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PERFORMANCE OF SIEVE TRAYS UNDER GS HEAVY WATER PROCESS CONDITIONS

Part I - Low Pressure Operation

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Part I - Low Pressure Operation

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ABSTRACT

Capacity and entrainment of sieve trays were measured under GS process conditions in a $6\frac{1}{2}$-ft-diameter tower. Blower capacity limited gas flow to a maximum F-factor of 1.7 at 225-230 psig operating pressure. Tests will be resumed with the increased blower capacity available at 270-275 psig.

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PERFORMANCE OF SIEVE TRAYS UNDER GS HEAVY WATER PROCESS CONDITIONS

INTRODUCTION

The maximum fluid handling capacity of sieve trays under GS process conditions enters into comparisons of future power costs for various types of nuclear reactors through its effect on the projected cost of heavy water. With our current technology, this projected cost should be based on the GS process[1] applied to modern plants equipped with sieve trays like those used to replace corroded bubble-cap trays at the AEC's Dana Plant. Proctor and Thayer[2] prepared a flowsheet and estimated investment and operating costs for a modern GS plant, basing their estimate of capacity on that obtained with sieve trays at Dana. Throughput at Dana was limited by pumping capacity but the less expensive sieve trays permitted greater flows with better tray efficiency than the plant's bubble-cap trays.[3]

By July 1963, design of a test facility to determine maximum flow capacity of sieve trays had been completed at the Savannah River GS Plant. To reduce construction and operating costs, the test unit was to be interconnected with and limited by the pressure of the existing GS Plant. In August 1963, after discovering severe external corrosion of carbon steel tower walls under foamglass insulation, GS Plant pressure was reduced 50 psi (at the proposed point of interconnection) until the strength of the towers could be determined by detailed inspection.

The detrimental effect of this decrease in pressure on sieve tray tests was recognized but it was decided to complete construction and operational checks of the test unit and obtain as much preliminary information as possible at the lower pressure. The unit was also designed to compare the liquid handling capacity of SRP segmental downcomers with the capacity of circular downpipes, but was not designed to concentrate D_2O nor to measure tray efficiency, because only one tower was to be used alternately to simulate both hot and cold tower operation.

The tests were part of the AECL Cooperative Program.

SUMMARY

The tests were conducted by circulating H_2S countercurrent to water through seven sieve trays in a tower 6-1/2 feet in diameter. Liquid entrained in the gas from the third to the fourth tray and differential pressures across various sections were measured, while holding the liquid-to-gas molar flow ratio (L/G) at the optimum required in an operating plant.

Low liquid entrainment, less than 0.5 mol per 100 mols of gas, was experienced up to the flooding point. Consequently, tray efficiency should not decrease significantly up to that point. This performance, coupled with earlier plant evaluation of sieve and bubble-cap trays, indicates that cold tower F-factors* as high as 1.8 should be attainable with sieve trays at tower exit pressures up to 275 psig, provided the plant is supplied with water of high quality. However, in the tests reported here, maximum flow at cold tower conditions was limited to an F-factor of 1.6 to 1.7 by blower capacity at 225-230 psig. Proctor and Thayer based their design on an F-factor of 1.5.

Feedwater quality caused wide variations in attainable flow. Trays flooded at F-factors as low as 1.2 during periods of heavy rainfall. Feedwater quality affected performance of all trays. In several tests flooding began at the bottom and progressed up the tower. Silicone antifoam increased attainable flows as much as 10% during periods of poor water quality.

Segmental downcomers and circular downpipes performed alike; neither limited flow and neither seemed to affect entrainment of liquid into the gas stream, after results were corrected for the effect of water quality.

Under hot tower conditions, blower capacity limited flow to an F-factor of 1.4 at normal L/G. In several runs at abnormal L/G, the trays tended to flood less as the temperature was increased.

FUTURE TESTS

Thus far, in tests at Dana and SRP, the associated equipment rather than the sieve trays limited throughput. Tests will be resumed when the pressure in the GS Plant is increased to 275 psig at the point of interconnection with the test facility.

* All F-factors quoted are based on the tower de-entrainment area — the full circular area less the area of one downcomer — and so may differ with F-factors reported by other authors. F-factor is defined as:

$$F = v\sqrt{\rho} \text{ where } \rho = \text{gas density, lb/cu ft}$$

v = gas velocity, ft/sec, based on de-entrainment area.

DISCUSSION

PROCESS DESCRIPTION

The process flowsheet is shown in Figure 1. Tower and tray design data are given in Appendix A.

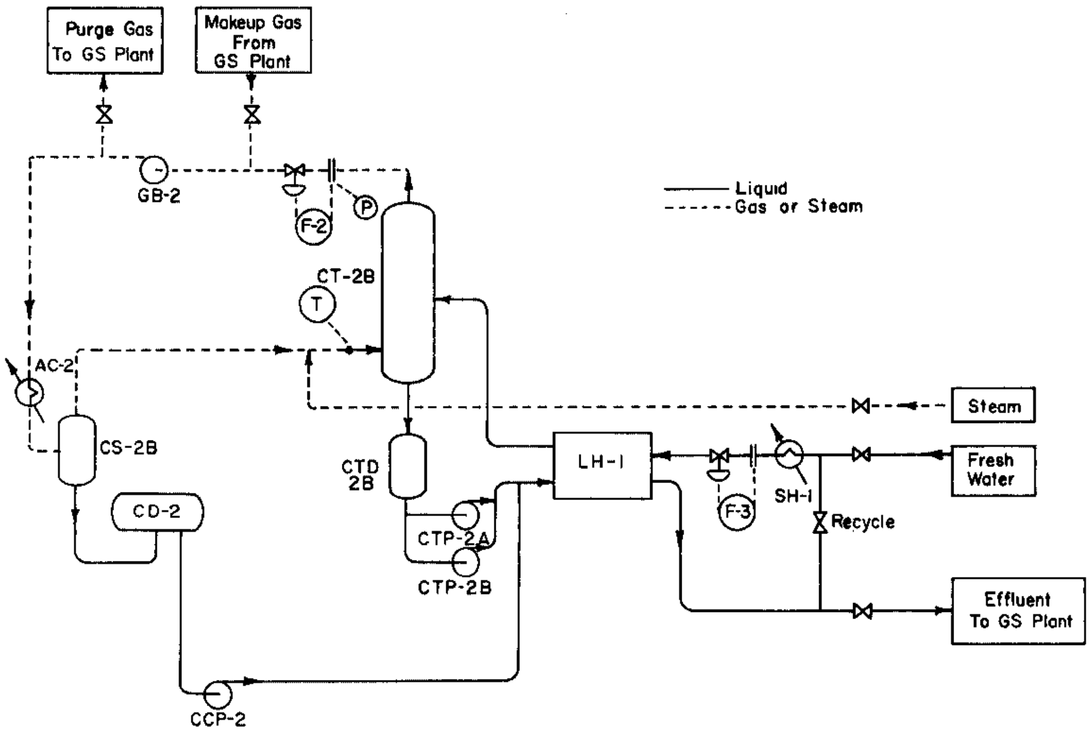

FIG. 1 PROCESS FLOW SHEET FOR SIEVE TRAY TEST

Process Flows

Gas was supplied to the test unit from the operating GS Plant and circulated by the blower, GB-2. A continuous gas drawoff to the purge tower in the GS Plant was necessary to maintain gas quality.

Likewise, gas flowed continuously from the GS Plant to the test unit to replace H_2S leaving in the purge gas and effluent liquid streams. For operation at hot tower conditions, steam at 250 psig was fed into the gas stream just before it entered the base of the tower, CT-2B. After preheating in the feedwater heater, SH-1, and liquid heater, LH-1, feedwater was distributed into the segmental downcomer from the eighth to the seventh tray. Effluent liquid was pumped from the level control drum, CTD-2B, combined with condensate from the condensate drum, CD-2, and passed through the tube-side of LH-1 to preheat incoming feedwater. The cooled effluent liquid, containing dissolved hydrogen sulfide gas, was added to feedwater for the GS Plant or was recycled back to the test unit.

Tower Internals

Figure 2 shows the test section of CT-2B. Bubble-cap trays 1 through 7 were replaced with sieve trays. To simulate the top of a GS cold tower, bubble-cap tray 8 was converted to a de-entrainment tray by removing the outlet weir, and bubble-cap trays 9 through 12 were removed. A drain line with an orifice was installed from tray 13 to tray 7. Bubble-cap trays 13 through 84 were left in place and were not involved in the test except to de-entrain liquid carried in the gas stream as indicated by liquid flow through the tray 13 drain-line meter.

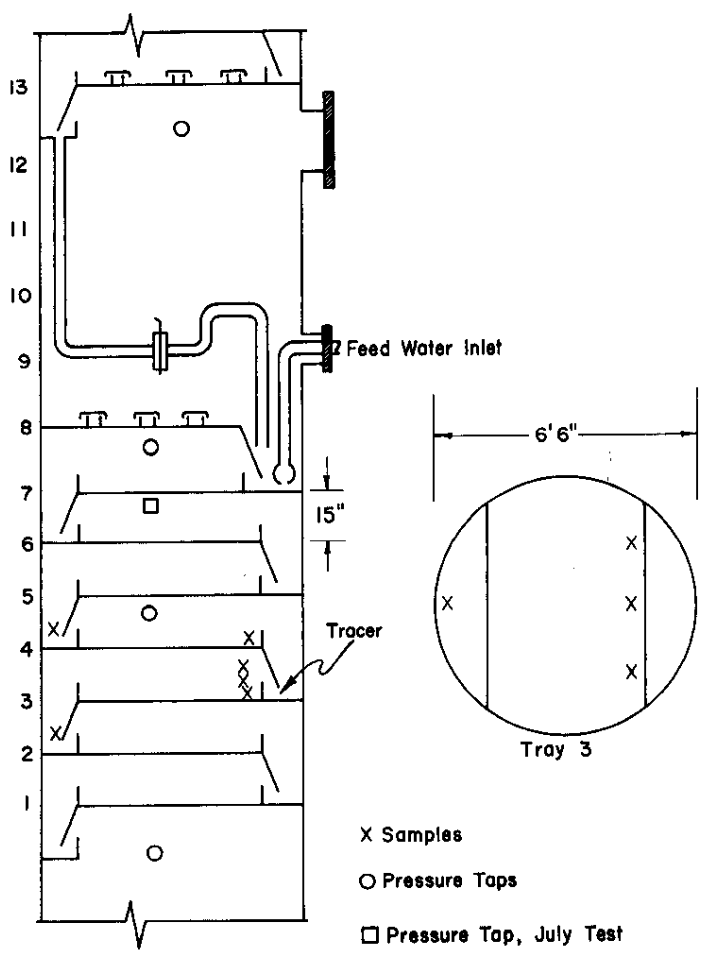

FIG. 2 SIEVE TRAY TEST SECTION IN CT-2B

CT-2B was originally designed so that water dropped from one tray to the tray below through a segment of tower cross section. A wall isolated the segment from the active part of the tray and a water seal was maintained at the base of the wall by a weir, as shown in Figure 3. After completing several tests, the segmental downcomers were modified by removing the wall and adding a horizontal plate with three 6"-diameter downpipes, as shown in Figure 4. These were the largest downpipes that would fit into the space.

