair of burners, or a total of four slots.

The Pacific Lines standard firedoor was used.

Each burner was equipped with the Coen hollow truncated cone type burner shield. These had been reinstalled on the main burners to reduce the tendency of the flame to withdraw from the main draft chute throats with consequent drumming.

When firing up and setting up the 4 pound rate, there was some smoke, chiefly due to the fact that the oil in the fuel tank was not thoroughly heated. The temperature indicated by tank thermometer was 115°. As this should have been close to 180° to feed the pilot burners, oil to the pilot burners was cut off for these tests. The

Coen oil heater brought the oil temperature up to 148° for the main burners for the 4 pound rate, and to 163° for the 7 pound rate. The thermometer in the line to the burners indicated 180° during the 7 pound rate.

When the throttle was first opened the boiler pressure dropped from 245 to 190 pounds and 45 minutes were required to recover working pressure of 245 pounds. The drop in boiler pressure was relatively small when changing to the 7 pound rate, and was quickly recovered.

The fire was quiet during these tests. Smoke was No. 0.2 Ringelmann, which was practically clear.

The front damper was open 2" at the 4 pound rate; excess air was 8.1%. At the 7 pound rate the front damper was open 4", and excess air was 6.9; CO was indicated at 0.2%.

The performance of the Coen burners appeared to be satisfactory at these rates and would permit the application of a nozzle of larger area. The basis for selecting the size used was the fact that it was the largest nozzle reported in connection with the 20" stack by Battelle, at the time of its selection.

There was no carbon in the firepan or on the crown sheet when tests were completed.

<u>Test B2-T11-AB</u> (Von Boden Burner - 3-1/2" size.)

Test series with T&NO standard burner in a T&NO firepan modified to Santa Fe style and a 9-1/2" nozzle with 1" cross split, was started.

Tests were begun at the 11 pound wye pipe pressure rate to permit good sanding of the flues and faster heating of firebrick and cylinder for the initial test.

At the conclusion of 11 pound test, rate was raised to 14.5 pounds and test data taken for about 10 minutes at which time boiler water started carrying over to the extent that steam temperature particularly in right steam pipe dropped to practically saturation and water level varied rapidly as much as 3".

Feedwater pump also stopped during this period and throttle was closed. Some time was required to get pump started and it appeared to be steam bound.

When pump had been started, throttle was again opened and water level was again very unstable. Water from pump was then injected through side check instead of top check and condition was relieved somewhat temporarily but recurred. Powdered antifoam was then placed in the tender and mixed in thoroughly.

Water level thereafter was quite stable and redirecting water through top check had no disturbing effect.

Test of tender water showed one or less grains hardness and accordingly but a one pound ball of compound per 4000 gallons had been put in tender. The continuous blowdown was used and at time of disturbance test of water showed 165 grains per gallon, however, no phosphate was found.

On second day of this series, test runs at 8 pounds, 14 and 4 pounds wye pipe test rates were made in the order named.

Excess air for all runs appeared high, 60% at the 4 pound and 35% at the 14 pound rate.

Trouble with carry over of boiler water continued. The last 15 minutes of the 14 pound test rate was disregarded account drop in steam pipe temperature. At close of last run, boiler water sample showed a dissolved solids content of 265 grains per gallon. After last run, boiler was blown off to reduce concentration.

On third day of this series boiler was fired up at start of day to run check points with the T&NO burner and for making firebox survey.

The intention was to run tests at rates of 6, 9, and 14 lbs. wye pipe pressure, but due to time lost account water carrying over into cylinders only the 6 and 14 lb. rates were run.

The boiler had been blown off following tests on previous day, but water sample from boiler as analyzed by Nalcometer showed 220 grains total solids and 176 grains actual by evaporation.

The continuous blowdown was open during one run only and thereafter was opened only between runs as it was not feasible to have it in operation during the test periods.

Two and a half lbs. of compound per 6000 gallons water were used on the second day and the early part of the third day to increase the antifoam concentration but results were unsatisfactory. Boiler water has been showing appropriate $PO_4$.

Boiler was blown off after the 6 lb. rate and antifoam compound used. This antifoam stopped the foaming enough to allow the 14 pound rate to be run.

Partial gas sample survey of firebox was made at 14 pound rate.

The excess air remained high, 56% at 6 pound rate and 38% at 14 pound rate. Stack was clear and the fire quiet.

After shutting down, a knob of carbon was observed extending

16 inches from flash wall. Carbon had been knocked off as well as possible, several times during the day and bottom hopper damper was kept nearly wide open to avoid hopper filling with unburned oil as occurred on the previous days tests.

Following completion of several additional series, with other burners, check tests were run at wye pipe pressures of 14½, 9½ and 6½ pounds again using the standard 3½" T&NO burner as previously installed.

Atomizer pressures of 16, 32, 14½ and 19 pounds were used with the above rates respectively; the bottom damper was open 8, 3 and 7 links.

There was fairly heavy drumming of the fire during the 14½ pound rate. There were some periods of drumming for the 9½ pound rate. The fire was quiet during the 6½ pound rate. Carbon extended 14" from the flash wall at the end of the 9½ pound rate.

Color from the stack was 0.08 to 0.12 Ringelmann with some puffs of No. 1 and No. 2 and heavier smoke.

The atomizer pressure was raised to 19 pounds for the last 15 minutes of the 6½ pound rate in an effort to stop oil dripping into the bottom hopper.

A 4 pound rate was set up, but in view of considerable flame in the bottom hopper, and accumulation of carbon on the flash wall, floor of firepan, and bottom draft castings, no further tests were made. Carbon extended 24" from the flash wall in the form of a horizontal hollow crater. Unburned oil dripped from this carbon through the bottom draft ports, causing the bottom ports to clog with carbon, and fire in the bottom hopper. Changes in atomizer steam pressure did not alleviate this condition.

Excess air was 34, 37, and 50%.

Moisture in the oil was 5.1%.

Antifoam compound was added to the feedwater. There were no indications of foaming. The continuous blowdown was operated between test rates.

Additional check tests were run at 12½, 8, and 4 pounds wye pipe pressure with the 3½" T&NO burner.

Atomizer pressures of 22.8, 36, and 24 pounds were used.

The bottom damper was open 7 links for the first rate, 8 for the second, and 6 links for the last rate.

