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STEAM SEPARATION DEVELOPMENT PROGRAM DA-251

Final Report on Free-Surface Separation at 1000 PSIG

By

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June 20, 1960

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GENERAL ELECTRIC

ATOMIC POWER EQUIPMENT DEPARTMENT

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ABSTRACT

Data are presented for the range of variables studied which include steam velocities, inlet steam qualities, water level and two vessel diameters.

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CONCLUSIONS

1. Free-surface separation of steam-water can be obtained approximately 1.1 ft/sec with resulting steam moistures below inlet requirements for steam dryers (7 percent maximum).

2. The stated average velocity is independent of vessel diameter from 19-1/2 inches to 36 inches.

3. The height required to obtain this separation above the indicated water level is 30 to 34 inches.

4. The data are presented in graphical form as individual runs since all attempts to present a correlation have been unsuccessful.

By cutting out this rectangle and folding on the center line, the above information can be fitted into a standard card file.

For list of contents—drawings, photos, etc. and for distribution see next page (FN-610-2).

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TECHNICAL INFORMATION MEMORANDUM

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STEAM SEPARATION DEVELOPMENT PROGRAM DA-251

Final Report on Free-Surface Separation at 1000 PSIG

I. INTRODUCTION

An interim report on free-surface separation was issued on March 19, 1959. The present report includes all data at 1000 psig both before and after that date.

II. CONCLUSIONS

Based on the series of runs for which a graphical presentation of data is included, the following conclusions have been drawn.

1. Satisfactory free-surface separation of steam-water mixtures is obtained at 1000 psig at average steam leaving velocities of up to 1.1 ft/sec.
2. This average velocity is independent of vessel diameter from 19-1/2 inches to 36 inches.
3. The height necessary to accomplish separation can presently only be deduced from indicated water level measurements to be approximately 32 inches in the range of vessel inlet qualities from 4 to 10 percent steam by weight.
4. Attempts at quantitative measurement of steam carryunder were unsuccessful.

III. DISCUSSION OF RESULTS

The data given in the report of March 19, 1959 established the following points:

1. Satisfactory free-surface separation is obtained in a 19.5 inch I.D. sleeve at average steam leaving velocities of up to 1.1 ft/sec.

2. The height of the free volume above the mixture level is controlling as to the quality at the dryer inlet.

Based on the above points, the tests reported here were aimed at investigating the following:

1. To study the effect of vessel diameter on the maximum average steam leaving velocity to give an acceptably low steam moisture content for dryer inlet conditions.
2. To study the effect of height from the indicated water level to a sample probe located at the inlet to the dryer section.

A. Data of Previous Report:

The configuration of the test vessel internal arrangement is shown in Figure 1. The 12-inch I.D. chimney and fan baffle at the bottom of the vessel was installed to insure segregation of the incoming mixture from the downcomer nozzle. The upper 19.5-inch sleeve reduced the effective area for free-surface separation to one-third of that available in the 36-inch vessel. In other words, for a given quantity of steam, the average steam leaving velocity would be 3 times higher in the sleeve than in the 3-foot diameter vessel. The indicated water level was maintained in the sleeve with circulation of water from the free-surface down through the annulus between the sleeve and chimney. No water was circulated over the top of the sleeve.

Figures 2, 3, and 4 show plots of the data which were previously presented in tabular form. Each set of test data is plotted versus time of the test day and consists of the measured quantities.

a. Steam flow -- total steam flow through the loop in thousands of pounds per hour.

b. Water level -- the indicated water level in inches above or below the vessel flange centerline.

c. Recirculation flow -- a total water flow through the loop in thousands of pounds per hour.

d. Moisture at dryer inlet -- this quantity is expressed as per cent water by weight in the steam above the mixture interface. The sample probe is located 25 inches above the centerline of the vessel flange (reference point for indicated water level). This quantity is calculated from electrical conductivity measurements on samples of loop inlet steam, outlet steam and recirculating water. This method of calculation is explained in Appendix I.

In addition to the above, the following plots of calculated quantities are shown on some graphs:

a. Average steam leaving velocity -- this velocity, given in ft/sec, is calculated from the steam flow based on a flat flow profile for the area of the 19.5-inch I.D. sleeve.

b. Vessel inlet quality -- this quantity is expressed as weight per cent steam entering the pressure vessel and thus is analogous to a reactor core exit quality. Note that this is as per cent steam by weight while Number d., above, is per cent water by weight.

c. Velocity at chimney outlet -- this velocity was calculated again

assuming a flat flow profile and is analogous to a reactor core channel outlet velocity.

The data plots are given as a series of points for each run. These points are connected by solid or dotted lines for convenience and are not intended to be continuous curves. The changes in these lines do however give an idea of the general movement of the variables.

Figure 2 shows the results of a run with low inlet steam qualities. Because of the high water recirculation rate, chimney discharge velocities are higher than those in subsequent runs and therefore the steam leaving velocity to give an acceptably low dryer inlet quality is low. However, at steam leaving velocities between 0.94 and 0.97 ft/sec the dryer inlet quality is independent of the indicated water level over a range of 34" to 29.5" from the sample probe.

Figure 3 shows the effect of higher steam leaving velocity at higher vessel inlet qualities. From the plots it is seen that the limit of steam leaving velocity is approximately 1.1 ft/sec for vessel inlet qualities in the range of 8 to 10 per cent. The effect of high recirculation rate shown in Figure 2 is again pointed up here in the period after 3:20 P.M. with the limiting steam velocity dropping to 0.94 ft/sec at 4 to 5 per cent vessel inlet quality.

Figure 4 shows the results of a run at higher vessel inlet steam qualities. At these higher qualities the velocities at the outlet of the chimney are low and thus little jetting is encountered. Acceptably low water content steam reaches the dryer inlet for the

range of steam flows and indicated water levels used.

B. Data Obtained Since Interim Report

Figure 5 shows the results obtained at constant steam and water flows with increasing indicated water level. The breakthrough of carryover occurred at -10 inches or an indicated distance of 15 inches from the surface to the sample probe.

Figure 6 was obtained with the vessel configuration shown in Figure 1-b. This differs from the earlier set-up only in having the dryer element removed. Since the dryer holder is 20 inches I.D., it can be considered an extension of the 19.5-inch I.D. sleeve. With this arrangement, sample probes placed before and after the dryer holder give a measure of how much drop-out of water is experienced in the 17-1/2 inch vertical distance between probes.

The first section of Figure 6 (3-25-59) shows that between the two probes, a minimun of 97 per cent of the water carried with the steam drops out.

On 3-26-59 (Figure 6) with higher indicated water level the drop-out is marked with a minimum of about 31 inches from the indicated surface to the upper probe. This data is not inconsistent with that of Figure 5 because Figure 5 is for 5.4 per cent vessel inlet quality while Figure 6 is for 9.3 per cent. The true height of the mixture above the indicated level would be greater for the 9.3 per cent case than the 5.4 per cent case.

The indicated water level was dropped to -3 inches at 3:50 P.M. (16 inches below the breakthrough point described above and the steam at the lower probe dropped to about 20 per cent water. This again confirms the 31 inches distance at 9.3 per cent.

C. Runs with 24-Inch I.D. Chimney

For this series of tests the vessel internals were arranged as shown in Figure 7. The 24-inch I.D. chimney was installed at the bottom of the vessel with a diffuser plate at the bottom of the chimney. There were 233 1/2-inch holes in the diffuser plate thus giving an open area approximately equal to the 8-inch schedule 80 inlet pipe. The diffuser plate provided a more uniform rising velocity in the 24-inch chimney thus eliminating the jetting encountered with the 12-inch I.D. chimney. A fan baffle was again used to eliminate direct impingment of water into the downcomer nozzle.