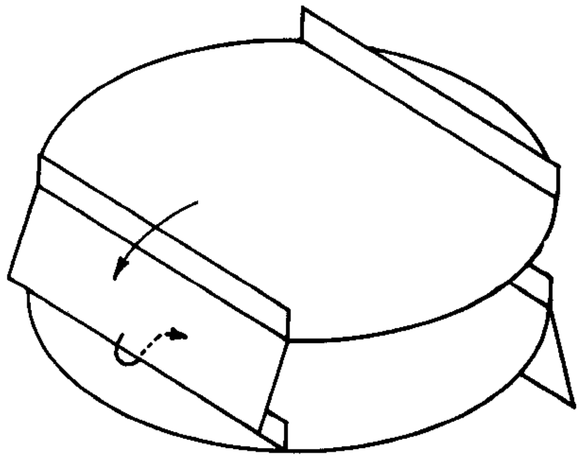

FIG. 3 SEGMENTAL DOWNCOMERS

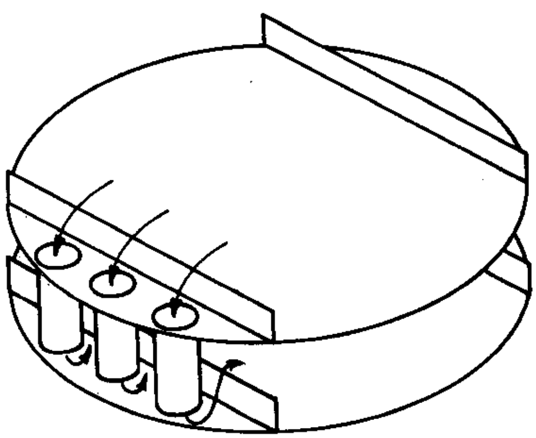

FIG. 4 DOWNPIPES

Differential Pressure Measurement

Pressure taps were installed below trays 1, 5, and 8; above tray 8; and in the downcomer to tray 3 (to measure froth level). The 1/2" pressure impulse lines entered the tower at the 9th-tray nozzle, along with the 4" feedwater line, and passed down through the trays to the above terminal taps. Openings where the impulse lines passed through trays were sealed to prevent leakage of gas. The differential pressures most useful in diagnosing tower operation were those across trays 1-7, 1-4, 5-7, and dry tray 8. After the first series of tests, the pressure tap in tray 3 downcomer was relocated below tray 7 to allow measuring differential pressure across the feed tray. The differential pressure across trays 1-7 was transmitted to the control room pneumatically and recorded continuously on a chart with a range of 0-50 inches of water. The remaining differential pressures were transmitted and recorded — one at a time, by proper valving at the field manifold — on a control room chart with a range of 0-20 inches of water.

Entrainment Measurements

Tray-to-tray entrainment of liquid into the gas stream was measured by analysis of fluorescein in liquid samples withdrawn from trays 3 and 4 while injecting a water solution of about 5000 ppm fluorescein dye through a distributor at tray 3 inlet weir. The 3 sample points at tray 3 inlet weir, shown in Figure 2, were used in initial tests to assure uniform distribution of fluorescein across this tray. Entrainment was calculated from a material balance, assuming that no fluorescein or entrainment escaped with the gas from the top of the tower:

$$(E' + L)C_4 = E'C_3$$

whence,

$$E = \frac{100\ (L/G)\ C_4}{C_3 - C_4}$$

where, E' = liquid entrained in gas, mols/hour

E = liquid entrained in gas, mols per 100 mols of gas

$= \frac{100E'}{G}$

L = water fed to test tower, mols per hour

G = total wet gas flowing through test tower, mols per hour

C_4 = concentration of fluorescein in liquid overflowing tray 4 outlet weir, ppm

C_3 = concentration of fluorescein in liquid overflowing tray 3 outlet weir, ppm.

Fluorescein concentrations were measured with a Beckman Model B Spectrophotometer. Precision ranged from ±2% at a concentration of 10 ppm fluorescein to ±7% at a concentration of 0.25 ppm. Assuming a sample dilution error of ±1% and flow measurement error of ±2%, the maximum theoretical error in calculated entrainment was ±10% for entrainments up to 13 mols liquid per 100 mols gas. Excellent reproducibility of entrainment data confirmed this accuracy. Figure 5 shows fluorescein concentrations at trays 3 and 4 and calculated entrainment from tray 3 to tray 4 plotted against time elapsed after starting fluorescein injection. Gas and water feed rates during this run were held constant at an L/G of 0.48. Based on these results, all subsequent entrainment data were taken at least one hour after starting fluorescein injection.

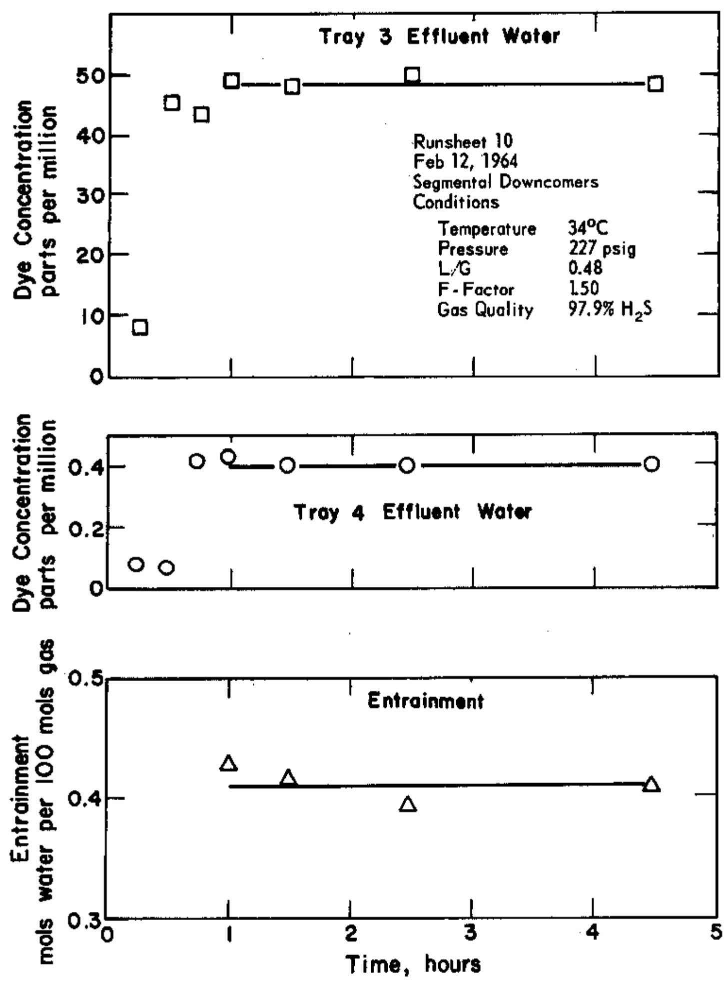

FIG. 5 TIME TO REACH STEADY STATE DYE CONCENTRATION

Major Process Variables

The reference pressure quoted throughout this report was measured at the upstream tap of the F-2 orifice meter (CT-2B off-gas), and so, is lower than the actual pressure at the sieve trays by the pressure drop across trays 13-84, about 3 to 4 psi.

The reference temperature quoted was measured at the gas inlet to the tower downstream of the steam inlet. The top tray operated at a higher temperature and the gas left at a higher temperature because of heat liberated when H_2S dissolved in the feedwater near the liquid inlet.

Mass flow of gas through the test trays was the sum of the flow through the F-2 orifice meter plus the calculated weight of dissolved H_2S that left in the effluent water.

Throughout this report, gas flow is expressed in terms of F-factor:

$$F = v\sqrt{\rho}$$

where v = gas velocity, ft/sec, based on the tower de-entrainment area, i.e., the full circular area less the area of one downcomer (31.9 sq ft).

ρ = gas density, lb/ft^3.

The reference pressure and temperature were used to calculate gas density; therefore, quoted F-factors, converted from mass flow, are about 1% higher than actually existed at the sieve trays due to the indefinite 3-4 psi drop across trays 13-84.

Instrument Accuracy and Precision

1. Absolute measurements. When a specific measurement is considered separately and apart from other measurements on the same instrument, interpretation should be limited by these accuracies:

Meter	Percent of Meter Reading
Orifice flowmeters (F-2, F-3)	±2
Differential pressure	
Trays 1-7 (PdRp-4)	±2
Selected trays (PdRp-3)	±1
Pressure (PRp-12, suppressed range, 210-230 psig)	±2
Temperature (TR2-2, thermocouple)	±1

Combined accuracies:

L/G	±3%
F-factor	±4%

2. Relative measurements. When several measurements from the same instrument are compared over a short period of time (a day, or so), the precision or relative accuracy of the readings is considerably better than the absolute accuracy. The consistency of the data during a particular test bears this out, but no attempt was made to estimate reproducibility.

TEST RESULTS

Detailed results from each individual test are presented in Figures 9a through 23c. The test covered by each of these figures is described further in a Synopsis on the facing page. In this report:

- Tray flooding is defined as a sharp upward break in a curve of tray ΔP versus F-factor. Because differential pressures were generally measured across more than one tray, this break is less sharp and less clearly defined than it would be for only one tray.
- Tray 7 is said to be flooded whenever the ΔP across tray 8 shows a significant increase.
- The capacity of sieve trays is taken as the maximum F-factor and/or liquid flow for stable operation of tray 7.