The fire drummed lightly during the high rate, at first and became quiet later. There were puffs of 0.2 to 1½ Ringelmann smoke, and heavier, with the density increasing to #5 as the test progressed. Atomizer steam pressure change did not reduce the smoke density. Carbon deposited on the flash wall was 10" for this rate.

For the 8 pound rate the fire was quiet. There were puffs of #1, 2 and 3 Ringelmann smoke from the stack, the density falling as the test progressed. Carbon at the end of this rate was 24" on the flash wall. Oil began to drip into the bottom hopper and burn.

Carbon was knocked down after this test run and the bottom air ports cleaned. This stopped the oil drip into the bottom hopper.

For the 4 pound rate, the fire was quiet. Smoke was 0.1 and 0.2 Ringlemann with puffs of #1 to #2 Ringelmann. For the last 10 minutes of this run oil was dripping and burning in the bottom hopper. Carbon extended out 15" from the center of the flash wall and 20" on the floor, with more carbon on the right side of the firepan.

Excess air was 38, 49 and 53%. Moisture in the oil continued at 5.1%.

<u>Test B3-T11-AB</u> (Great Northern Burner)

During initial firing up for tests in this series, it was noted that some carbon was accumulating on the floor of the firepan from the Great Northern oil burner at 1° elevation angle, and the angle of elevation was accordingly increased to 2°.

Test rates were run at 9, 14 and 4 pound wye pipe pressures. The bottom damper was open 6 links for these rates. Excess air was 48% at the 9 pound rate, 34% at the 14 pound rate, and 61% at the 4 pound rate. The atomizer steam pressure at the oil burner was 21, 32, and 26-22 psig for the 9, 14, and 4 pound rates, respectively. The fire was usually quiet with occasional periods of light drumming, which became continuous towards the end of the 4 pound rate.

The stack color was clear to very slightly hazy.

A partial firebox survey was made at the 14 pound rate. Carbon on the flash wall was about 15" thick at the end of this rate, judging from what could be seen through the 2" side air tubes. Most of the carbon on the flash wall had been consumed at the end of the 4 pound rate, as only 4" remained; carbon on the floor of the firepan was 4" thick at the front bottom port and tapered out approximately a foot ahead of the port. There was also a thin tapering section of carbon on the right side of the brickwork at the front 2" draft tubes.

The Great Northern burner atomized the oil at low firing rates to the extent that the flame was somewhat similar to a torch, and burned closer to the burner than with the Von Boden burner. Some oil dribbled in unatomized condition from the under side of the burner lip, particularly on the left side of the firepan.

Water was blown off at end of the tests to reduce concentration and a boiler water sample taken.

Tests with the Great Northern oil burner were continued for a second day but were made at wye pipe pressures of 4, 6½, 11½, and 14½ pounds. Atomizer steam pressures at the burner were 20, 20, 27, and 26 psig respectively. The bottom damper was open 6 links except for the 14½ pound rate in which it was open 3 links. Excess air was 57, 50, 43 and 32 per cent for these rates, respectively. The fire was usually quiet, with a few periods of light drumming.

The color from the stack was clear with some slight haze.

Carbon at the end of the 14½ pound rate was as follows; 24" on the flash wall and 6" on the floor at the front bottom port which tapered out 12" ahead of the port. There was a 6" wide clear space on each side between the carbon on the floor and the side walls of the firepan.

Unatomized oil continued to dribble from the under side of the burner lip, mostly on the left side of the firepan.

<u>Test B3-T12-AB</u> (Great Northern Burner)

Tests were run using the Great Northern burner set 14" above the floor, at wye pipe pressures of 14½, 9½, 6½, and 4 pounds.

Atomizer pressures were 22, 28, 25, and 23 pounds. Bottom damper was open 9, 5, 3 and 2-1 links. The burner elevation was changed from the $1^{\circ}$ to the $2^{\circ}$ setting after the 14½ pound rate.

Smoke was 0.2 to 0.4 Ringelmann at the start of the 14½ pound rate and increased to #1 and #2 later. Smoke was #3 and 4 during the partial firebox survey, but after the survey was completed and the flues were sanded, varied from 0.5 to 2 Ringelmann.

For the other rates, the smoke varied from 0.05 to 0.15 Ringelmann, except that there were puffs of 0.2, and 0.3, and 0.4 Ringelmann smoke during the 9½ pound rate.

Excess air was 31, 41, 48, and 53%.

At the end of the test runs there was a wedge of carbon on each side of the firepan ahead of the side draft ports, with thickness and width of one foot, tapering out about a foot ahead of the side ports. There was a thin layer of carbon on the floor extending forward from the front bottom port.

There was practically no carbon on the flash wall.

Moisture in the oil was 4.35%. No oil dripped through the bottom draft ports.

<u>Test B3-T13-AB</u> (Great Northern Burner)

With this firepan arrangement, the Great Northern burner was placed at a $3^{\circ}$ elevation angle setting to reduce the amount of oil which had sprayed on the floor while firing up.

Tests were run at wye pipe pressures of 14½, 9½, 6½, 4 and 14½ pounds. The 14½ pound rate was run for 1/2 hour after completing the 4 pound rate, for comparison with the results of the 14½ pound rate set up as the first test.

Atomizer pressures were 88 pounds for the first 14½ pound rate, 70 pounds for the 9½, 6½, and 4 pound rates, and 80 pounds for the last 14½ pound rate.

The bottom damper was closed for all except the 6½ pound rate, during which time it was open 1 link.

A partial firebox survey was made during the first 14½ pound rate. For the first 14½ pound rate smoke was 0.15 with puffs of 0.2 to 0.7 Ringelmann; for the final 14½ pound rate, smoke was 0.3 with puffs 0.4 to 1.8 Ringelmann. The fire was quiet.

For the 9½ pound rate, smoke was 0.15 with puffs of 0.2 to 0.6 Ringelmann. Drumming was light to medium.

For the 6½ pound rate, smoke was 0.08 with puffs of 0.1 to 0.5 Ringelmann. There was medium drumming which lightened periodically.

For the 4 pound rate, smoke was 0.07 with puffs of 0.1 to 0.2 Ringelmann. Drumming was medium.

It was noted that a relatively small restriction at the burner port would lessen the intensity of drumming.

Excess air was 32, 43, 48, 51 and 33%.

Moisture in the oil was 5.3%.