In the test run summarized in the plots of Figure 8, the effect of indicated water level is again pointed up. With a steam flow of 55 M lb/hr (0.95 ft/sec) severe carryover was encountered at an indicated water level of +6 inches. Carryover became less than 5 per cent at -3 inches and remained less than 5 per cent at 60 M lb/hr (1.035 ft/sec) for indicated water levels -2 to -4 inches.

In Figure 9 the indicated water level-steam purity interdependence is again shown with break point at about -3 inches. From this and the previous figure it is fairly well established that the limiting indicated distance is approximately 43 inches in the 8 to 10 per cent inlet quality range. This again is not incompatible with the 31-inch indicated distance obtained from Figure 6 because due to the arrangement with the 24-inch I.D. chimney, a -3 inch level is below the upper edge of the chimney thus the water-steam mixture overflowing and separating at the top of the chimney is considerably higher. The velocity head pile-up would be about 1.9 inches on top of a water overflow height at the top of the chimney of approximately 5.9 inches. Using the 2" plus 5.9" above the chimney lip the distance

for separation becomes about 32 inches or comparable to the distance cited above.

Figure 10 shows the results obtained for average steam leaving velocities to 0.86 ft/sec. This corresponds to a steam flow of 50 M lb/hr. The only rises in steam leaving moisture followed flow changes and therefore were undoubtedly due to system instability and not steady state conditions.

The run of Figure 11 shows the effects at higher velocity in the range of 10 per cent inlet quality. The steam flow rate of 60 M lb/hr gives an average steam leaving velocity of 1.03 ft/sec. The carryover indicated at this condition is probably due to vessel height limitations rather than the velocity alone. This is stated because of the sharp decrease in moisture with time from 4:00 P.M. to a more steady lower value at 4:20 P.M. Experience with the loop has shown that if severe carryover takes place, it continues until the steam flow or water level is decreased (e.g. Figure 6 - lower probe 1:40 to 3:30 P.M. - 3-26-59). At an indicated -3 inches the water level could not effectively be lowered as explained above.

Figure 12 shows the result of an increase in recirculating water flow at a steady 40 M lb/hr steam flow. To check this effect the water flow was dropped and the indicated water level raised 4 inches while steam moisture returned to less than 1 per cent.

Figures 13 and 14 show the results of two runs at very similar conditions of steam and recirculating water flows. Vessel inlet qualities

are rather high and the primary difference in conditions is the indicated water level. The steam moisture plot approximates the indicated water level plot in both figures, but the variations in moisture shown in Figure 13 are considerably less than those in Figure 14. Thus the point to point indicated water level difference of 4 to 6 inches between the two plots must account for the steam moisture difference. This narrow band of difference leads to a distance from indicated water level to sample probe of 32 to 34 inches for this higher inlet quality range.

APPENDIX I
METHOD OF CALCULATION

All data given in the accompanying sheets are straight forward except for the steam purity values which are given as per cent water by weight. The method of obtaining these values is explained below.

The per cent water by weight is obtained from electrical conductivity primary data. This method is based on the fact that salts soluble in water have a negligible solubility in steam up to pressures in the 2400 to 2500 psi range. Therefore, any recirculating water salts present in the steam at 1000 psig must be associated with droplets of the recirculating water. The electrical conductivity of a condensed steam sample is then proportional to the concentration of water droplets in the steam and the concentration of ionized salt in these droplets. The conductivity of such a steam sample is also affected by dissolved gases in the sample but the method described here eliminates this gas effect.

The Moss Landing Loop is filled with plant feedwater. This water has a specific conductance of 4 micromhos/cm cube or less (250,000 ohm-cm or greater). For the test, 1 to 2 pounds of sodium chloride is added to the recirculating water in the loop to bring its conductivity to the range of 1000 to 2000 micromhos/cm cube (approximately 500 to 1000 ppm NaCl).

During the test, three conductivity measurements were made on continuously flowing condensed and cooled samples for each moisture value in the steam leaving the loop. These are:

1. Recirculating water (C_1).
2. Steam from the plant entering the loop (C_2).

3. Steam leaving the loop (C_3).

The three conductivity readings are corrected to the reference temperature of 77°F (25°C).

The difference (C-3) minus (C-2) corrects the outlet steam for any gas effects, since the loop operates as a degasser with the exit steam vented to atmosphere. Thus, at steady state the only gases present are those entering with the steam from the plant.

Thus the per cent water in the steam leaving the loop is equal to:

