SOUTHERN PACIFIC COMPANY

RECOMMENDATIONS
FOR
INTERIM IMPROVEMENTS

SACRAMENTO LOCOMOTIVE
STANDING TEST PLANT

San Francisco, Calif.
December 8, 1948.

Report No. ST-3

RESEARCH PROGRAM

ON

OIL BURNING

STEAM LOCOMOTIVES

****

R E C O M M E N D A T I O N S

F O R

I N T E R I M   I M P R O V E M E N T S

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LOCOMOTIVE STANDING TEST PLANT

SACRAMENTO, CALIFORNIA

ENGINE SP-4401

****

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

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FOREWORD

During the conduct of standing tests on locomotive SP-4401, Class GS-1, made at Sacramento Locomotive Test Plant, in connection with research program on oil burning steam locomotives, as authorized by GMO-35006, observations and investigations have been made of various factors involved in the proper combustion of fuel oil, heat transfer, feedwater injection, and other details of locomotive boiler operation. The purpose of this report is to summarize the results of such observations and studies so that due consideration can be given to the recommendations resulting therefrom, as summarized on pages 2 to 7, inclusive.

These recommendations have been designated as "interim" improvements, in that they are intended to provide desirable modifications which should be taken advantage of pending the final outcome of the overall research program.

While it is difficult and, in some cases, impossible to evaluate the exact savings resulting from the recommended improvements, it can, nevertheless, be assumed that the advantages as outlined in report can be realized, based on results of observation and tests on locomotive SP-4401, on which testing conditions were accurately controlled, and from careful studies into factors involved. In some cases, recommendations can be taken advantage of promptly, while in others it will be necessary to make further study regarding the applicability to the various classes of steam locomotives, other than the Class GS-1, represented by test locomotive SP-4401.

RECOMMENDATIONS

The following recommendations for interim improvements are made, based on results of observation and tests conducted on locomotive SP-4401 and studies made in connection therewith, as explained in detail under Conduct of Tests and Discussion of Results, beginning on page 8:

1. FIRING VALVES:

Design of orifice in plug valves controlling flow of fuel oil to burner should be modified to the single taper contour, as shown by photograph on page 15 to provide more accurate adjustment of rate of flow, particularly at low firing rates. The present firing valves give very coarse adjustment at low firing rates, such as spot fires and drifting fires, and the improved valves will greatly extend the degree of adjustment as indicated by graphs, pages 23 to 26, inclusive, for 1-1/2" size valve, and pages 27 to 30, inclusive, for the 2" size valve.

Based on current consumption, reasonable estimates indicate that a saving of at least 1.45% in fuel consumed can be obtained by reason of closer regulation of firing rate with the improved valves. Closer regulation of firing valve can also be expected to result in reduction of carbon formation in firebox and reduction in smoke nuisance, which is particularly essential at locations where local smoke ordinances are in effect.

2. FIREBRICK APPLICATION:

Method of bricking locomotives should be standardized in order to provide improved distribution of heat on firebox sheets where possible, and to obtain additional heat transfer through surfaces now covered by brickwork. From experience with test locomotive, it is apparent that this class locomotive is ordinarily bricked too high on the side sheets. This condition also applies to most other classes of locomotives. It is recommended that brickwork cover only two rows of staybolts on side sheet, rather than the four rows now customarily covered. Furthermore, it is the practice on some districts to brick up throat sheet and wings more than is necessary to protect the pan and mud ring properly.

As the greatest heat transfer occurs through firebox sheets, exposing additional firebox heating surface will improve heat distribution. By reducing height of brickwork at throat sheet and side sheets on locomotives of the GS Class, an increase of approximately 25 square feet in firebox heating surface can be obtained, which represents a potential gain in firebox evaporative capacity of approximately 2,400 pounds per hour, which should improve the steaming of the locomotive. On other classes of locomotives, proportional gains may be expected.

Study should be given to the method of applying firebrick to locomotives. Present practice calls for bricking the walls up solid against pan, door sheet and side sheets, without any allowance for expansion. It is recommended that consideration be given to providing 1/2" expansion joints of asbestos fibre or other suitable medium, both longitudinally and transversely, to permit movement of brick without buckling of brick setting. Consideration should also be given to applying 2-1/2" thick floor on firepan, in accordance with T&NO practice, instead of 4-1/2". This will reduce weight of brick supported by firepan, and should also reduce the tendency for flame to sweep floor with consequent deposition of carbon.

3. HEAT LOSS FROM NON-INSULATED SHEETS:

Lagging and jacketing should be applied to the bottom of shell under combustion chambers and to the outside side sheets below running boards. Based on calculations, approximately 120 square feet of surface on a GS Class locomotive, in these locations, is not insulated. If properly insulated, additional heat will be retained in the boiler, rather than radiated to the atmosphere. Under average operating conditions, a calculated fuel saving of approximately 1.2% may be realized for this class of power, as detailed in report. If necessary, lagging and jacket arrangement on bottom of combustion chamber can be made sectional to permit work on flexible staybolts without disturbing remaining jacket. The later classes of AC locomotives are already provided with insulation on outside side sheets.

4. BOILER FEEDWATER INJECTION:

Consideration should be given to the installation of top boiler checks to injector and feedwater heater hot pump delivery pipes, based on results of application to test locomotive. As indicated on graph, page 53, the temperature distribution throughout boiler shell is greatly improved by the injection of water into steam space at top of boiler, as compared with side injection below water level used at present. Other benefits of top or water space spray checks are detailed in report.

5. OIL BURNER APPLICATION:

Results of tests indicate that alignment of burner has a definite effect on the steaming quality of locomotive, amount of carbon formation, temperature distribution in sheets, etc. On test locomotive, it was found that burner remained in alignment when secured to frame, in accordance with T&NO practice, as compared to general Pacific Lines practice of securing to firepan. Expansion and contraction of firepan tends to throw burner out of line. Piping adjacent to burner should also be secured to frame. Adequate clearance must be maintained between burner support bracket and firepan, and any restriction due to cross brace at bottom of burner hood casting should be eliminated. To minimize carbon formation, present burner should be tilted slightly upward to align with point on vertical centerline of firebox, and 14" to 16" above floor of firepan at flash wall.

6. EXHAUST STACK, NOZZLE AND FRONT END:

All obstructions should be removed from exhaust stack, such as sand ejectors, booster exhaust pipes, and feedwater exhaust pipes, as these interfere with proper exhaust jet action in stack. Experience with test locomotive indicates that exhaust nozzle and cross split accumulate carbon within a relatively short period of time, as shown on photograph, page 57. Such accumulations greatly increase back pressure with resulting increased fuel consumption. As result of this experience, it is recommended that carbon be removed from nozzle and cross split, as well as from entry of exhaust steam pipe from nozzle to feedwater heater, at least at each quarterly inspection, in addition to the annual removal of entire exhaust stand and exhaust pipe to heater for complete elimination of carbon.

Alignment of nozzle with stack should be checked by properly standardized methods on all locomotives going through shops for Class 4 or heavier repairs, or whenever stack and exhaust stand are removed. Misalignment may cause improper steam jet action and, possibly, down drafts in stack.

7. <u>SOOT REMOVAL</u>:

Improved means of sanding locomotive tubes and flues or otherwise removing soot accumulation from these heating surfaces should be developed to obtain the benefits in additional heat transfer available from removal of deposits on fire side of heating surfaces. Enginemen should be cautioned that unusually high superheat, as shown by locomotive pyrometers, generally indicates that tubes and flues need sanding.

Carefully controlled tests of a commercial sludge solvent and a combination sludge solvent and soot remover for use in residual fuel oils did not indicate any benefits to be derived from the dosages recommended by manufacturer.

8. <u>FEEDWATER HEATER EQUIPMENT</u>:

Modifications should be made to Worthington Type "S" feedwater heater equipment, consisting of application of top air vent to heater and elimination of present cold water bypass in heater with application of proper length spray sleeve. By these modifications, it is estimated that a net saving in fuel consumption over the operating range can be obtained with locomotives on which Type "S" equipment is installed, together with improved feedwater pump performance. These savings are illustrated graphically on page 65.

9. <u>FUEL OIL TEMPERATURE AT BURNER</u>:

Observations made on test locomotive indicated possibility of better fuel economy with higher oil temperatures at burner. This is confirmed by recommendations of major oil supplier that minimum viscosity of fuel oil at burner for steam atomization should be 350 SSU (Seconds Saybolt Universal), which, with present residual fuel furnished to Pacific Lines, corresponds to a minimum temperature of 175°F. at the burner. Present instructions restrict oil temperature to 150°F. maximum. Inasmuch as trend is toward higher viscosity fuel, the minimum temperature to produce 350 SSU viscosity at oil burner may have to be elevated even above 175°F. in the future. Higher temperature at burner produces better atomization with lower atomizing steam consumption. Dial thermometers indicating temperature of oil at burner should be installed on locomotives not already so equipped in order that proper temperature can be maintained at all times.

Results of road tests conducted a number of years ago also confirm the fuel saving available with higher oil temperatures at burner, and indicate that raising this temperature from 150°F. to 180°F., with Pacific Lines' fuel, should produce savings in fuel consumption of approximately .7%. Further investigation will be made on this subject during ST-5 studies on oil burners at Standing Test Plant.

CONDUCT OF TESTS AND DISCUSSION OF RESULTS

1. IMPROVEMENT IN FIRING VALVE DESIGN:

In the study of various factors relating to combustion of fuel oil in the test locomotive, it was evident that the present common standard design of the plug valve orifice in the firing valve, as shown by photograph on page 15, does not permit the accurate control of oil flow through the valve, particularly at low firing rates. Because of the contour of this orifice, the regulation of the firing valve over the normal range encountered in service does not allow best utilization of the teeth on firing valve quadrant in cab. At low firing rates, the difference between adjacent teeth on the quadrant actually represents a large increment in amount of oil passing through the valve, as illustrated graphically on page 26 for 1-1/2" size valve, and on page 30 for 2" size. For example, the difference in flow rate through the 2" size valve for one tooth movement of the firing valve handle on quadrant near the opening position represents as much as, or more than, 40 gallons per hour, based on carefully controlled calibrations made at Standing Test Plant with present standard operating temperature of fuel oil. With higher operating temperatures, as recommended in Section 9, page 6, this increment will be accentuated. With the present standard oil feed valve, a very carefully regulated spot fire on locomotive SP-4401, in test plant, required 16.6 gallons per hour; however, despite constant attention and the utmost care in making fuel valve adjustments, the safety valve released once and injector had to be used twice to reduce the pressure. It can be readily realized, therefore, that the accurate adjustment of such low firing rates in regular service is extremely difficult, if not impossible, with the present firing valve. Diagrams drawn on an enlarged scale, showing the opening characteristics of the present plug valve against the port in valve body, is shown on page 31 for 1-1/2" size, and on page 35 for 2" size valve.

A careful study was made of possible shapes and dimensions of orifices in plug valve and body as shown on pages 31 to 38, inclusive, to determine the most desirable opening characteristics based on minimum modification to present valves and related equipment.

Photographic illustrations of various orifice contours studied are shown on pages 15 to 21, inclusive, as follows:-

Pages 15 and 16 show views of single taper orifice compared with present standard, both "head on" and "opening edges."

Pages 17 and 18 show same views with double taper orifice and indicate the larger diameter of plug necessary with this design.

Page 19 shows double taper orifice valve superimposed on present standard orifice to give a comparison of the size and shape.

Pages 20 and 21 show views of diamond port plug compared with present standard, both "head on" and "opening edges."

Graphic representations of calculated areas through the various orifices studied are shown on pages 23, 24, 27 and 28. Flow rates with fuel oil at 150°F. are shown on pages 25, 26, 29 and 30 for the standard and recommended orifices. From these graphic results, it is evident that the control of oil flow is greatly improved by the redesigned orifice, giving as much as four times the accuracy of adjustment at the lower flow rates.

There are two methods by which the improved orifice contour can be applied to the oil feed cocks. If present plug diameters are maintained, it will be possible to provide an orifice tapered on one side, only, as shown on pages 38a and 38b, which would permit a maximum area equivalent to that through 1-1/2" or 2" extra strong pipe, depending on size valve used. By locating these one-sided orifices in line on either side of plug, the operation of valve can be either clockwise or counter-clockwise and still provide desired throttling of oil flow at low firing rates.

However, special care must be taken in the manufacture of these single tapered orifices to insure that openings on plug and in valve bodies are in exact register, so that leading edge of port on both sides of plug will open simultaneously, regardless of whether plug is turned clockwise or counter-clockwise. This will require more accuracy in manufacture of plug valves than was necessary with former symmetrical shaped orifice. Critical dimensions are indicated on diagrams, pages 38a and 38b.

The second possibility for using the improved orifice contour is to provide a symmetrical orifice as shown on pages 34 and 38. Such an orifice will permit greater area for flow through the plug, but will necessitate increase in diameter of plug as shown by photographs, pages 17 and 18, in order that proper lap can be provided when valve is in closed position. Increase in diameter of plug will mean that one tooth movement on present quadrant will result in greater distance of travel at periphery of plug with resultant loss in sensitivity. To compensate for this, the quadrant radius would have to be increased in proportion to that of the plug valve. Photograph, page 19, shows comparative contours on double taper and common standard plugs superimposed.

With the enlarged plug and symmetrical orifice, the necessity for exact registration of entering edges on plug and valve body is not critical as it is with the single tapered design.

The diamond shaped ports shown on pages 32 and 36, and by photographs on pages 20 and 21, do not permit so large a passage for oil flow as the single tapered design using present diameter. While the diamond to diamond ports give good area characteristics at low firing rate, their use would necessitate a change in diameter of both plug and valve body as well as an increase in radius of firing quadrant to obtain sufficient area to avoid restriction in oil passage.

Therefore, considering all features of the various designs of plug valve orifices, it is recommended that the single tapered contour as shown on page 38a for 1-1/2" feed cock, and page 38b for 2" feed cock be adopted as an interim improvement. This design will require the minimum changes in existing plug valve and will provide equivalent area for oil flow to that through oil feed pipe. Also, the use of this improved design will not require changes in existing quadrant. Application of improved type firing valve on test locomotive demonstrated the advantages of closer control of firing rates.

Further investigation is being conducted with disc type firing valve having lunar shaped orifices, as illustrated by photograph, page 22. Further study will be given to the possibilities of development of a practical valve of disc type construction to determine whether it possesses sufficient additional advantages over the plug type valve to merit eventual adoption. However, for the purpose of immediate improvement and fuel savings, it is recommended that the modified type plug valves, as proposed above, be installed.

While it is difficult to develop the overall fuel saving resulting from the use of the improved plug valve, a reasonable assumption can be made of the magnitude of this saving. Based on careful study of available information on the number of hours during which locomotives stand under spot fires, both in road service and switching service, or operate under drifting throttles when descending grades, conclusion has been reached that a potential saving of 1.45% in fuel oil consumption can be realized because of closer control of oil flow and reduction in unnecessary operation of safety valves, due to present difficulty in proper control of fire.

Based on improved flow rates as indicated by graphs on pages 25, 26, 29 and 30, and considering this additional sensitivity in the opening of teeth on quadrant with the new orifices, as compared with the present standards, a more than three to one improvement in control of the fire is indicated. This improvement should make possible a reduction in fuel consumption with low fires. With this improvement in control, and considering that normal spot fires actually used in service with present firing valve consume from 20 to 30 gallons oil per hour, and drifting fires will average 60 gallons per hour, it is a reasonable conclusion that a saving of 5 gallons per hour average on switching locomotives and 7-1/2 gallons average on road locomotives can be realized.

As previously mentioned, carefully controlled spot fire on test locomotive SP-4401 required only 16.6 gallons per hour. Such low average adjustments can be readily made with improved valve, but are difficult to obtain with present valve due to the very much larger increment between two settings on quadrant near opening edge of orifice.

Furthermore, the improved firing valve will permit the closer control which will be even more necessary if the recommended higher oil temperature at burner is adopted, which is desirable for reasons outlined under Item 9, page 6, and should also reduce the amount of carbon formation in firebox as well as aid in abating smoke nuisance.

On basis explained above, estimated fuel saving for Pacific Lines with improved firing valve was determined in the following manner:-

An average of 230 steam switching locomotives are in service on Pacific Lines, and assuming that these locomotives have a 60% utilization and that they are on spot fires 30% of time in service, a total of 362,664 hours per year on spot fire is obtained. Applying an average saving of 5 gallons per hour estimated for the improved firing valve, a total of 1,813,320 gallons per year, or 43,174 barrels per year, is obtained.

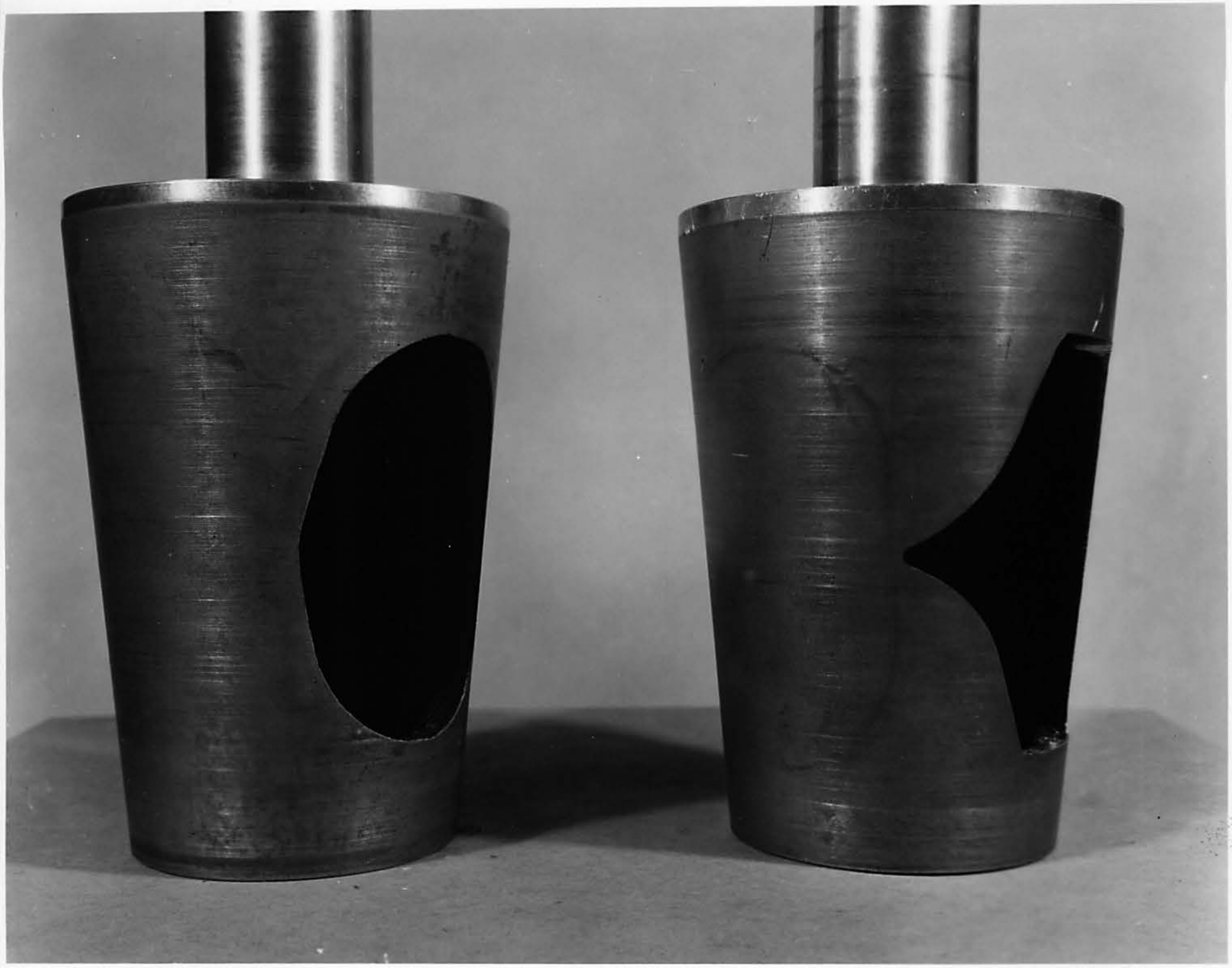
On the basis of 1,188 steam road locomotives average in operation on Pacific Lines and, assuming these locomotives have an 80% utilization and that they are on spot fire and other low firing rates, either standing or drifting, 17% of the time, a total of 1,415,336 hours per year at low firing rates is obtained. By applying the average saving of 7-1/2 gallons per hour estimated for the new firing valve, a total annual saving of 10,615,200 gallons, or 252,743 barrels, is obtained.

The total saving in both road and switch service for locomotives would be 295,917 barrels per year. Based on daily consumption of 56,000 barrels, or annual consumption of 20,440,000 barrels of residual fuel, the estimated percentage saving of fuel with improved firing valve would then be 1.45%.