At end of tests there was 4" of carbon on the right side just in front of the side ports, 10" high on the side wall, starting 4" above the floor. There was 3" of carbon on the left side at the same location extending 14" up the side wall starting from floor of firepan. This carbon extended a foot in front of the side ports. There was also a small amount of carbon at the base of the flash wall. Otherwise the firepan was free of carbon.

<u>Test B3-T13-AC</u> (Great Northern Burner)

Tests in this series were run at wye pipe pressures of 13½, 9, 6 and 3 pounds, using 7/8" cross split on 9½, nozzle, and Great Northern burner at 3° setting. Bottom of burner was 15-5/8" above lower surface of bottom firepan plate. The lip of the burner coincided approximately with the center line of the 8" ID port.

Atomizer pressures were 70, 52, 26 and 26 pounds.

Bottom damper was open 1 link for all of the rates except for the 9 pound rate when it was shut.

A partial firebox survey was made during the 13½ pound rate. Smoke was 0.2 with puffs of 0.3 to 1.1 Ringelmann. There was light drumming.

For the 9 pound rate smoke was 0.08 with puffs of 0.2 to 0.3 Ringelmann which decreased to 0.12 Ringelmann as the test progressed. There was medium drumming.

For the 6 pound rate the smoke indicator registered 0.07 with puffs of 0.1 to 0.15 Ringelmann; 0.07 Ringelmann for the 3 pound rate. Drumming was of medium intensity for both of these rates.

Moisture in the oil was 7.0%.

Excess air was 30, 38, 41, and 42%.

At end of tests there was relatively little carbon in the firepan. At front of the side ports, carbon was 1" thick on the side walls, 10" high, extending 4" ahead of the side ports. There was 8" of clear space under this carbon. A small amount of carbon formed at the base of the flash wall.

It was noted that the drumming could be stopped by restricting the upper section of the burner port.

Test B3-T14-AD (Great Northern Burner)

At the start of these tests, the boiler was brought up to working pressure, and fire cut to a spot fire. The spot fire burnt at the flash wall and dense white smoke appeared at the stack. As the spot fire was not satisfactory, the burner was raised so that the bottom of Great Northern oil burner was 16¼" above the lower surface of the bottom firepan plate, and was left at the 3° setting. This did not improve the spot fire noticeably.

The throttle was opened for setting up a 12½ pound rate. As there was then some heavy smoke, various horizontal rows of side draft ports were blanked off with side plates in an effort to improve combustion.

The burner elevation was changed to the 1° setting and burner was later dropped so that bottom of the burner was 16" above bottom of firepan, measured outside of the firepan, 3/8" higher than setting for tests B3-T13-AC. This lessened the smoke density. A series of tests were run at 12, 9, 6, and 3 pounds wye pipe pressures, with Great Northern burner at 16" height, 1° elevation setting. The T&NO firepan had the third and fifth upper horizontal rows of 2" ID side ports shut. The front bottom transverse draft port chute inlet was restricted to 3/4" height opening at the top. The bottom damper which controls the two back bottom transverse ports was open 2 links. These 3 bottom ports are each equipped with a 2-3/4" x 28" port draft casting, No. ST-297. The bottom hopper was similar to the T&NO bottom hopper except that it was widened above the engine frame to accommodate the two rear bottom transverse ports, and there was no fixed air opening at the front.

The burner port was 8" inside diameter with bottom 12" above the outer bottom of the firepan. The flared approach on this port was cut off on the sides to permit the adjustable burner bracket to be moved close to the end of the firepan.

The boiler was equipped with the Pacific Lines standard fire door.

Atomizer pressures were 76, 46, 68 and 22 pounds at burner respectively for the 12, 9, 6 and 3 pound wye pipe pressures.

Smoke color for the 12 pound rate was No. 1 with puffs of 1½ to 2.2 Ringelmann. The fire was quiet. Excess air was 16%.

For the 9 pound rate the smoke ranged from 0.3 to 0.7 Ringelmann. There was very light drumming.

For the 6 pound rate the smoke was 0.2 with puffs to 1.8 Ringelmann. There was light drumming. 8" of carbon was visible on the flash wall at the end of this rate. Excess air was 28%.

For the 3 pound rate, smoke at first was 0.2 with puffs up to 1.1 Ringelmann. This density reduced later to a range of from 0.1 to 0.4 Ringelmann. There was light drumming. Excess air was 28%.

At the end of the tests there was 2" of carbon on the lower flash wall. There was no carbon on the other parts of the firepan. Considerable slag fused on the burner wall from sanding.

Moisture in the oil was 6.8%.

<u>Test B4-T11-AB</u> (Rock Island Burner)

These tests were run using the Rock Island burner (2° angle of elevation), at wye pipe pressures of 9½, 14½, 6½, and 4 psig.

Some unatomized oil sprayed from under the lip of this burner, more on right side of the firebox than on the left and considerably less than for the Great Northern burner.

The bottom damper was open 5 links.

Atomizer pressures of 30, 24, 27, and 28.5 pounds at the burner were used for the wye pipe pressures of 9½, 14½, 6½, and 4 pounds respectively.

There was some slight haze from the stack at the three high rates, although in general, the stack was practically clear. Stack was clear at the 4 pound rate.

After the 14½ pound rate, the zero point on the smoke indicators was reset to 0.05 R, to prevent the pointers from striking the stops at the zero point.

The fire was usually quiet, although some slight drumming developed during the 4 pound rate.

Excess air was 43, 31, 51 and 57% for the tests in the order as run.

There was about 15" of carbon on the flash wall during the 14½ pound rate, as observed through the 2" side air ports, and this was knocked down with a bar.

At the end of the test runs, a 9" point of carbon remained on the flash wall, although most of the deposit was about 4" thick. Carbon on the floor was about 8" thick at the front bottom port and tapered out to a point about 20" ahead of this port. There was a clear space of about 6" on either side of the floor carbon.

The boiler water foamed during the 14½ pound rate, and some time was required after this rate was reduced before the foaming quieted sufficiently for the 6½ pound rate.

A partial firebox survey was made at the 14½ pound rate.

A separate fuel oil sample was taken for each rate, on account of the high moisture content.

Test B5-T11-AB (Von Boden Burner - 4¼" size)

Tests in this series were run with the 4¼" Von Boden burner at wye pipe pressures of 9½, 14½, 6½, and 4 pounds. Atomizer pressures of 21½, 35, 17, and 17 pounds were used with these rates respectively.