$$\frac{(C_3) - (C_2) \times 100}{(C_1)}$$

MOSS LANDING STEAM SEPARATION TEST VESSEL

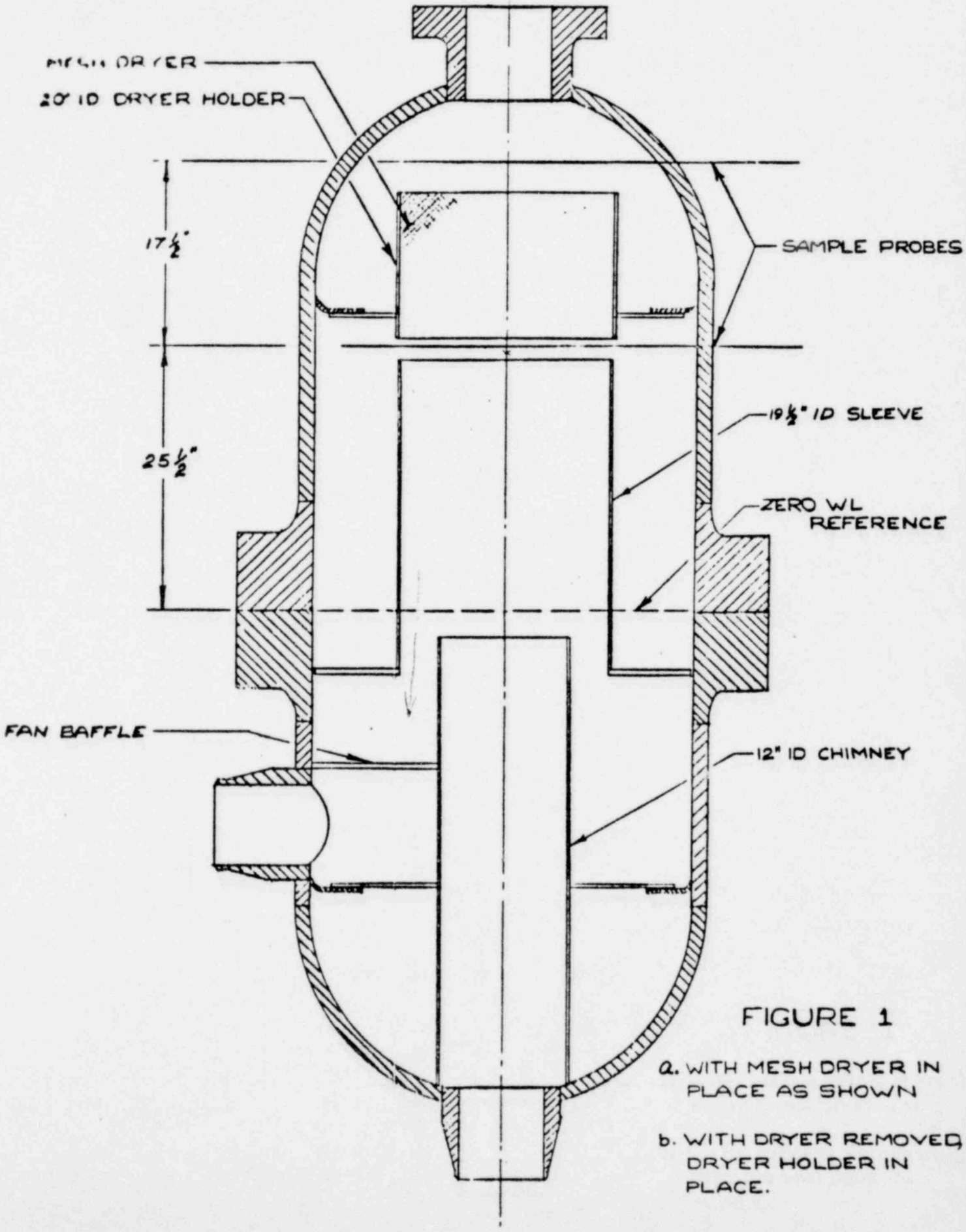
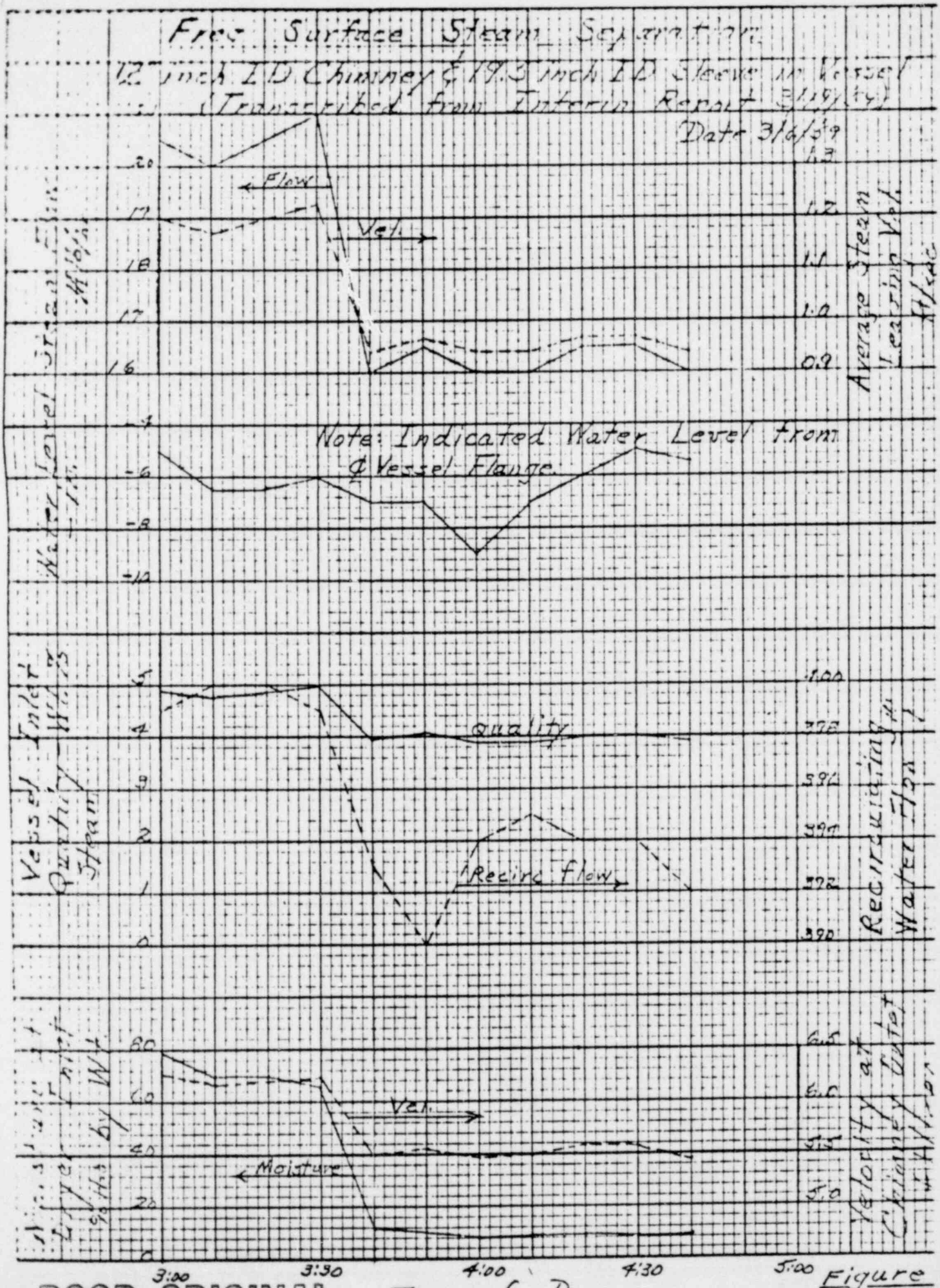


FIGURE 1

a. WITH MESH DRYER IN PLACE AS SHOWN

b. WITH DRYER REMOVED, DRYER HOLDER IN PLACE.



Figure

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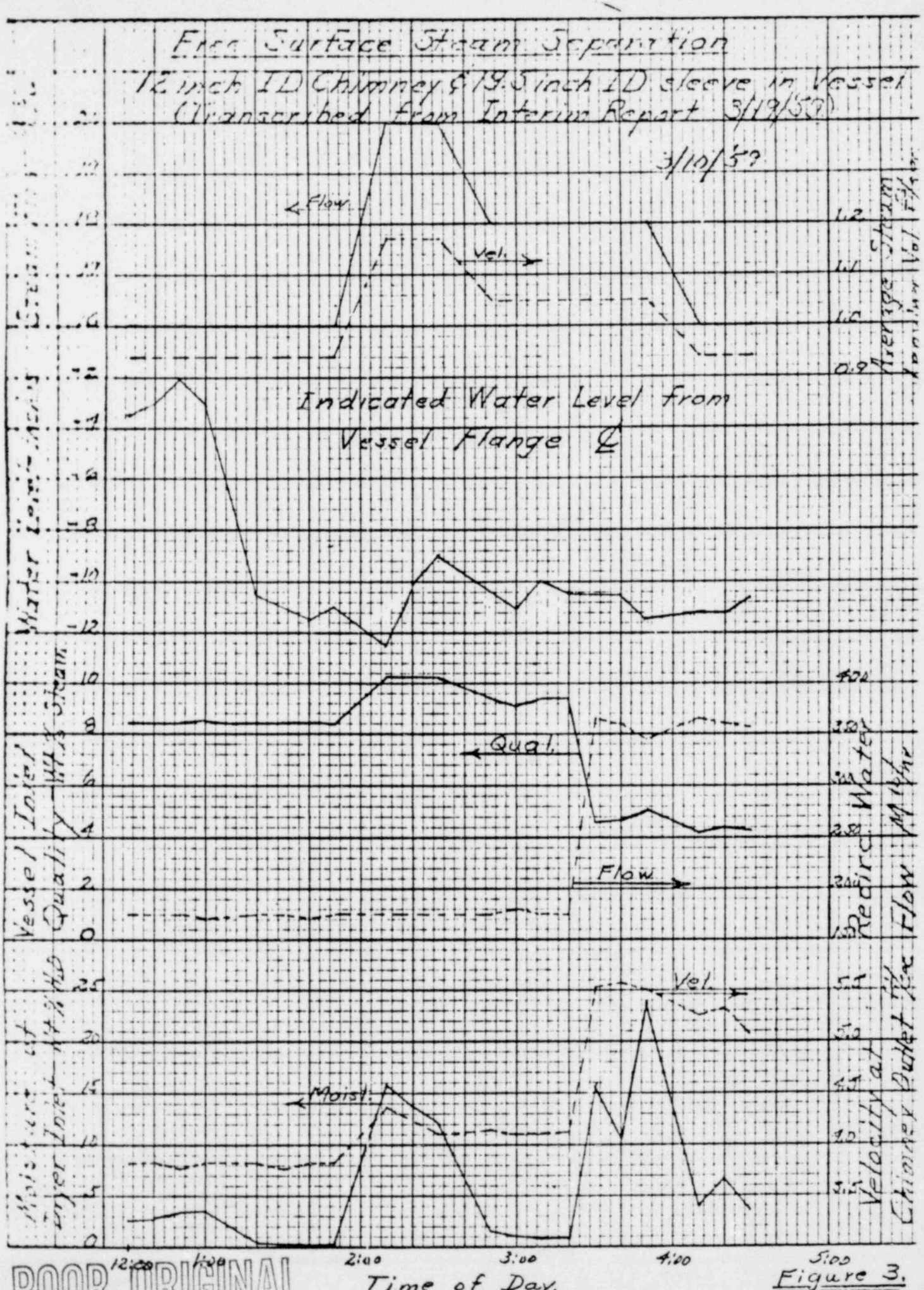

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Figure 3.