Common Standard   Single Taper

Comparative Contours - Plug Valve Orifices

Photo Lab. No. ST 60-1

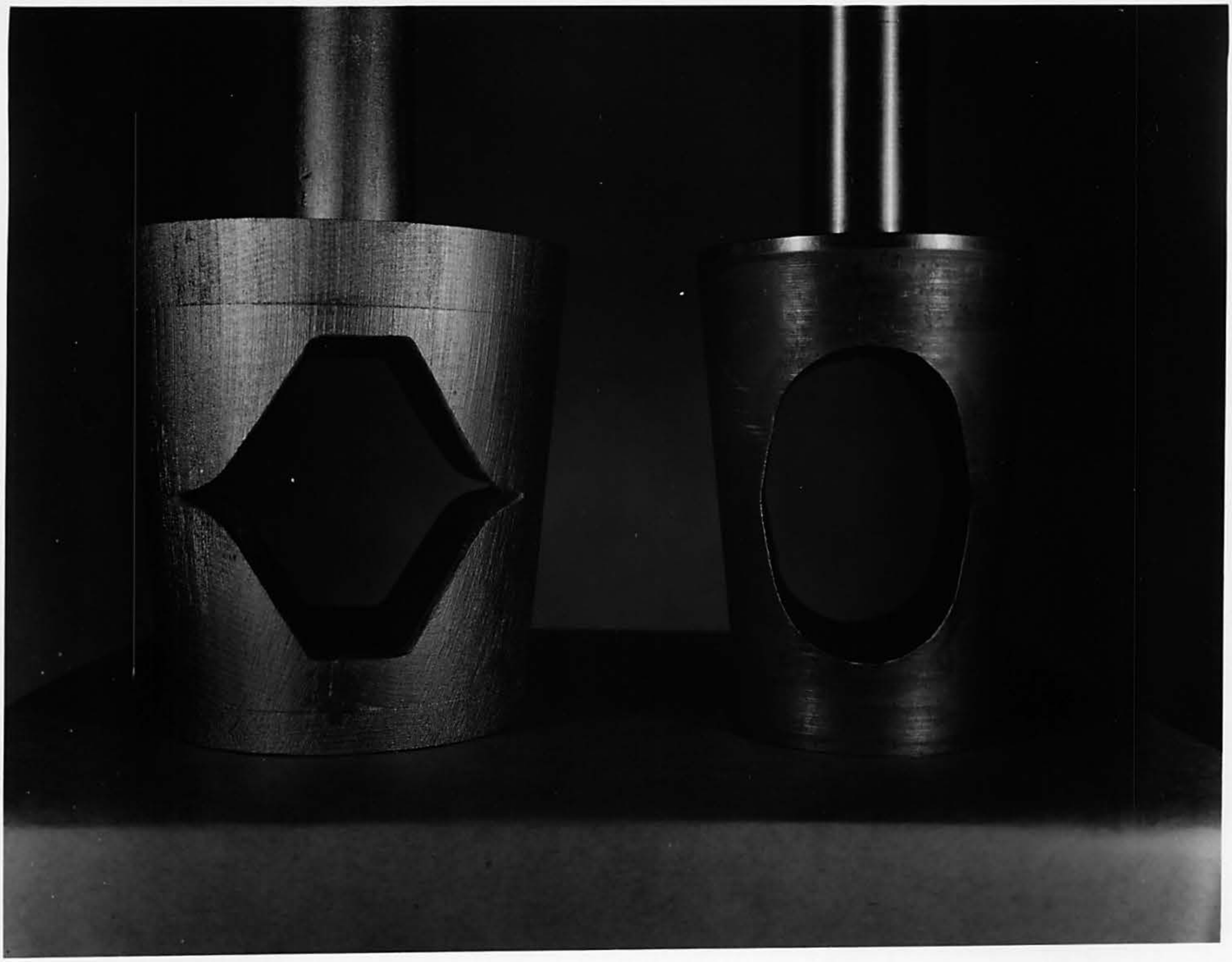


Common Standard

Single Taper

Comparative Contours - Plug Valve Orifices

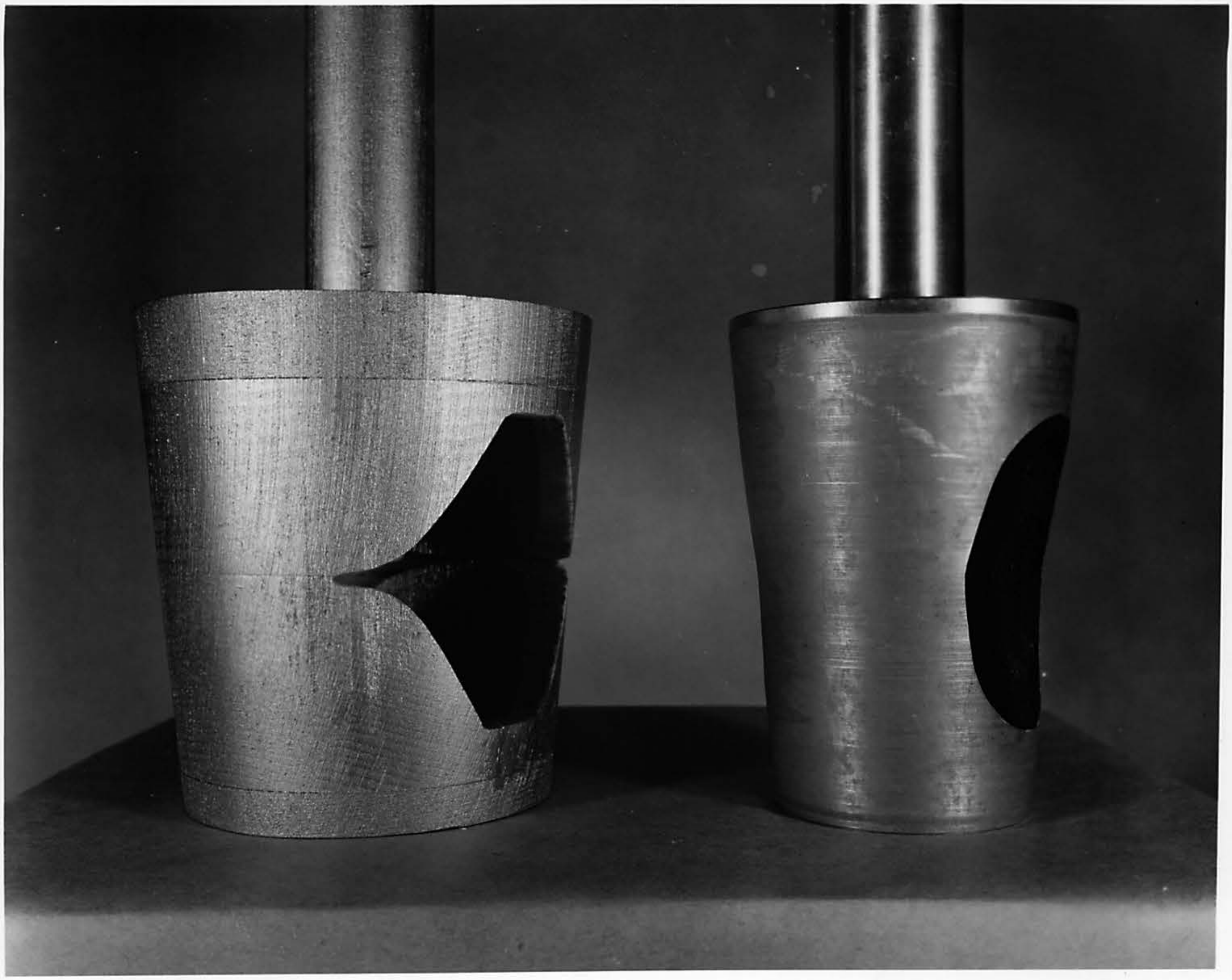
Photo Lab. No. ST 60-2



Double Taper Common Standard

Comparative Contours - Plug Valve Orifices

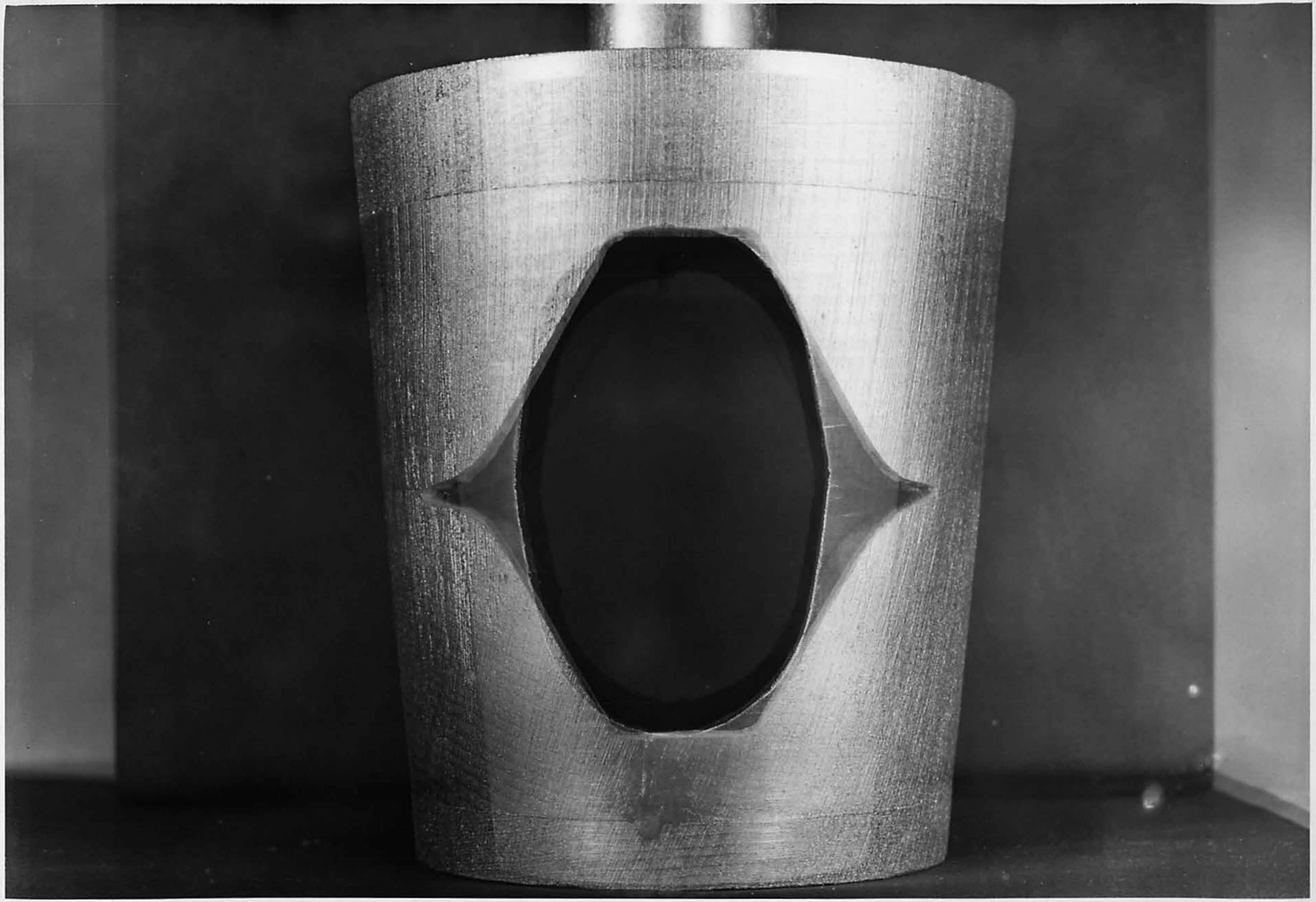
Photo Lab. No. ST 60-3



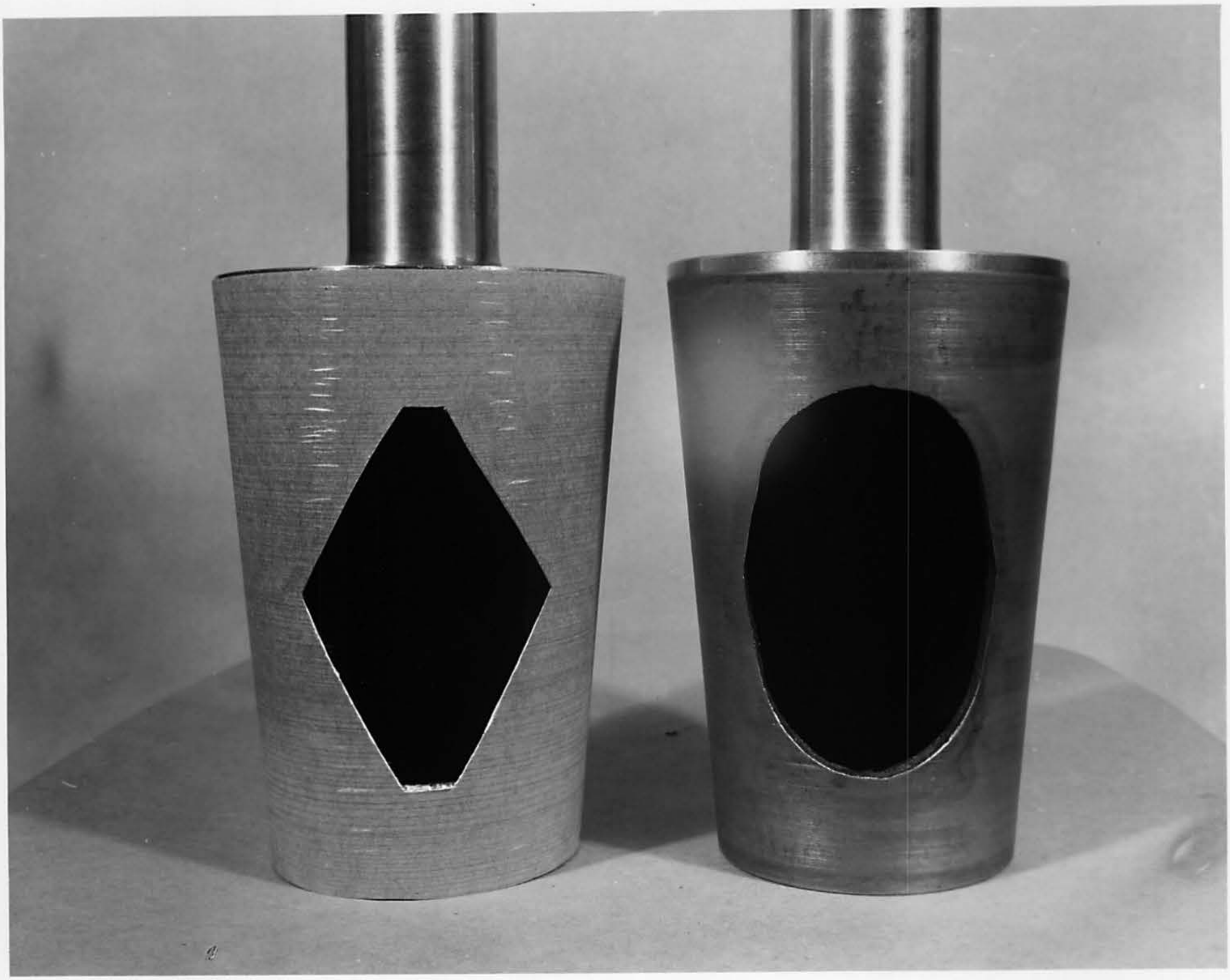
Double Taper   Common Standard

Comparative Contours - Plug Valve Orifices

Photo Lab. No. ST 60-4



Double taper and common standard plug valves - Study of comparative contours superimposed by double exposure.



Diamond Ports Common Standard

Comparative Contours - Plug Valve Orifices

Photo Lab. No. ST 60-6

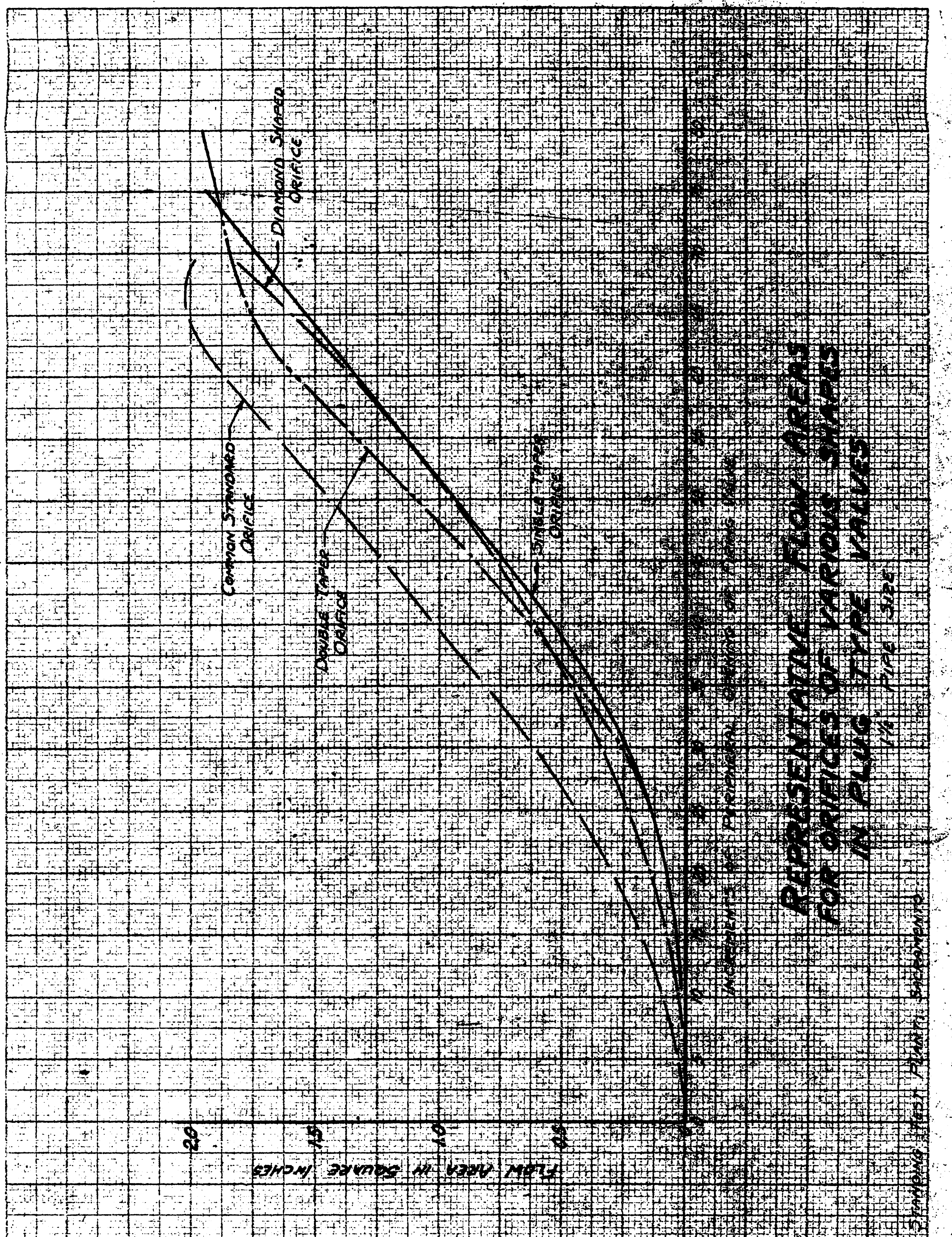
Diamond Ports — Common Standard

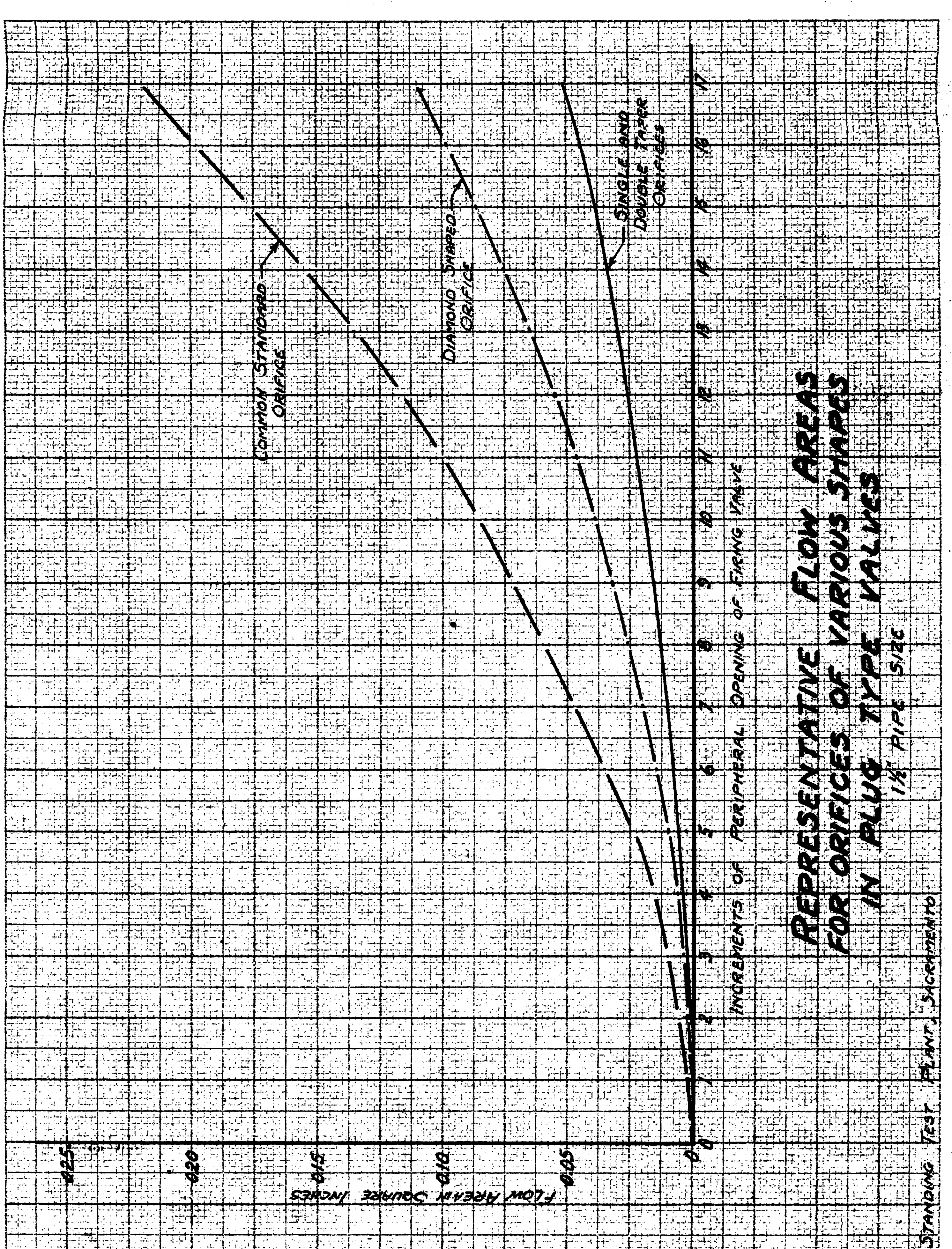
Comparative Contours - Plug Valve Orifices