The bottom damper was open 8 links.

Color from the stack was slightly hazy with puffs of 0.3, 0.4 and 0.5 Ringelmann smoke for the 9½ and 14½ pound rates. The burner was realigned slightly after the 9½ pound rate.

The stack was practically clear for the two lower rates, with very slight haze visible.

The average oil sample taken for the four rates had a moisture content of 5.6%.

Excess air was 47, 31, 52 and 61%.

A partial firebox survey was made at the 14½ pound rate.

Approximately 15" of carbon was on the flash wall at the end of the 14½ pound rate. This was reduced to 8" during the two last rates, and only a small mound was on the floor just ahead of the front bottom port.

The hot water meter was inoperative for the last 3 rates on account of a small piece of steel entering meter and blocking the nutating disk.

Antifoam was used, and the quantity was increased during the 14½ pound rate on account of foaming.

The tests were repeated with the 4¼" Von Boden oil burner, $2^{o}$ elevation angle at wye pipe pressures of 14½, 9½, 6½ and 4 pounds, because of the difficulties with the meter, and foaming.

Atomizer pressures of 39, 42, 42.5-25, and 25 pounds were used for these rates, respectively. The 42.5 pound atomizer pressure was too high for the 6½ pound rate so that smoke developed and some oil dripped into the bottom hopper, and the pressure was therefore reduced to 25 pounds for the last 15 minutes of this run. 25 pounds atomizer was also high for the 4 pound rate, as oil from the flash wall began to feed into the bottom hopper, the front of which became red hot. This stopped when atomizer was reduced to 17 pounds after the run was completed.

The bottom damper was open 8 links for the two high rates, and 7 links for the two low rates.

The stack was clear to slightly hazy for the 14½ and 9½ pound rates, with some puffs of from 0.2 to 0.4 Ringelmann smoke.

For the 6½ pound rate, color from the stack was clear with puffs of slight haze at the start. The density of the puffs increased to No. 1 and 2 Ringelmann as the test proceeded. The stack was clear to slightly hazy for the final 15 minutes of this rate, after atomizer pressure was reduced.

Color from the stack was clear to very slightly hazy for the 4 pound rate.

The fire was quiet for all test rates.

About 15" of carbon accumulated on the flash wall during the two high rates. At the end of the tests there was 10" of carbon on the left side and 15" on the right side of the flash wall, increasing to 19" at the floor of the firepan on the right side. There was no carbon on the floor of the firepan ahead of the front bottom port.

Excess air was 27, 36, 46 and 54%. Moisture in the oil continued at 5.6%.

Antifoam compound was sued and no difficulty was experienced from foaming on this day.

The continuous blowdown system was turned on between test runs.

While setting up the first test rate, various horizontal rows of 2" side draft ports above the second row were blocked off temporarily. None of these combinations was as satisfactory as the original arrangement on account of increased density of smoke.

Test B6-T11-AB (Clark Burner - Florida East Coast Ry.)

Tests of this series were run with the Florida East Coast burner, at wye pipe pressures of 14½, 9½, 6½, and 4 pounds.

Atomizer steam pressures at burner were 48, 44, 37, and 21 pounds.

The bottom damper was open 1 link for all except the 4 pound rate when it was closed.

There was some light drumming during the 9½ pound rate, and medium periodic drumming during the 4 pound rate.

During the 4 pound rate, the flame turned upwards about 2 feet ahead of the flash wall, but would reach the flash wall during the periods of drumming. A relatively small amount of oil reached the flash wall during this rate, and the scattered drops could be observed to burn momentarily at the points of impingement.

During the period of firing up before the test runs, the fire was observed to strike the floor brick of the firepan a short distance from the burner, and a thin layer of carbon had accumulated at this point. This increased to a ridge about 3" wide by $1\frac{1}{2}$" high during the $14\frac{1}{2}$ pound rate. At the end of the 4 pound rate, this deposit had increased to approximately 10" wide by 30" long, directly in line with the burner and tapered vertically from the 10" height toward the burner to a thin section. The back face of this wedge of carbon was undercut by a clear space which tapered from a 6" height at the back face for a foot ahead down to the floor of the firepan. Carbon on the flash wall was 6" thick.

The exhaust from the stack was practically clear. Only a very slight haze was apparent most of the time. There were a few puffs slightly darker, which were 0.2 Ringelmann on the smoke indicator.

A partial firebox survey was made for the $14\frac{1}{2}$ pound rate.

Excess air was 30, 40, 47, and 49%. Moisture in the oil was 4.3%.

One ball of treatment for silica and one enlarged measure of antifoam were used when filling the tender from the 5000 gallon mark.

No difficulty was experienced from foaming.

This burner produced excellent small fires, with flame close to the burner and torch like.

<u>Test B6-T12-AB</u> (Clark Burner-Florida East Coast Ry.)

This series was made with the Florida East Coast burner raised to 14" above floor brick.

Tests were at wye pipe pressures of 12 and 8 pounds. Atomizer pressures were 32 and 28 pounds. The bottom damper was open 7 links for the 12 pound rate, and 1 link for the 8 pound rate.

The fire was quiet and burned with a white flame. Oil spray leaving the burner appeared somewhat darker and heavier from the lower half of the burner.

Color from the stack was clear with some puffs of slight haze. The smoke indicator dial registered 0.04 Ringelmann usually.

There was no tendency for oil to drop into the bottom hopper.

At the finish carbon on the floor of the firepan was 2" thick, starting about 18" ahead of the 2" side draft ports in two ridges which merged and covered the full width of floor brick about 6" ahead of the side draft ports, and extended to the bottom draft ports. There was in addition an inverted crescent of carbon on the flash wall, extending forward about 3".

Excess air was 39 and 44%. Moisture in the oil was 5.6%.

Additional tests were made using the Florida East Coast burner in this firepan arrangement at wye pipe pressures of 14½, 9½, 6½ and 4 pounds. The bottom damper was open 3 links for the two high rates and 1 link for the two low rates.

Atomizer pressures were 54, 60, 32 and 32-38 pounds.

A partial firebox survey was made during the 14½ pound rate.

During firing up period prior to test runs, the fire would drum when the oil rate was high. For the test rates the fire was quiet, showing a slight tendency to drum when the fire door peephole was open to sand flues during the 6½ pound rate.

