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SECTION	Sodium Reactors	A Division of North American Aviation, Inc.	GO 7508
GROUP	Sodium Components	TECHNICAL DATA RECORD	LEDGER ACCT. 3621
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OTHER			TWR 20608
		PROJECT: U Alloy Fuel Evaluation	DATE March 13, 1961
			PAGE 1 OF 24

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SUBJECT: Hydraulic Tests of a Prototype Hallam Fuel Element (SU-9) to be Tested in SRE

CONTENTS:

I STATEMENT OF PROBLEM

A fuel element assembly (designated as SU-9) has been fabricated to test in the SRE a variable orifice similar to the Hallam design. In order to accurately predict the performance of this element in the SRE and to formulate an effective in-core experimental program, pressure drop-flow data are required. To obtain such data, hydraulic tests in a water loop were performed.

II. SUMMARY OF RESULTS AND RECOMMENDATIONS

Pressure-drop measurements were made across a mockup of a Hallam prototype fuel element in a test section installed in the Hallam Hydraulic Loop. The flow channel was identical to an SRE fuel channel and included simulated upper and lower plenums. The fuel element mockup was equipped with a Hallam-type variable orifice at the channel exit and a fixed orifice in the strainer basket at the bottom of the element. Tests were performed to determine the optimum size for the fixed orifice and the temperature adjustment capability of the variable orifice using this optimum fixed orifice.

To obtain the predicted 4.1 lb/sec sodium coolant requirement at a core pressure drop of 1.85 psi, a 3/4-in. fixed orifice was determined to

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be the optimum. With this fixed orifice size the variable orifice will be approximately 1 in. withdrawn during full-power operation. Adjusting the orifice over its entire range of 3 in. from fully inserted to fully withdrawn covers a temperature range from 1040°F to 875°F which is approximately ± 80°F about the nominal outlet temperature of 960°F. This adjustment temperature range is almost identical with the desired range of ± 75°F.

Curves are presented which will aid in determination of operating characteristics of the element with other fixed orifice sizes should the core pressure drop or required flow rate of coolant be changed.

III. EQUIPMENT USED

An existing mockup of an SRE process tube, which is located in the HNPF water test loop and includes simulated upper and lower plenums, was used for this experiment. A description of the test loop and process tube is given on Page 2 of Reference 1. Water, which was heated to approximately 150°F, passed from a storage tank through a 750-gpm pump, a throttling valve, an ASME standard flange-tapped square-edge orifice plate, up through the process tube, and returned to the storage tank. Pressure drops across the flow-metering orifice and test section were measured with both inclined and U-tube manometers using mercury or Meriam No. 3 (sp. gr. 2.96) as indicating fluids. Test section pressure drops were measured across the fuel bundle and also from plenum to plenum, see Figure 1a. The fuel element mockup was supported in the test section at the same elevation (relative to the moderator spacer-ring mockup) it will have in the SRE when the element is hot. An extension to the orifice drive tube projecting through the element support flange was used to adjust the orifice plug position. The plug position was measured with a 6-in. scale using the fully inserted position as a reference; the maximum error in plug positioning during the experiment is estimated to be less than 1/32 in.

IV. METHOD USED AND DISCUSSION OF RESULTS

The initial series of tests consisted of pressure-drop measurements across the test section from plenum to plenum with the plug of the variable orifice adjusted from fully inserted to 3 in. withdrawn, at 1/2-in. increments. The first element design included a 2-in. fixed orifice in the strainer assembly. The results of these tests are presented in Figure 2. Measurements were repeated three times at each orifice plug position to determine the reproducibility of data. No variations between successive test runs were observed indicating that the orifice plug could be re-positioned precisely.

To obtain the desired outlet temperature of 960°F with this fuel element in the SRE, the required flow rate is estimated to be 4.1 lb per sec (Ref. 2). The fixed orifice plates attached to the standard 5-rod fuel elements now in the SRE core are sized to produce a core pressure drop of 1.85 psi at full flow (Ref. 3); therefore, the SU-9 variable orifice must be adjusted to provide the same core pressure drop of 1.85 psi at a flow rate of 4.1 lb per sec. To enable a more accurate determination of the orifice plug position to obtain the desired value of 4.1 lb per sec, a curve (see Fig. 3) of flow rate vs orifice plug position at a core pressure drop of 1.85 psi was cross plotted from Figure 2. For the 2-in. fixed orifice, the plug position at 4.1 lb per sec is noted to be 3/32-in. open.

Since the primary purpose of the SU-9 element is to obtain in-core data on the operation of a variable orifice, flexibility in the flow adjustment about the nominal flow rate is a necessity. Admustment of the variable orifice in the reactor will result in changes in the channel outlet temperature and this change in temperature is a good measure of the flexibility of the variable orifice.

The power, Q, removed by the coolant in a fuel channel may be calculated by

$$Q = \dot{W} c_p (T_{out} - T_{in}) \tag{1}$$

The inlet temperature, T_{in}, is assumed to be 500°F and the nominal outlet temperature, T_{out}, is assumed to be 960°F at full power. The outlet temperature may be calculated by the following formula

$$T_{out} = L \frac{4.1}{\dot{W}} \times 460 + 500 \tag{2}$$

with L (the power level expressed as the fraction of full power) and $\dot{W}$ (the flow rate through the channel). Figure 3b was constructed using Equation (2) and Figure 3a. Figure 3b shows that, with a 2-in. fixed orifice, the outlet temperature may be varied from 980°F to 790°F by adjusting the variable orifice plug over the entire range from fully inserted to 3 in. withdrawn. This is a range from +20°F to -170°F about the nominal outlet temperature of 960°F. In the SRE, the desired range of temperature control is ± 75°F about nominal; thus, there is a wide disparity between the desired and obtainable temperature range.

In order to approach the desired control-temperature range, the minimum flow rate (flow rate with the orifice plug in the fully inserted position) must be reduced; an obvious solution is to increase the flow impedance of the fuel element assembly. The strainer-guide assembly, which attaches to the bottom of the fuel bundle, contains a fixed orifice plate which supports the upper conical screen (Figure 1b). The channel coolant flows through the 2-in. hole in this fixed orifice plate and also through the annulus formed by the plate OD and the process tube ID. The plate OD was dictated by clearance considerations; the 2-in. hole size was dictated by strength considerations to support the basket rods and upper screen. Reduction of the hole diameter (hereafter referred to as fixed orifice diameter) would: (1) increase the total fuel-element flow impedance, (2) increase the stiffness of the plate, and (3) change the portion of the total coolant flow passing through the fixed orifice. Use of smaller fixed orifice sizes was discussed with SRE personnel and received tacit approval contingent upon acceptable hydraulic characteristics (Ref. 3).

To increase the flow impedance by this means, the consequences of increasing the bypass flow must be considered. The screen openings in the strainer are 0.059-in. square; the annulus surrounding the fixed orifice plate is 0.061-in. thick. The annulus is therefore approximately as effective as the screen openings in trapping any particulate matter in the channel coolant. Of the total particulate matter trapped by the strainer, the fraction trapped in the annulus may be assumed to be directly proportional to the fraction of the flow through the annulus to the total flow. Since the screens and the annulus are equally effective strainers, reduction of the fixed orifice size should have no effect on the efficiency of the strainer. Any particulate matter trapped in the annulus is unlikely to be removed with the fuel element during handling and will fall back into the lower plenum; however, if the SU-9 fuel element is removed from the SRE and particulate matter is observed on the strainers, a method of estimating the total matter contained in the coolant is desirable. The following analysis provides a means of so estimating.

Pressure drop across the flow paths through and around the fixed orifice plate are equal. The pressure drop across the annulus is

$$\Delta P_a = \frac{K_a \rho \dot{W}_a^2}{A_a^2 \rho^2 2g} \qquad (3)$$

The pressure drop across the fixed orifice and screen is

$$\Delta P_{o+s} = \frac{K_o \rho \dot{W}_o^2}{A_o^2 \rho^2 2g} + \frac{K_s \rho W_o^2}{A_s \rho^2 2g} \qquad (4)$$

Since $\Delta P_{o+s} = \Delta P_a$, then

$$\frac{K_a \dot{W}_a^2}{A_a^2} = \dot{W}_o^2 \left[\frac{K_o}{A_o^2} + \frac{K_s}{A_s^2} \right] \qquad (5)$$

or

$$\frac{\dot{W}_a}{\dot{W}_o} = \left[\frac{K_o}{K_a} \left(\frac{A_a}{A_o} \right)^2 + \frac{K_s}{K_a} \left(\frac{A_a}{A_s} \right)^2 \right]^{1/2} \qquad (6)$$

and since

$$\dot{W}_t = \dot{W}_a + \dot{W}_o \qquad (7)$$

then

$$\frac{\dot{W}_a}{\dot{W}_t} = \frac{\dot{W}_a/\dot{W}_o}{1+\dot{W}_a/\dot{W}_o} \qquad (8)$$

$\frac{\dot{W}_a}{\dot{W}_t}$ is the fraction of the total flow rate which passes through the annulus. Loss coefficients, K_a, K_s, and K_o were determined from Ref. 4. The fraction of flow through the annulus for orifice sizes from 0 to 2-in. diameter is plotted in Figure 4; the bypass flow varies from a minimum of 21% with a 2-in. hole to the obvious 100% with no hole. The fraction of total trapped material accumulated in the annulus therefore also varies from 21% to 100%.

Use of Figure 4 and estimation of any observed quantity of particulate matter on the screen may then serve as a means of estimating the total matter removed by the strainer; hence, the quantity contained in the coolant stream.

Hydraulic tests were performed with different fixed orifice sizes. Tests with a 1/2-in. fixed orifice were run at variable orifice positions from fully inserted to 3 in. withdrawn, at 1/2-in. intervals (Fig. 5). Tests with 3/4-in., and 1-1/4-in. fixed orifices were performed only at settings of fully inserted and 3 in. withdrawn (Fig. 6 and 7); the intermediate positions were skipped to reduce the total number of tests required.