History of Test Operation and Feedwater Effects

For many years, feedwater quality has been a seasonal limitation in the operation of the Savannah River GS Plant where it causes carry-over of liquid from the top of the first stage cold towers into the gas blowers. Under these conditions, to maintain optimum L/G, gas flow must be decreased to match the decrease in liquid flow on the lower trays caused by flooding on the top tray. Silicone antifoam* eliminates mild carryover, but during periods when heavy rains overflow surrounding swamps and thoroughly roil the river, silicone has little effect.

Flooding of the top sieve tray and carryover also limited flows in the test unit. Figure 6 records these limitations during the three test periods and provides a capsule history of the tests and of variations in feedwater quality. The F-factors plotted in this figure correspond to flooding rather than stable operation of tray 7 because most of the data were obtained by brief excursions to high flow without recording intermediate conditions (Figures 13 and 14).

* General Electric "GE-60" or equivalent.

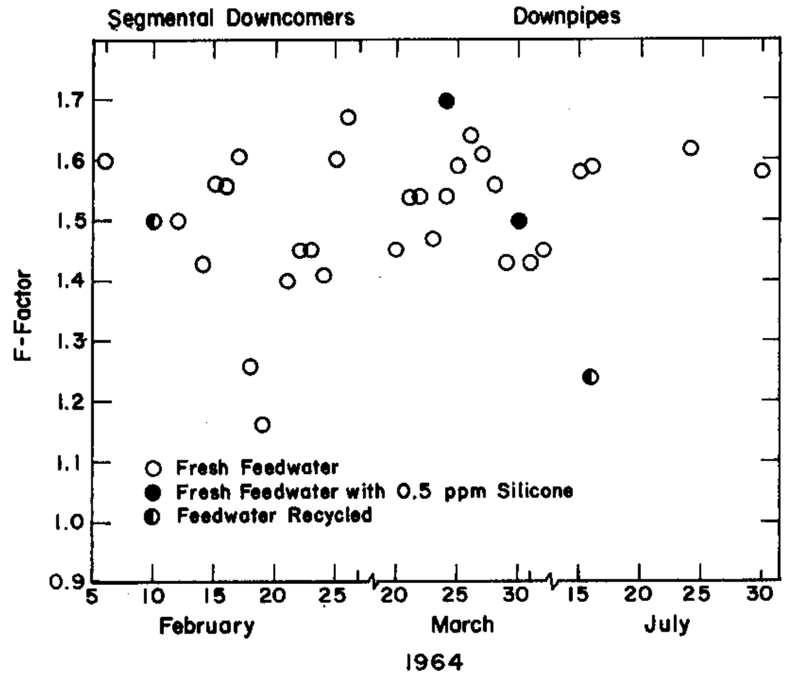

FIG. 6 VARIATIONS IN FEEDWATER QUALITY, 35°C L/G=0.50

Tests with segmental downcomers were started on February 4, flows were increased to maximum on February 6, and tests were continued through February 27 while experiencing wide variations in feedwater quality and maximum attainable flow. Maximum blower capacity was reached at an F-factor of 1.72 on February 18 during a test at 33°C with an abnormally low L/G (Figure 19b). During all sieve tray tests, GS Plant flows were suppressed to a maximum F-factor of 1.35 by blower capacity at the low operating pressure, but despite these normally low flows, poor water quality and carryover, February 18-20, required addition of silicone antifoam to hold flows at this level.

The test unit was shut down February 27 to replace segmental downcomers with circular downpipes, and operation was resumed on March 20. Maximum blower capacity was reached at an F-factor of 1.70 on March 24 at process-optimum L/G for cold tower operation but with flooded trays (Figure 15c). During the second test period, GS Plant flows were suppressed to an F-factor of 1.2 by carryover March 29 to 31 despite silicone addition. Testwork was terminated April 3 and the unit was shut down to await the end of the typical spring carryover season.

Tests with downpipes were resumed July 15. Maximum blower capacity at process-optimum L/G under stable cold tower conditions was achieved on July 30 at an F-factor of 1.65* while adding 0.5 ppm silicone

*The 3% difference in F-factor at blower capacity between February - March and July is within the ±4% accuracy for F-factor determinations.

(Figure 17d). On the same day, without silicone, stable operation was limited to an F-factor of 1.54 by tray 7 flooding (Figure 17e). Following these tests, the unit was placed in standby condition to await full-pressure operation of the GS Plant.

Results at Cold Tower Conditions

1. Recycled Feedwater and Feedwater Turbidity. Two tests with recycled feedwater under cold tower conditions were conducted to eliminate the effect of dissolving H_2S at the feed tray, but this effect, if any, was masked by poor water quality.

On July 16, in tests with downpipes and recycled feedwater (Figure 18), flooding of the feed tray limited stable operation to an F-factor of 1.17, significantly lower than the F-factor of 1.50 achieved with fresh feedwater the same day (Figure 17b). Recycled feedwater also limited flows to an F-factor of 1.40 during an earlier test with segmental downcomers on February 10 (Figure 11). In both tests, the recycled water was quite turbid whereas fresh feedwater and associated effluent were visually clear. Apparently, the turbidity was generated when recycled water — saturated with H_2S — passed through feed piping normally exposed to only fresh water.

During the many years carryover has plagued the GS plant, turbidity is the only aspect of water quality that appears to correlate with carryover, and this has correlated only in a one-way fashion, i.e., feedwater turbidity is usually high when carryover occurs, but carryover does not always occur when feedwater turbidity is high.

2. Segmental Downcomers versus Circular Downpipes. V. R. Thayer proposed that poor separation of liquid and gas in segmental downcomers caused flooding and carryover and that circular downpipes should perform better despite smaller flow area. Maximum flows achieved under stable operation with these two types of downcomers are tabulated below:

	Segmental Downcomers	Circular Downpipes
Data from Figure No.:	10	17d
Date	Feb 26	July 30
Maximum F-factor	1.65	1.65
Silicone, ppm	0	0.5
ΔP/tray, in. H_2O	3.2	3.2
Temperature, ^oC	35	34
Pressure, psig	229	229
Limitation	Tray flooding	Blower capacity

In comparing these results, two conflicting factors must be considered:

- If silicone had been added to the feedwater, more stable operation and higher flows would probably have been attained with segmental downcomers.*

- On the other hand, at the same meter reading, flows in February and March were probably 3% lower than those in July due to different meter calibrations. (Compare tests at maximum blower capacity: Figures 15c and 19b in February-March versus Figure 17d in July. Because blower capacity had not been reached during stable operation in the test shown in Figure 15c, the F-factor of 1.67 actually corresponds to a lower flow than the F-factor of 1.65 shown in Figure 17d.)

For a precise comparison, the major variable — water quality — overshadows both of the above factors, making evaluation by straight comparison of maximums a doubtful undertaking. However, for a rough comparison, the tabulated data show that the two types of downcomers have about equal capacity.

Entrainment of liquid into the gas stream should also be considered in assessing downcomer capacity. Entrainment rates for both types of downcomers during February and March are summarized in Table I and plotted against F-factor in Figure 7. Although segmental downcomers seem to perform better, feedwater quality must be considered again. In this case, the effect of feedwater quality can be eliminated if the maximum flow for stable operation during each test is considered to be an index of water quality and all other flows are expressed on a relative basis as a percent of that maximum. The data, plotted this way in Figure 8, show completely equivalent performance for both types of downcomers at low operating pressure.

3. Nature and Location of Flow Limitation. The fact that two radically different downcomers perform equally well — one with a flow area only 45% of the other — indicates that the area of downcomers in the present GS towers does not limit throughput.

* Although pumped, silicone did not reach the feedwater because line holdup had been underestimated. The error was not discovered until downpipes had been installed.

TABLE I

Sieve Tray Entrainment

Correlation with flood point

Date	Fig. No.	F-factor Data Point	F-factor Max Stable for Test	F-factor Percent of Max Stable Flow	Entrainment mols/100 mols
		Segmental Downcomers			
2-4	9a	0.94	1.50	63.2	0.15
2-4	9a	1.10	1.50	73.4	0.09
2-5	9a	1.20	1.50	80.0	0.14
2-5	9a	1.30	1.50	86.6	0.14
2-5	9a	1.40	1.50	93.3	0.25
2-5	9a	1.50	1.50	100.0	0.37
2-6	9a	1.60	1.50	106.7	0.49
2-12	4	1.50	-	-	0.41
2-24	9b	1.00	1.56	64.1	Nil
2-24	9b	1.09	1.56	69.9	Nil
2-24	9b	1.19	1.56	76.8	Nil
2-25	9b	1.29	1.56	82.7	0.21
2-25	9b	1.40	1.56	89.8	0.26
2-25	9b	1.52	1.56	97.5	0.43
2-25	9b	1.56	1.56	100.0	0.55
2-25	9b	1.64	1.56	105.1	0.98
2-26	10	1.67	1.65	101.2	1.00
		Circular Downpipes			
3-23	15a	1.47	1.45	101.3	0.50
3-24	15c	1.70	1.67	101.8	6.10 (a)
3-30	16a	1.10	1.40	78.6	0.13 (a)
3-30	16a	1.21	1.40	86.5	0.21 (a)
3-30	16a	1.31	1.40	93.5	0.28 (a)
3-30	16a	1.40	1.40	100.0	0.70 (a)
3-30	16a	1.50	1.40	107.0	1.57 (a)
3-31	16b	1.10	1.31	84.0	0.17
3-31	16b	1.20	1.31	91.6	0.20
3-31	16b	1.31	1.31	100.0	0.33
3-31	16b	1.37	1.31	104.7	0.73

(a) Silicone added.