Color from the stack was clear for all rates except the 4 pound rate during which puffs of #1 to 1½ Ringelmann smoke developed. After sanding flues and increasing atomizer, the smoke density decreased.

For the 4 pound rate the fire turned upward about 16" ahead of the flash wall at 32 pound atomizer pressure. When atomizer pressure was increased to 38 pounds during the last 15 minutes, the fire reached the flash wall.

No oil dripped through the bottom draft ports with this burner.

At the end of the tests there was a small amount of carbon on the flash wall. Carbon formed on the floor and left side of the firepan ahead of the side draft ports. The deposit was 14" high starting at the left front side draft tubes and tapering down towards the bottom of the burner wall. There was a clear space of one foot width at the floor between this carbon and the right side of the firepan, and the carbon sloped up steeply towards the left side from this clear space. This carbon on the left side was due to the direction of the steam jets at the bottom of the burner which threw the oil towards the left side. It was noted previously that the lower jets carried a higher proportion of the fuel oil than the upper jets, as indicated by a darker color spray from the bottom of the burner.

This carbon accumulation evidently caused the increase of smoke density during the low rate.

Moisture in the oil was 5.02%, and the density continued to be slightly high, at 8.42 pounds per gallon.

Excess air was 28, 38, 49 and 60%.

Test B6-T13-AB (Clark Burner - Florida East Coast Ry.)

After applying the additional bottom airport, tests were run at wye pipe pressures of 14½, 9½, 6½ and 4 pounds, using the Florida East Coast Oil burner at a $1^{o}$ tilt. Bottom of the burner was 15¼" above the bottom of the firepan, measured outside of the firepan, that is, center line of burner was 1/2" above center line of the 8" ID draft port.

Atomizer pressures were 49, 52, 55 and 53 pounds at burner. The bottom damper was open one link for all of the test rates.

Drumming of the fire was light to medium for the high rate, light for the 9½ pound rate, and medium for the two lower rates.

A partial firebox survey was made during the 14½ pound rate. Smoke during this rate was 0.1 with puffs of 0.15 to 0.2 Ringelmann. Smoke was 0.08 to 0.07 Ringelmann for the three lower rates.

Excess air was 36, 49, 53 and 56%.

During the individual tests, moisture in the oil was 5.3, 5.0, 5.2 and 5.4%, respectively.

At the end of the tests the firepan was free of carbon with the exception of a small 4" knob at the front of the left bottom 2" side port.

Repairs had been made to the feedwater heater float valve and the flow of cold feed water was more sensitive to changes in spray chamber water level than previously and less time was required to set up the various test rates.

The boiler pressure began to rise rapidly when it became necessary to refill the oil tank during the 14½ pound rate, as the air pressure increased from $8\frac{1}{2}$ pounds to 10 pounds. The boiler safety valve was prevented from popping by adjusting the oil controller while on automatic position.

<u>Test B7-T12-AB</u> (Chamber Type Tubular Burner)

When the fire was started, using the tubular oil burner, it was noted that considerable oil sprayed on the right side of the firepan and on the floor at the low firing rate used to raise steam to working pressure. The burner was therefore pointed towards left side of the firepan and the elevation angle changed to a $3^{\circ}$ setting to improve spray distribution in the firepan.

The bottom of the burner tube was $16\frac{1}{4}$" above the bottom of the firepan. The bottom of the 8" ID burner port was 12" above the bottom of the firepan outside. As applied, the center line of the burner was $1\frac{1}{4}$" above the centerline of the burner port.

After the burner was pointed towards left side of firepan, the oil continued to impinge on the floor and on the right side. However, when the throttle was opened and the firing rate increased, the fire appeared to be well distributed in the firepan.

Various atomizer pressures were tried and 30 to 40 pounds appeared optimum. Above 40 pounds, the oil capacity of the burner was restricted, and the engine would smoke when atomizer pressure was a little under 30 pounds. Twenty-six pounds was fair for the spot fire as too much atomizer would cause the fire to periodically go out and reignite.

The burner produced a smoky fire at low fires, before the throttle was opened. This may have been due to the shortness of the burner as made, which caused some of the oil to impinge on the burner port. Considerable time was required to raise the boiler pressure to 240 pounds.

Tests were run at wye pipe pressures of 14½, 9½ and 6½ pounds. Atomizer pressures were 39, 40 and 28-26 pounds. The bottom damper was open 8 links.

A partial firebox survey was made during the 14½ pound rate. Smoke was 0.15 - 0.3 Ringelmann with some puffs of 0.6 Ringelmann smoke. During the two lower rates, color from the stack was practically clear, ranging from 0.1 to 0.15 Ringelmann.

Fire was quiet for these rates.

Some carbon formed on the flashwall during the high rate. This had reduced to an 8" mound on the right side of the flash wall when the tests were over. There was also a small piece on the floor of the firepan just ahead of the front bottom port, on the left side. Otherwise, the floor and sides of the firepan ahead of the bottom port were free of carbon.

Moisture in the oil was 4.8%.

To complete this series, tests were continued a second day and boiler pressure was 120 pounds when fire was started, and as on the previous day, the firing up process was slow, and the low fire unsatisfactory, with oil impinging on the floor and right side of the firepan. However, after the throttle was opened, the burner functioned satisfactorily. This burner whirls the oil in a clockwise direction as one faces the burner and appears to throw more oil from the upper half of the burner judging from the color of the spray as viewed through the burner port.

Tests were run at wye pipe pressures of 12, 8 and 4 pounds wye pipe pressures. Atomizer pressures were 28, 39 and 26 pounds. The bottom damper was open 9 links.

Smoke was 0.1 Ringelmann, with puffs of 0.2 to 0.5 Ringelmann for the 12 pound rate, 0.15 to 0.4 for the 8 pound rate during which there was light drumming.

There was 9" of carbon on the flash wall after the 12 pound rate, 14" after the 8 pound rate and 7" after the 4 pound rate, mostly on the right side of the wall. At the end there was also a 2" layer of carbon on the left half of the firepan floor, extending from the bottom port and tapering out 18" ahead of the bottom port.

Fuel oil contained 4.7% moisture.

In draining the fuel line while atomizer steam pressure was on, it was noted that the atomizing steam caused back pressure in the burner and oil line, similar to a blow back.

Test B7-T13-AB (Chamber Type Tubular Burner)

These tests with the tubular burner were run at wye pipe pressures of 14¼, 9½ and 6½ pounds. Atomizer pressures were 28-30, 29 and 29 pounds.