Data from Figures 2, 5, 6, and 7 for fully inserted and 3 in. withdrawn plug positions are cross-plotted in Figure 8 for core pressure drops of 1.85 psi and 2.50 psi. The range of flow rates for a particular fixed orifice size may be determined from this Figure. For example, at a core pressure drop of 1.85 psi and using a 1-in. fixed orifice the flow rate may be adjusted between 3.7 and 5.4 lb/sec.

Data are presented in a more useful form in Figure 9, in which the coolant exit temperature is plotted against the fixed orifice diameter. For example, at a core pressure drop of 1.85 psi and using a 1-in. fixed orifice, with the reactor operating at full power, the channel outlet temperature may be varied between 845°F and 1015°F by adjusting the variable orifice. Since the permissible channel outlet temperature may be varied only ± 75°F from the nominal outlet temperature, the variable orifice should not be adjusted over its entire range when the reactor is at full power. However, this problem may be overcome by obtaining test data on the variable

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orifice while the reactor is operating at a 50% power level and full flow. The core temperature rise will then be 50% of the full-power core temperature rise and variations in temperature due to orifice adjustment will be halved (Figure 10).

This method for obtaining test data on the variable orifice over its entire range is not necessary for all fixed orifice sizes. For example, the range of temperature adjustment (at full power and with a core pressure drop of 1.85 psi) using a 3/4-in. fixed orifice is from 875°F to 1040°F or $\sim \pm$ 80°F. Almost the entire range of adjustment may be utilized without resorting to the above method of flow not matching power level.

Using a smaller fixed orifice diameter results in a narrower possible temperature range. The smaller fixed orifice may therefore be concluded to be safer for two reasons: (1) less chance of operator error, (2) less effect if the orifice drive fails. The 3/4-in. orifice appears to yield a satisfactory temperature range and is recommended for use on the SU-9 fuel element if a core pressure drop of 1.85 psi is used in the SRE. If a core pressure drop of 2.50 psi is used, a 1/2-in. fixed orifice appears preferable. Since the core pressure drop might conceivably be changed in the SRE (by installation of different orifice plate sizes on the 5-rod elements) Figures 11, 12, and 13 plotting flow rate and channel outlet temperature vs core pressure drop were constructed for fixed orifice sizes of 1/2-in., 3/4-in., and 1-in. diameter. Operating characteristics for any core pressure drop ranging from 1.2 psi to 3.2 psi may be observed from these curves.

In addition to operation at the extremes of orifice adjustment, the intermediate plug positions are of interest. Figure 3 shows the channel exit temperature and flow rate vs variable orifice plug-position for the 1/2-in. and 2-in. fixed orifice sizes. In addition, the exit temperature vs plug position for 3/4-in. and 1-1/4-in. fixed orifices was estimated and dotted in. The effect on exit temperature of a particular orifice adjustment may be determined from this figure.

In previous Hallam variable orifice development reports, the temperature sensitivity of the orifice (which is defined as the change in exit temperature per change in plug position) has been determined and plotted. This criterion, while useful, may be construed to imply that an operating hazard could exist while, in fact, none does. Figure 14, a plot of temperature sensitivity vs plug position was constructed to show that sensitivity in itself may be misleading. For example, the sensitivity in the range from fully inserted to 1/4-in. withdrawn is noted from Figure 14 to be 135°F/in. to 300°F/in. or an average of 220°F/in. This average sensitivity is greater than the entire temperature change from fully inserted to fully withdrawn.

Perhaps a more useful tool for indicating the effects of orifice adjustment is the curve in Figure 15 of temperature sensitivity in °F/single orifice adjustment increment. For this variable orifice, the maximum increment is 0.0333-in. without removing the orifice adjustment tool and resetting the drive mechanism. The maximum temperature change per adjustment is less than 10°F, which is not apparent from the usual sensitivity curve. The sensitivity of this variable orifice is obviously low, which is desirable to minimize the effects of any operator error during orifice adjustment.

NOMENCLATURE

Symbol	Item	Dimension
A	area	ft^2
c_p	specific heat	Btu/lb-°F
g	gravitational constant	ft/sec^2
K	form loss coefficient	dimensionless
L	power level	dimensionless
ΔP	pressure drop	psf
Q	power	Btu/sec
T	temperature	°F
V	velocity	ft/sec
$\dot{W}$	flow rate	lb/sec
ρ	density	lb/ft^3

Subscript	Item
a	annulus
o	orifice, fixed
s	screen
t	total

REFERENCES

1. TDR 4644, "Pressure-Drop Measurements Across a 4-Rod Fuel Element to be Tested in SRE," 5 November 1959, by R. J. Begley.
2. Personal communication with M. King.
3. Personal communication with G. Gower.
4. "Flow of Fluids through Valves and Pipes," Crane Company Technical paper.

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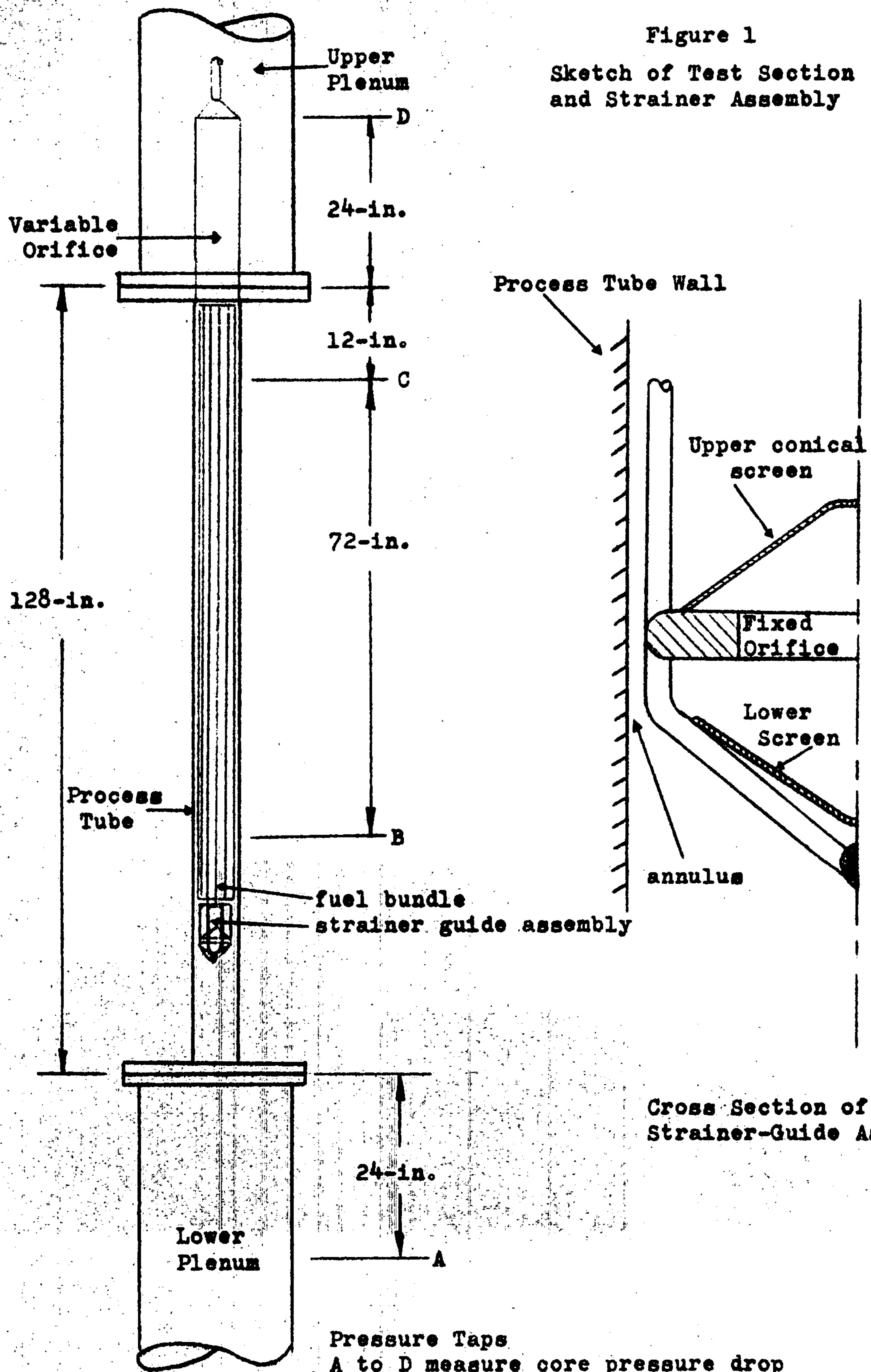
Figure 1

Sketch of Test Section and Strainer Assembly



Cross Section of Strainer-Guide Assembly

Pressure Taps
A to D measure core pressure drop
B to C measure bundle pressure drop