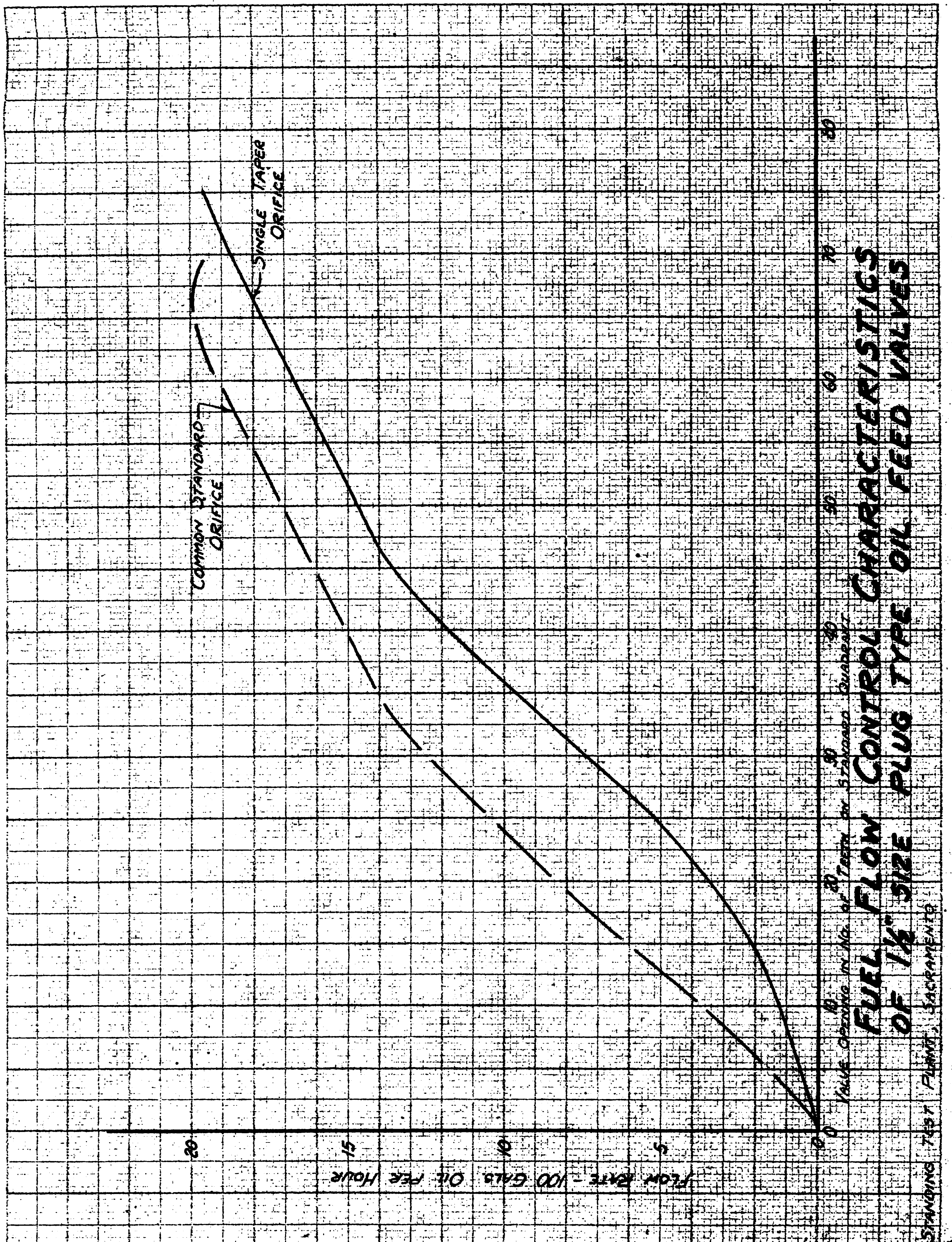
Photo Lab. No. ST 60-7

Disc Type Oil Cock--Lunar Orifices

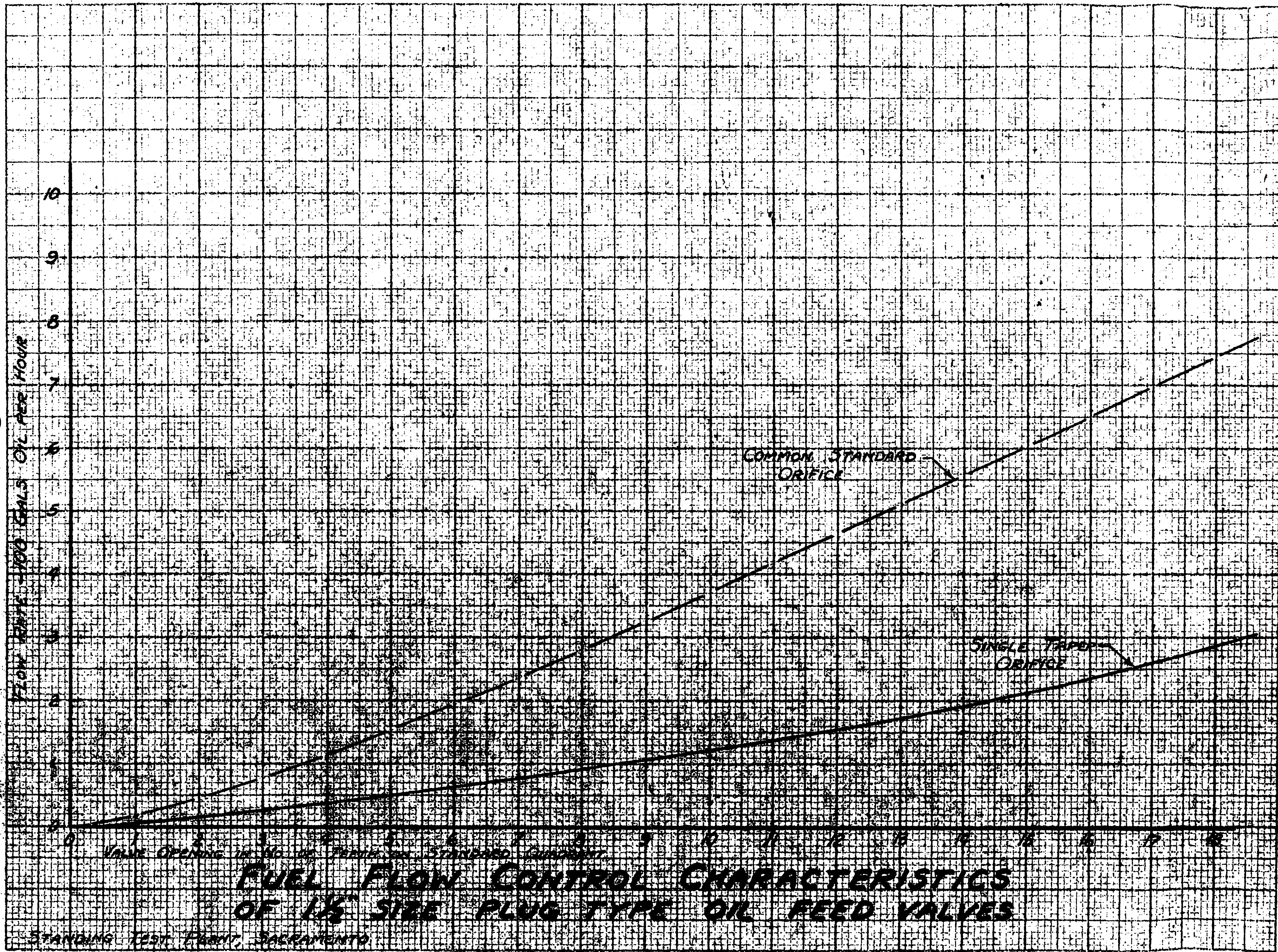
Photo Lab. No. ST 60-8

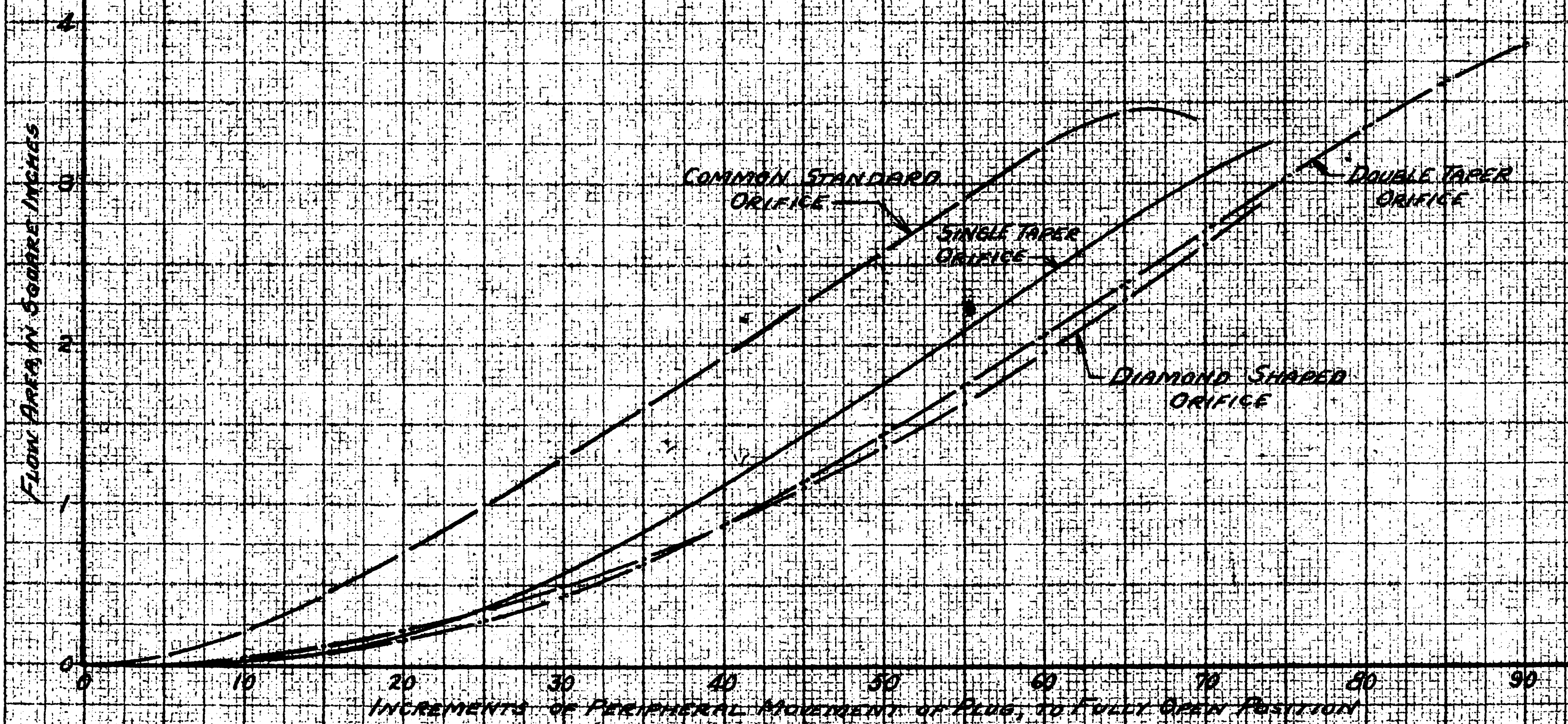

REPRESENTATIVE FLOW AREAS
FOR ORIFICES OF VARIOUS SHAPES
IN PLUG TYPE VALVES
1½" PIPE SIZE
FLOW AREA IN SQUARE INCHES
COMMON STANDARD ORIFICE
DOUBLE TAPER ORIFICE
SINGLE TAPER ORIFICE
DIAMOND SHAPED ORIFICE
2.0
1.5
1.0
0.5
0


REPRESENTATIVE FLOW AREAS
FOR ORIFICES OF VARIOUS SHAPES
IN PLUG TYPE VALVES
1½" PIPE SIZE
COMMON STANDARD ORIFICE
DIAMOND SHAPED ORIFICE
SINGLE AND DOUBLE TAPER ORIFICES
FLOW AREA IN SQUARE INCHES
0.25
0.20
0.15
0.10
0.05
0
INCREMENTS OF PERIPHERAL OPENING OF FIRING VALVE
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
STANDING TEST PLANT, SACRAMENTO



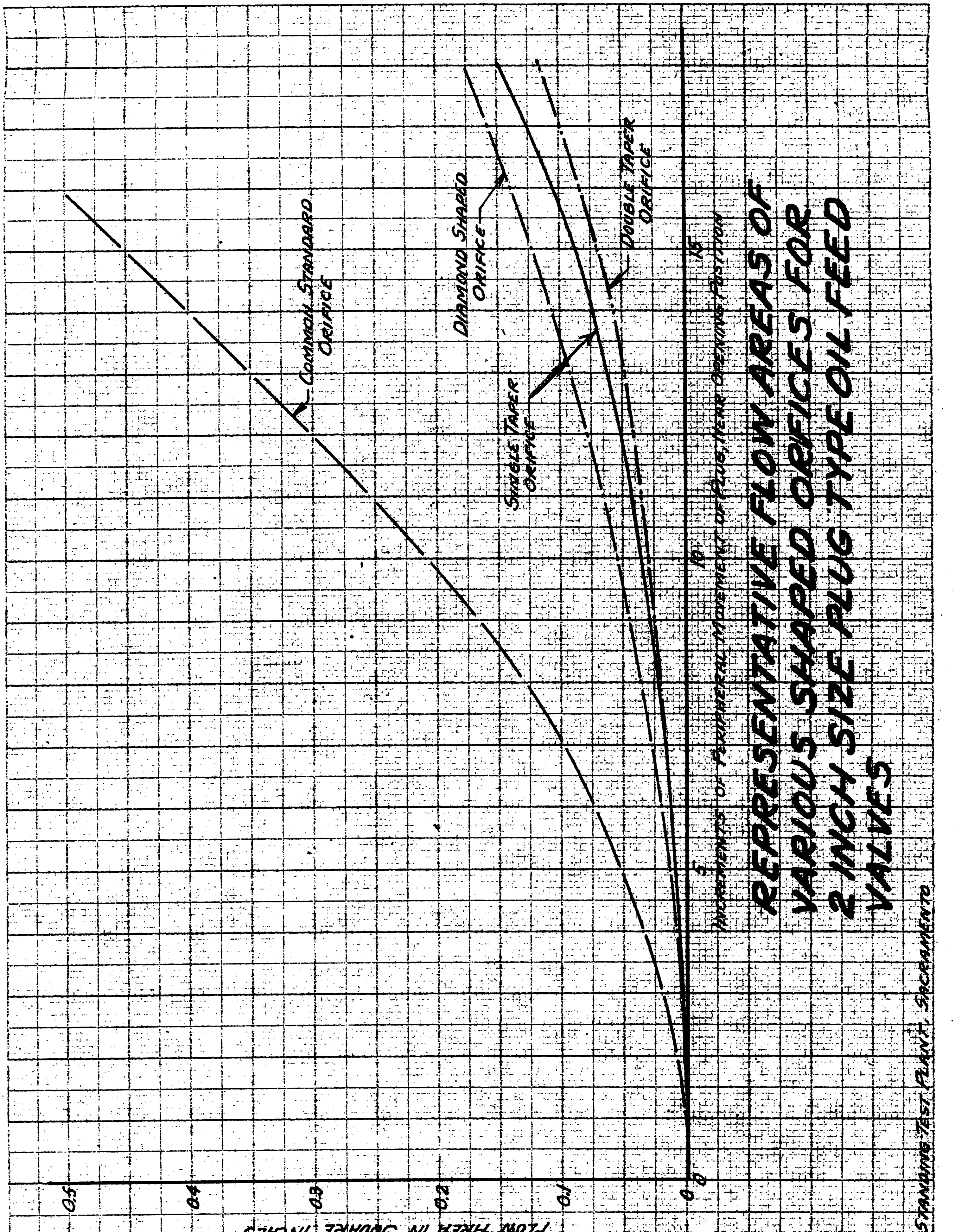
FUEL FLOW CONTROL CHARACTERISTICS
OF 1½" SIZE PLUG TYPE OIL FEED VALVES
VALVE OPENING IN NO. OF TEETH ON STANDARD QUADRANT
0
10
20
30
40
50
60
70
80
FLOW RATE - 100 GALS. OIL PER HOUR
0
5
10
15
20
COMMON STANDARD ORIFICE
SINGLE TAPER ORIFICE
STANDING TEST PLANT, SACRAMENTO

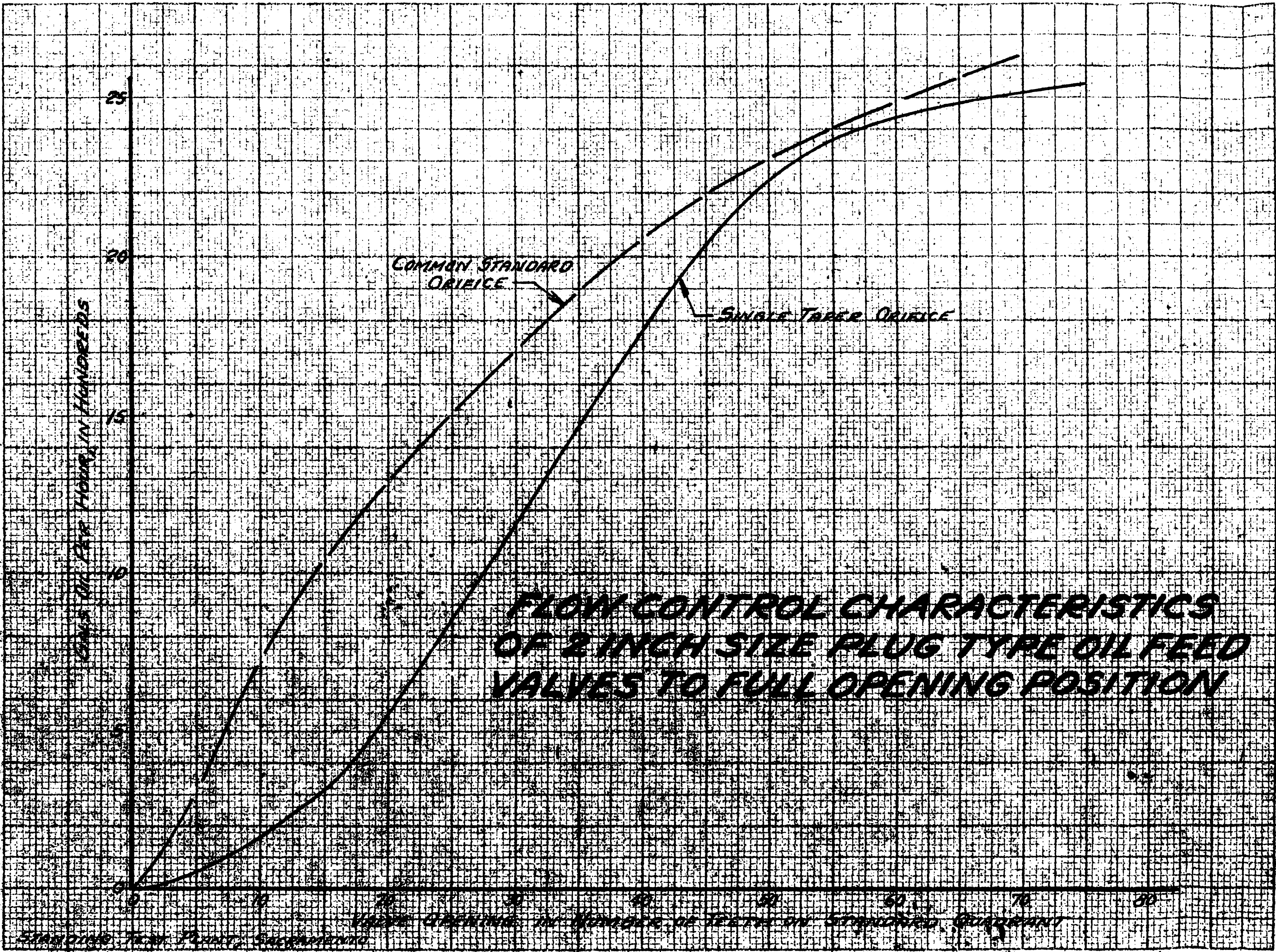

FUEL FLOW CONTROL CHARACTERISTICS
OF 1½" SIZE PLUG TYPE OIL FEED VALVES
COMMON STANDARD ORIFICE
SINGLE TAPER ORIFICE
FLOW RATE - 100 GALS OIL PER HOUR
0 1 2 3 4 5 6 7 8 9 10
VALVE OPENING IN NO. OF TEETH ON STANDARD QUADRANT
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
STANDING TEST PLANT, SACRAMENTO