Figure

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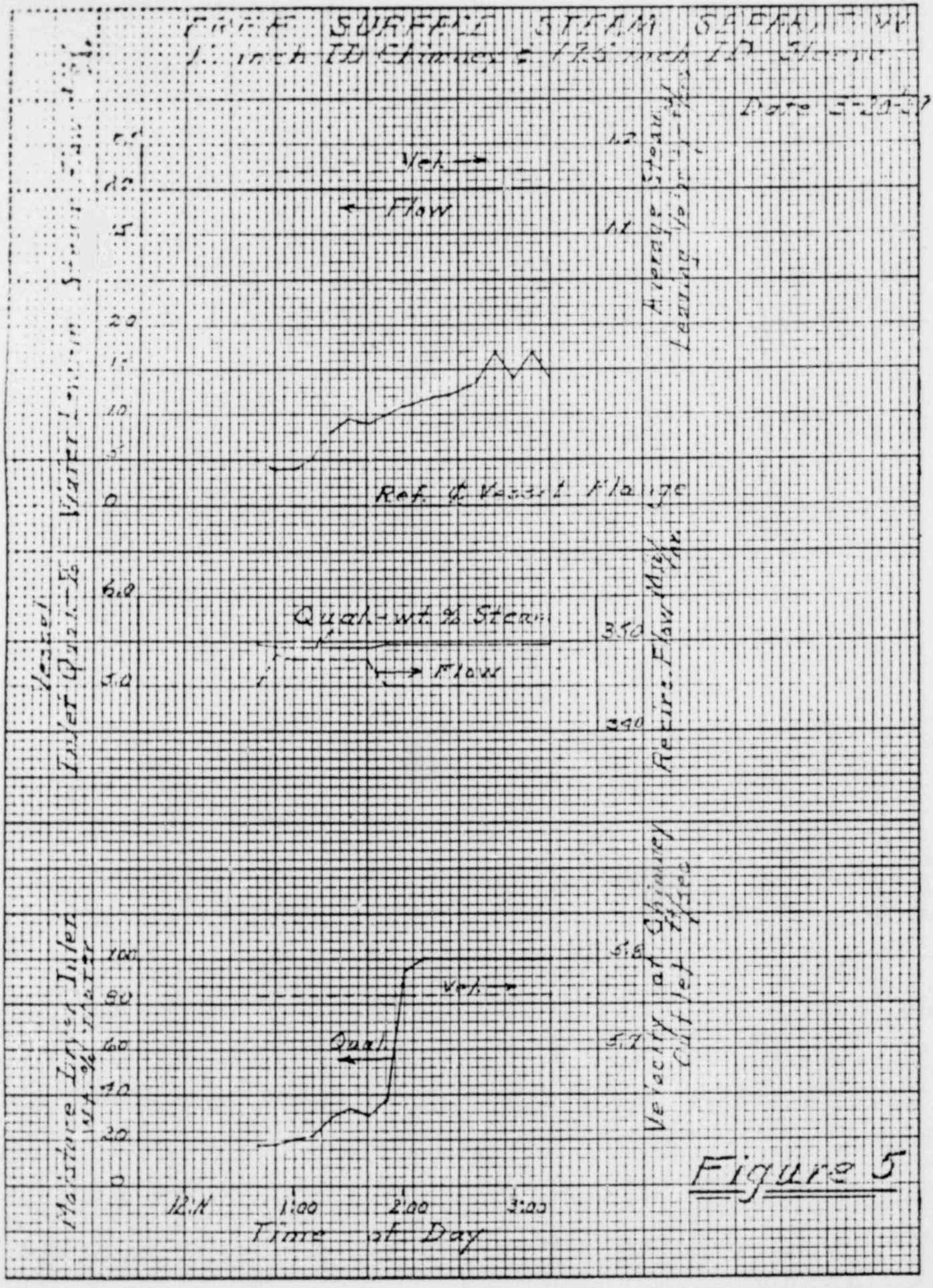

Figure 5

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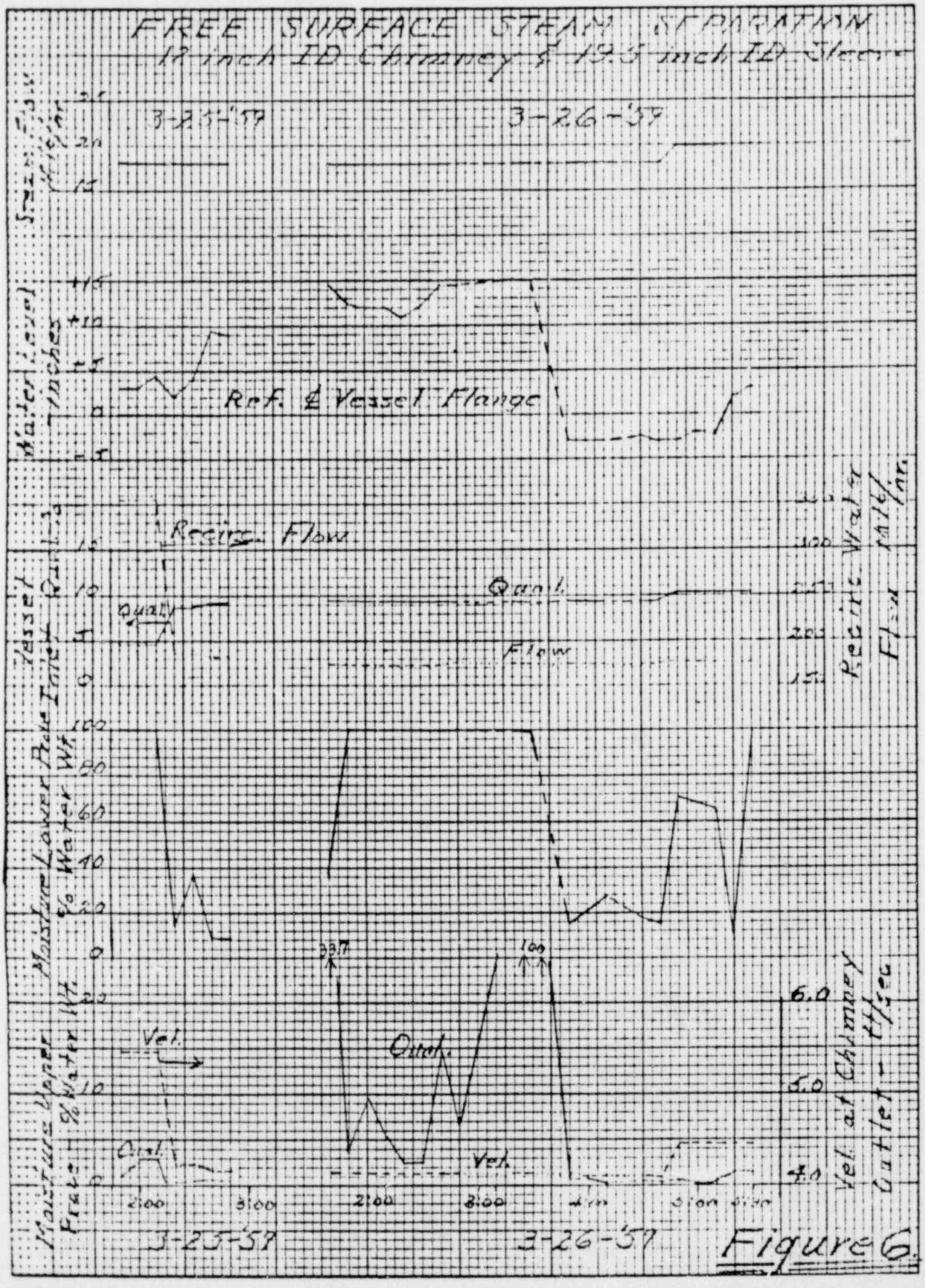

Figure 6.