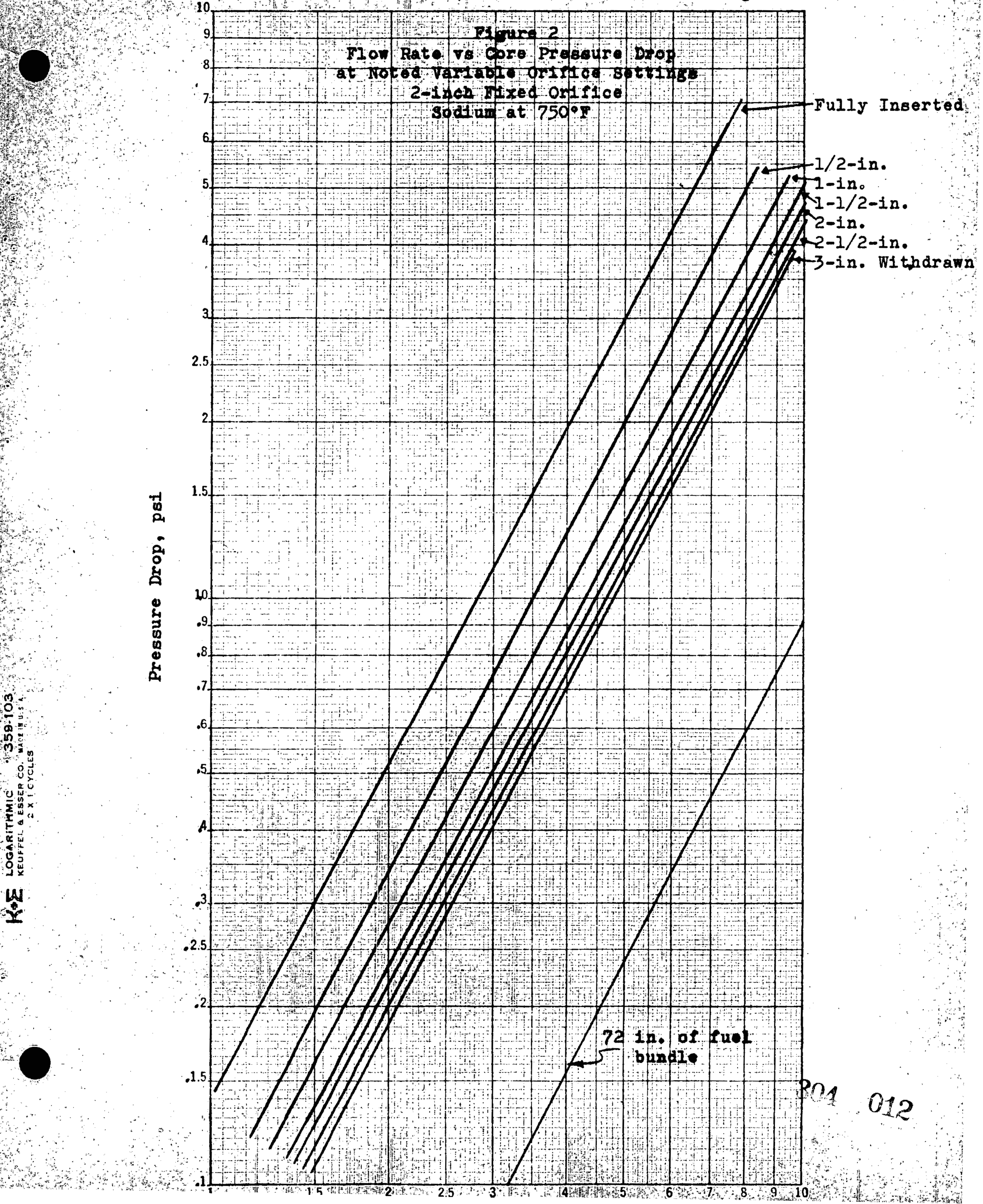
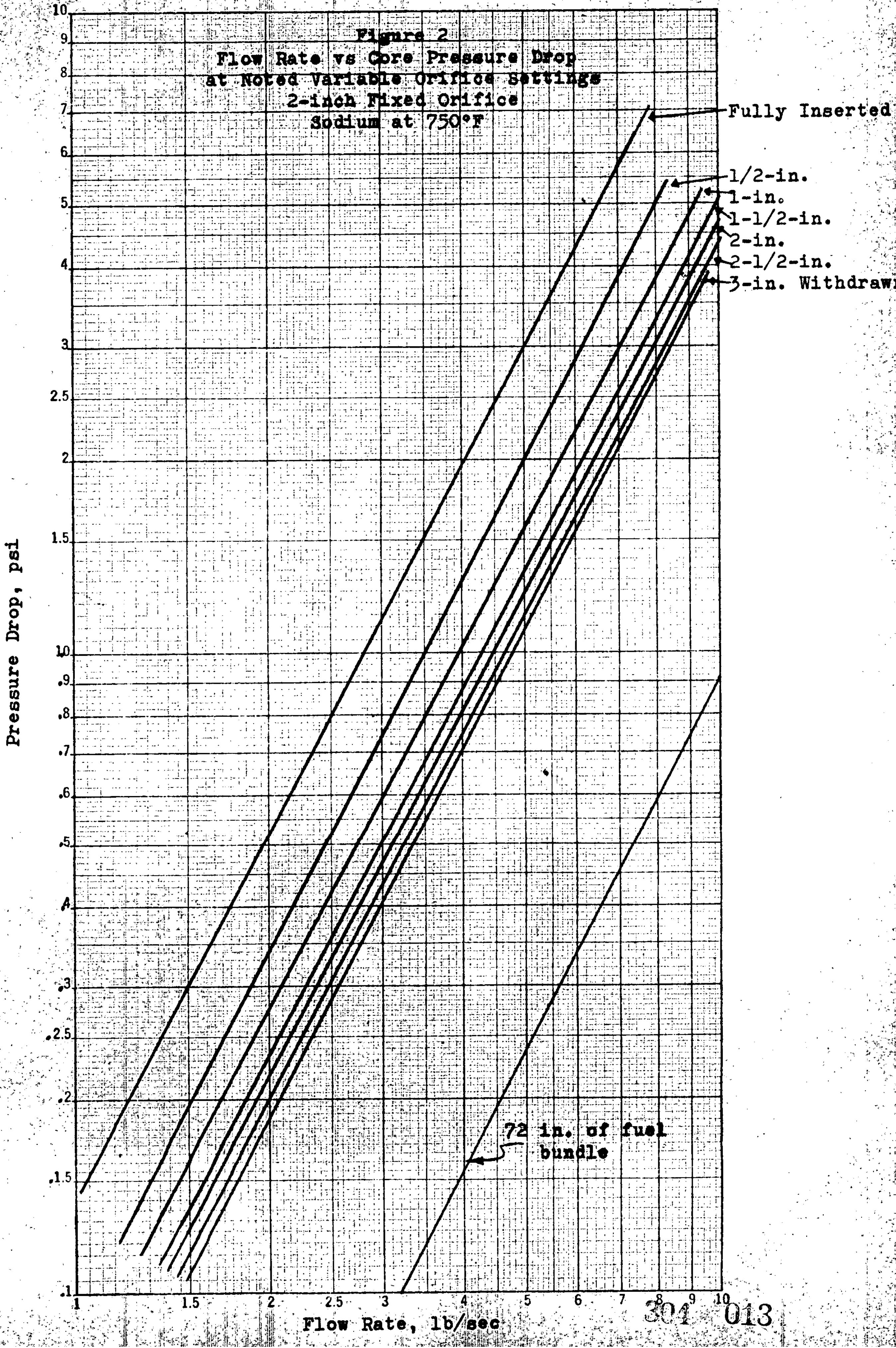


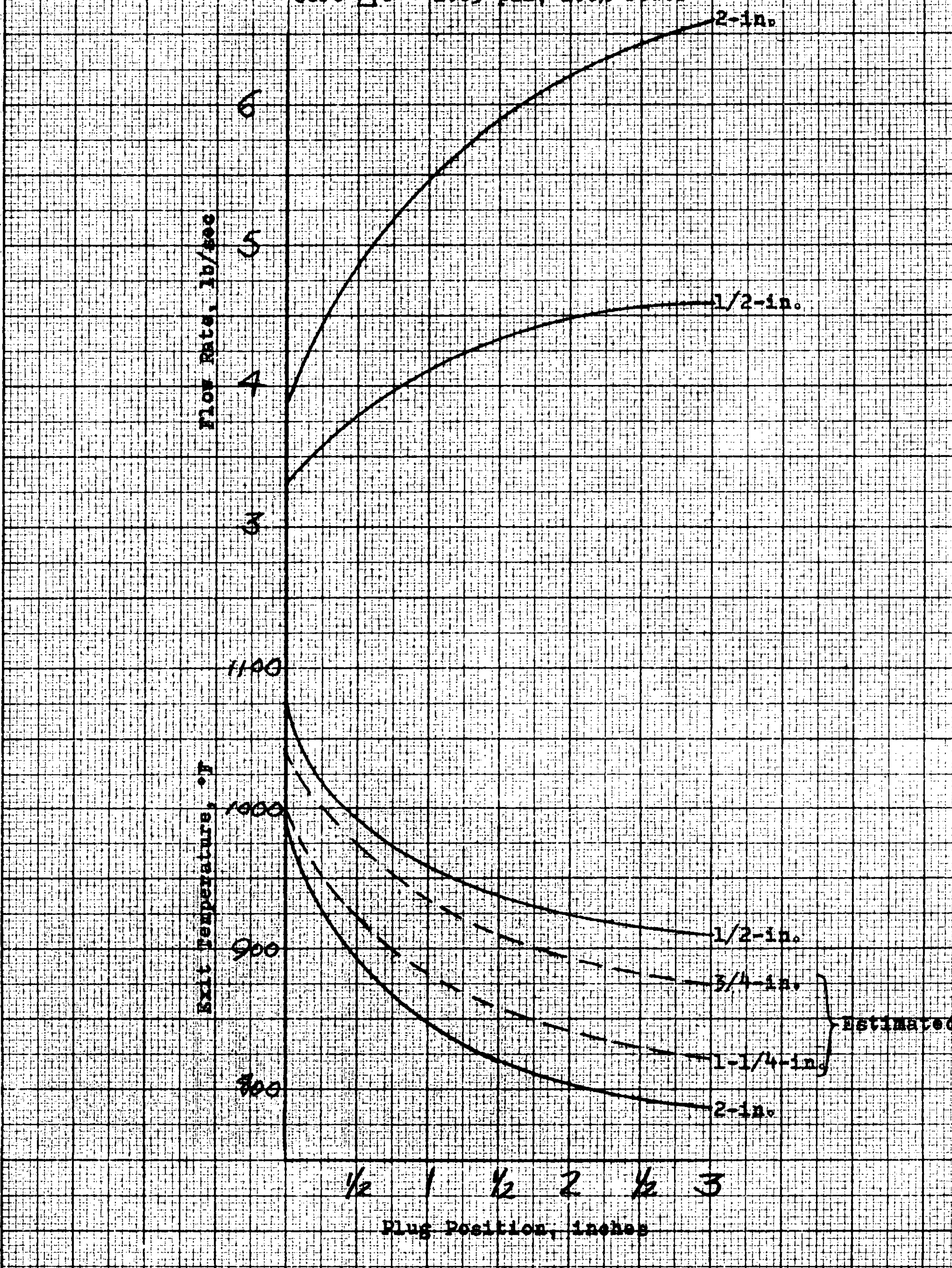
Figure 2
Flow Rate vs Core Pressure Drop
at Noted Variable Orifice Settings
2-inch Fixed Orifice
Sodium at 750°F
Fully Inserted
1/2-in.
1-in.
1-1/2-in.
2-in.
2-1/2-in.
3-in. Withdrawn
72 in. of fuel
bundle
Pressure Drop, psi
K+E LOGARITHMIC 359-103
KEUFFEL & ESSER CO. MADE IN U.S.A.
2 X 1 CYCLES