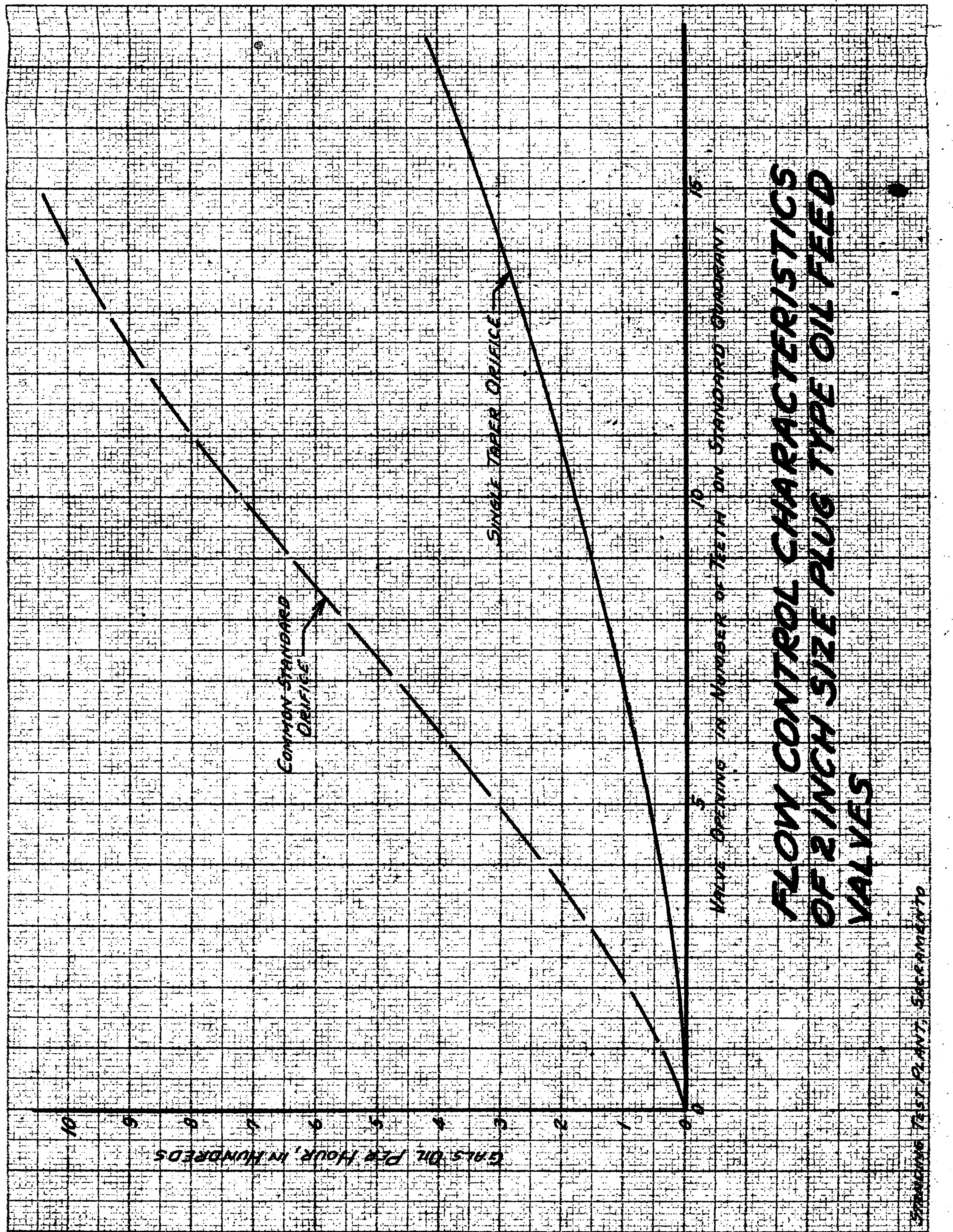


REPRESENTATIVE FLOW AREAS OF VARIOUS SHAPED ORIFICES FOR 2 INCH SIZE PLUG TYPE OIL FEED VALVES

STANDARD TEST PLANT, SACRAMENTO


REPRESENTATIVE FLOW AREAS OF VARIOUS SHAPED ORIFICES FOR 2 INCH SIZE PLUG TYPE OIL FEED VALVES
COMMON STANDARD ORIFICE
DIAMOND SHAPED ORIFICE
DOUBLE TAPER ORIFICE
SINGLE TAPER ORIFICE
FLOW AREA IN SQUARE INCHES
INCREMENTS OF PERIPHERAL MOVEMENT OF PLUG, HERE OPENING POSITION
0
5
10
15
0.1
0.2
0.3
0.4
0.5
STANDING TEST PLANT, SACRAMENTO

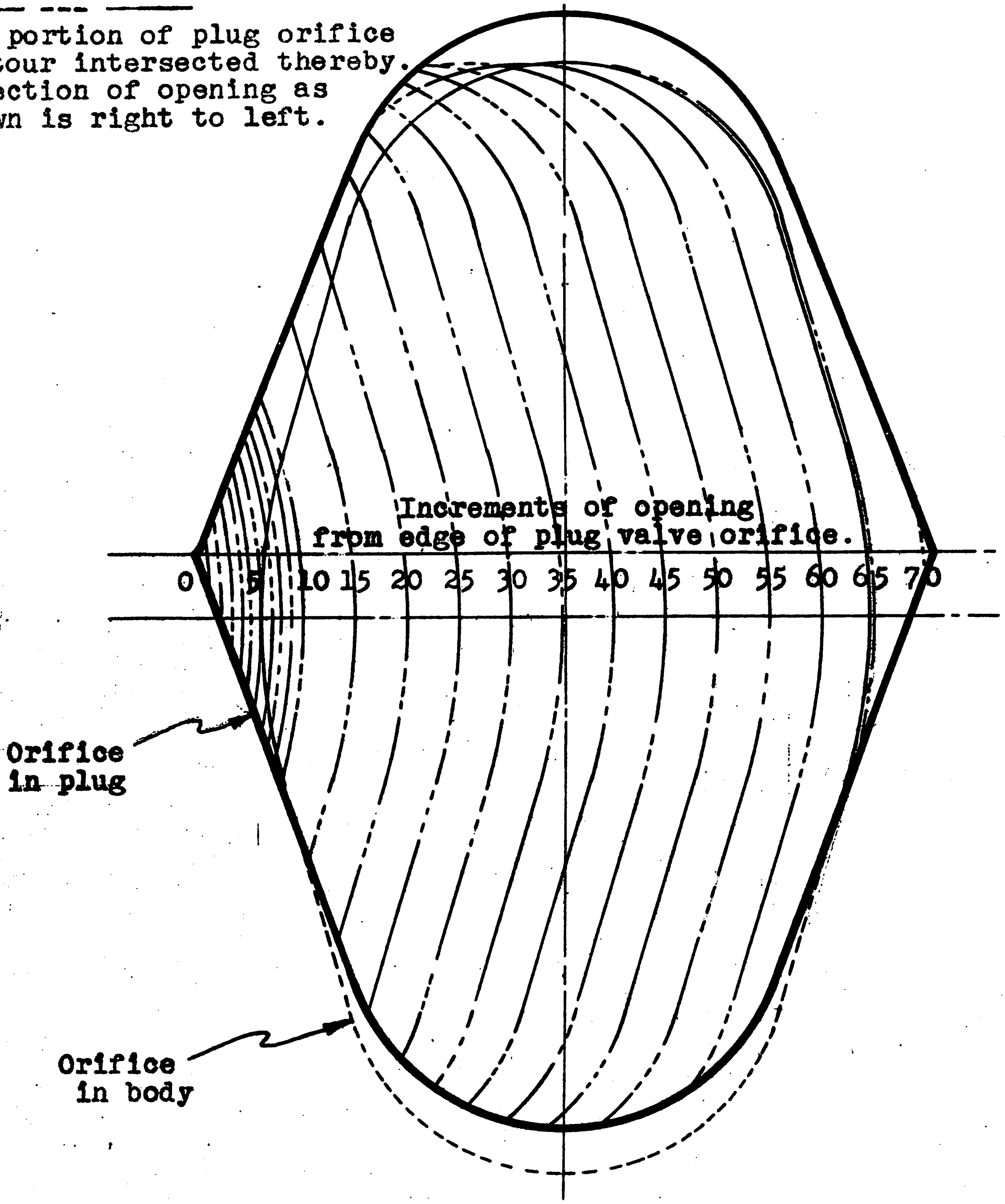

FLOW CONTROL CHARACTERISTICS
OF 2 INCH SIZE PLUG TYPE OIL FEED
VALVES TO FULL OPENING POSITION
COMMON STANDARD ORIFICE
SINGLE TAPER ORIFICE
GALS OIL PER HOUR, IN HUNDREDS
VALVE OPENING IN NUMBER OF TEETH ON STANDARD QUADRANT
STANDARD TEST PLANT, SACRAMENTO
0
5
10
15
20
25
10
20
30
40
50
60
70
80


FLOW CONTROL CHARACTERISTICS
OF 2 INCH SIZE PLUG TYPE OIL FEED
VALVES
VALVE OPENING IN NUMBER OF TEETH ON STANDARD QUADRANT
GALS. OIL PER HOUR, IN HUNDREDS
SINGLE TAPER ORIFICE
COMMON STANDARD ORIFICE
0
5
10
15
1
2
3
4
5
6
7
8
9
10
STANDING TEST PLANT, SACRAMENTO

NOTE: Projected contours are shown. Positions of edge of orifice in body for various positions of plug are shown by ——— --- ———. Area of opening is enclosed by ——— --- ——— and portion of plug orifice contour intersected thereby. Direction of opening as shown is right to left.

←—Direction of plug movement.

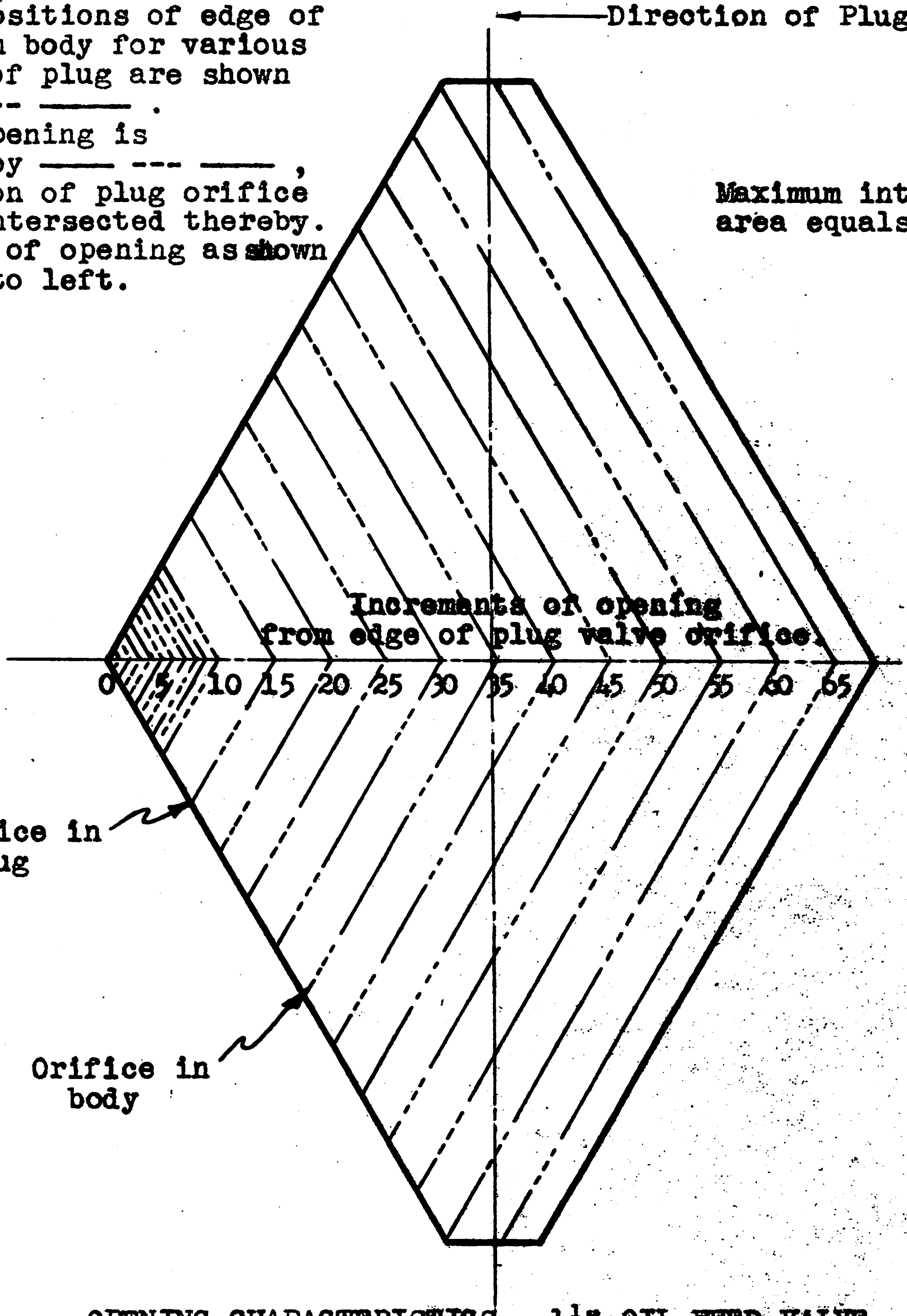
Maximum intersected area equals 2.0 sq. in.



OPENING CHARACTERISTICS - 1½" OIL FEED VALVE

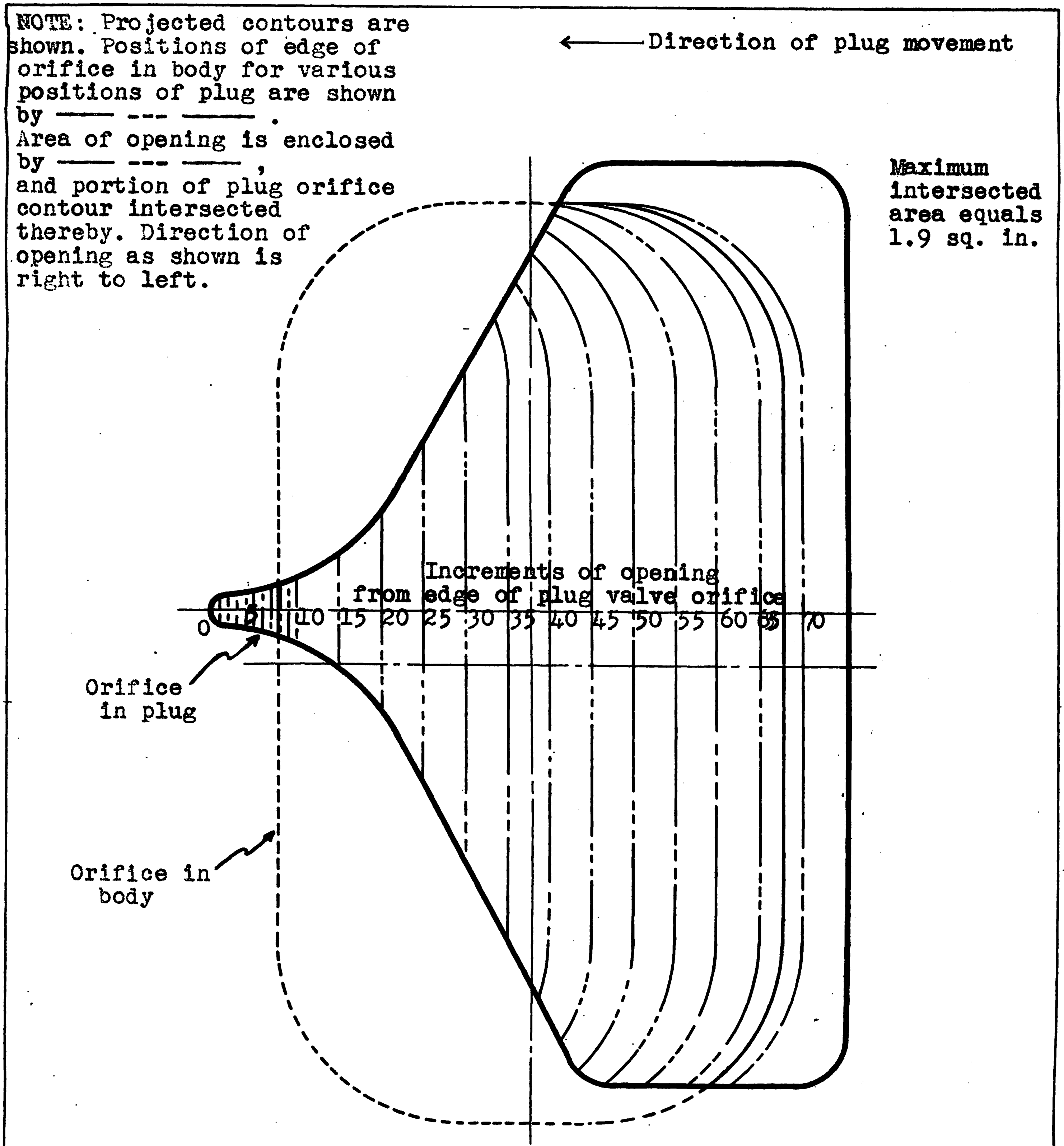
Common Standard Orifice in Plug vs. Common Standard Orifice in Body

NOTE: Projected contours are shown. Positions of edge of orifice in body for various postions of plug are shown by ——— --- ——— .
Area of opening is enclosed by ——— --- ——— , and portion of plug orifice contour intersected thereby. Direction of opening as shown is right to left.



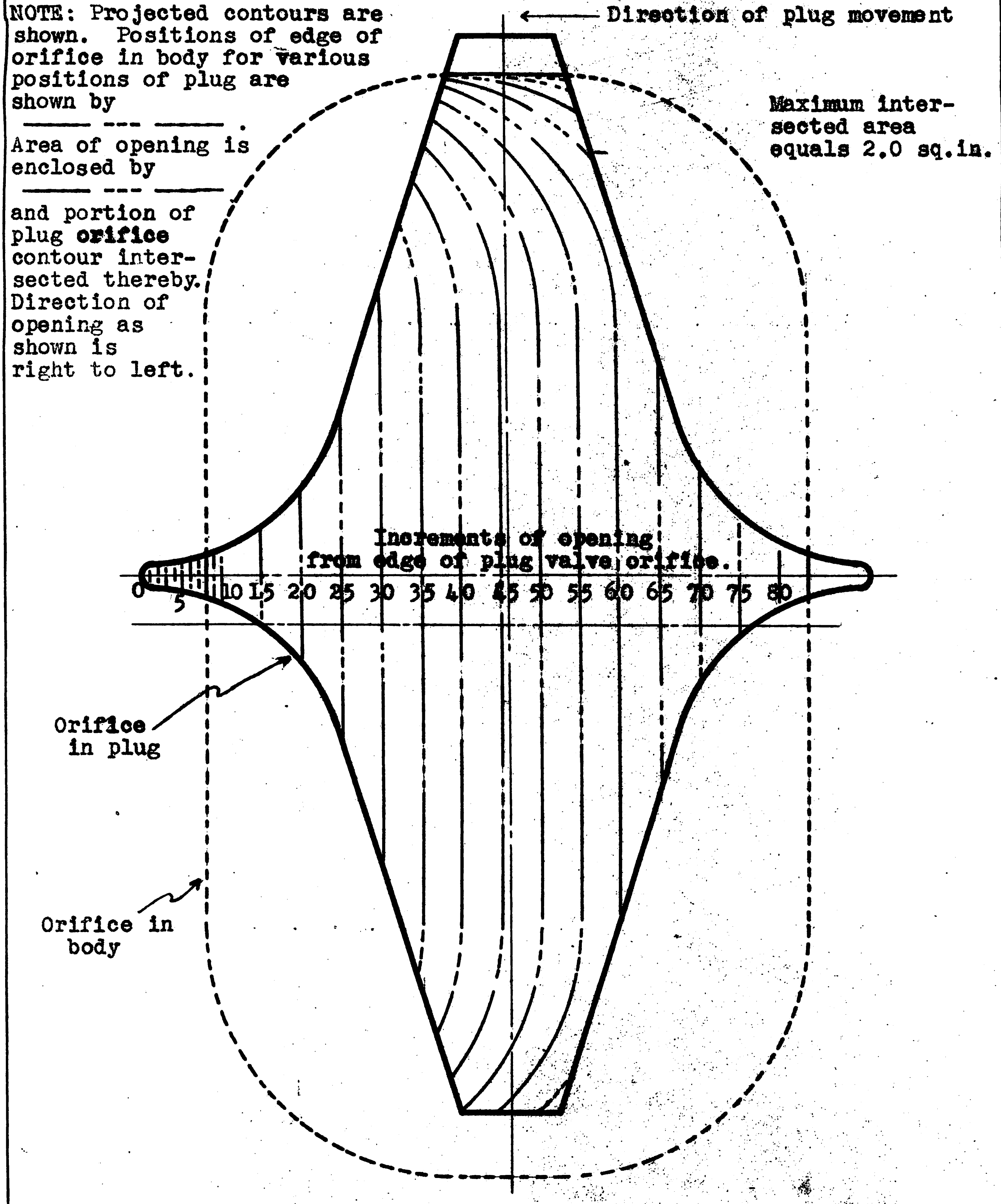
OPENING CHARACTERISTICS - 1½" OIL FEED VALVE