The bottom damper was open 1 link.

Smoke ranged from 0.08 to 0.1 Ringelmann. There were some puffs of 0.15 to 0.2 Ringelmann smoke at the high rate.

The fire drummed lightly for all of the rates, periodically somewhat more heavily at the high rate.

Excess air was 36, 47 and 54%.

A 4 pound wye pipe pressure rate was set up for test, but this run was not completed because of erratic action of the feed-water pump.

Near the end of the second 15 minutes at the 14½ pound rate, the steam pressure rose abruptly to popping pressure, which resulted in a break of approximately an hour between the first 15 minutes and the last half hour of data for this rate.

At the end of the test runs there was 12" of carbon on the flash wall. There was a thin layer on the floor extending from the front bottom port forward 1 foot. There was a 2" layer on the floor between the front and intermediate bottom port which increased to a 6" mound on the left side. There was also a small deposit of carbon at the front end of the side ports.

Moisture in the oil was 6.2%.

Test B8-T17-AB (Multiple Diamond Channel Burner)

Test arrangement for this series was as follows: A 9½" nozzle, 1" cross split, basket spark arrester, 24" stack in standard position; 2½" sleeve in feedwater heater spray chamber, T&NO firepan, burner port and firedoor with modified ATSF side draft ports (40 -2" I.D. draft tube on each side of firepan), two 2-3/4" x 28" bottom draft ports with castings No. ST-297, taking air from rear bottom hopper equipped with damper at front and rear ends; Vee channel burner; bottom of burner 9-7/8" above outer bottom of firepan; burner had slight upward tilt. Top boiler check used.

Tests were run at wye pipe pressures of 9½, 14, 6½ and 4 pounds.

For the 9½ pound wye pipe pressure, exhaust nozzle pressure was 8.1 pounds; firebox draft 5.9"; smokebox draft 12.8". Atomizer pressure was 40 pounds for 8 minutes, 80 pounds for 17 minutes 52-50 pounds for the last 20 minutes. Baffler door damper was open 1", hopper front damper open 5°; hopper rear damper was shut at first and set at 1/4 open after 10 minutes operation. Color from stack was 0.1-0.15 Ringelmann with puffs of 0.2-0.4 Ringelmann; after 10 minutes this darkened to 0.15-0.6, with puffs to 1.2 Ringelmann and darker. The fire was quiet at first, drummed lightly with increased atomizer and opening of hopper rear damper. After 20 minutes of test, steam to the burner top atomizer jets was shut off on account of oil running out of the rear bottom draft port. $O_2$ ranged from 6.8 to 8.1%; $CO_2$ from 9.8 to 10.3%.

For the 14 pound wye pipe pressure, exhaust nozzle pressure was 12.2 pounds; firebox draft 6.9"; smoke box draft 16.3"; atomizer pressure was 47 pounds; baffler door damper 4" open; hopper front damper 30° open; hopper rear damper 5° open. Drumming of the fire was medium. Smoke was 0.2-0.4 with puffs to 0.7 Ringelmann and a few darker. The burner top steam jets were cut in again for this test. $O_2$ was 5.6 to 6.2%; $CO_2$ 11.7 to 12.3%.

For the 6½ pound rate, exhaust nozzle pressure was 5.4 pounds; firebox draft 4.2"; smoke box draft 9.0"; atomizer pressure was 44 pounds for 7 minutes 30-24 for the last 38 minutes. Baffler door damper was 1" open; hopper front damper 10° open; hopper rear damper 25° open. Fire was quiet with some light periodic drumming. Smoke color was 0.1-0.15 for the first 7 minutes then increased to

0.15-0.4 Ringelmann with some darker puffs up to No. 1 smoke. $O_2$ varied from 6.4 to 9.0%; $CO_2$ 9.9-11.1%.

For the 4 pound wye pipe pressure, exhaust nozzle pressure was 3.2 pounds; firebox draft 2.8"; smokebox draft 5.8". Atomizer pressure 23 pounds. Baffler door damper was 1" open; hopper front damper 10° open; hopper rear damper 3° open. There was very light periodic drumming of the fire. Color from the stack was 0.1 to 0.13 Ringelmann. $O_2$ ranged from 8.6 to 9.6%; $CO_2$ 9.7-9.9%.

Carbon accumulation on the flash wall was knocked down periodically for the first 3 test runs, but was allowed to accumulate during the 4 pound wye pipe pressure test rate, and there was 24" of carbon on the flash wall when the throttle was closed. There was practically no carbon on floor or sides of firepan ahead of the front bottom port.

<u>Test B9-T15-AD</u> (Alexander Rotary Cup Burner)

As initial tests of this series had evidently been affected by the formation of carbon between the Alexander Rotary burner atomizing cup and housing, which stopped the rotation of the turbine and cup, this series of tests was rerun at wye pipe pressures of 3, 5½, 7½ and 10 pounds and arrangements were made to increase the oil temperature about 10°.

For the first test, wye pipe pressure averaged 3.1 pounds; exhaust nozzle pressure 2.2 pounds; firebox draft 4.9"; smokebox draft 6.7". Oil temperature 150° at burner; atomizer pressure 25 pounds; turbine pressure 53 pounds. Front damper 30° open; front bottom damper shut; rear bottom damper wide open. Smoke color was 0.2-0.4 Ringelmann; fire was quiet; $O_2$ 2.9%; $CO_2$ 14.1%.

Excess air was 13.3%.

For the 5.5 pound wye pipe pressure, exhaust noazle pressure was 4.2 pounds; firebox draft 5.8"; smokebox draft 9.3". Oil temperature 155° at burner; atomizer pressure 27 pounds; turbine pressure 59 pounds; front damper 50°open; front bottom damper 25° open; rear bottom damper wide open. Smoke color 0.15-0.2 Ringelmann; the fire was quiet; $O_2$ 4.5%; $CO_2$ 12.7%. Excess air was 26.0%.

For the third test rate, wye pipe pressure averaged 8.6 pounds; exhaust nozzle pressure 6.7 pounds; firebox draft 8.9"; smoke box draft 14.4". Oil temperature 156° at burner. Atomizer pressure 30 pounds; turbine pressure 60 pounds; front damper 40° open; front bottom damper 30° open; rear bottom damper wide open at first, 60° open later; smoke color 0.2 with puffs of 0.3-0.4 Ringelmann. Drumming of fire was light with some of medium intensity. $O_2$ 3.8%; $CO_2$ 13.3%; excess air 21.1%.