K+E LOGARITHMIC 359-103
KEUFFEL & ESSER CO. MADE IN U.S.A.
2 X 1 CYCLES

Figure 3
Flow Rate and Coolant Channel Exit Temperature
vs Variable Orifice Plug Position with Fixed Orifices Noted

Core ΔP = 1.85 psi, 100% Power



Plug Position, inches

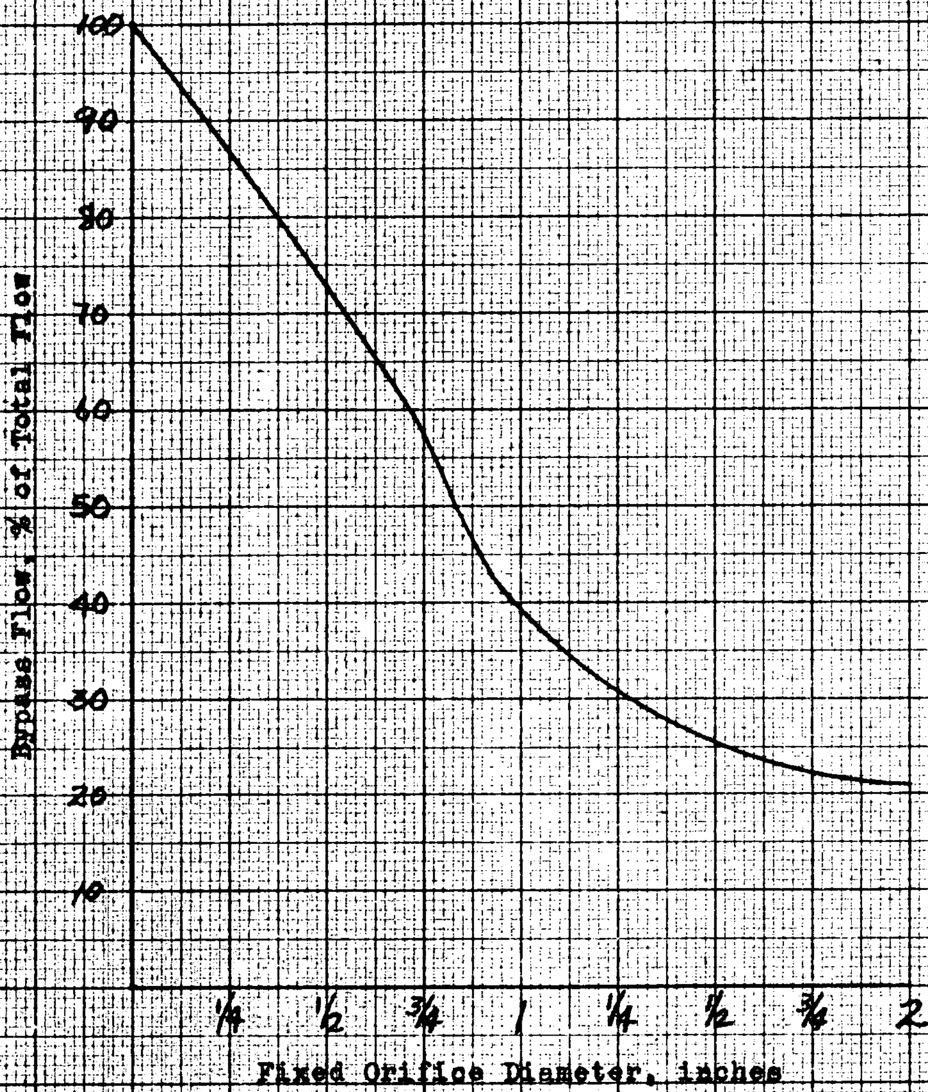


Figure 4
Bypass Flow Through Annulus
Surrounding Fixed Orifice
vs
Fixed Orifice Diameter