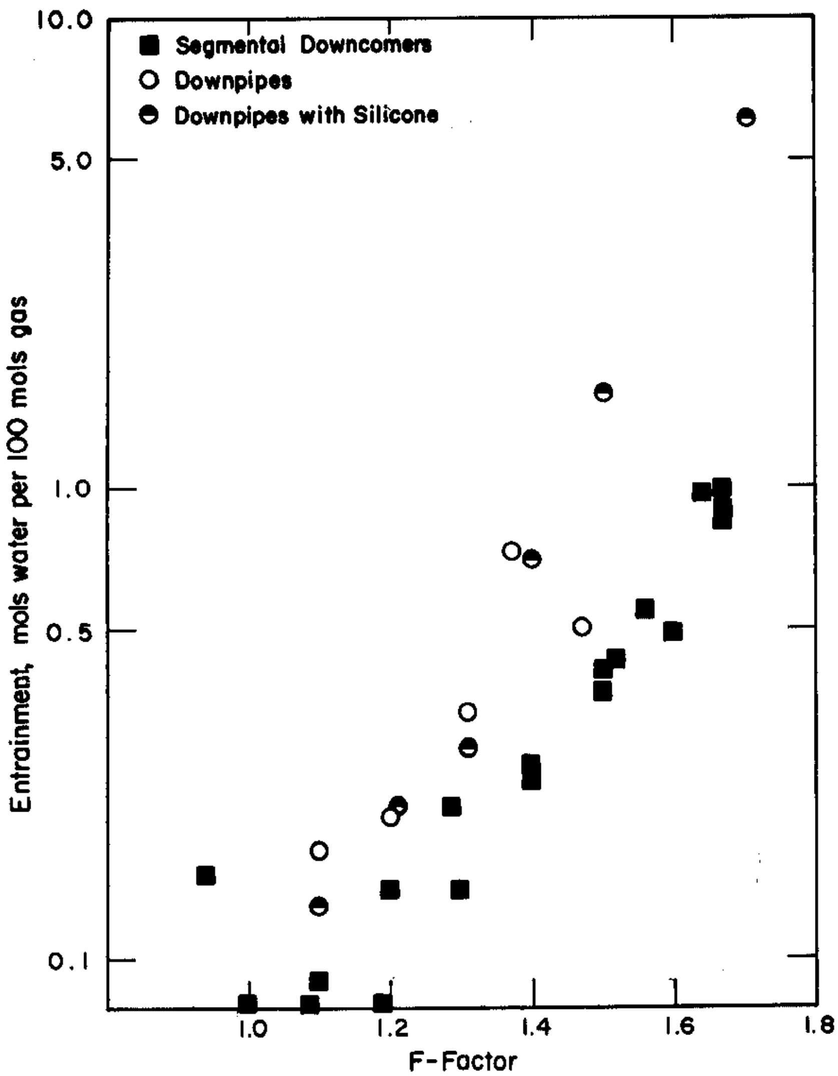

FIG. 7 ENTRAINMENT WITH DOWNPIPES AND SEGMENTAL DOWNCOMERS

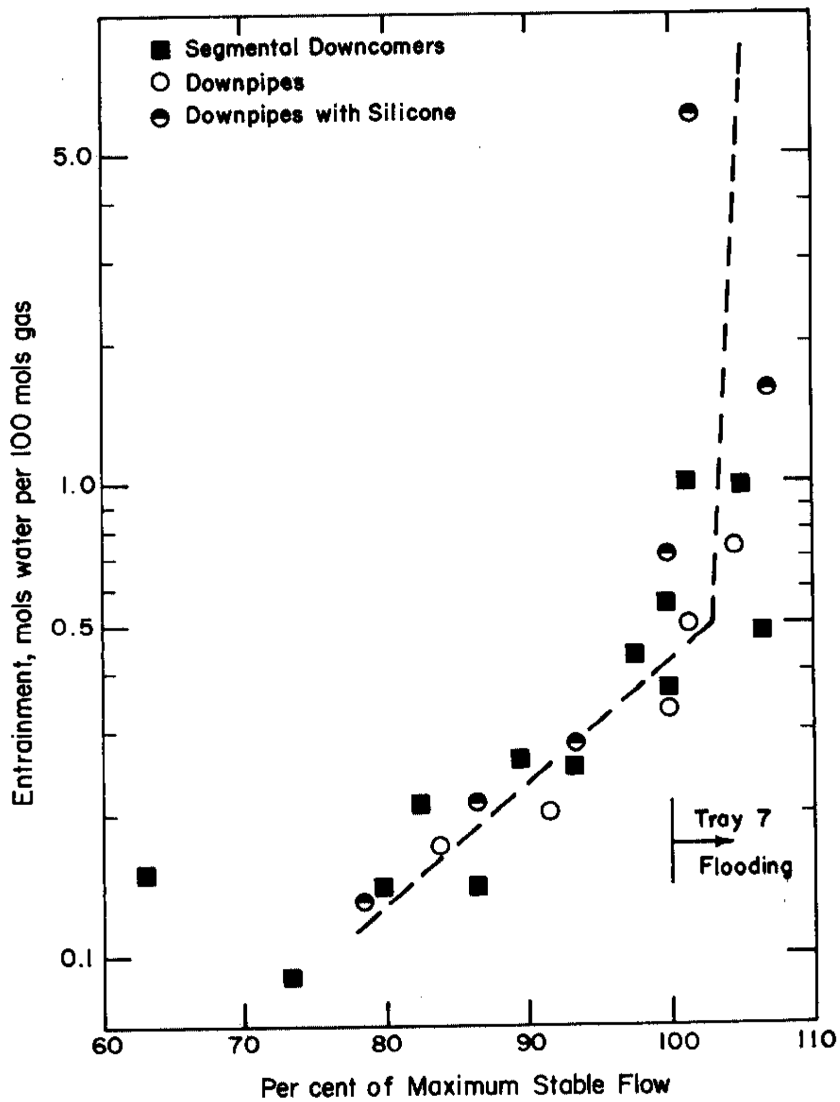

FIG. 8 ENTRAINMENT VERSUS PERCENT OF MAXIMUM STABLE FLOW

Further, the correlation of entrainment with water quality, indirectly established by Figure 8, shows that the effect of water quality is not confined to the top (feed) tray since the entrainment was measured between trays 3 and 4. Carryover of liquid from the top tray of the first stage cold tower into the gas blower — the ultimate limitation in SRP GS Plant operation — is merely the final manifestation of a condition that can develop initially at any point in the tower. This is confirmed by a close examination of differential pressure data from these tests. The table below, which summarizes remarks from the synopses of several typical tests, illustrates the variation in location of the initial flooding point and the upward sequence of tray flooding as F-factor increases.

	F-factor at flooding					
Figure No.	17a	17b	17c	15b	10	9b
Trays 1-4	1.40	1.33	None	-	-	None
Trays 5-6	1.50	1.46	1.59	-	-	None
Some Lower Tray of Unknown Location	-	-	-	1.40	1.57	-
Tray 7	1.58	1.50	1.62	1.52	1.67	1.6
	Circular downpipes				Segmental downcomers	

In summary, mechanical design of downcomer parts is not the source of capacity limitation nor is any particular tray more the source than another. Instead, the quality of feedwater seems to be the key limitation and the specific quality most suspect is turbidity. This aspect of Savannah River water quality is probably not unique, and at the high flows being considered, almost any source of water would probably be similarly limited. Designers of new GS Plants should look carefully at their water treatment facilities.

4. Application to New Design. Maximum flow capacities during normal and test operation at the two U.S. plants — Dana and Savannah River — are summarized in Table II. In all cases, equipment other than trays limited flow.

Proctor and Thayer based future plant capacity on the Dana Plant sieve tray tests rather than the SRP Unit 18 test because the prolonged Dana tests emphasized tray efficiency and pressure drop. The SRP test (cut short by shutdown of that third of the Plant) emphasized performance of condensate separators and heat recovery equipment and did not determine tray efficiency, nor entrainment, nor for that matter, maximum capacity of the gas blowers.

TABLE II

Maximum Flows Previously Demonstrated

F-factors in this report are based on the tower de-entrainment area[a], i.e., the full circular area less the area of one downcomer. Dana Plant values were recalculated from previous publications to this same basis.

Bubble-Cap Trays	Date	Maximum Gas Flow[a] F-factor	lb/(hr)(sq ft)	Tower exit Pressure, psig	Temp, °C	Limitation
Dana GS Plant	1956	1.35	6400	245	35	Pumps
SRP GS Plant	Mar 1965	1.35	6200	225	32	Blowers
	Aug 1965	1.45	6900	245	33	Blowers
	Feb 1963	1.65	8300	275	34	Blowers
Sieve Trays						
Dana GS Plant	Aug 1956-Mar 1957	1.50	7200	245	35	Pumps
SRP Unit 18[b]	Aug 1957	1.60	8100	270	33	Condensate Separators

(a) Both F-factor and mass velocity are based on the tower de-entrainment area of 86.5 sq ft. The full circular area of these towers is 95.2 sq ft.
(b) Test operation with sieve trays in only first stage cold tower and bottom ten trays of first stage hot tower (humifidier).

Concurrent with publication of Proctor's and Thayer's proposed design[2], modification of SRP steam piping permitted a 10 psi increase in tower pressure and a corresponding increase in gas flow to the F-factor of 1.65 shown in Table II for February 1963.

5. Effect of Silicone Antifoam. The effect of silicone in suppressing tray flooding was evaluated three times by comparative tests on the same day or succeeding days. The results are summarized in the following table.

Figure No.	Date	Silicone Added ?	Maximum F-factor	% Increase in Flow With Silicone
15b	Feb 24	No	1.50	11
15c	Feb 24	Yes	1.67	
16b	Mar 31	No	1.31	8
16a	Mar 30	Yes	1.40	
17e	July 30	No	1.54	7+
17d	July 30	Yes	1.65*	

* Blower capacity.

Results at Hot Tower Conditions

One run at process-optimum L/G at hot tower conditions (Figure 12) confirmed the expected low limit in blower capacity at high temperature (the blower pumps about the same actual cubic feet per minute as inlet conditions change, so attainable F-factor and mass flow of gas vary accordingly). Maximum flow was reached at an F-factor of 1.45 without flooding. No further tests were performed with optimum L/G at hot tower conditions.

Other Results at Abnormal L/G

Three series of tests explored the effect of temperature on liquid capacity at constant gas flow conditions — either mass flow of gas, constant at 200,000 lb/hr (Figures 21a, b, c and 22a, b, c, d) or F-factor, constant at 1.4 (Figures 23a, b, c). The decrease in tendency to flood as temperature increases agrees with operating experience in GS Plant hot towers where flooding does not occur unless downcomer flow is restricted by mechanical pluggage.

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2. J. F. Proctor and V. R. Thayer. Economics of Heavy Water Production. Chem. Eng. Progr., 58 (4), 53-61 (1962).