For the 11 pound wye pipe pressure, exhaust nozzle pressure was 8.7 pounds; firebox draft 10.7"; smokebox draft 17.5". Oil temperature 156° at burner; atomizer pressure 30 pounds; turbine pressure 60 pounds; front damper 45 open, front bottom damper 30° open; rear bottom damper wide open. Smoke color 0.5-0.8 Ringelmann; drumming of the fire was light to medium; $O_2$ 3.0%; $CO_2$ 13.8%; excess air 16.0%.

The side ports on the front bottom hopper were closed for these tests except that during the high rate the cover plates were removed for a short time, increasing $O_2$ from 3.8% on indicator to 4.8%, and reducing the drumming somewhat. Smoke density increased to No. 4 Ringelmann.

There was eight inches of carbon on the flash wall at the end of these tests. Carbon was 4" thick at the side of the rear bottom draft port and extended 20" ahead of the flash wall.

Moisture in the oil was 0.33%.

The spot fire prior to the test was satisfactory at 20 gals. per hour rate. The front damper was half open for this fuel rate, and the stack was clear.

Test B9-T15-AE (Alexander Rotary Cup Burner)

Tests were run at wye pipe pressures of 3, 5, 8 and 10 pounds. Locomotive was equipped with a 5/8" cross split, Pacific Lines type. Equipment otherwise was the same as for previous series.

For the 3.1 pound wye pipe pressure, exhaust nozzle pressure was 2.1 pounds; firebox draft 2.8"; smokebox draft was 4.9"; fuel turbine pressure 58 pounds; front damper wide open; front bottom damper $60^\circ$ open; rear bottom damper $65^\circ$ open; $O_2$ 3.7%; $CO_2$ 13.4%; excess air 20.4%; smoke 0.3 with puffs of 0.4-0.6 Ringelmann smoke; there was very light drumming of the fire.

Some carbon formed below the burner on the left side of the floor, and an arm of carbon built about 6" down from the firepan into the draft hopper. Some oil sprayed on the sides of the front hopper, quickly burned when the steaming rate was raised for the 5 pound test.

For the 5 pound wye pipe pressure, exhaust nozzle pressure was 3.7 pounds; firebox draft 4.7"; smoke box draft 8.0". Oil temperature was 156° at burner; atomizer pressure 49 pounds; turbine pressure 59 pounds; front damper wide open; front bottom damper 60° pounds; rear bottom damper 80° open; $O_2$ 3.7%; $CO_2$ 13.2%; excess air 20.4%; smoke at first was 0.5 to 1.6 Ringelmann, later was 0.2 to 1.4 Ringelmann. Drumming was light with periods of heavy drumming which lightened somewhat as the test progressed.

For the 8.2 pound average wye pipe pressure, exhaust pressure was 6.2 pounds; firebox draft 7.6"; smokebox draft 12.9"; atomizer pressure 69 pounds; turbine pressure 65 pounds. Oil temperature was 161°; front damper wide open; front bottom damper 80° open; rear bottom damper wide open; (the front damper was closed to 40° for a short time, which reduced drumming a little, and was then reset to 70° open.) $O_2$ 2.5%; $CO_2$ 14.2%; excess air 12.9%; smoke 0.4 to 0.8 Ringelmann, reducing to 0.3 Ringelmann later. Drumming was medium to heavy and drummed flame from the rear and front ports.

For the 10 pound wye pipe pressure, exhaust nozzle pressure was 7.7 pounds; firebox draft 10.1"; smokebox draft 16.2". Oil temperature 162° at burner; atomizer pressure 69 pounds; turbine pressure 56 pounds; front damper wide open; front bottom damper 60° open; rear bottom damper wide open; $O_2$ 2.0%; $CO_2$ 14.5%; excess air 9.8%; smoke 0.9 to 1.8 Ringelmann. There was heavy continuous drumming.

The front bottom hopper side ports were opened for a short time between test rates and the smoke density went up to No. 5 Ringelmann. When they were closed, the smoke density dropped. For all of these tests the side ports were closed.

There was 8" of carbon on the flash wall at the end of these tests, also an arm 6" high by 4" thick tapering to 2" thick at the end, formed on the left side of the diagonal wing wall in line with the burner outlet, extending 18" from the burner wall.

Test B10-T18-AC (Nagel Oil Economizer Process)

Locomotive equipment during this series was as follows: Nagel type firepan. Three Nagel micronizer oil burners at rear of firepan. One-eighth inch width of primary air slots in NOEP shields, and 1-1/2" clearance for secondary air around the shields; 1" transverse air slot in bottom of firepan, 11" ahead of side corners of firepan; 7/8" standard type cross split; 9-1/2" exhaust nozzle, 24" stack at standard height. Basket spark arrester; 2-1/2" sleeve in feedwater heater spray chamber. Spray chamber steam check valves removed. Pacific Lines firedoor. Sargent-Loedige quick opening blower valve. The main hand firing valve was used to control oil flow after setting the 6 separate oil pressure and atomizer valves for optimum fire and smoke conditions.

Boiler was brought up to working pressure using the center one, of the three Nagel burners. It was necessary to relight this fire four times, possibly on account of moisture in the oil, or in the atomizing steam from house supply.

An 8.8 pound wye pipe pressure was set up for test. Exhaust nozzle pressure was 7.4 pounds; firebox draft 6.1"; smokebox draft 12.0". $O_2$ was 5.5%; $CO_2$ 11.8%; excess air 34%. Smoke was 0.15 to 0.4 Ringelmann. Fire was quiet.

For the 13.2 pound wye pipe pressure, exhaust nozzle pressure was 10.9 pounds; firebox draft 8.1"; smokebox draft 16.3". $O_2$ was

4.6%; $CO_2$ 12.4%. Excess air 27%. Smoke ranged from 0.2 to 0.6 Ringelmann. The fire was quiet.

For the 5.9 pound wye pipe pressure, exhaust nozzle pressure was 4.8 pounds; firebox draft was 4.4"; smokebox draft 8.5". $O_2$ was 5.5%; $CO_2$ 11.8%; excess air 34%. Smoke varied from 0.15 to 0.7 Ringelmann. The fire was relatively quiet with only light pulsation.