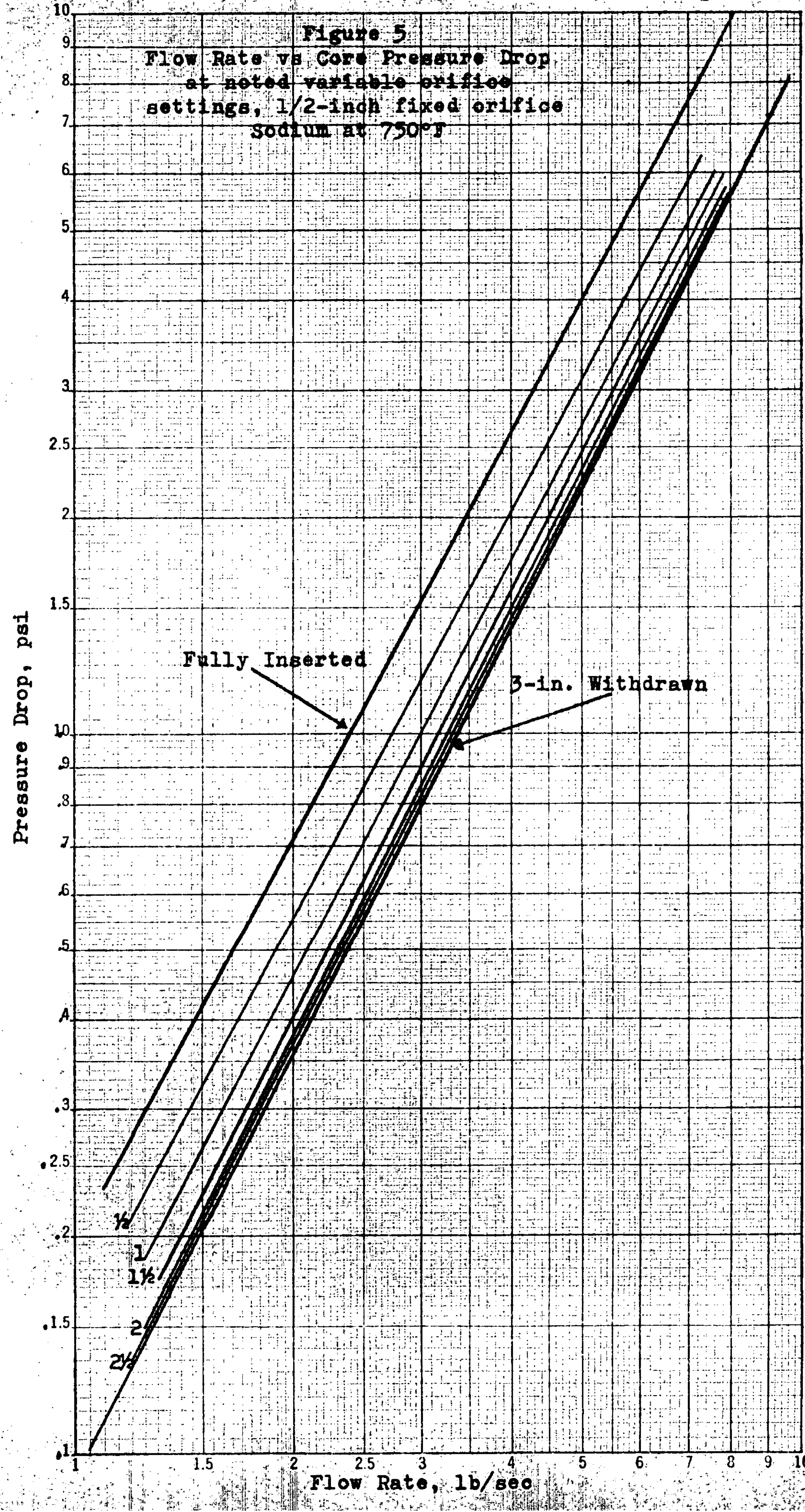


Figure 5
Flow Rate vs Core Pressure Drop
at noted variable orifice
settings, 1/2-inch fixed orifice
Sodium at 750°F
Fully Inserted
3-in. Withdrawn
½
1
1½
2
2½
Pressure Drop, psi
Flow Rate, lb/sec
10
9
8
7
6
5
4
3
2.5
2
1.5
1.0
.9
.8
.7
.6
.5
.4
.3
.25
.2
.15
.1
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1.5
2
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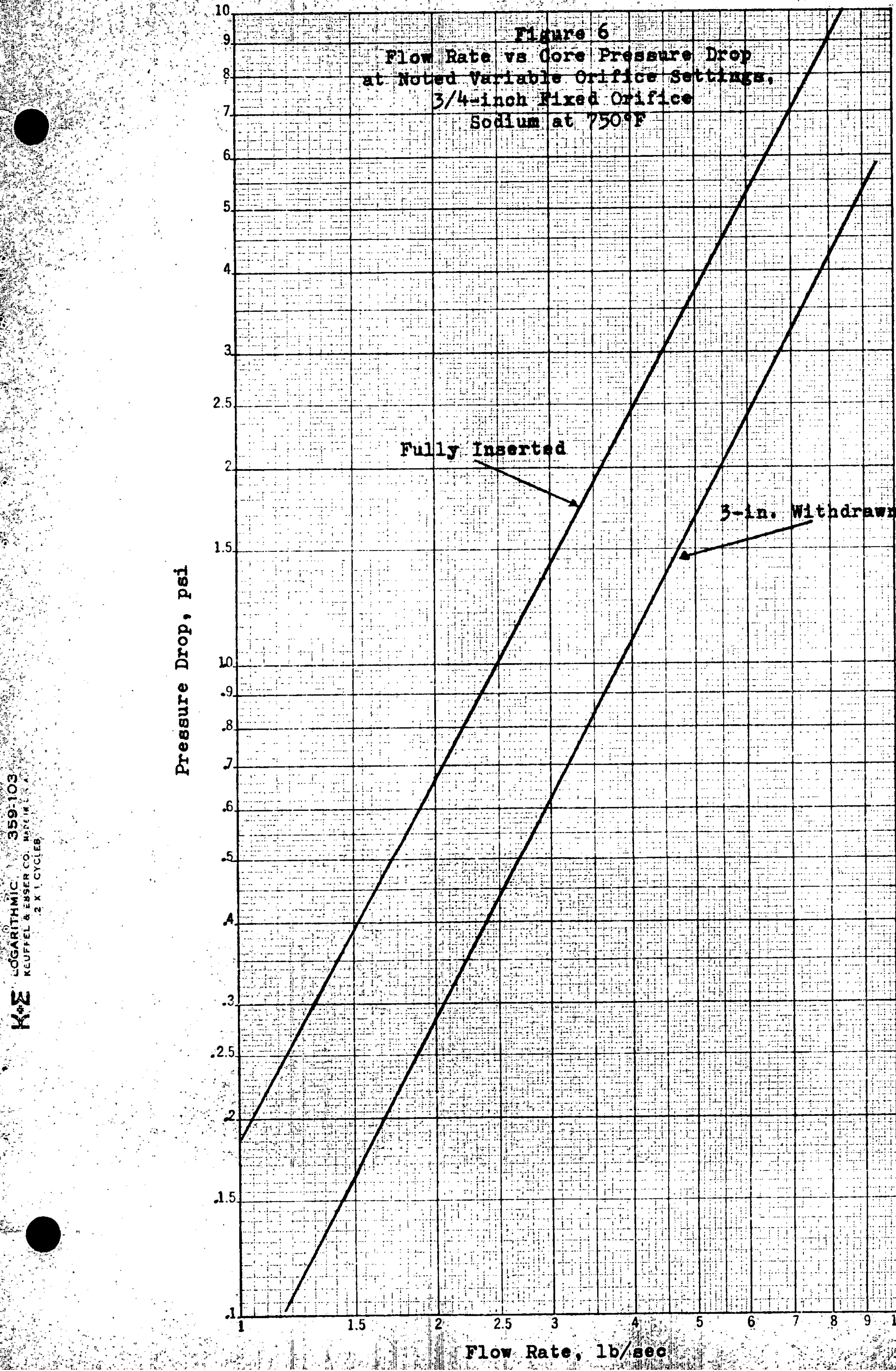
Figure 6
Flow Rate vs Core Pressure Drop
at Noted Variable Orifice Settings,
3/4-inch Fixed Orifice
Sodium at 750°F
Fully Inserted
3-in. Withdrawn
Pressure Drop, psi
Flow Rate, lb/sec
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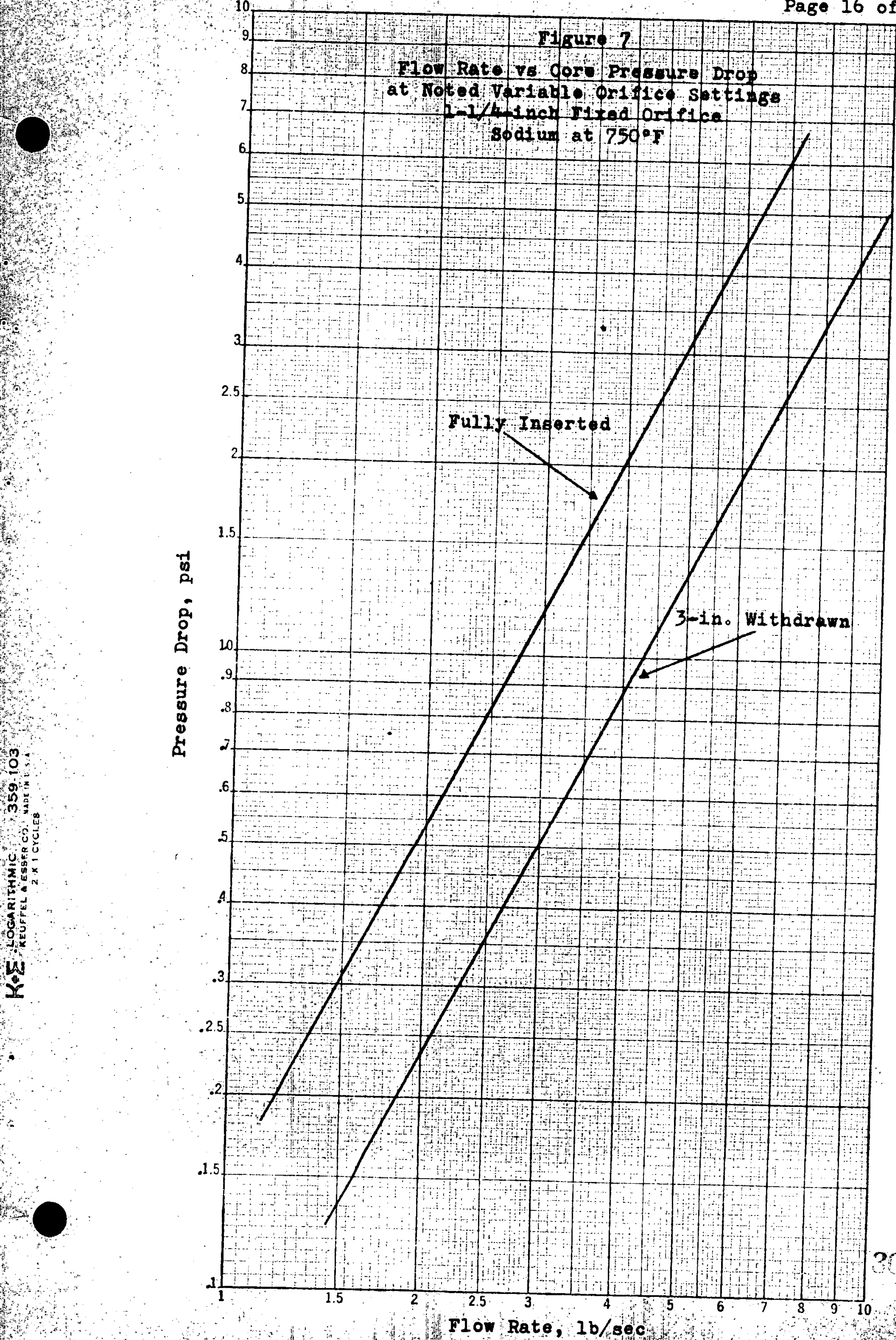
Figure 7
Flow Rate vs Core Pressure Drop
at Noted Variable Orifice Settings
1-1/4-inch Fixed Orifice
Sodium at 750°F
Fully Inserted
3-in. Withdrawn
Pressure Drop, psi
Flow Rate, lb/sec
10
9
8
7
6
5
4
3
2.5
2
1.5
1.0
.9
.8
.7
.6
.5
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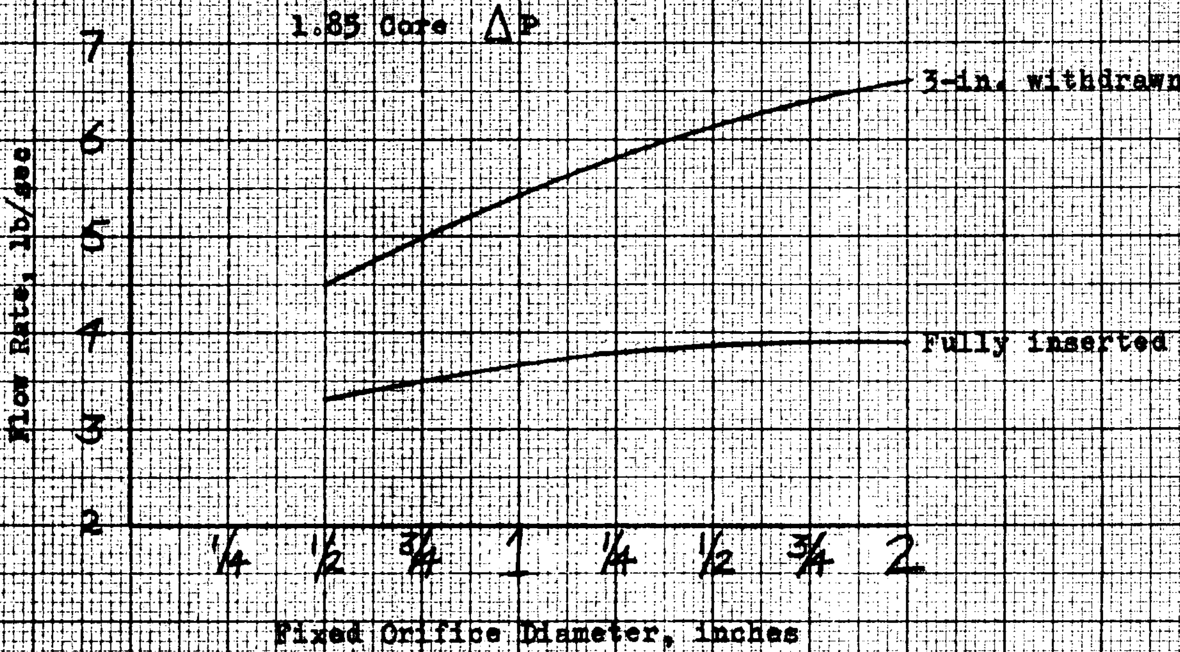