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MOSS LANDING STEAM SEPARATION
TEST VESSEL

Scale 1"=1'-0"
Aug 12-8-59

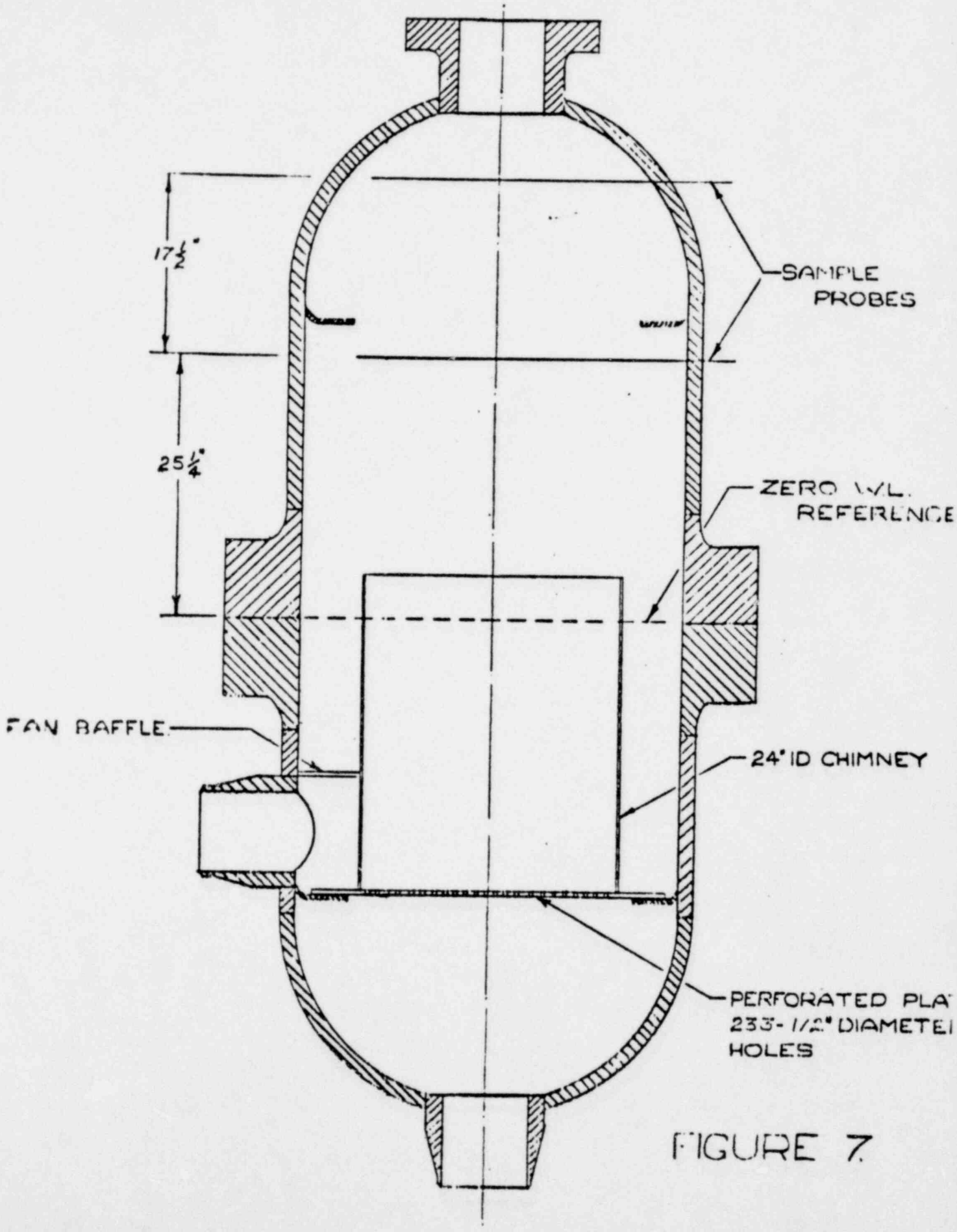

FIGURE 7.

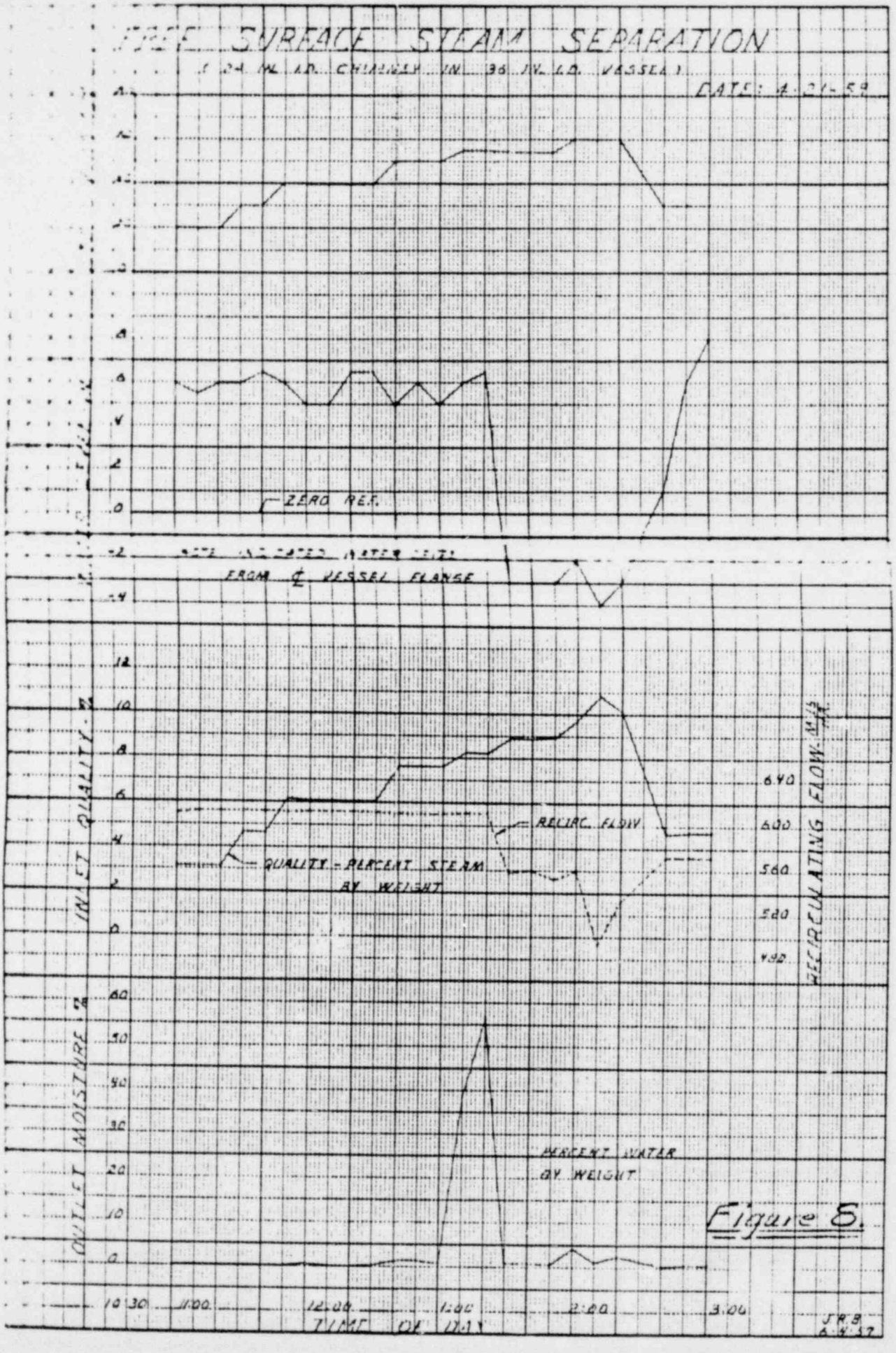

Figure 8.