Diamond Orifice in Plug vs. Diamond Orifice in Body
(Requiring new plug and valve body)

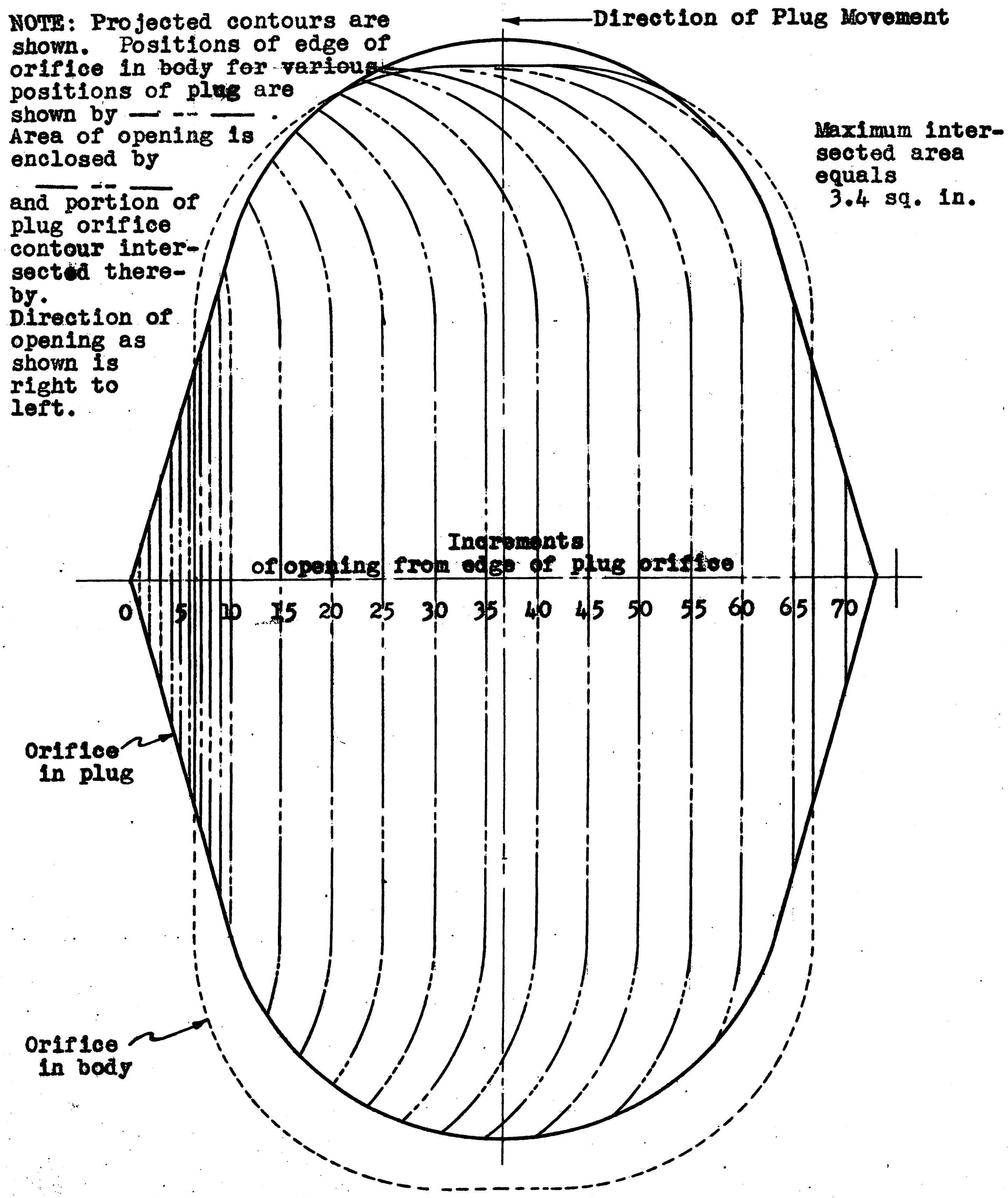


OPENING CHARACTERISTICS - 1½" OIL FEED VALVE

Single Taper Orifice in Plug vs. Common Standard Orifice in Body
(Requiring new plug only)



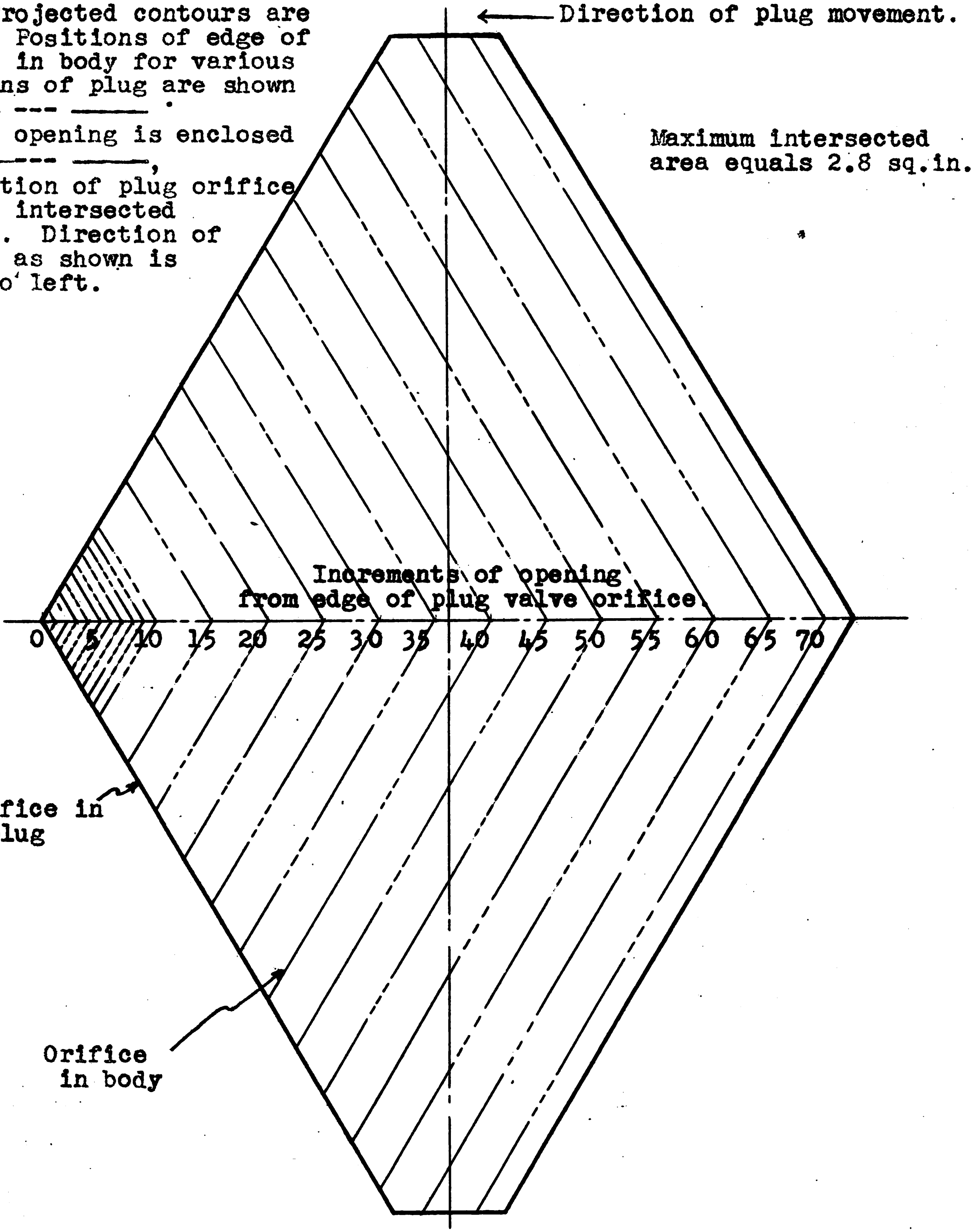
OPENING CHARACTERISTICS - 1½" OIL FEED VALVE
Double Taper Orifice in Plug vs. Common Standard Orifice in 2" Valve Body
(Requiring new plug applied in present 2" valve body)



OPENING CHARACTERISTICS - 2" OIL FEED VALVE

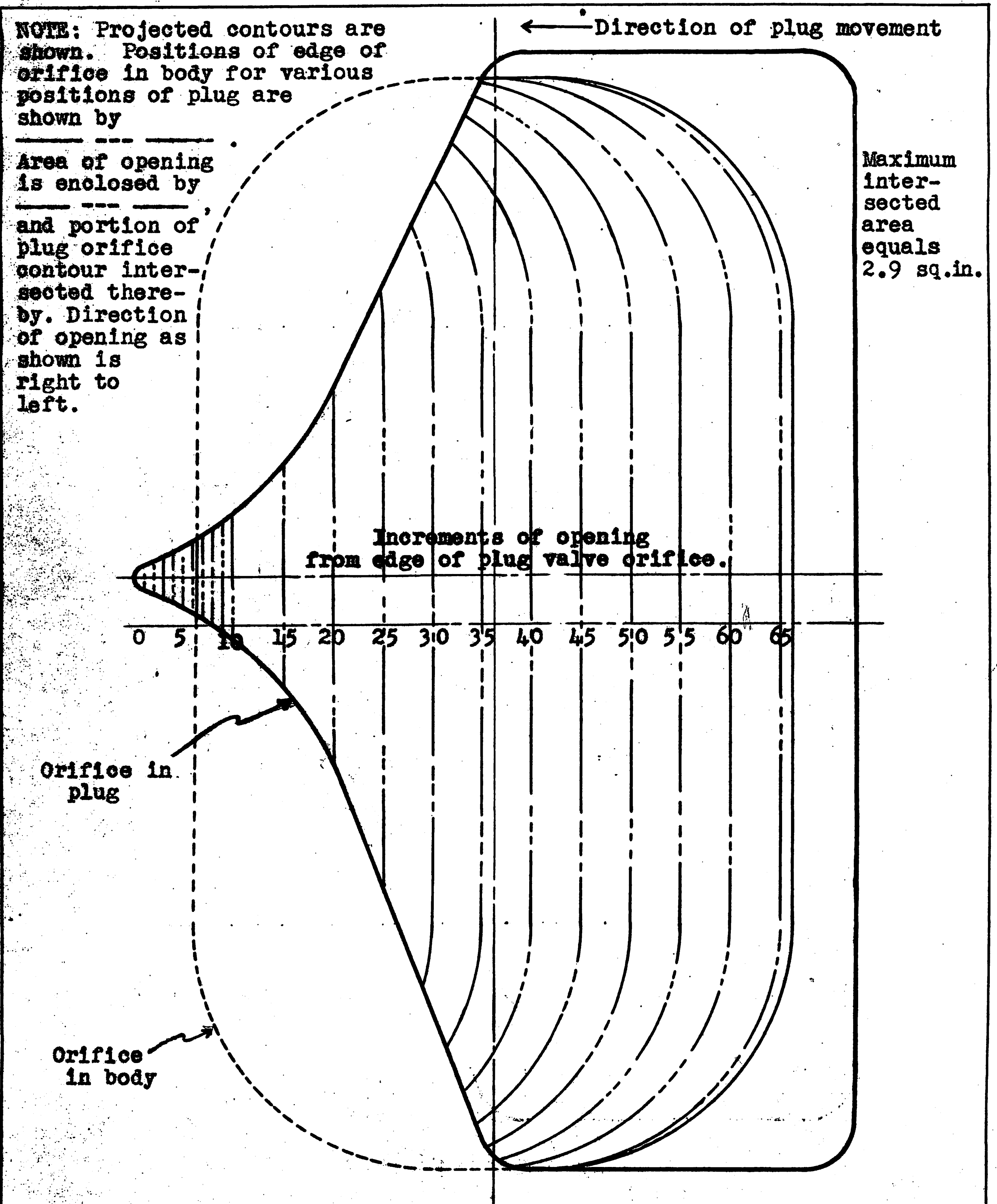
Common Standard Orifice in Plug vs. Common Standard Orifice in Body

NOTE: Projected contours are shown. Positions of edge of orifice in body for various positions of plug are shown by ——— --- ———.
Area of opening is enclosed by ———--- ———, and portion of plug orifice contour intersected thereby. Direction of opening as shown is right to left.

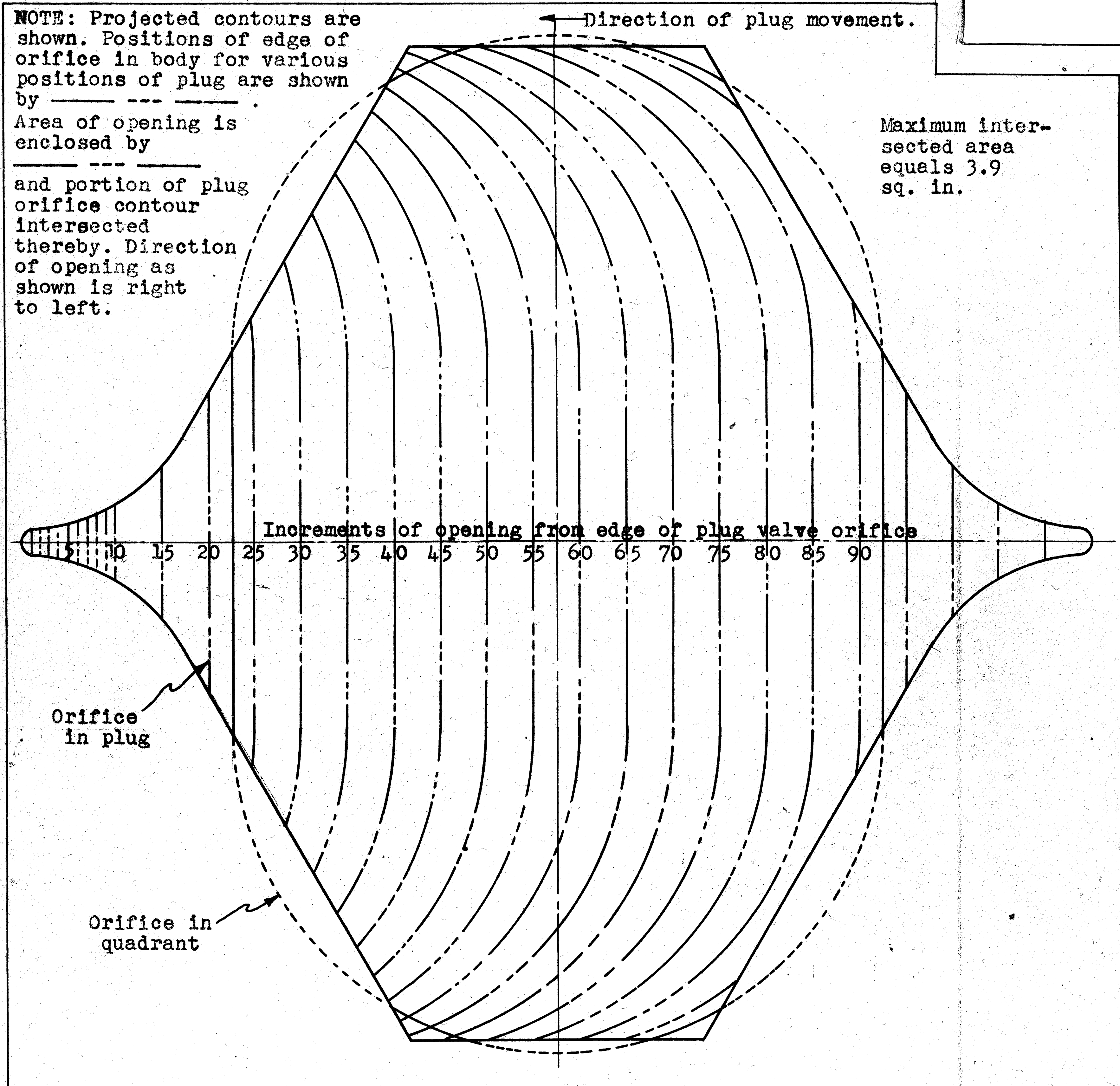


OPENING CHARACTERISTICS - 2" OIL FEED VALVE

Diamond Orifice in Plug vs. Diamond Orifice in Body
(Requiring new plug and valve body)



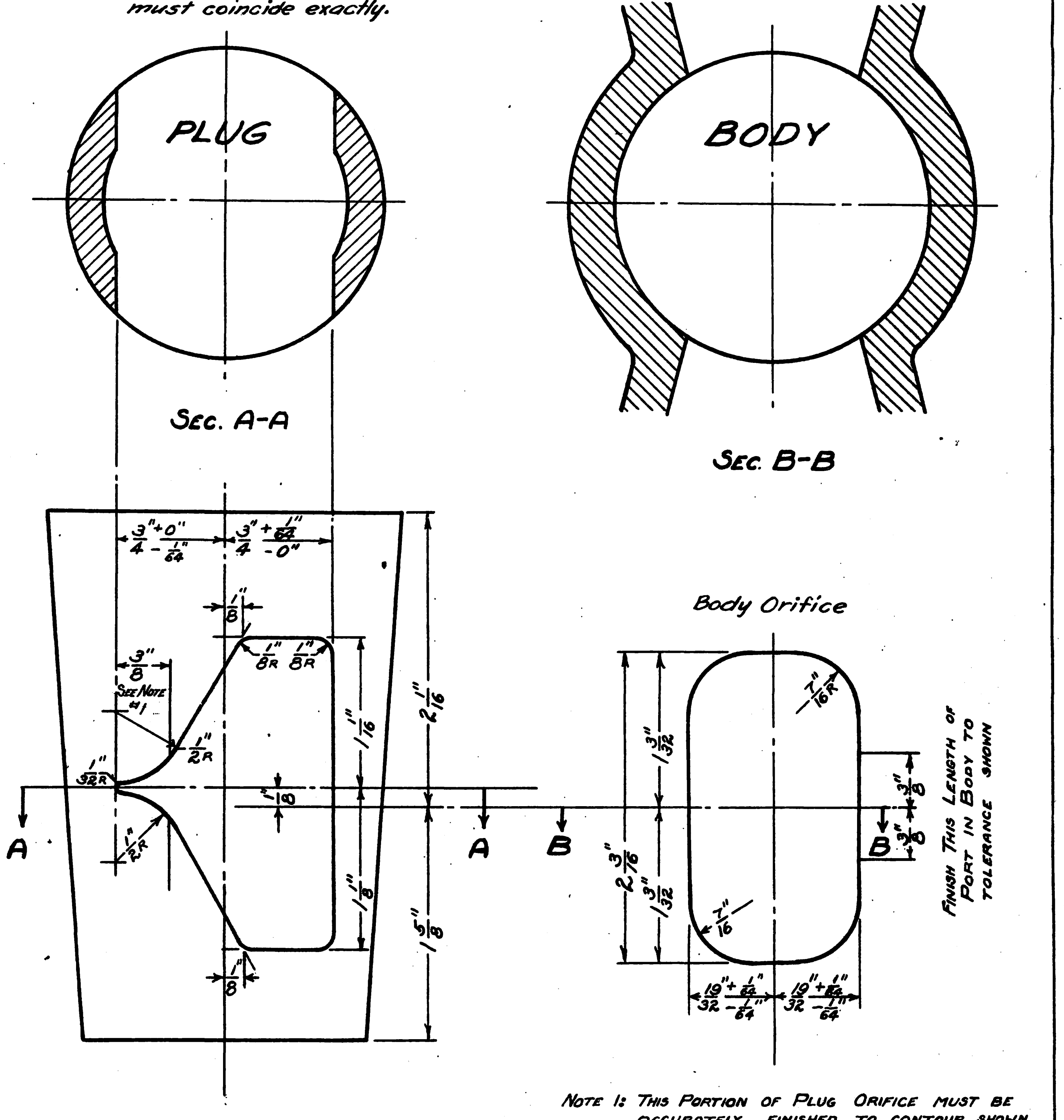
OPENING CHARACTERISTICS - 2" OIL FEED VALVE
Single Taper Orifice in Plug vs. Common Standard Orifice in Body
(Requiring new plug only)



OPENING CHARACTERISTICS - 2" OIL FEED VALVE

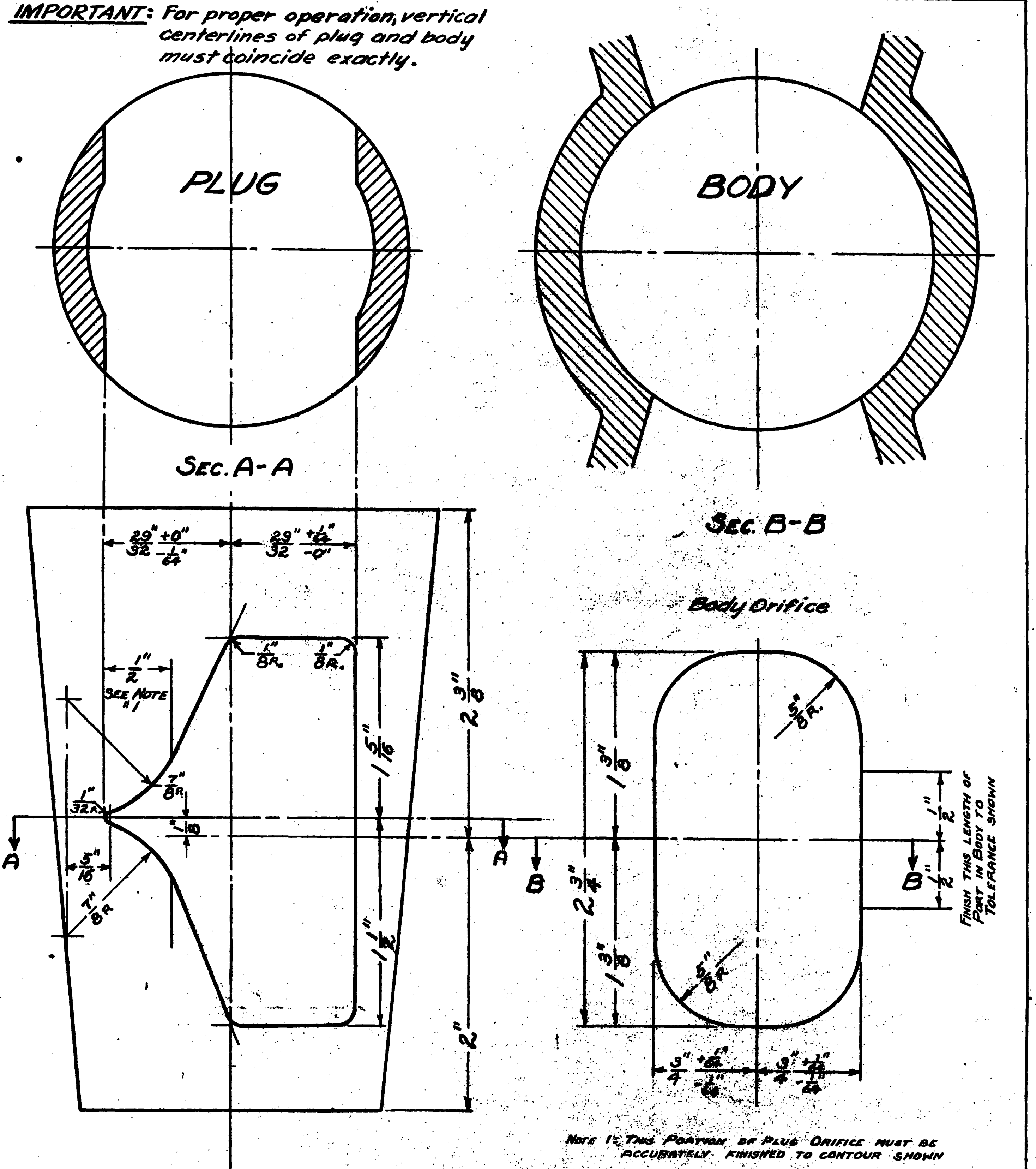
Double Taper Orifice in Plug vs. Enlarged Orifice in Body
(Requiring larger diameter valve and quadrant)

IMPORTANT: For proper operation, vertical centerlines of plug and body must coincide exactly.