3. J. F. Proctor. A New Look at Distillation - 2. Sieve and Bubble-Cap Plates, Comparative Performance. Chem. Eng. Progr., 59, 47-54 (1963).

APPENDIX A

Tower and Tray Design Data

TOWER

Major Dimensions

Inside diameter: 6 ft 6 in.
Height: 114 ft
Original number of trays: 84

Modifications

Trays 1 through 7: Sieve trays installed
Tray 8: Outlet weir removed (de-entrainment tray)
Trays 9, 10, 11, 12: Removed
Tray 13: Drain water fed to seventh tray
Water feed to seventh tray
Tray 7: ΔP tap installed below tray before July series of tests

TRAYS

<u>Original Bubble Caps</u>

ID	4-1/8 in. (16 gage)
Riser OD	2-7/8 in. (16 gage)
Slot height	1-1/4 in.
Slot width	1/8 in.
Slots per cap	52
Slot area per cap	7.95 sq in.
Riser area per cap	5.94 sq in.
Reversal area per cap	9.72 sq in.
Annular area per cap	6.86 sq in.
Skirt clearance (bottom of slot to plate)	1/8 in.
Tray to top of riser	1-1/2 in.
Tray to top of cap	2-5/8 in.

<u>Original Bubble Cap Trays</u>

Tray spacing	15 in.
Tray area	30.5 sq ft
Caps per tray	103
Riser area	4.26 sq ft (14.0% of tray area)
Slot area	5.69 sq ft (18.7% of tray area)
Cap reversal area	6.95 sq ft (22.8% of tray area)
Cap annular area	4.91 sq ft (16.1% of tray area)
Weir length	49 in.
Outlet weir height	2-1/4 in.
Adjustable	±1/2 in.
Inlet weir height	3 in.
Clearance between downcomer and plate below	2-1/2 in.
Bottom seal pan weir height	3-1/2 in.

<u>Sieve Trays</u>

Tray area, tray spacing, and weir lengths same as above.

Perforation diameter	1/4 in.
Perforation spacing	21/32 in. between triangular centers
Perforated area	2.62 sq ft (8.6% of tray area)
Outlet weir height	1-1/4 in.
Width of calming section	
at outlet weir	2 in.
at inlet weir	2 in.
Inlet weir height	3 in.

Figure 9a Synopsis

Runsheets 1 and 2

Tray stability limit: F-factor 1.50

Flows were increased every 3 to 6 hours, while maintaining process-optimum L/G at cold tower conditions. Fluorescein was injected continuously. Effluent liquid from trays 3 and 4 was sampled for dye analysis and ΔP's recorded at steady state, just before increasing flows to the next set of conditions. Erratic changes in ΔP's, recorded on both ΔP instruments, were probably caused by changes in feedwater quality during the long intervals between points. ΔP's indicate, and entrainment from tray 3 to 4 seems to confirm, that all trays began to flood above an F-factor of 1.3.

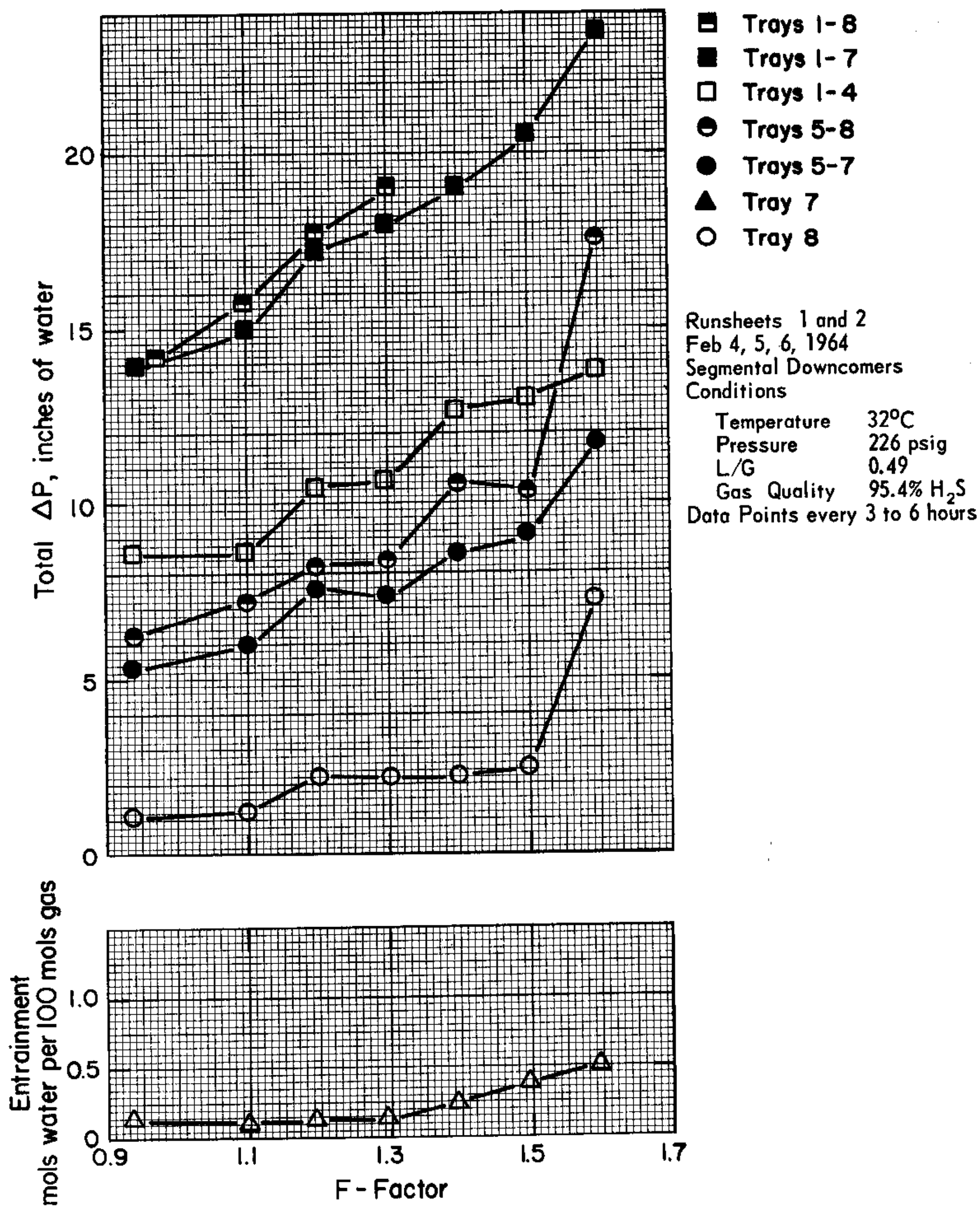

FIG. 9-a COLD TOWER CONDITIONS, SEGMENTAL DOWNCOMERS, SLOW FLOW INCREASES

Figure 9b Synopsis

Runsheets 16 and 17

Tray stability limit: F-factor 1.56

This repeated test shown in Figure 9a (Runsheets 1 and 2). Flows were increased every 4 hours, while maintaining process-optimum L/G at cold tower conditions. Fluorescein was injected, beginning two hours before each flow increase, and tower liquid was sampled and data recorded just before each increase. Both ΔP instruments (trays 1-7 on one, trays 1-4, 5-7, 5-8, and 8 on the other) confirm unexplained dip in ΔP across trays 5-7 at F-factor 1.56, perhaps caused by a rapid change in water quality. Tray 7 flooded above an F-factor of 1.56. Liquid carryover, returning from tray 13, rapidly increased from 0 to more than 10 gpm at F-factor 1.64.