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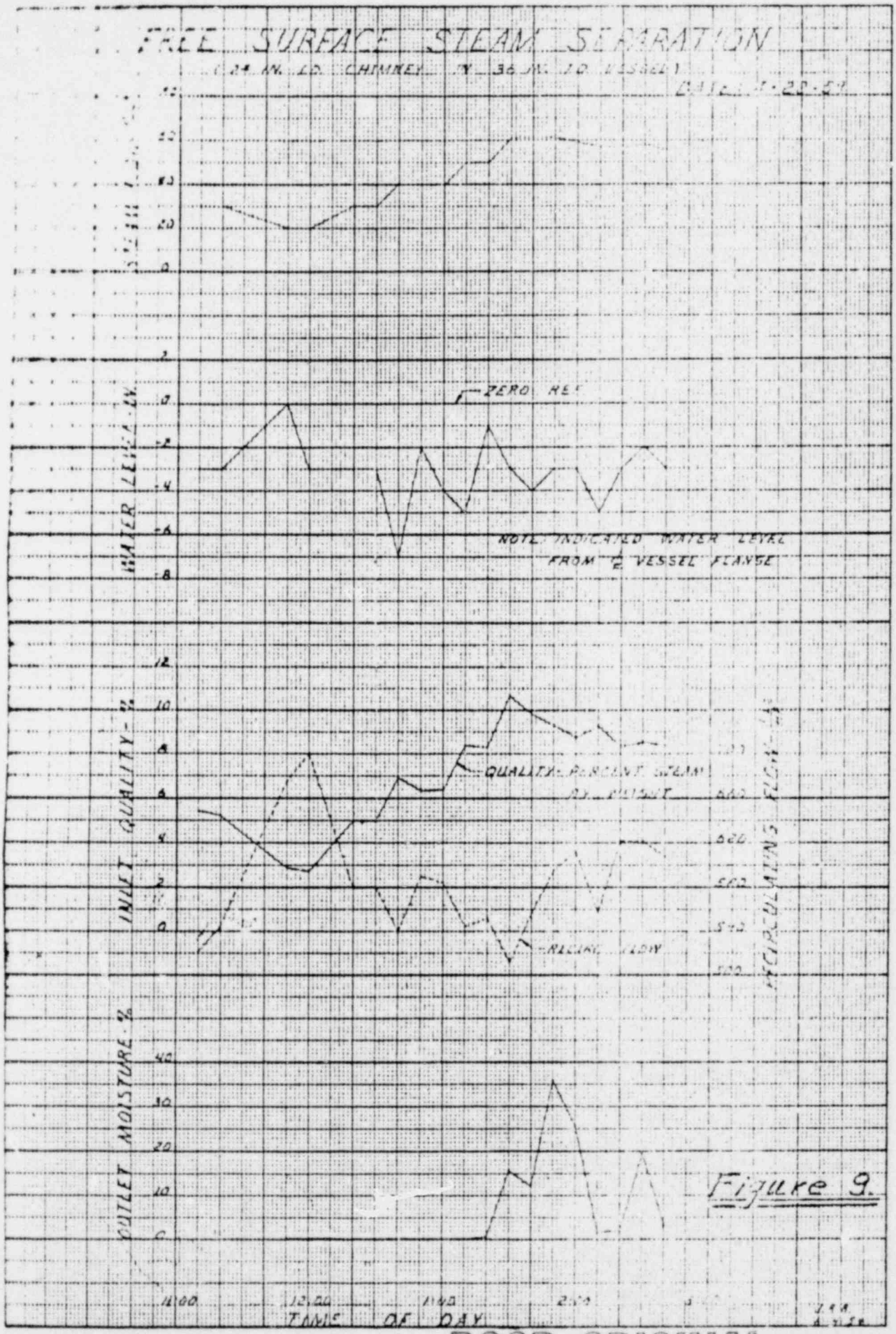

Figure 9.

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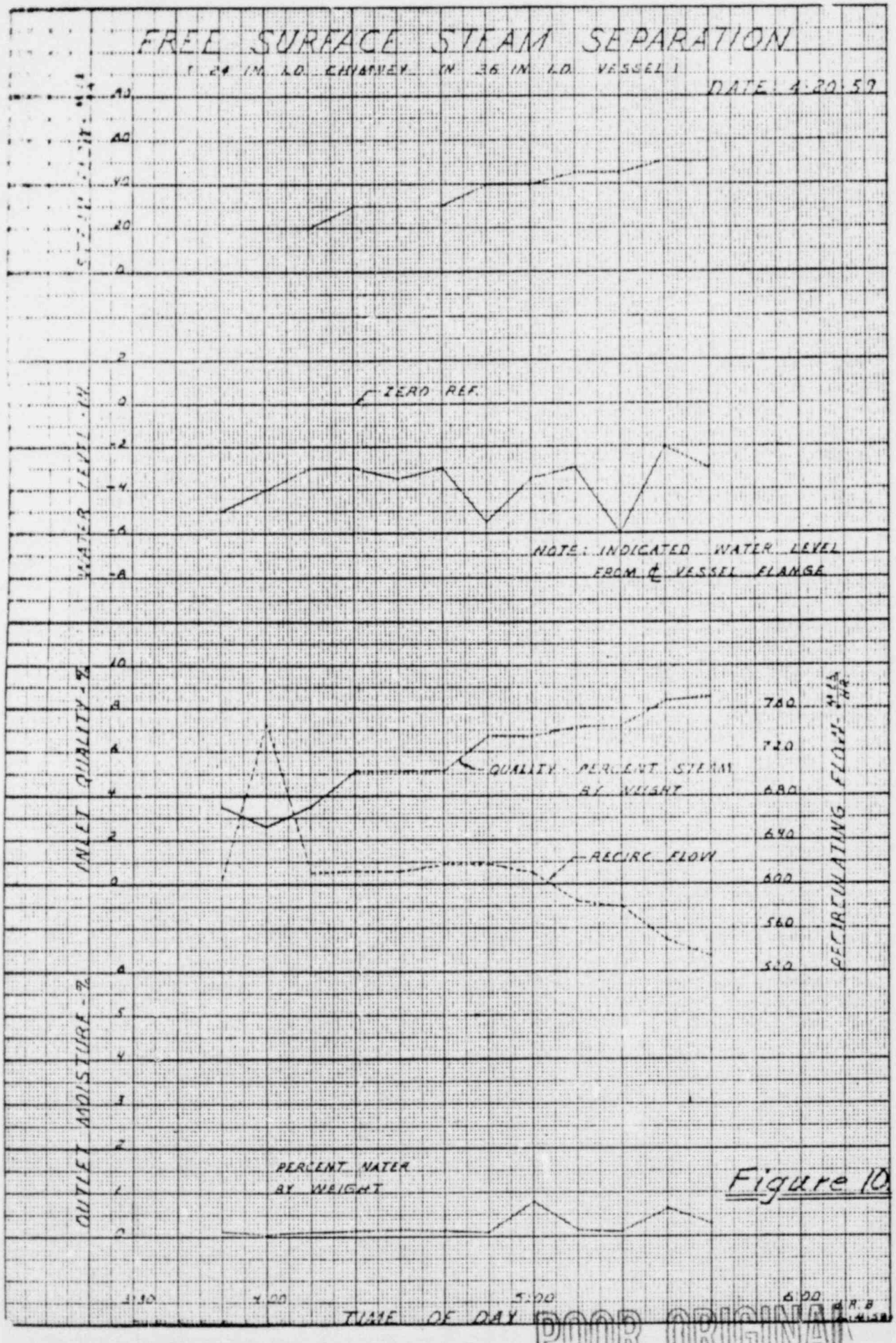