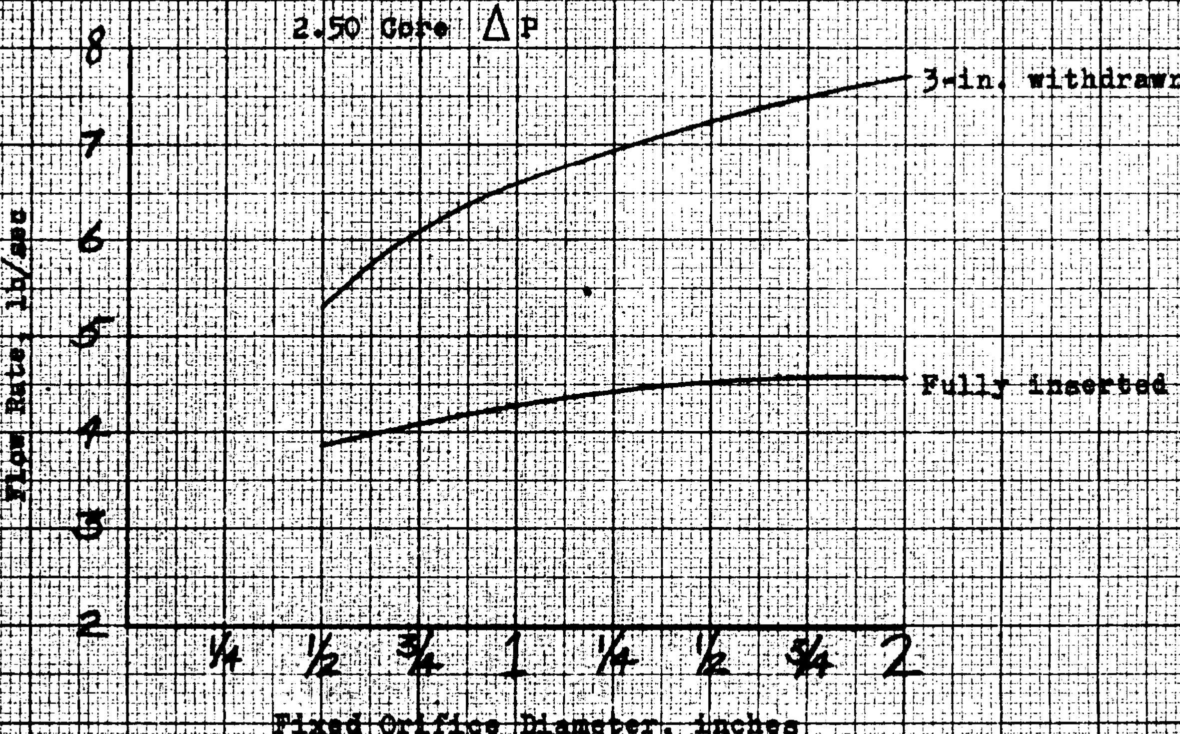
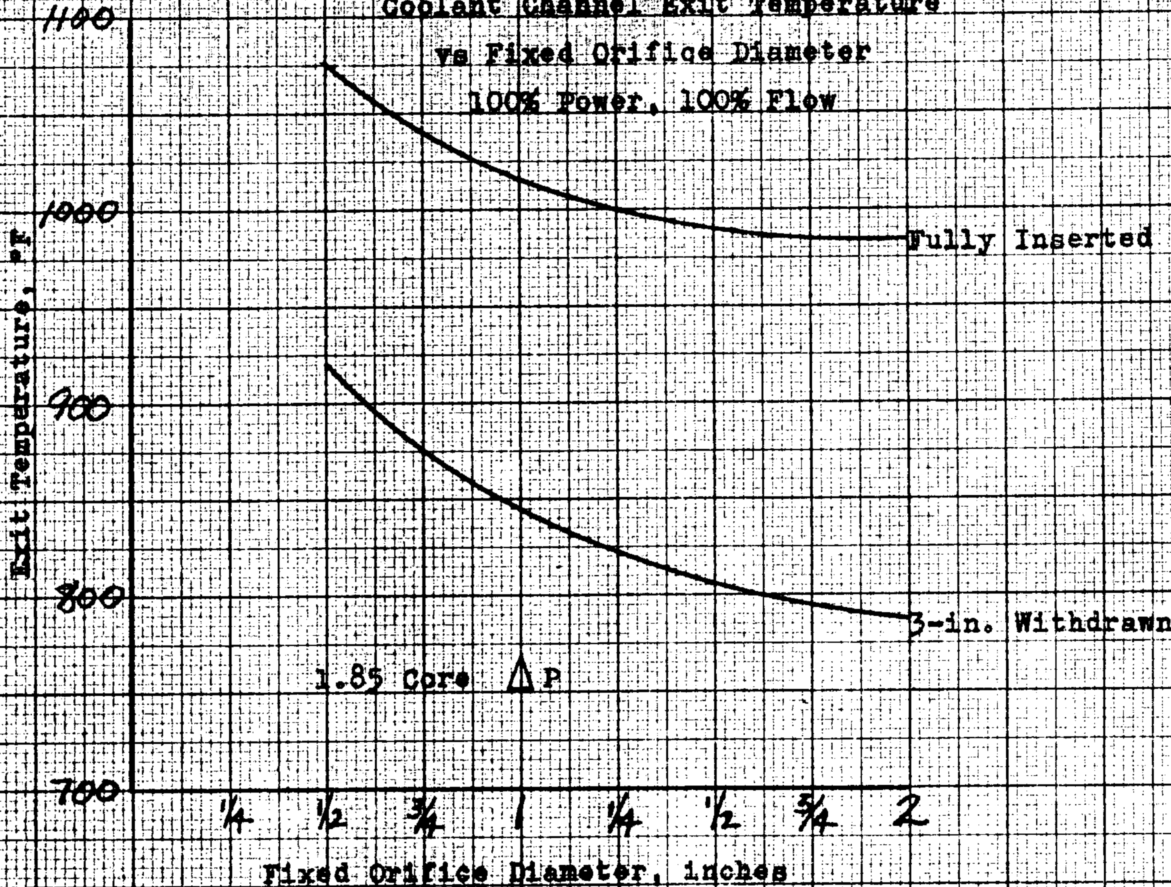


Figure 8
Flow Rate vs Fixed Orifice Diameter

Figure 9

Coolant Channel Exit Temperature
vs Fixed Orifice Diameter
100% Power, 100% Flow



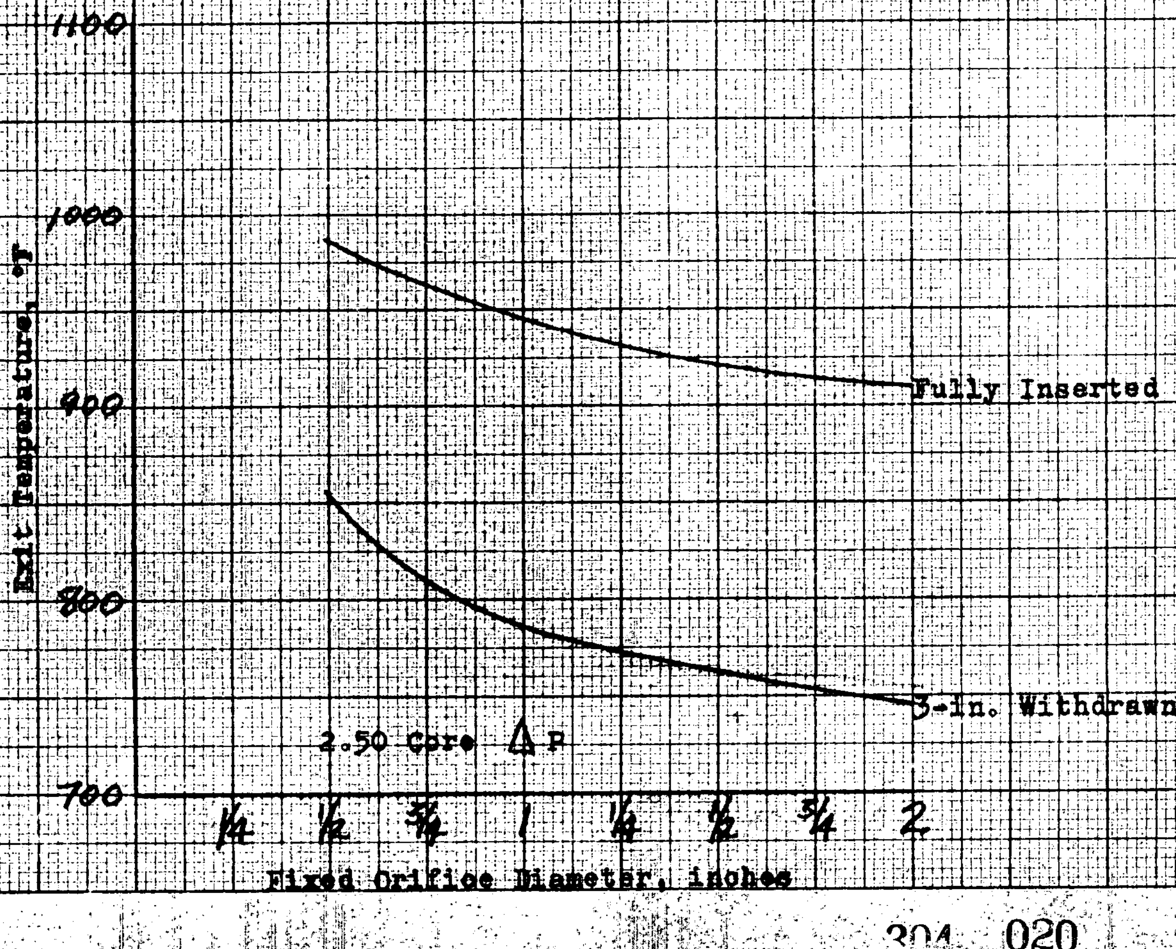
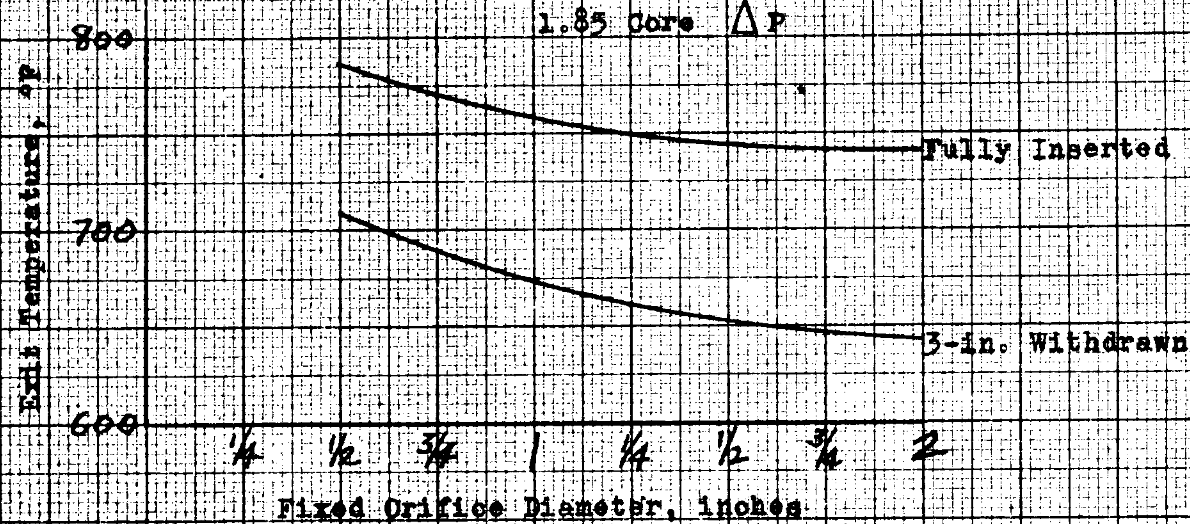