NOTE 1: THIS PORTION OF PLUG ORIFICE MUST BE ACCURATELY FINISHED TO CONTOUR SHOWN

IMPROVED OIL FEED VALVE
1½" PIPE SIZE



IMPROVED OIL FEED VALVE
2" PIPE SIZE

2. <u>Improvement in Application of Firebrick to Locomotives</u>:

During the course of standing tests, with locomotive SP-4401, it has been necessary to renew and replace brickwork numerous times, because of modification in testing arrangements and because of repairs. This has afforded opportunity to observe the advantages and disadvantages of certain factors relating to firebrick installation, as explained below.

a) <u>Height of Firebrick on Side Sheets and Throat Sheet</u> -

It has been general practice on Pacific Lines for many years to extend the height of firebrick on side sheets to include four rows of staybolts above mud rings, whereas the T&NO and many other oil-burning roads cover not over two rows of staybolts. Test locomotive has been satisfactorily operated with the reduced height of firebrick and, based on calculations made, benefits can be derived from exposing additional evaporating surface to firebox heat. By lowering the brickwork to not more than two rows of staybolts on side sheets and eliminating excessive bricking on throat sheet, including wings, an increase of about 25 square feet in firebox heating surface is exposed which results in better distribution of heat, resulting in an increased evaporative capacity of 3.2% and a saving of about 280 firebrick, decreasing weight on firepan by 2,240 pounds for GS-1 Class locomotive. Method by which these savings were determined is detailed on page 41.

In view of the above savings, it is recommended that consideration be given to this modification and that the various classes of locomotives be studied to determine what changes can be made to expose additional heating surface, as outlined.

b) Expansion Joints in Brickwork -

Present bricking practice calls for application of firebrick solid against pan, door sheet and side sheets, without any allowance for expansion. When brick is applied in this manner, the expansion of brick and firepan causes distortion and buckling of brick setting as shown by photograph, page 42. Experiments have been made on test locomotives by applying expansion joints, both longitudinally and transversely. This is accomplished by leaving a 1/2" space at each end of all walls and filling these spaces with asbestos fibre, or other suitable compressible medium, properly prepared. When engine is fired up and brick expands, these expansion joints take up the movement without submitting the brick to undue strain, thereby resulting in a more integral brick setting with greater strength having less liability to break down in service. It is recommended that this improvement be given further service trials to determine whether it should be adopted as standard practice.

c) Thickness of Firebrick on Floor of Pan -

Present practice on Pacific Lines requires installation of brick on floor of pan with 4-1/2" thickness. T&NO practice calls for installation of this brick with 2-1/2" thickness. This latter practice, which is used on other oil-burning roads, would result in additional clearance between burner and floor of pan and reduce the tendency for flame to sweep the floor with resultant formation of carbon deposits thereon. It would also reduce the weight of brick supported by firepan and the number of brick and labor required to lay them. It is recommended that the brick be applied in this manner on floor of pan, and be given service trial to determine if it should be made standard practice.

Estimated Increase in Firebox Evaporating Capacity Due to Removal of Brickwork on Throat and Side Sheets Above Second Row of Staybolts, Class GS-1 Locomotives

Firebox evaporation, uncorrected -	80.0 lbs. per hour per sq. ft. of firebox area.
13% correction for feedwater heater -	10.4 lbs. per hour per sq. ft. of firebox area.
5% correction for oil burning locomotives -	4.0 lbs. per hour per sq. ft. of firebox area.
Total calculated firebox evaporation -	94.4 lbs. per hour per sq. ft. of firebox area.

Increase in firebox evaporative surface available from removal of brickwork on throat and side sheets, above second row of staybolts. = 25 square feet

Increase in potential firebox evaporation from removal of above bricks — 94.4 x 25 = 2,360 or 2,400 pounds per hour

The limit of economical evaporation is usually the capacity of the feedwater heater hot pump, which is 9,000 gallons per hour, or 75,000 pounds per hour, for a GS-1 Class locomotive, with standard feedwater equipment.

At rate of 75,000 pounds per hour, an evaporation of 2,400 pounds per hour is -

$$\frac{2400}{75,000} \times 100\% = 3.2\% \text{ of total evaporation.}$$

A saving of up to 280 bricks per locomotive per complete renewal of brickwork will be made, also installation labor costs and maintenance. Weight saving per locomotive will be approximately 2,240 pounds for 280 brick.

---o---

Appearance of buckled brickwork in flash wall - Test Locomotive SP 4401.

3. <u>Insulation on Bottom of Combustion Chamber and Outside Side Sheets:</u>

T&NO practice calls for application of lagging and jacketing to portion of exterior of boiler shell under bottom of combustion chamber and below running board, whereas Pacific Lines does not require insulation in this area. The portion of outside side sheets below running boards are not insulated on either Pacific Lines or T&NO. The absence of lagging on these surfaces which are exposed to atmospheric temperature results in loss of heat, the major portion of which would be confined within the boiler if surfaces were properly insulated. A study has been made of potential savings which would be available on a locomotive of the GS-1 Class if the exterior surfaces in question were insulated. Results of this study follow:

Computation of Heat Losses and Oil Equivalent, for GS-1 Class Locomotives; Losses Due to Unlagged Sections of Combustion Chamber and Firebox

Location	Plate Thickness	Area Sq.Ft.	Volume Sq. Ft. x Ins.	Average Thickness Inches	Average Thickness Feet
Side sheet	5/8"	64.0	40.0		
Back head	1/2"	4.5	2.25		
Throat	7/8"	18.0	15.75		
3rd Course	1-1/16"	40.0	42.5		
		126.5	100.5		
Add 5% for laps -			5.0		
			105.5	.835	.0685

$$\text{Heat flow, } Q = \frac{t_2 - t_1}{\left(\frac{1}{(hA)_i}\right) + \left(\frac{L_1}{(K_1A_1)}\right) + \left(\frac{L_2}{(K_2A_2)}\right) + \left(\frac{1}{(hA)_o}\right)} = \frac{\Delta t}{\Sigma R}$$

- $\frac{1}{(hA)_i}$ — Resistance, film of water
- $\frac{L_1}{(K_1A_1)}$ — Resistance, steel sheet
- $\frac{L_2}{(K_2A_2)}$ — Resistance, insulation (Omit when not insulated)
- $\frac{1}{(hA)_o}$ — Resistance, film of air

Q - BTU per hour
A - Area, square feet
K - Thermal conductivity, BTU/(hrs)(sq.ft.)(°F per foot)
@ 392 °F. = 26 for steel
" = .05 for magnesia, 85%

$$h = \text{film coefficient} = \frac{\text{Ratio of thermal conductivity}}{\text{Effective film thickness}} = \frac{K}{L} \text{ effective}$$

Usual range of h, BTU per hr. per sq.ft., per °F.

For air, outside surfaces - natural convection	= 1-3	Assume 3
For air, outside surfaces - forced convection	= 5-20	Assume 12
For water, inside surfaces -	=20-2000	Assume 1000

Average thickness
boiler sheet - .0685 ft.; $\frac{L}{KA} = \frac{.0685}{26} = .00265$, say .003 per sq.ft.

Thickness,
85% Magnesia - 2/12 ft.; $\frac{L}{KA} = \frac{2/12}{.05} = 3.33$, per sq. ft.

For still air - $\frac{1}{hA} = 1/3 = .333$

For air @ 30 mph, approximately - $\frac{1}{hA} = \frac{1}{12} = .083$

For water film, assume - $\frac{1}{hA} = \frac{1}{1000} = .001$

BTU's available per gallon of oil at 75% boiler efficiency:

18,300 x 8.33 x .75 = 114,200 BTU's/gallon

CALCULATIONS ON FUEL SAVING RESULTING FROM INSULATING ADDITIONAL BOILER SHEETS

Operation	$t_1-t_2 = \Delta t$	ΣR			$\frac{\Delta t}{\Sigma R}$ = $\frac{BTU}{Hr, sq.ft.}$	+5% a/c Proj. Stays
Standing	405°-0° = 405°	.001 + .003 + .333		= .337	1202	1262
(No lagging)	405°-90° = 315°	" " "		= .337	935	982
@ 30 mph(approx)	405°-0° = 405°	.001 + .003 + .083		= .087	4660	4895
(No lagging)	405°-90° = 315°	" " "		= .087	3620	3804
Standing	405°-0° = 405°	.001 + .003 + 3.33	.333	= 3.667	111	
(2", 85% Magnesia)	405°-90° = 315°	" " "	"	= 3.667	86	
@ 30 mph(approx)	405°-0° = 405°	.001 + .003 + 3.33	.083	= 3.417	119	
(2", 85% Magnesia)	405°-90° = 315°	" " "	"	= 3.417	92	

Estimated

Operation	Ambient Temp. °F	Heat flow from surface: BTU/Hr per square foot Unlagged	Lagged	Saving a/c 2" of 85% Magnesia BTU/(hr)(Sq.Ft.)		Heat saving per GS-1 Locomotive a/c 120 Sq. Ft. Lag. BTU per hr.	Gals Oil saved per Loco Hour @ 75% B.E.	Fuel Rate Gals/hr.	Oil Saved %
Standing	0°	1262	111	1151 x 120	=	138,000	1.21	30	4.03
Running	0°	4895	119	4776 x 120	=	573,000	5.02	500	1.00
Standing	90°	982	86	896 x 120	=	107,600	.94	30	3.13
Running	90°	3804	92	3712 x 120	=	446,000	3.90	500	0.78

Assuming that 20% of total oil burned is used standing, and 80% running, % fuel saving account 2" of 85% magnesia lagging on 120 square feet of surface would be:

Estimated Fuel Saved

0° Ambient Temp: (20% of .0403 = .008
(80% of .0100 = .008
.016 or 1.6%

90° Ambient Temp: (20% of .0313 = .006
(80% of .0078 = .006
.012 or 1.2%

From the foregoing analysis, it is evident that a calculated fuel saving of from 1.2 to 1.6%, depending on ambient temperature, could be realized by proper insulation on boiler shell under combustion chamber and outside wrapper sheets below running board and cab. Lagging and jacketing on bottom section of boiler shell below running board could be made independent of that on top of boiler shell in order to facilitate working on questionable staybolts. On outside side sheets, it is only necessary to extend the lagging and jacketing to the second row of staybolts above mud ring, inasmuch as firebox side sheets are covered by brickwork below this point. Later classes of AC locomotives are already provided with this insulation and jacketing on outside side sheets.

4. <u>Installation of Top Boiler Check</u>:

Test locomotive has been equipped with top boiler check, also known as steam space spray check, to determine the advantages from this method of feedwater injection as compared with present standard side boiler checks. Diagram showing a typical application of top check is shown on page 52. The advantage claimed for the top boiler check is that the water entering boiler through check and spray nozzle passes through the steam space in a thin conical film and becomes heated to approximately saturated steam temperature before reaching water surface in boiler. As water entering the boiler is heated to approximately the temperature of live steam, all of the water in the boiler is at the same temperature, and usual differentials in temperature that cause much of the trouble with boiler and firebox sheets and staybolts are avoided. Improved locomotive operation also results as the drop in steam pressure is eliminated that is encountered when a sudden demand for high output of the boiler is made after a period of standing or drifting. Elimination of excessive forcing of the fire to maintain steam pressure when starting can result in fuel saving as well as reduction in soot and smoke formation. Also, the injection of water spray in steam space will liberate entrained air in steam space where it will be drawn off with steam supply to cylinders. With present method of feedwater injection through side checks, air is absorbed by boiler water with resultant corrosive action on tubes and flues. This is particularly important for water from the injector where there is no other de-aerating feature provided.

Boiler maintenance is probably the largest repair problem on steam locomotives and the most important contributing factor is the damage resulting from expansion and contraction, occurring both in the engine house and on the road because of the frequent changes in boiler output necessary due to operating variations in grade, speeds and stops.

It is known that when steam is used from a locomotive boiler the major portion is generated at the firebox end and a circulation of the water in the boiler is thereby set up which is away from the firebox at the surface of the water and toward the firebox in the lower portions of the boiler. Consequently, the practice has developed of injecting the feedwater, which is usually 100 to 200 degrees cooler than the boiler water, into the forward portion of the boiler below the normal water level with the intention of allowing the heat absorbed from the tubes and flues to warm this incoming water to some higher temperature before it reaches the firebox sheets.

This relatively cool water, impinging on and surrounding the lower flues in varying amounts, and of varying temperatures, causes these flues to be continually changing in length as compared with those in the upper portions which are normally constant in temperature and length. The upper flues are longer because they are immersed in the water of boiler temperature. This causes a continual working of the tubes and flue sheets which necessitates frequent and extensive repairs.

As the locomotive is operated over the varied grades, the feedwater temperature and amount are usually changing and, at the tip-over on a grade, it is, of course, vitally important with conventional type steam locomotives, that the water level in the boiler be raised quickly so as to be sufficient to keep crownsheet fully covered. Under certain conditions, there are also times when throttle is being closed that water must be added rapidly as otherwise the level would drop undesirably because of settling due to reduction in steam demand. At such times, when enginemen must put water into the boiler at a high rate, it is not always possible to be sure that there will be sufficient exhaust steam pressure to heat feedwater to normal temperature, thus causing a most undesirable temperature variation in the boiler, with attendant stresses and strains.

Because of such instances, and others where instructions are not heeded and feedwater pumps are used by enginemen when the exhaust steam at nozzle is insufficient to heat the feedwater to the usual temperature, efforts have been made to alleviate the resulting stresses and strains by application of so-called "drifting control valves" which either restrict the speed of the feedwater pump to the point where the exhaust steam from the pump will heat the water, or admit sufficient boiler steam to the heater to raise the feedwater temperature. These devices, at times, do not operate as desired, have some other complications, and, at best, cannot produce the highly desirable boiler temperature feedwater resulting from the action of the steam space spray check as illustrated by the diagram on page 52.

Considering the wide variations in rate of adding water to the boiler in service, and instances where no exhaust steam or an insufficient amount is available to heat the water, together with the deficiencies and variations in temperature distribution in the boiler during intermittent times of injector operation, as when drifting and standing, the advantages of the steam space spray check, as shown by graph on page 53, are as follows:-

a) Substantially smaller temperature differences between top of boiler shell and the points in the lower portions, even when unheated water at 68°F. was pumped directly into boiler through the steam space spray check. With the top of the boiler shell at a temperature higher than the lower portions, the top of the boiler becomes relatively longer because of temperature expansion. Since the boiler is constrained at three points to the locomotive frame, it cannot, therefore, relieve itself by distortion, and the effect of the temperature expansion is additional tensional stresses in the lower portions with some reduction occurring in the normal tension in the upper section because of the reaction. As it is apparent from the variation in the temperature differences with steam rate, as shown on the graph, the variation in stresses in the boiler shell is considerable during normal service when side boiler checks are used.

These temperature stresses are complicated in nature and, while it is believed their longitudinal component would be about 200 psi per degree Fahrenheit difference between top and bottom of shell, the intermediate boiler supports and the general construction and conditions existing on a locomotive make their exact magnitude uncertain. The frequency of cracks from stress corrosion and leaking rivets in the lower portions at circumferential seams on many of our boilers is evidence that the effects of temperature stresses are usually concentrated and localized by other factors.

b) On the graph, substantially less variation is shown in temperature differentials at widely different steam rates as encountered in operation. This smaller variation would have a very beneficial effect on the life of tubes, flues and flue sheets, in addition to diminishing the difficulties with other portions of the boiler, and even if the feedwater pump were not shut off promptly when the main throttle is closed, the temperature differentials would be smaller than at present during normal operation.

c) The chart also shows improvement in temperature differentials when using injector which is very desirable, since injectors are normally used intermittently, except when engine is not equipped with feedwater pump. The intermittent disrupting of the boiler temperatures is probably more harmful to the boiler than the sometimes greater, but more constant, temperature differences resulting from the steady injection of water with the feedwater pump.

In view of the advantages outlined above for top or steam space spray check, and inasmuch as this type of check is used by other railroads on large locomotives, it is recommended that consideration be given to their application, preferably to larger types of steam locomotives, such as AC, MT, GS and F Classes.