Figure 10

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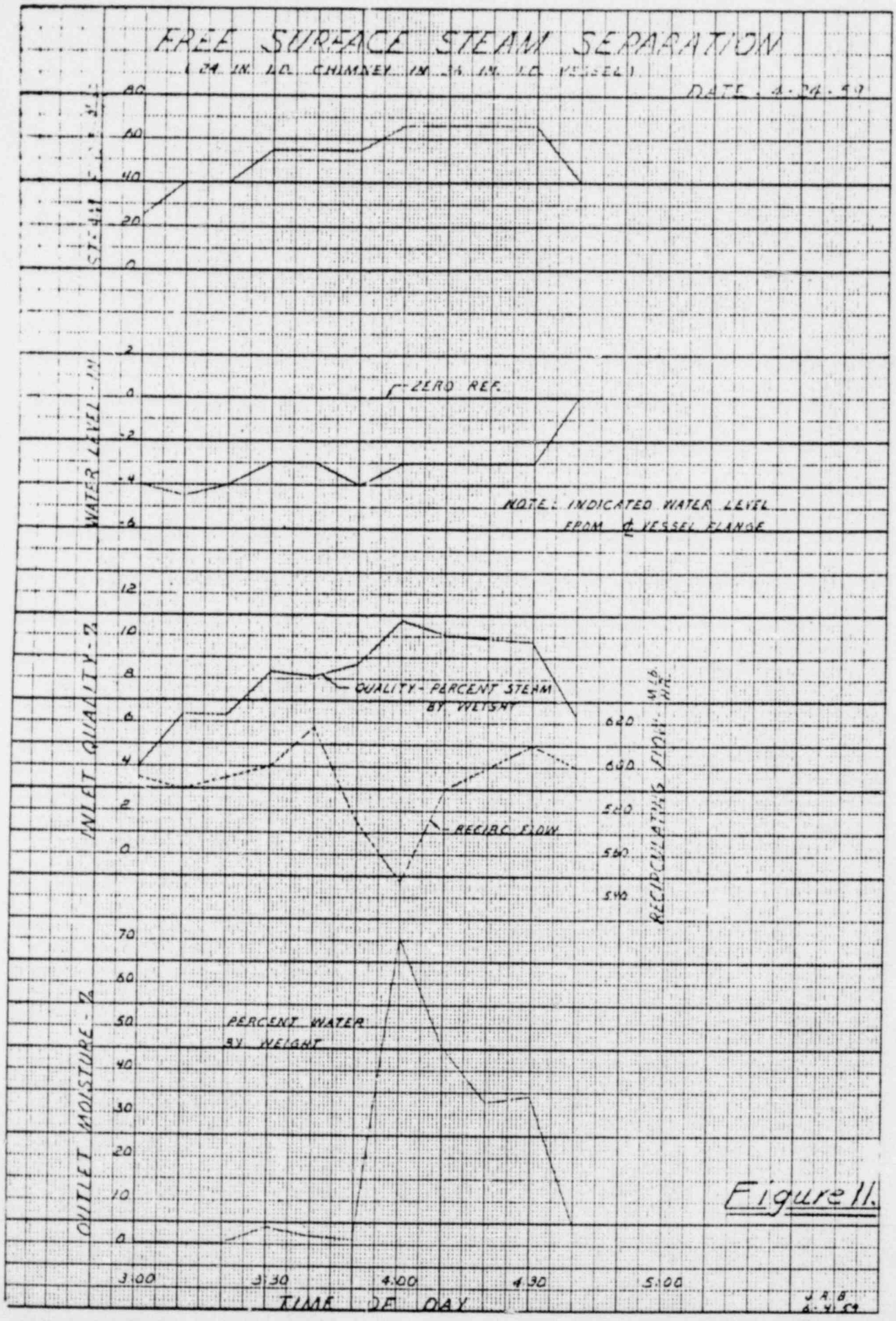

Figure 11.

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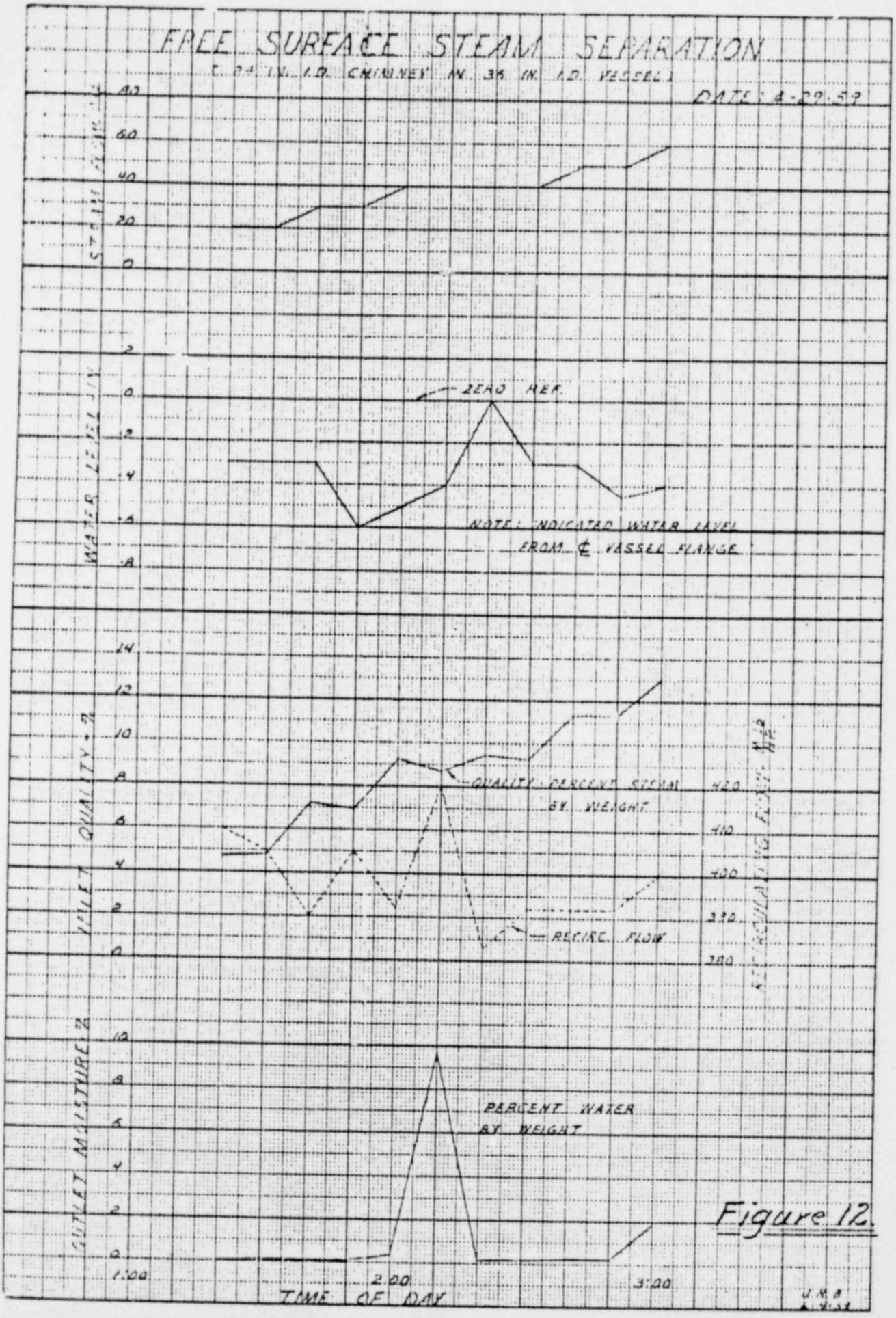

Figure 12.