Figure 10

Coolant Channel Exit Temperature
vs Fixed Orifice Diameter
50% Power, 100% Flow



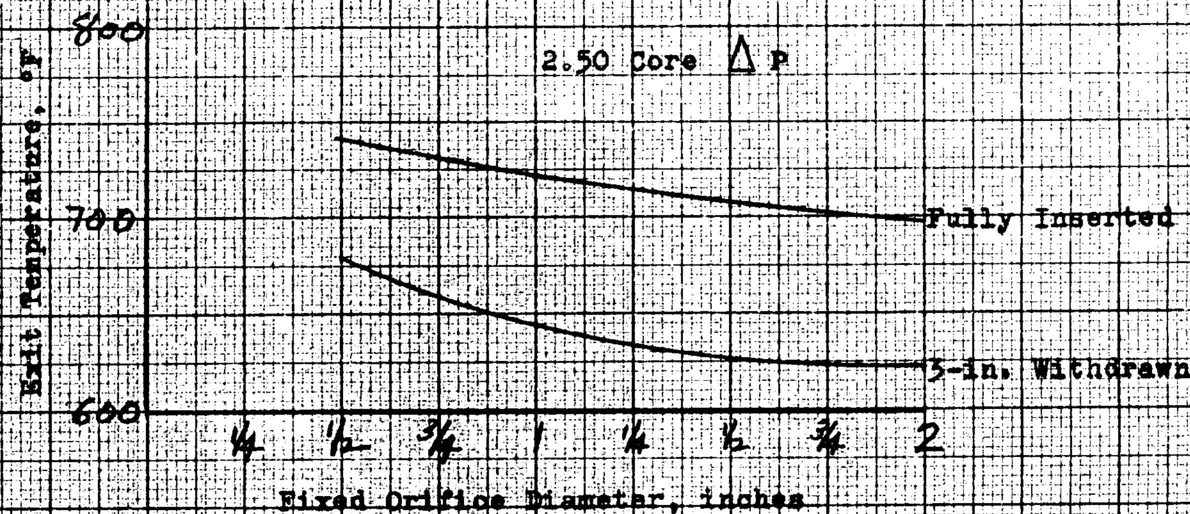


Figure 11

Flow Rate and Coolant Channel

Exit Temperature vs Core Pressure Drop

1/2-inch Fixed Orifice

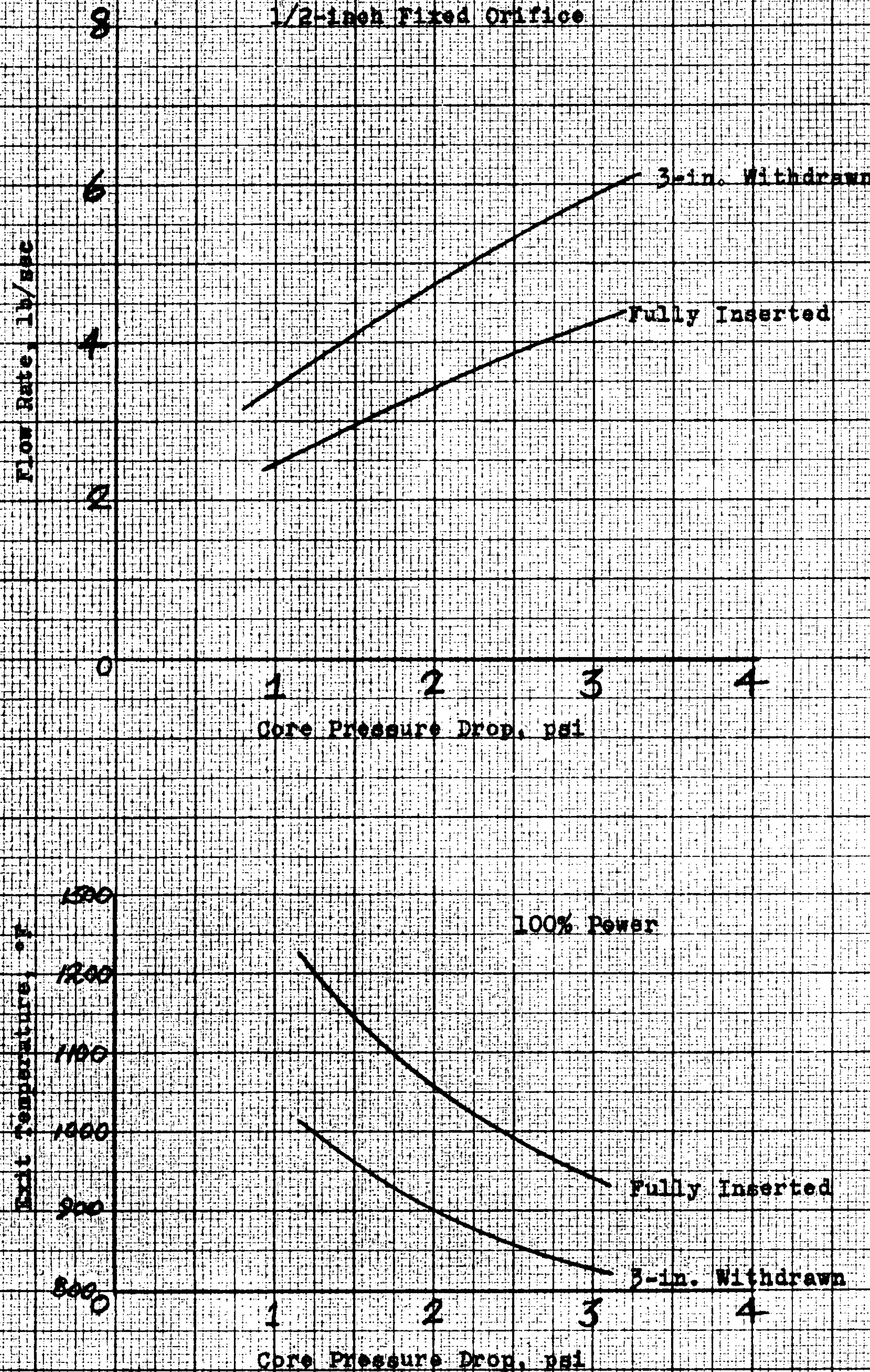


Figure 12

Flow Rate and Coolant Channel

Exit Temperature vs Core Pressure Drop

3/4-inch Fixed Orifice