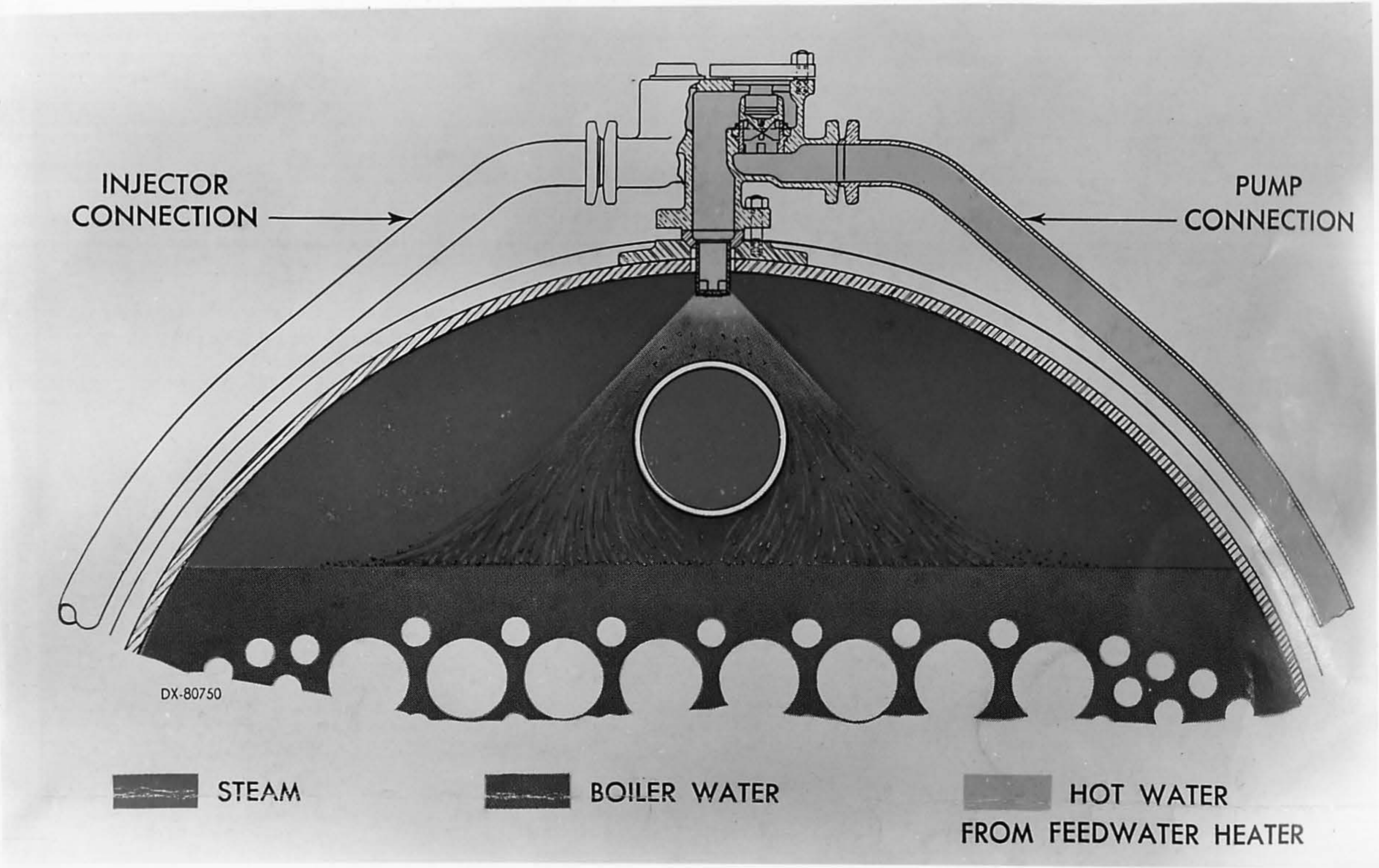
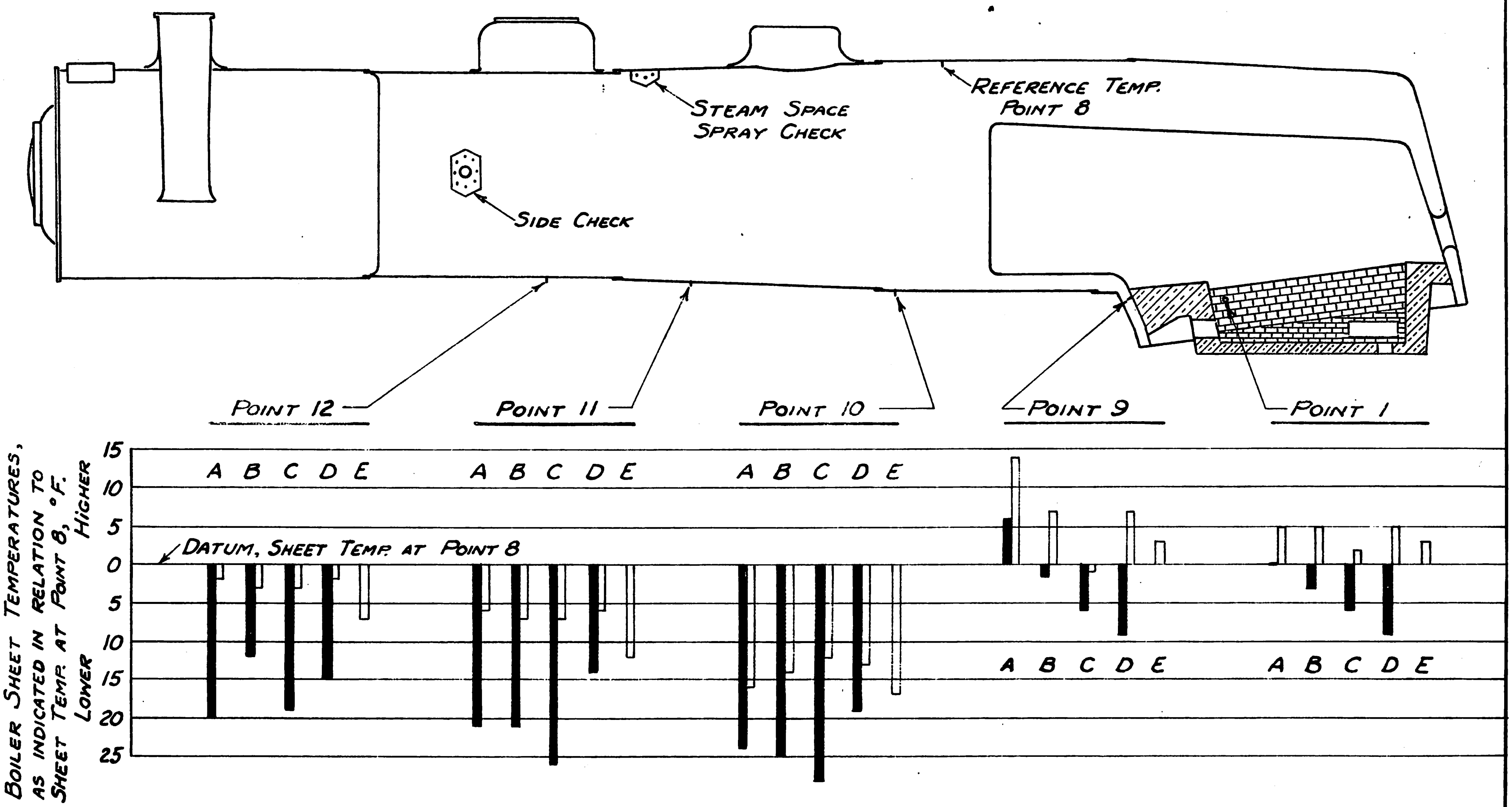


Diagram of top or steam space spray check.



SIDE BOILER CHECK

STEAM SPACE SPRAY CHECK

A FWH OPERATION, 230° F. WATER, HIGH STEAM RATE
B FWH OPERATION, 200° F. WATER, LOW STEAM RATE
C FWH OPERATION, 200° F. WATER, LOW STEAM RATE
D INJECTOR OPERATION, 200° F. WATER, LOW STEAM RATE
E FEEDWATER PUMP, 68° F. WATER, 60 TO 75 G.P.M., THROTTLE CLOSED

TYPICAL BOILER SHEET TEMPERATURE DIFFERENCES, COMPARING USE OF STEAM SPACE SPRAY CHECK AND STANDARD SIDE BOILER CHECK FOR WATER ENTERING BOILER

STANDING TEST ENGINE 4401

STANDING TEST PLANT, SACRAMENTO

5. <u>IMPROVEMENT IN BURNER APPLICATION</u>:

Pacific Lines practice has provided for securement of burner support bracket to firepan, whereas T&NO practice specifies application of bracket to frame. Both methods of securement have been tried on test locomotive, and it is evident that the frame support is preferable to mounting on firepan. During the numerous tests conducted during course of program, it has been determined that expansion, contraction, and warping of firepan will throw burner out of line with resultant impairment in firing and excessive heating of evaporating surfaces. Use of burner support bracket secured to frame will necessitate lengthening of burner body and provision of a machined leveling surface for use with new bracket. Restriction caused by cross brace at bottom of burner hood casting should be removed before installation of burner. The oil piping adjacent to burner must also be bracketed to frame if burner support is relocated on frame. If locomotive design does not permit a securement of oil piping to frame, it will be necessary to maintain burner support on firepan, otherwise differential expansion will cause misalignment of burner. However, where design permits, it is recommended that burner and adjacent piping be secured to frames for reasons stated.

To minimize carbon formation, present burner should be tilted slightly upward to align with point on vertical centerline of firebox, and 14" to 16" above floor of firepan at flash wall, based on experience with test locomotive.

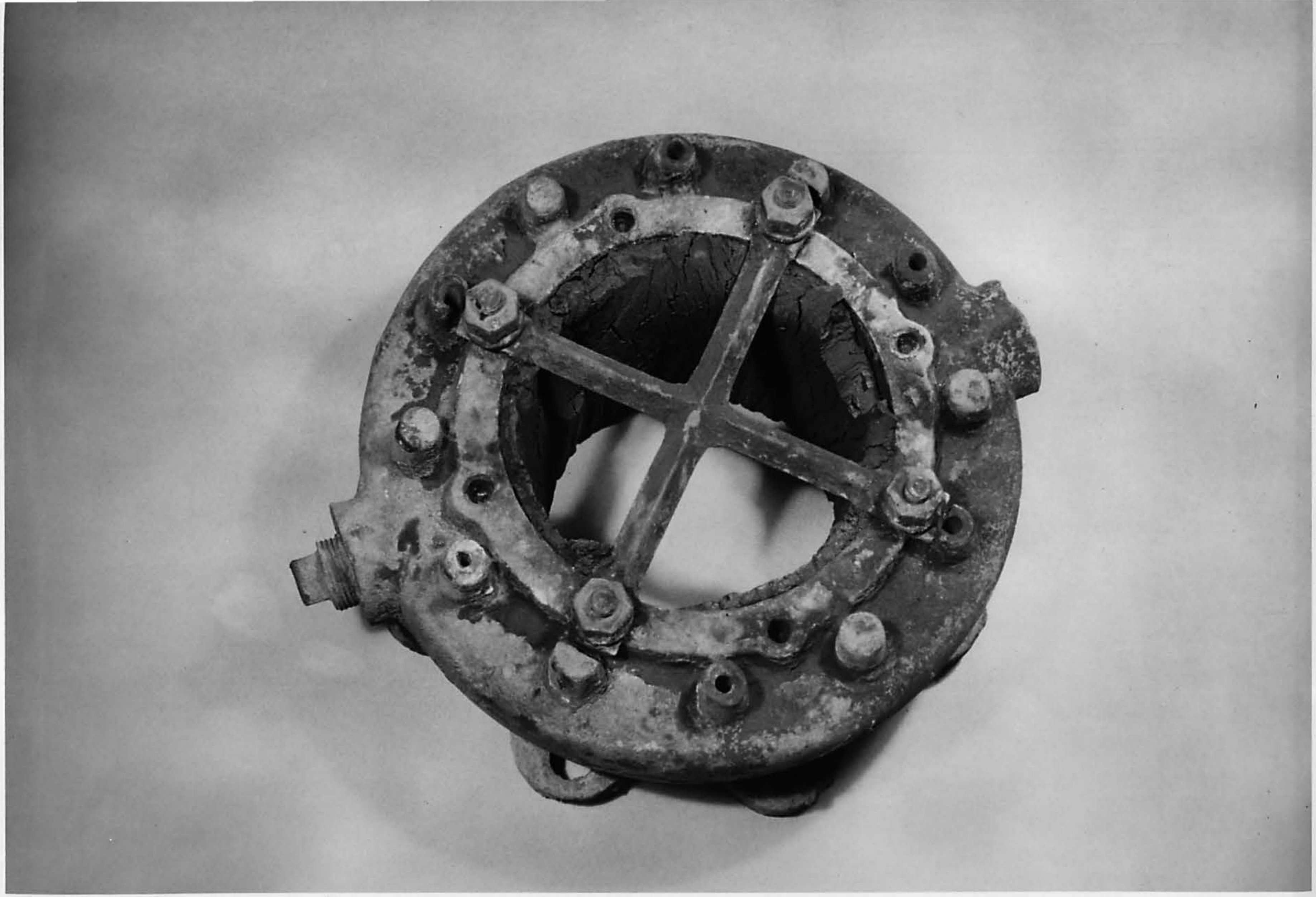
6. <u>IMPROVEMENTS IN SMOKEBOX DETAILS</u>:

a) <u>Removal of Carbon from Exhaust Stand</u> - Photograph, page 57, shows typical accumulation of carbon in nozzle and on cross split. This photograph illustrates the necessity for periodic removal of these accumulations in order to avoid restriction in passage for exhaust steam with consequent increase in back pressure and fuel consumption. From the rate of accumulation of these deposits, it is recommended that carbon be cleaned from these surfaces at least at each quarterly inspection and, also, from the entry of exhaust steam pipe from nozzle to feedwater heater, in addition to the removal of entire exhaust stand and exhaust steam pipe to feedwater heater for complete cleaning of carbon. Other obstructions which project into stack, such as sand ejectors, booster exhaust pipes, and feedwater exhaust pipes, causing interference with exhaust jet and proper drafting, should be removed therefrom.

b) <u>Alignment of Stack and Nozzle</u> - At the start of standing tests, it was necessary to realign stack and exhaust nozzle. As misalignment no doubt exists on other locomotives in service, it is recommended that alignment be checked on each locomotive to insure proper action of exhaust steam jet. This should be done on locomotives going through shops on Class 4 or heavier repairs, or whenever stack or exhaust stand are removed for any reason. Excessive misalignment of nozzle with smoke stack may cause down draft in stack, which must be eliminated.

In aligning locomotive stacks, accurate methods must be used and the following practice is recommended:

Level frame in longitudinal and transverse directions and check exhaust stand seat on cylinder casting; this must also be level. Set exhaust stand on seat and bolt in place. Check exhaust nozzle seat; this should be level in two directions. Apply exhaust nozzle and lay off center of nozzle on wood or metallic insert. Drop a plumb line from the top center of stack, positioning line so that the vertical center of the plumb line passes through the center of the exhaust nozzle. Using calipers, adjust stack and extension to be central with plumb line, being sure that the top center of the stack remains in alignment with the exhaust nozzle as adjusted above.



Carbon accumulated in Locomotive Exhaust Nozzle from cylinder lubricating oil during operation in service

7. SOOT AND SLUDGE REMOVAL:

Experience gained during standing tests shows a possibility of development of a more efficient means for sanding or otherwise removing soot from fire side of heating surfaces and tubes and flues to insure proper heat transfer. In the interest of determining potential benefits from use of commercial sludge solvents, tests were conducted in locomotive SP-4401 with two commercial products, identified as Product "A" and Product "B" for purposes of this report.

During the conduct of tests with Product "A", sanding according to regular practice with untreated oil was employed, inasmuch as manufacturer did not claim soot removal properties for this material, and flues were thoroughly sanded prior to each test run. Dosage of two quarts per thousand gallons of oil was made. Results of test showing smokebox temperatures, firing rate and boiler efficiency -vs- water rate (equivalent evaporation) are shown on page 62. From these results, it is evident that the untreated fuel oil is superior in all respects and that no improvement from the additive was obtained.

For test of Product "B", which is claimed to be a combination soot and sludge remover, one quart of compound was added to each 1,000 gallons of fuel oil per manufacturer's original recommendations. At completion of first series of tests, preparations were made for a second series employing double the recommended dosage of Product "B", namely, 2.3 quarts per thousand gallons of fuel oil, volume corrected to 60°F.

Results of test are shown on graph, page 63. As stated on this graph, no sanding was done during operation of the test with

Product "B", inasmuch as the manufacturer claims soot prevention and removal properties for this material. At expiration of this second series of tests, engine was heavily sanded and large amounts of soot were discharged at test plant stack. Fully five minutes of sanding flues were required before a clear stack could be obtained. Recording and other instruments showed that during sanding, superheat temperatures and front end temperatures dropped. When engine was thoroughly sanded out, both of these temperatures were back to those normal for proper operation.

This graph sheet shows the pertinent curves of boiler efficiencies, firing rates, and flue gas temperatures -vs- water rates (equivalent evaporation) for the control tests with untreated fuel and the several tests with treated fuel. These curves show the untreated fuel, with flues sanded regularly, to be superior in all respects, the boiler efficiency being highest and the fuel rate and flue gas temperatures being lowest for identical water rates.

The higher flue gas temperatures are indicative of soot formation on the evaporative surfaces. The high metal temperature of a portion of the superheater units prevents soot formation thereon, so the superheating surface is relatively unaffected by smoking. Therefore, because of the higher firing rate resulting from lowered boiler efficiency, together with the higher flue gas temperatures resulting from lowered heat transfer to the evaporative surfaces, the temperature of the superheated steam is higher and this may, in some instances, be construed as an improvement. However, the fact that the temperature of the flue gases is higher, is obvious proof of their greater heat content, all of which is lost.

Supplementing the above tests with sludge solvents, a further investigation was made to determine the effect of Product "A" on the depression of pour point of fuel oil, based on claim that this material would expedite unloading time of fuel oil at locations where low atmospheric temperatures are encountered.

Sample of untreated fuel oil from the Tracy supply and sample of the same fuel oil with one pint per 1000 gallons of fuel oil of Product "A" added were tested in full accordance with procedure and requirements of Specification ASTM D 97-39 for Pour Point, with results as follows:-

	As Received		With Product "A"	
Sample	No.1	No.2	No. 1	No. 2
Pour Point, °F.	35	35	35	35

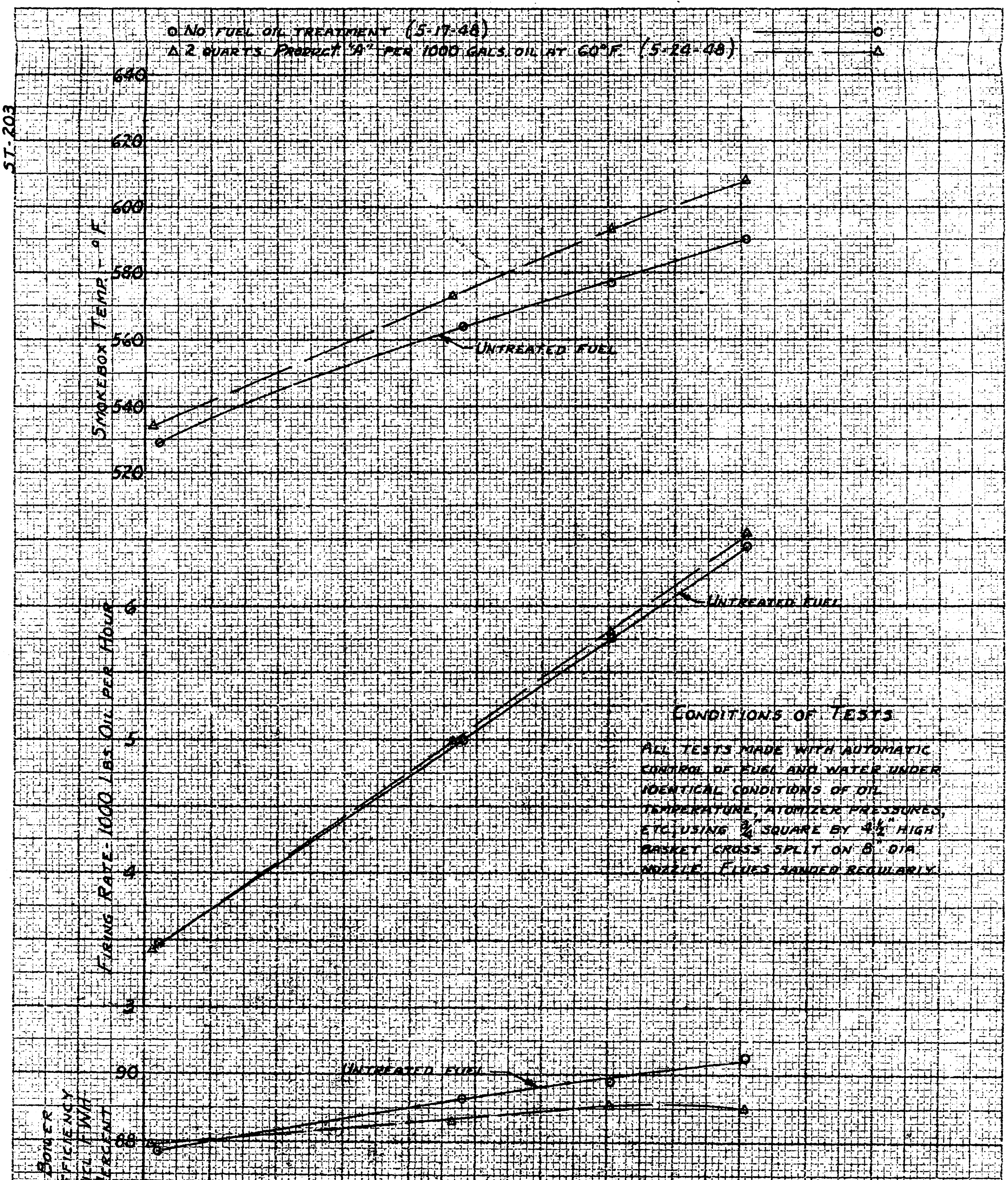
To supply a scientific and critical evaluation, it was decided to determine the viscosity curve at various temperatures of this fuel oil with and without addition of Product "A". These tests were made on a Zeitfuchs' Kinematic Viscosimeter, employing the dark tubes. This type viscosimeter is on the suspended level principle and, therefore, has no head variation. Uniformity of temperature is controlled to within .01°F. Timing of flow rates was done with synchronous electric timer to .1 of a second. The results at different temperatures in Seconds Saybolt Universal are shown in table below:-

	As Received	With Product "A"
SSU Visc. @ 100 °F.	4958.83	4962.43
@ 130 °F.	1300	1300
@ 210 °F.	130.8	130.8

This method is exceedingly accurate and discloses no detectable difference in viscosities at temperatures tested for the oils with and without the addition of Product "A". In fact, the treated oil showed slightly higher viscosity at 100 degrees. As the temperature is decreased, the viscosity approaches infinity at the pour point and the pour points, as previously shown, were identical. These two tests thoroughly demonstrate that between 210°F. and 35°F., there was no reduction whatsoever in the viscosity of the oils with or without treatment.

One further test was made with Product "A" to simulate dumping time from a tank car. An 18" inside diameter air reservoir, 8 feet in length, was mounted vertically and filled with oil from Tracy supply. Untreated oil was drained from 2" diameter plug at the bottom until exactly 93 gallons of oil had flowed out. Under mean flow temperature of 61°F., 33 minutes were required for this amount of oil to flow. Manufacturer's recommended amount of Product "A" was then incorporated and the mixture circulated between containers five times to secure thorough incorporation. After standing to allow temperature to drop, an identical amount of oil was drained as in previous case. Under mean discharge temperature of 58°F., 40 minutes were required for 92.8 gallons of oil to discharge.