For the 3.0 pound wye pipe pressure, exhaust nozzle pressure was 2.4 pounds; firebox draft was 4.4"; smokebox draft 8.5". $O_2$ was 6.5%; $CO_2$ 11.2%; excess air 43%. Smoke ranged from 0.15 to 0.6 Ringelmann. The fire drummed lightly.

The NOEP shields were red hot particularly at the low rate, but cooled at the higher rates on account of higher air flow through vanes and draft ports.

After setting the 6 separate atomizer and oil valves, the fire was hand controlled by the main firing valve. Oil pump pressures were 95, 93, 97 and 102 pounds respectively for the above tests. There was no difficulty in maintaining full boiler pressure with this arrangement. Relatively little soot was deposited in the flues at the high rates.

There was a very small piece of carbon on the firepan floor ahead of the center burner when tests were over.

On the second day of these tests, 6 pound wye pipe pressure steaming rate was established in order to quickly reach temperature stabilization of boiler and brickwork, and the boiler flues were thoroughly sanded.

A 3 pound wye pipe pressure was then set up for test and Battelle's firebox survey. Exhaust nozzle pressure was 2.3 pounds; firebox 2.3"; smokebox draft 4.4"; $O_2$ was 6.9-8.1% and $CO_2$ 10.7 - 11.3% on indicators. Smoke varied from 0.2-0.9 Ringelmann, and was increased by the insertion of firebox probes, reducing to 0.2-0.4 when the probes were removed. The fire was quiet with light pulsation.

After setting the 6 separate atomizer and oil pressure valves the oil flow was controlled by the automatic control valve for the test and firebox survey.

When the survey was over, small scattered flakes of carbon were glowing on the firepan floor, evidently having come from the NOEP shields.

On the third day in this series, the boiler was brought to working pressure using the center Nagel micronizer oil burner, air atomized. When fire was first started some oil dripped from the burner to the outside of firepan through the secondary air passage around the NOEP shield. The smoke was black for a short period and then cleared. The two side burners were cut in and throttle opened to set up a 2.7 pound wye pipe pressure steaming rate. When brickwork and boiler temperature had stabilized, a 13 pound wye pipe pressure was established for test and Battelle firebox survey.

For this test, wye pipe pressure was 12.9-13.0 pounds; exhaust nozzle pressure 10.7-10.9 pounds; firebox draft 7.6-7.8"; smokebox draft 15.5 to 15.8". Smoke was 0.8-1.4, reducing to 0.3-0.6 Ringelmann later. The fire was quiet. $O_2$ was 4.1-4.5%

and $CO_2$ 13.2-13.5% on indicators.

After the test and firebox survey were finished, the two outer NOEP shields were moved in to give a secondary air clearance of 1-1/4", which reduced smoke to 0.3-0.5 Ringelmann. A further reduction to 1" secondary air annulus width for the two outer NOEP shields reduced smoke to 0.2-0.3 Ringelmann. The center NOEP shield was left 1-1/2" clearance setting because of difficulty in changing its position while hot. The above reduction in smoke was not due entirely to change in position of NOEP shields, as exhaust nozzle pressure had changed from original 10.7-0.9 pounds to 11.3 pounds and 11.7 pounds for the new settings in the order given; and due to foaming there was apparently carry over in the left superheater units which reduced left steam pipe temperature from original 696° to 632°.

There were a few scattered flakes of carbon on floor of the firepan when above test was completed.

<u>Test B11-T19-AC</u> (Gyrojet Burner ST-323)

Because of limited time, tests of but 1/2 hour each were made at rates of 13, 9-1/2, 6 and 3 pounds wye pipe for obtaining information on operating characteristics of an intermediate style of Gyrojet burner in the tapered firepan.

A slight readjustment of the front damper position from that fixed by the regular linkage seemed to reduce a tendency of the fire to drum at the two high rates but appeared to be of no value at the two low rates.

Superheat temperatures ran from 560° at the low rate to

$649^{\circ}F$ at the high rate.

Test B12-T19-AD (Gyrojet Burner ST-366)

Four half hour tests were made with the original design of the Gyrojet burner and the 3/4" cross split on the 9-1/2" nozzle. The firepan was as originally built.

Dampers were adjusted to keep excess air low, consistent with the clearest stack possible, except at high rate, dampers being wide open. At the high rate there was slight drumming and stack was not clear.

The flue gas oxygen recorder showed 2% and less during all runs but it probably was not entirely correct in that low a range.

Some difficulty was experienced with maintaining small spot fires because the heavy aspirating effect of the atomizing jets would periodically exhaust all oil from the burner proper, whereupon the flame would float away from the burner and go out. For this reason, investigations were made of several means of eliminating the spasmodic flow at very low rates, which resulted in use of a small diameter, tubular insert in the oil outlet, as illustrated elsewhere. The burner with this modification was then used in the succeeding, and final test.

Test B13-T20-AC (Gyrojet Burner ST-366A)

Tests were made using the final modification of the Gyrojet burner, which had a 5/8" OD tube at center of oil passage, extending 5/8" out into the 1-1/4" long mixing chamber. The firepan had an 8" diameter non-tapering burner port; 18" x 20 throat size, bottom air port; front and bottom dampers connected to control lever under feed valve quadrant; and the $9\frac{1}{2}$" nozzle was equipped with 7/8" cross split. Boiler side check used for feedwater.

Tests were run at wye pipe pressures of $6\frac{1}{2}$, $9\frac{1}{2}$, 13 and 3 pounds. Dampers were 5/8 open for the low rates, 3/4 for the next rate, wide open for the high rate, and 5/8 open for the low rate. Atomizer pressures were 40-36, 50-60, 66, and 38 pounds.

As had been expected there was a light ring of fire around the inner surface of the non-tapered burner port which was not evident with the Venturi type burner port. In view of this, a tapered or Venturi type of burner port should last considerably longer in road service than the non-tapered type.

Smoke density was relatively low, averaging 1/2 Ringelmann at the high rate. There was but a very thin layer of carbon in a ring around center of the flash wall when the tests were over.

Numerous trial settings of very small spot fires during the firing-up period and following the tests, showed that the addition of the small tube or vortex breaker had satisfactorily corrected the difficulties at very low oil flows and the negligible amount of carbon formed during the regular tests proved that the tube had had no deleterious effects at higher rates.

This completed the standing test series.