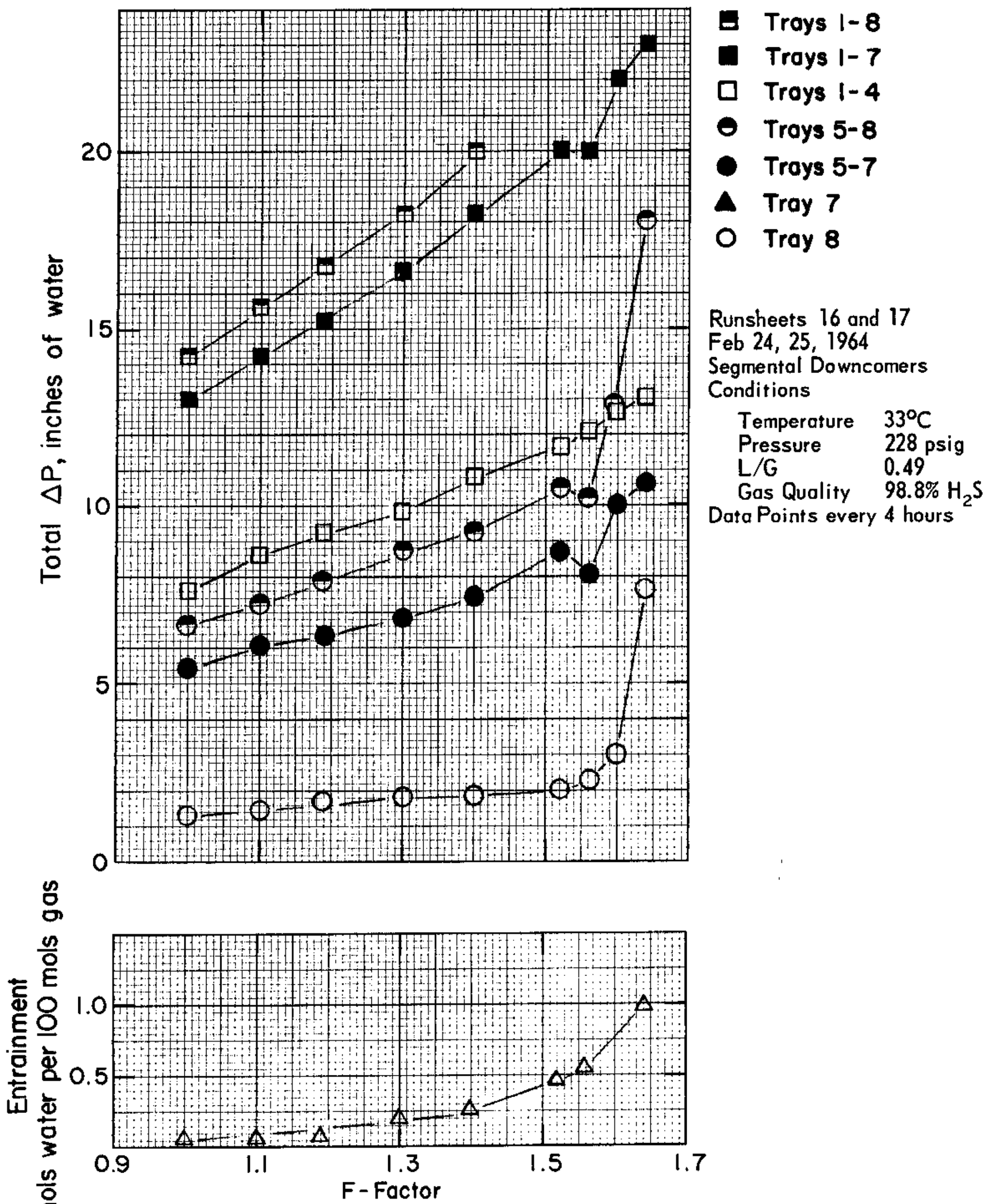

FIG. 9-b REPEAT 9-a TEST

<u>Figure 10 Synopsis</u>

Runsheet 18

Tray stability limit: F-factor 1.65

Flows were increased every 10 minutes, maintaining process-optimum L/G at cold tower conditions. ΔP's on trays 1-7 and tray 8 were measured on separate instruments and recorded just before each flow increase. Break in trays 1-7 ΔP curve near F-factor of 1.57 indicates a lower tray flooded first, then tray 7 began flooding at an F-factor of 1.67. F-factor 1.65, shown in this run, was the highest stable flow obtained in the spring without silicone injection at process-optimum L/G. All ΔP's were recorded at the flood point, and fluorescein injection was started. Tower liquid samples, taken 45, 60, and 75 minutes after injection began, showed entrainment from tray 3 to tray 4 of 1.0, 0.8, and 0.9 mols water per 100 mols gas. Trays 8 and 1-7 ΔP's were recorded (the highest points) midway through liquid sampling.

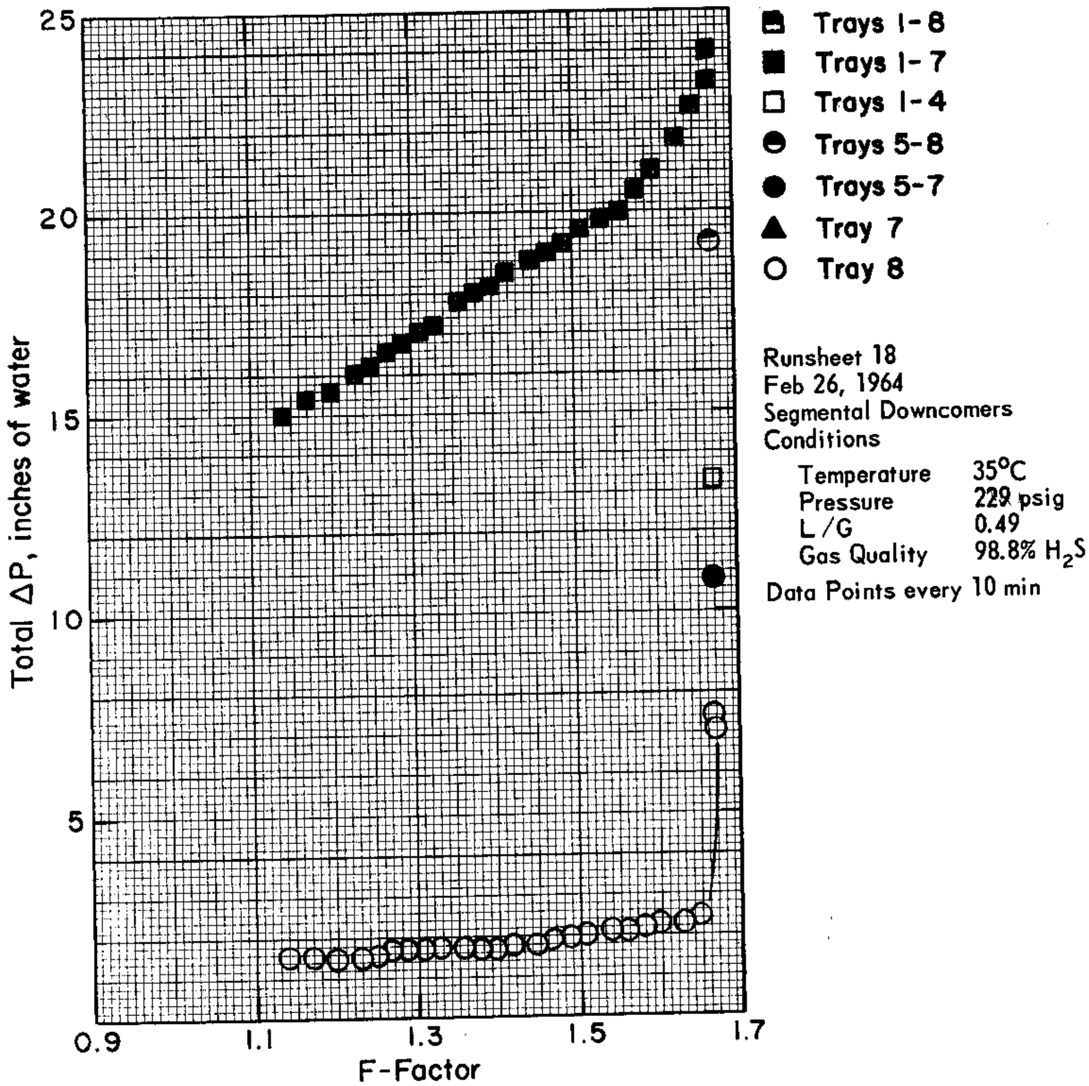

FIG. 10 COLD TOWER CONDITIONS, SEGMENTAL DOWNCOMERS, RAPID FLOW INCREASES

Figure 11 Synopsis

Runsheet 5

Tray stability limit: F-factor 1.40

Effluent liquid was recycled as feed to CT-2B. Flows were increased every hour, while maintaining process-optimum L/G at cold tower conditions. Entrainment could not be measured (dye would also recycle). Tray 8 ΔP increased abruptly at an F-factor of 1.52 and the test was stopped. ΔP's indicate trays 1-4 began flooding above F-factor 1.1 more severely than trays 5-7.

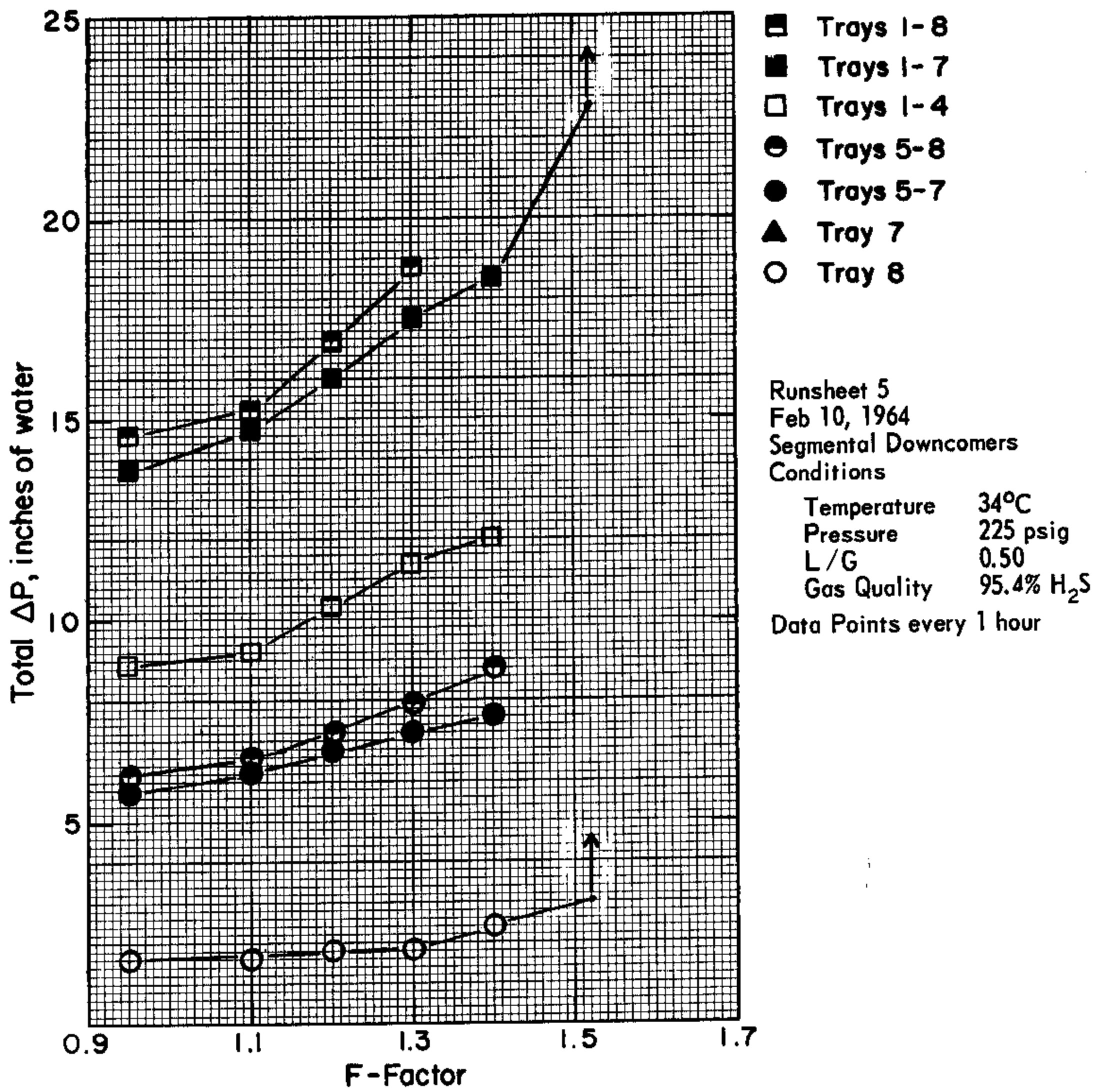

FIG. 11 RECYCLED FEEDWATER, SEGMENTAL DOWNCOMERS

Figure 12 Synopsis

Runsheets 3 and 4

Blower capacity limit: F-factor 1.45 (hot)

Flows were increased every 5 hours, while maintaining process-optimum L/G at hot tower conditions. Fluorescein was injected during the last 2 hours at each flow level. Effluent liquid from trays 3 and 4 was sampled and ΔP's recorded at steady state, just before increasing to the next flow level. Recorded data and notes do not explain constant ΔP across trays 5-7 up to F-factor 1.21.