Conditions could not be controlled closer, but with only 3 degrees lower temperature, the oil treated with Product "A" required seven minutes more to discharge than the untreated oil, proving that there is no validity to claims that Product "A" will reduce the unloading time of oil in tanks.

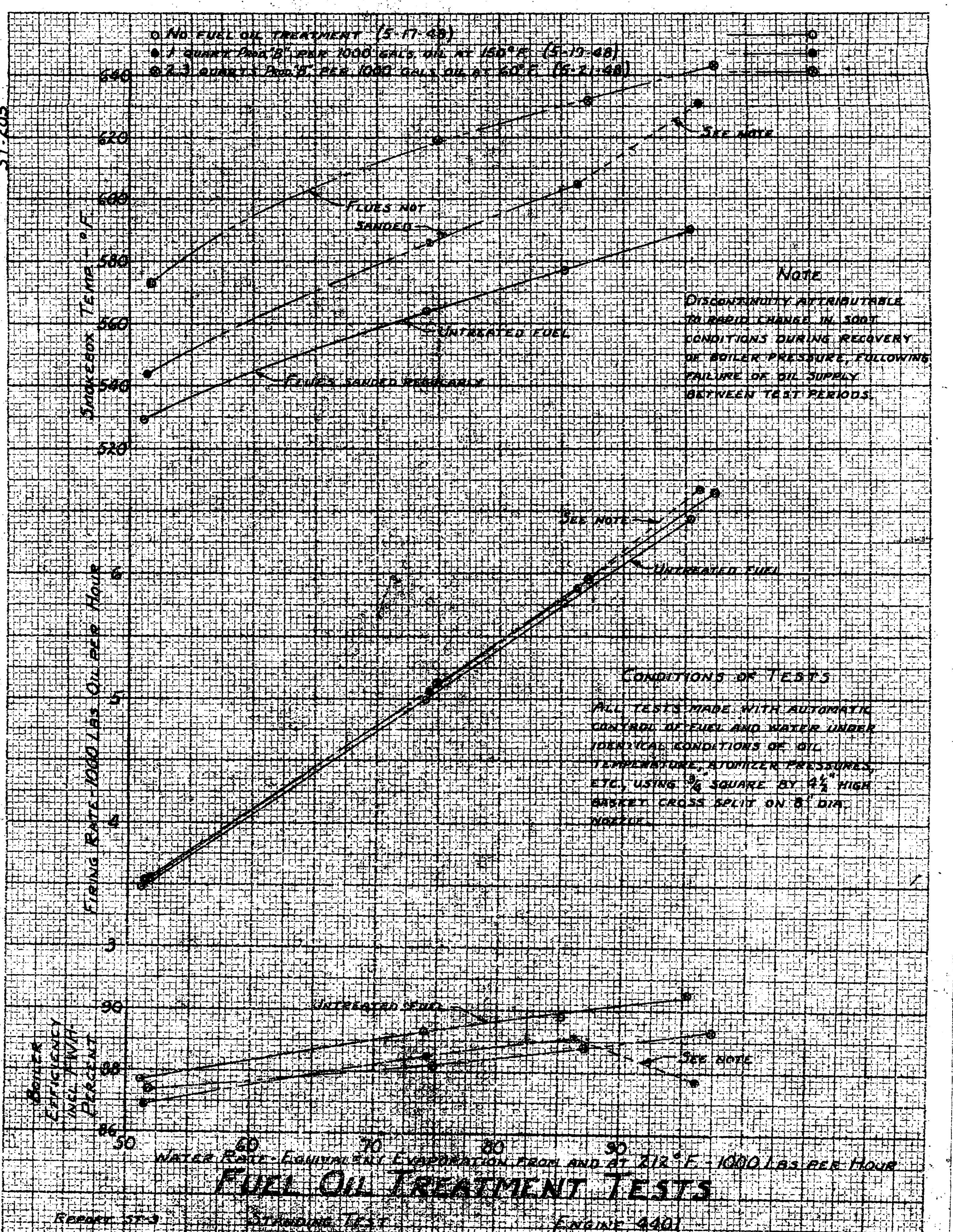


Fuel Oil Treatment Tests

Report ST-3 | Standing Test | Engine 4401

Standing Test Plant, Sacramento

ST-203



Fuel Oil Treatment Tests

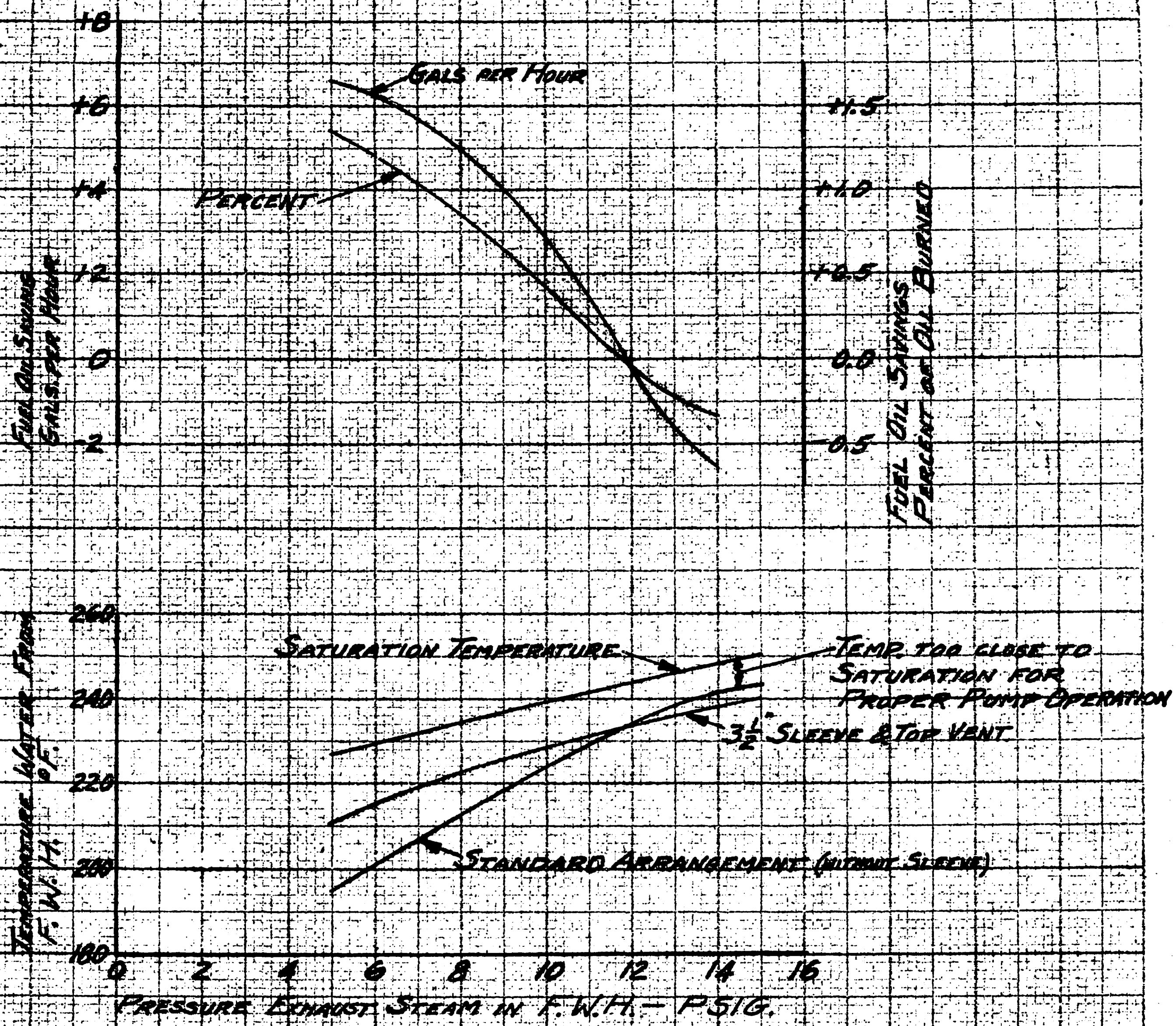
Report ST-3 Standing Test Engine 4401

Standing Test Plant, Sacramento

8. <u>IMPROVEMENTS IN FEEDWATER HEATER ARRANGEMENT, WORTHINGTON TYPE "S":</u>

The estimated savings in gallons of oil per hour per locomotive, and the percentage of fuel saved relative to pressure of exhaust steam in feedwater heater, are indicated on page 65. Although a loss is shown for the 3-1/2" sleeve arrangement at exhaust steam pressures above 12 pounds on account of the higher feedwater temperatures with present standard arrangement, present temperatures are too high for satisfactory feedwater hot pump operation, allowing pump to race because of cavitation.

The arrangement with 3-1/2" sleeve and top vent furnishes hotter feedwater than with present Pacific Lines standard arrangement at exhaust steam pressures below 12 pounds; the temperatures being as close to saturation temperatures as pump operation without cavitation will permit over the range of exhaust steam pressures shown, indicating a net saving in fuel oil. There are a number of locomotives on Pacific Lines equipped with Type "S" feedwater heaters to which these modifications are applicable. In order to obtain above benefits, it is recommended that all Type "S" feedwater heaters on Pacific Lines be modified in accordance with T&NO practice.



ESTIMATED SAVINGS EFFECTED BY REMOVAL OF 3/8" COLD WATER BYPASS IN F.W.H. AND APPLICATION OF TOP VENT TO HEATER CHAMBER, AND 3½" SLEEVE. BASED ON STANDING TEST STEAM RATES AND 31° A.P.I. FUEL OIL, ASSUMING 75% BOILER EFFICIENCY.

9. <u>ADVANTAGES OF INCREASED FUEL OIL TEMPERATURE AT BURNER</u>:

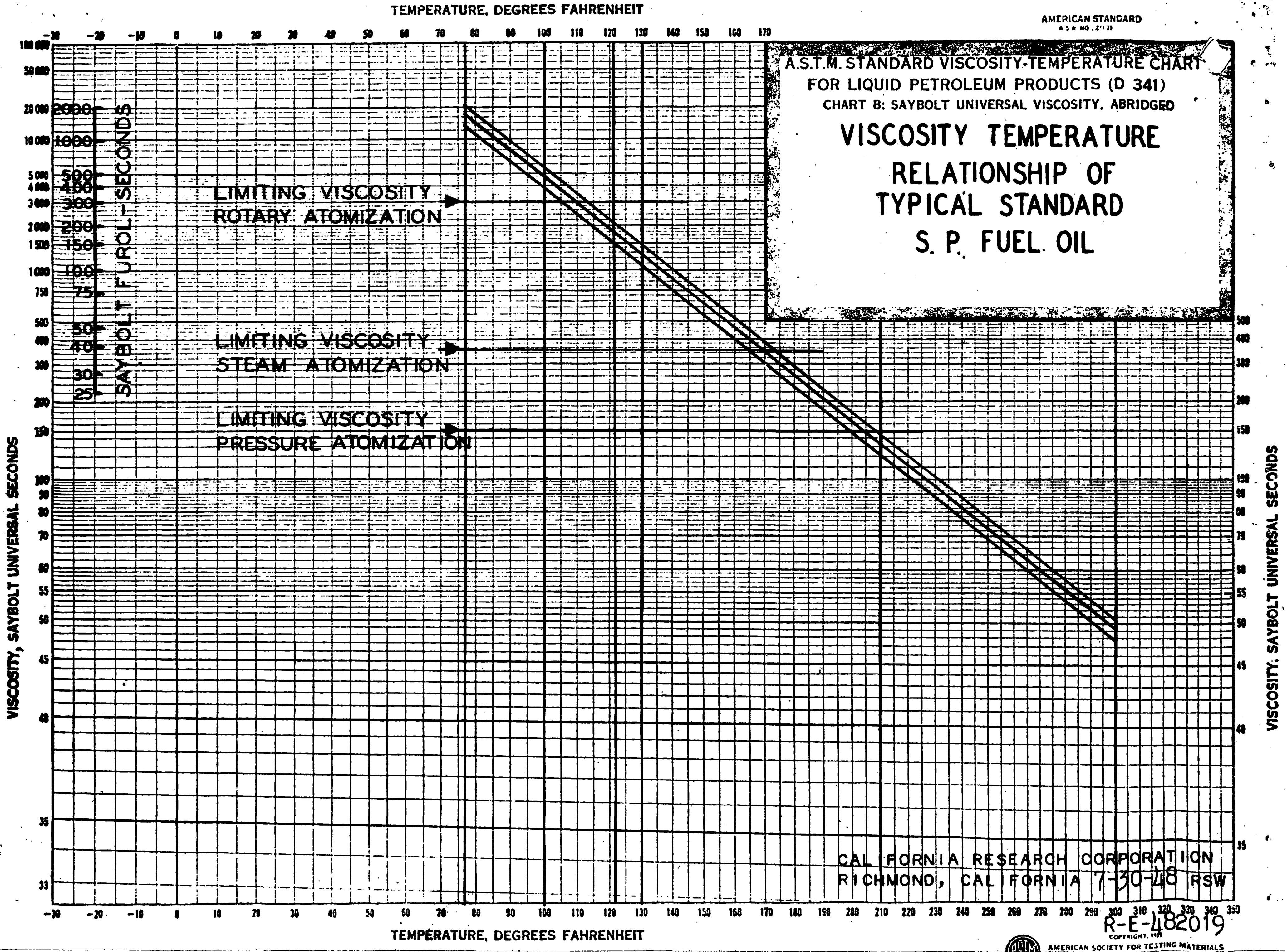
The residual type fuel oil most commonly used by steam locomotives on Pacific Lines is a very thick, sticky, viscous liquid at temperatures around 70°F. At lower temperatures, it tends toward a solid state and at a temperature usually near 35°F. it reaches the pour point at which it is solid and will no longer flow. As the temperature of the oil is raised above the pour point, the viscosity decreases and the oil becomes more and more fluid, flowing readily, like water, when heater sufficiently.

Obviously, the oil in the viscous, sticky state is extremely difficult to disperse in a manner suitable to efficient flame propagation, and to do so would be much more difficult and require relatively much greater energy than when the oil is reduced to a thin, fluid state by adequate heating.

The viscosity of the oil, at the temperature concerned, is the ultimate criterion for judging the suitability of the oil for atomization at a burner by any one of the three commonly employed means. Common practice and experience have established the highest viscosities at which oils can be effectively dispersed or "atomized" for burning for each of these three methods, rotary, steam, and pressure atomization, the maximum viscosities ranging downward in that order.

The variation of viscosity with temperature is shown on page 67 for the fuel oil typical of that supplied Pacific Lines in largest quantities. Since there are some variations in the oil supplied, the upper and lower ranges are shown with the middle line indicating the average characteristics.

This chart, which is based on information and recommenda-



TEMPERATURE, DEGREES FAHRENHEIT
AMERICAN STANDARD
A.S.T.M. STANDARD VISCOSITY-TEMPERATURE CHART FOR LIQUID PETROLEUM PRODUCTS (D 341)
CHART B: SAYBOLT UNIVERSAL VISCOSITY, ABRIDGED
VISCOSITY TEMPERATURE RELATIONSHIP OF TYPICAL STANDARD S. P. FUEL OIL
SAYBOLT FUROL-SECONDS
LIMITING VISCOSITY ROTARY ATOMIZATION
LIMITING VISCOSITY STEAM ATOMIZATION
LIMITING VISCOSITY PRESSURE ATOMIZATION
VISCOSITY, SAYBOLT UNIVERSAL SECONDS
CALIFORNIA RESEARCH CORPORATION
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tions of the major fuel supplier, also shows the upper limit or maximum viscosity above which experience has shown the oil cannot be atomized by each of the three means without attendant difficulties and deficiencies in firing. It will be noted on the chart that highest viscosity suitable for the steam atomization method, which is used on all Southern Pacific Lines, is about 350 Saybolt Seconds Universal, and that for fuel supplied Pacific Lines this limiting viscosity is obtained only by heating the oils to temperatures of approximately 175°F. at the burner, depending on the exact fuel oil involved.

Rule 23 of Rules and Information for the Firing and Handling of Locomotives states that, "The oil shall be heated to temperature sufficient to insure proper flow of oil to burner and proper atomization and combustion, but not to exceed 150°F." This limiting temperature is less than the minimum necessary for proper steam atomization of the major portion of the fuel supply for Pacific Lines, as indicated graphically on page 67.

At the time the change to high viscosity fuels occurred, a number of years ago, the need for adequately high oil temperatures was brought out by excessive steaming difficulties and carbon formation in locomotives in service. Carefully conducted service tests at that time proved the advantages of high oil temperatures, and sometime thereafter 180°F. was established as the standard temperature for the high viscosity fuel oils.

Subsequently, the permissible temperature was reduced to 150°F., and it has since been maintained at this figure on the basis of possible hazard because present fuel oil specification allows a minimum flash point of 150°F. and possibility of boilovers with existing tank heater arrangement. Actually, practically all the steam locomotive fuel furnished Pacific Lines has a flash point above 210°F., with some few instances, however, of oils being furnished with flash point down to 175°F.

Experience with test locomotives and observations at test plant confirm the desirability of raising the permissible oil temperature above the present limit to improve the firing of the high viscosity residual type oil with resulting benefits to be expected from reduction of cold oil type steaming difficulty with the usually attendant higher fuel consumption; less tendency for carbon formation; better oil atomization with lowered atomizing steam consumption; and reduced smoking - all of which are favorable to fuel economy.

The carefully conducted road tests on effects of oil temperatures, previously mentioned, indicated the possibility of achieving fuel savings of approximately 0.7% by elevating the permissible temperature for the high viscosity residual type fuels to at least 175°F.

Firing experience at that time, and in the test plant, clearly showed the need for more exact fuel control and should the present limiting fuel firing temperature be raised as recommended, the value of the improved design of oil feed valves (Item 1, page 2) will be greatly enhanced.

Further observations and experience on test locomotives and at test plant regarding fuel temperatures are that the present standard engine oil heaters are not entirely adequate as a means of controlling oil temperature at burner except in certain territories of long continuous grades and where low ambient temperatures are experienced. On AC Class locomotives operating cab end ahead in low ambient temperatures, the long length of oil piping requires such high capacity heaters and, at the same time, the length of piping serves to permit the flowing oil to mix in the pipe and become more stable in temperature than is the case on other classes of locomotives and in other climates.

The present size and style of engine oil heater is such that even on AC Class locomotives in high ambient temperatures the proper control of oil temperature by its use is difficult and oil temperature tends to fluctuate. In rolling grade territories where rate of fuel flow varies to any appreciable extent, this condition is aggravated because of the frequent changes in oil flow and the slow response of the oil temperature to the fireman's control valve, particularly when oil flow is being reduced.

Similar difficulties with engine oil heater due to the slow response and the tendency for the oil to gas in the heater, caused its use on the engine in the test plant to be abandoned in favor of raising the temperature in the oil tank and other means of controlling oil temperature.

One other difficulty noticed in the controlling oil temperature by means of engine oil heaters is that, when used, the usually slight opening of the steam control valve causes channeling of the steam through the small aperture in the valve with consequent rapid erosion and pitting which thereafter may preclude valve closing off steam supply completely. This leakage with low oil flows such as spot fires may be sufficient to overheat the oil in the heater section, causing gas pockets which cause extreme pulsing of the fire with hazard of flash backs.

It is suggested that engine oil heaters, when applied, be provided with two valves, one conveniently placed as at present for control and one closer to source of steam supply in cab, which should be opened wide when engine oil heater is in use. This would eliminate tendency of present single control valve to develop leaks account steam channeling. The present design of closed steam heater installed in bottom of tender tank over oil outlet consists of horizontal bends of pipe which tend to heat the entire body of oil in the tank. Investigation of designs of tank heaters used by other oil burning railroads shows that a number use a drum type of steam heater, which is installed in bottom of tank, through which the oil is obliged to pass on its way to outlet. This latter type of heater does not require carrying the entire body of oil in tank at an elevated temperature as the oil supplied to feed pipe is heated while passing through heater to outlet. The temperature of oil over the heater can be maintained only high enough to permit flow to heater. This should serve to reduce steam consumption for heating oil in tender tanks and minimize potential hazard of boil-over or explosion, inasmuch as top surface of oil body is not at such an elevated temperature that would cause vapor formation above surface. Oil could be elevated to higher firing temperature when leaving heater without the necessity of elevating the entire tank of oil to this temperature.

Present standard closed heater design could be modified somewhat along similar lines to the drum heater by a series of baffles installed between pipes of heater loops and by proper entrance and exit locations for oil in heater. This modification would serve to direct oil leaving tank through a passage across heating pipes, thereby elevating temperature of oil at tender tank outlet above that in the main oil body in tank. Present heater arrangement does not take full advantage of effective heating surface of steam heat pipes in the elevation of outlet oil temperature.

In the interest of elevating firing temperature of fuel oil at burner as recommended, as well as reducing steam consumption to heat oil, study should be made into oil heater design, both in tender tank and on engine oil pipe line, to determine what improvements can be made therein.

To insure saving that could result from maintaining the proper firing temperature of oil at all times, it is also recommended that dial thermometers indicating oil temperature at burner be installed on all steam locomotives not now so equipped.

If a sturdy thermostat arrangement could be designed suitable for locomotive service, oil temperature at tank outlet could be automatically maintained within proper range. However, thermostat design already tried in service did not prove sufficiently durable and reliable for locomotive use and was, therefore, unsatisfactory.

10. <u>MODIFICATIONS IN FIREPAN DESIGN AND DRAFT ARRANGEMENT</u>:

Study is being continued on various modifications in firepan air admission and design. The results of this study will be included in Report ST-4 - FIREPAN TESTS.