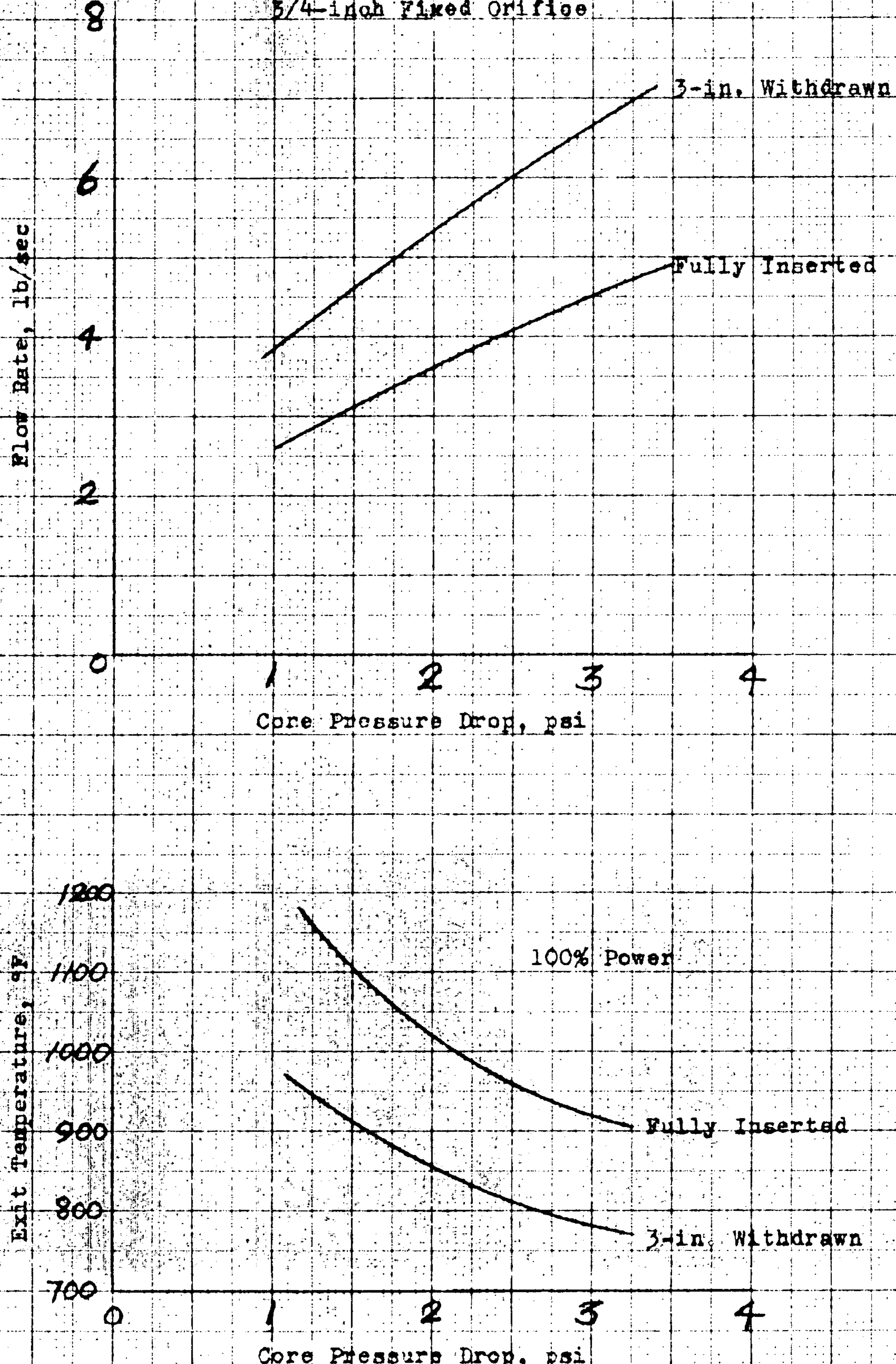


Figure 13

Flow Rate and Coolant Channel

Exit Temperature vs Core Pressure Drop

1-inch Fixed Orifice

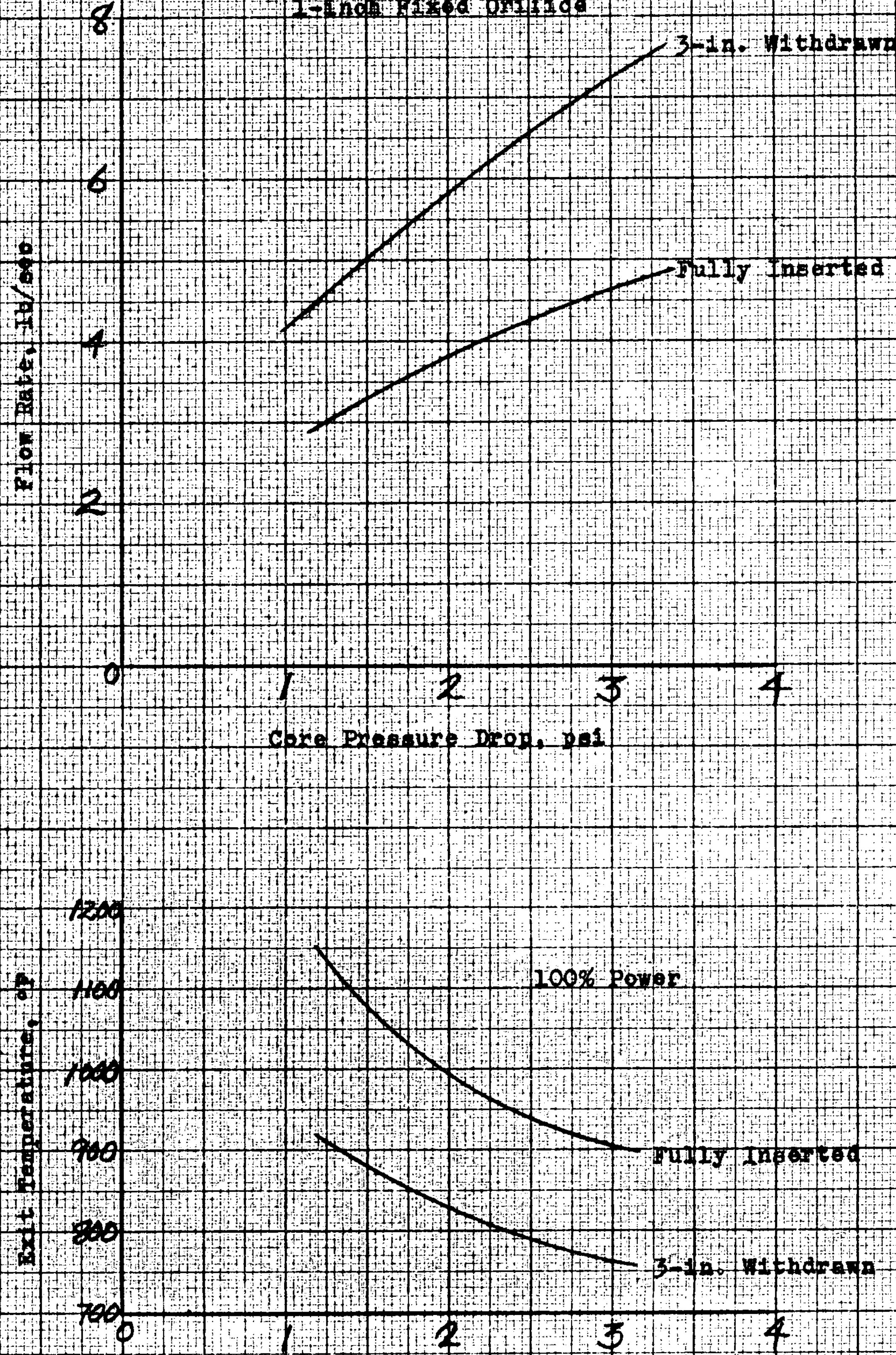


Figure 14

Temperature Sensitivity

vs Variable Orifice Plug Position

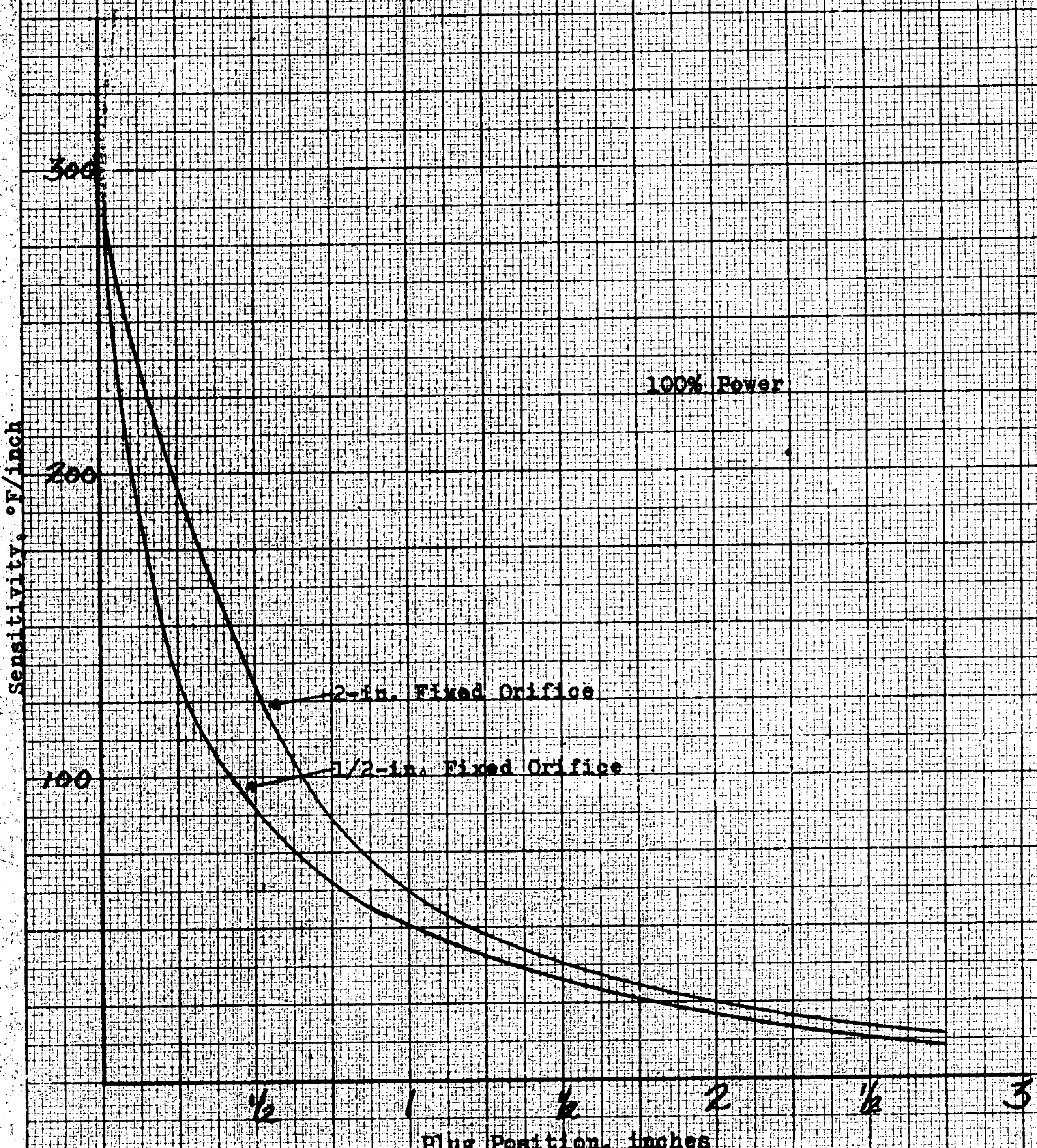


Figure 15

Temperature Sensitivity

vs Variable Orifice Plug Position