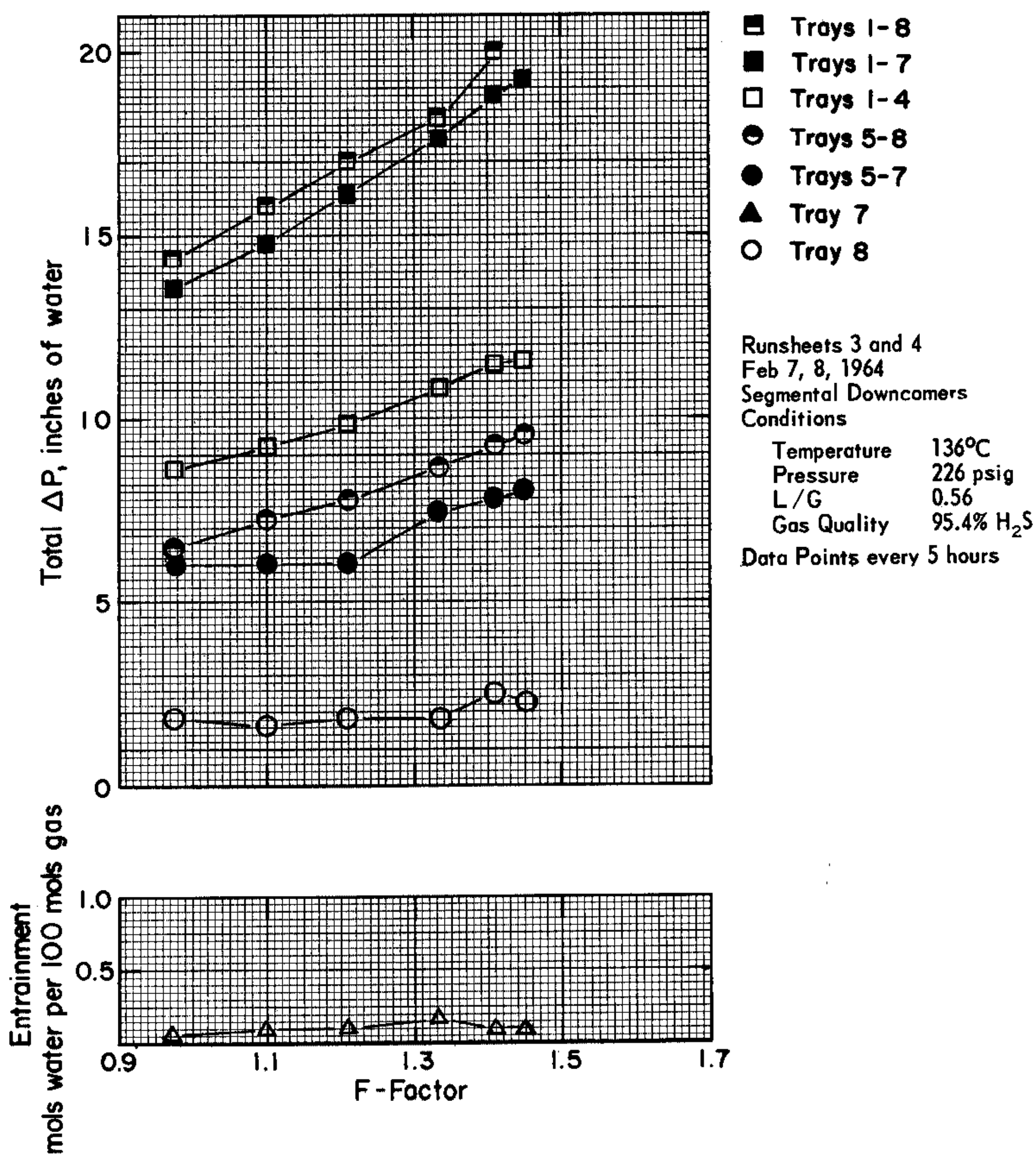

FIG. 12 HOT TOWER CONDITIONS, SEGMENTAL DOWNCOMERS

Figure 13 Synopsis

General Runsheets 12 and 15A

Two hours before shift change during the period February 14 through February 24, flows were increased every 5 minutes — while maintaining process-optimum L/G at cold tower conditions — until tray 8 ΔP increased above 3 inches of water. On February 21 this increase in tray 8 ΔP occurred at F-1.21 and was accompanied by more than 10 gpm of liquid return from tray 13. Blower seal oil and silicone antifoam were being injected into GS plant feedwater at this time to suppress liquid carryover from the first stage cold towers.

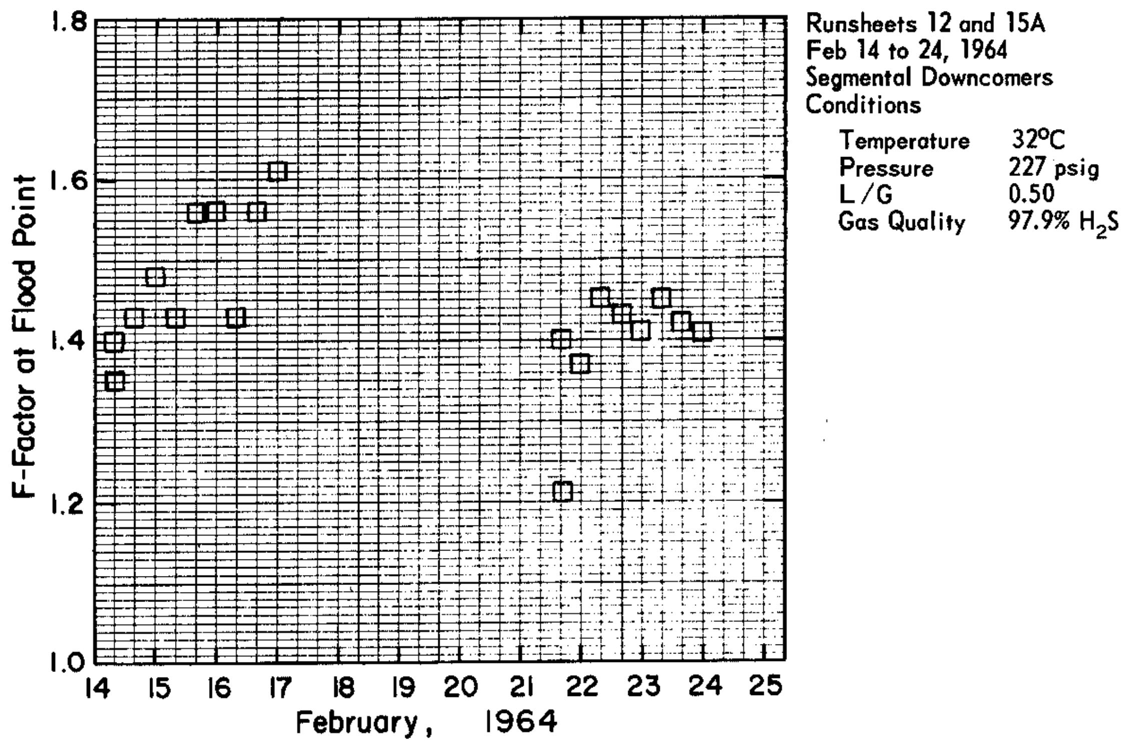

FIG. 13 PERIODIC CHECKS OF FLOOD POINT WITH SEGMENTAL DOWNCOMERS

Figure 14 Synopsis

General Runsheet 22

Two hours before shift change during the period March 20 through April 1, flows were increased every 5 minutes — while maintaining process-optimum L/G at cold tower conditions — until tray 8 ΔP increased above 3 inches of water.

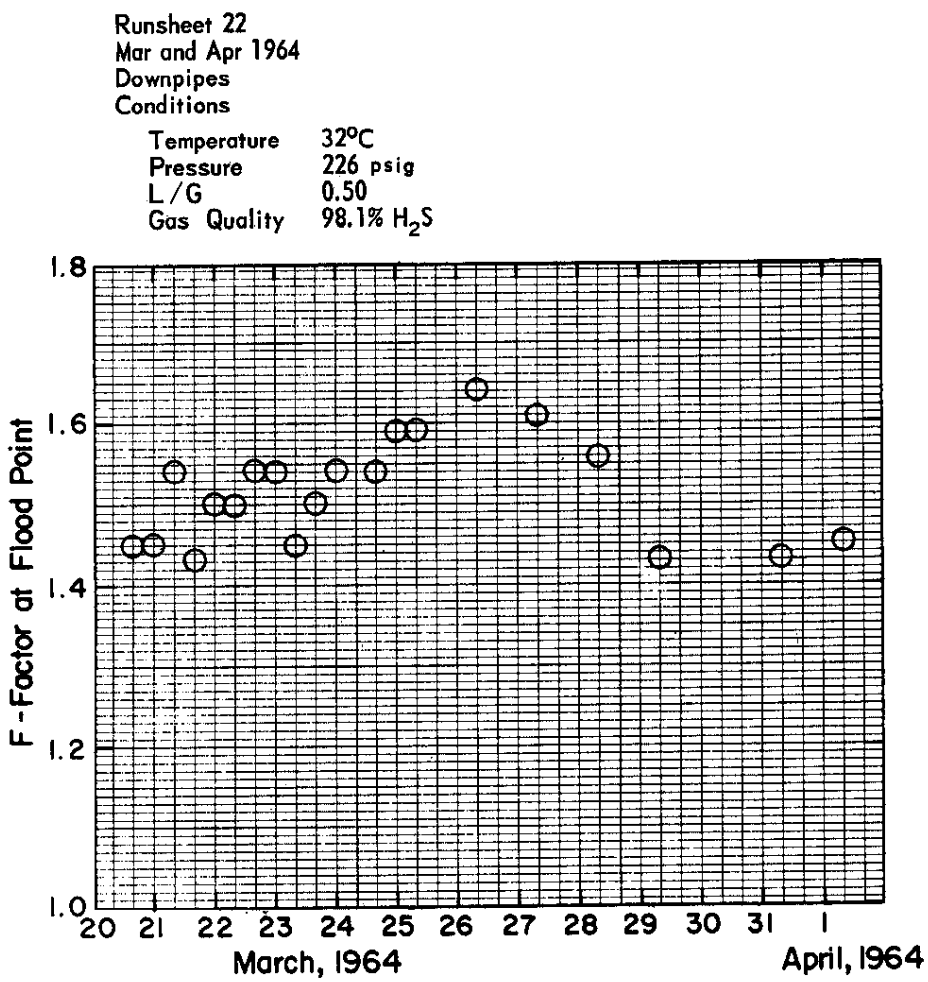

FIG. 14 PERIODIC CHECKS OF FLOOD POINT WITH DOWNPIPES

Figure 15a Synopsis

Runsheet 21B

Tray stability limit: F-factor 1.45

This test, the first with circular downpipes, was made in the same manner as the last test with segmental downcomers, shown by Figure 10. Trays 1-7 flooded above an F-factor of 1.45. Tower liquid, sampled at the flooding point 60 and 90 minutes after fluorescein injection began, showed entrainments of 0.55 and 0.45 mols water per 100 mols gas. Liquid carryover, returning from tray 13, rapidly increased from 0 to more than 10 gpm after operating 35 minutes at an F-factor of 1.47.