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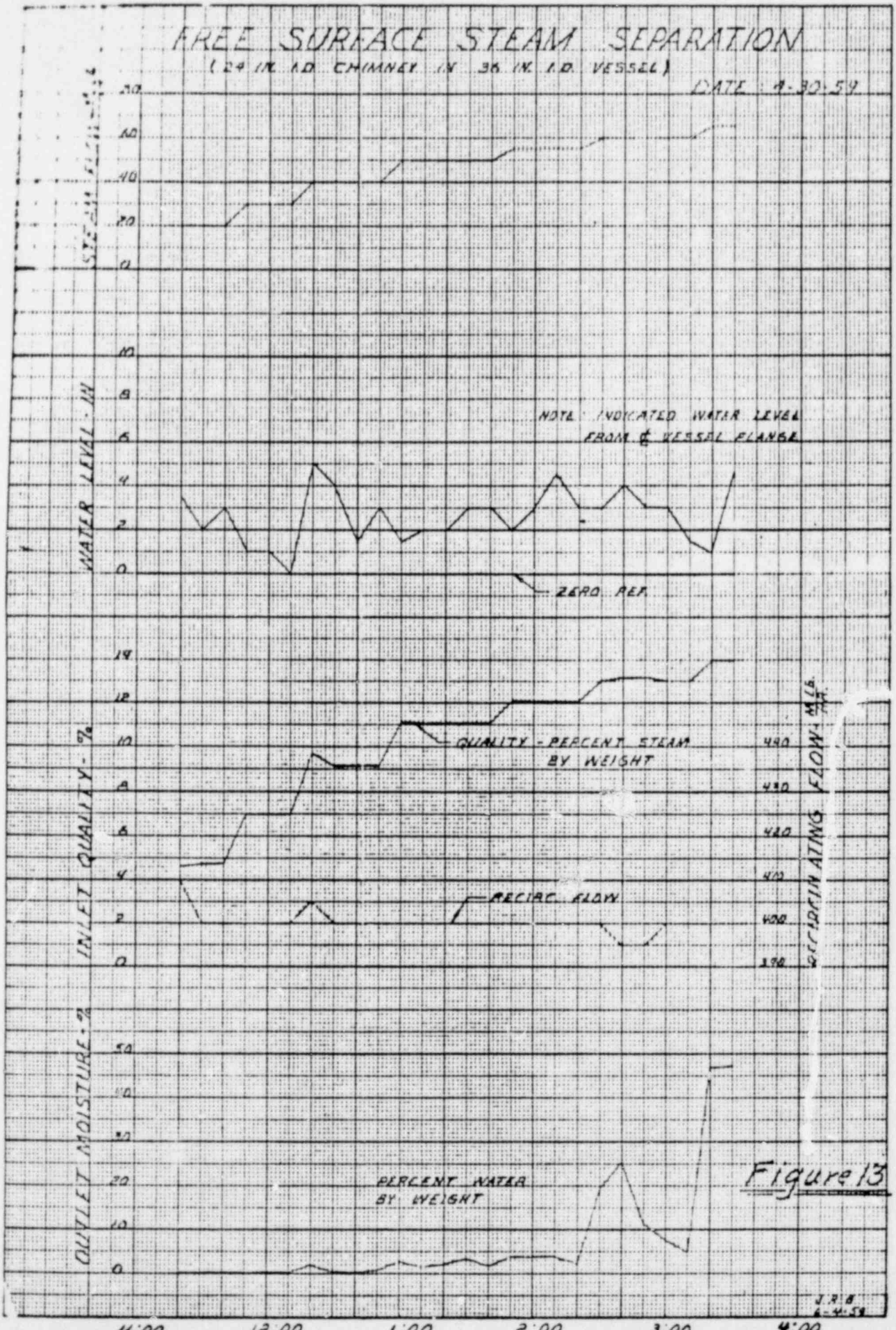

Figure 13

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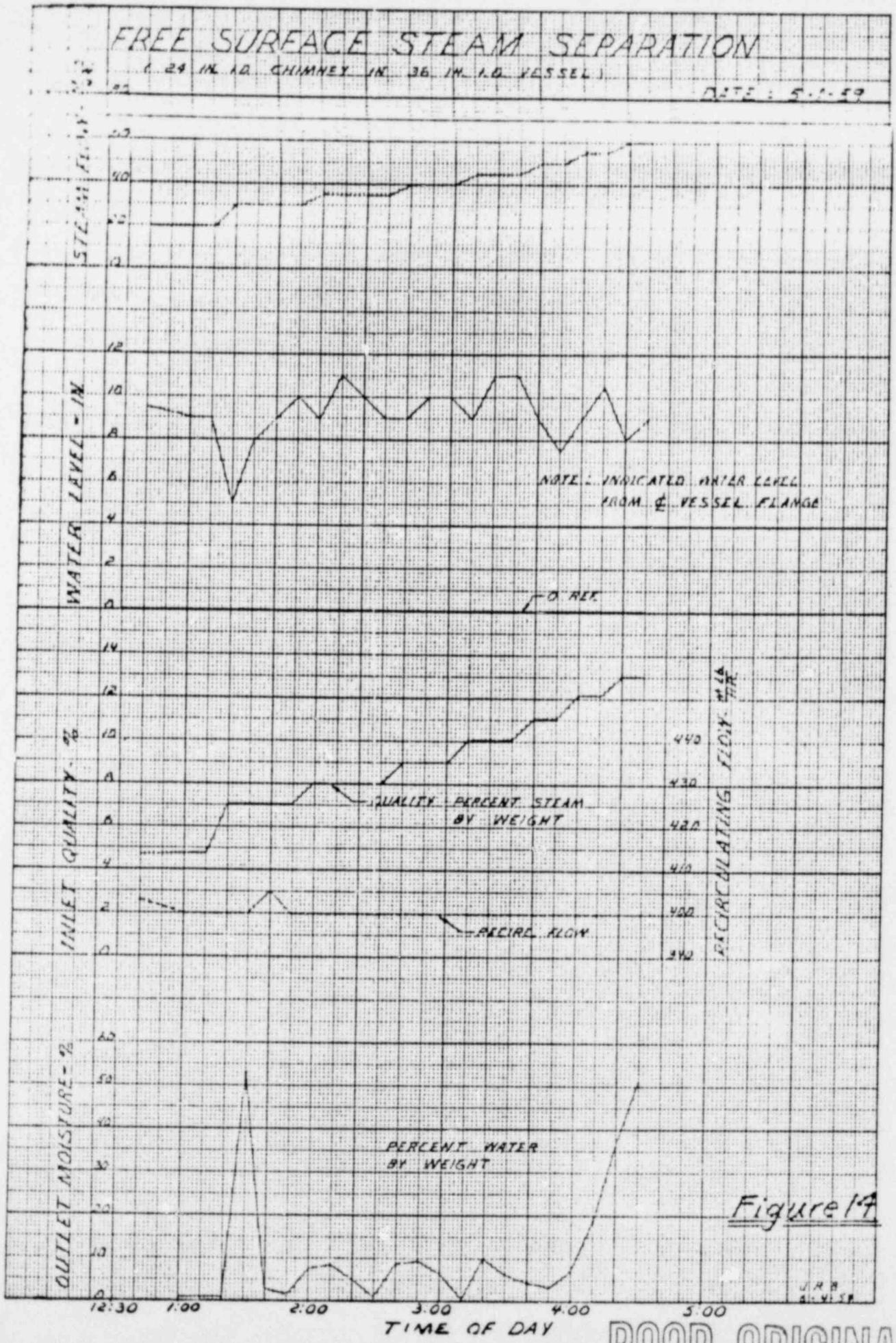

Figure 17

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