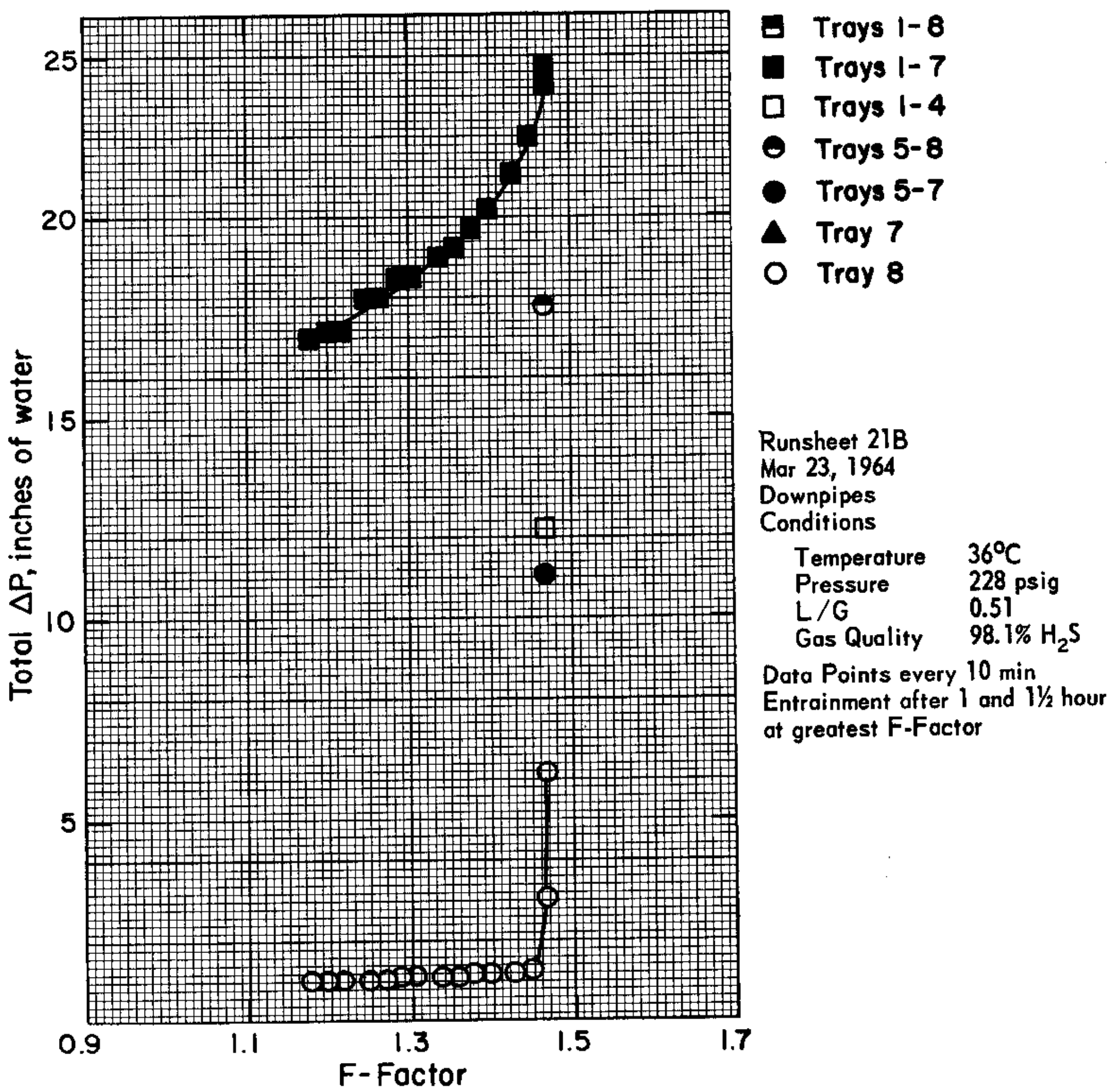

FIG. 15-a COLD TOWER CONDITIONS, DOWNPIPES, RAPID FLOW INCREASES

Figure 15b Synopsis

Runsheet 21C

Tray stability limit: F-factor 1.50

This test, without silicone antifoam addition, and the next, immediately after with silicone addition, shown by Figure 15c, were both performed on February 24 under conditions otherwise similar to the first test with downpipes shown by Figure 15a. Although all ΔP's were not measured, the early break in trays 1-7 ΔP curve near F-factor 1.40 indicates some lower tray flooded first, then tray 7 at F-factor 1.52. Entrainment was not measured.

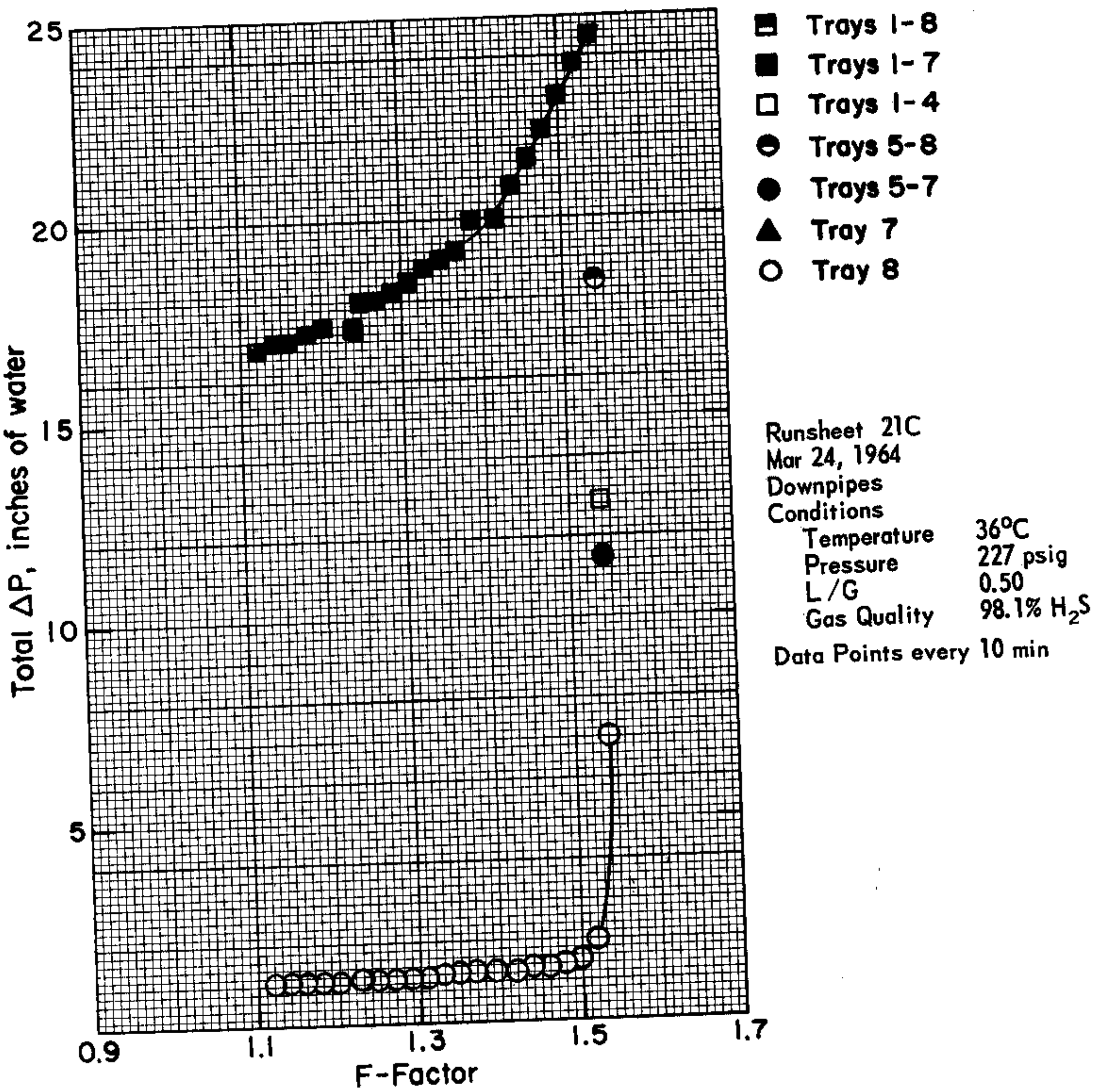

FIG. 15-b REPEAT 15-a TEST

Figure 15c Synopsis

Runsheet 21C (continued)

Tray stability limit: F-factor 1.67

The test shown by Figure 15b was repeated immediately with 0.4 ppm silicone added to the feedwater. Trays 1-7 flooded above an F-factor of 1.67. Fluorescein was injected during flooding and tower liquid was sampled 60 minutes after injection began. The entrainment from tray 3 to tray 4 — 6.1 mols water per 100 mols gas — was the highest recorded throughout the sieve tray tests.

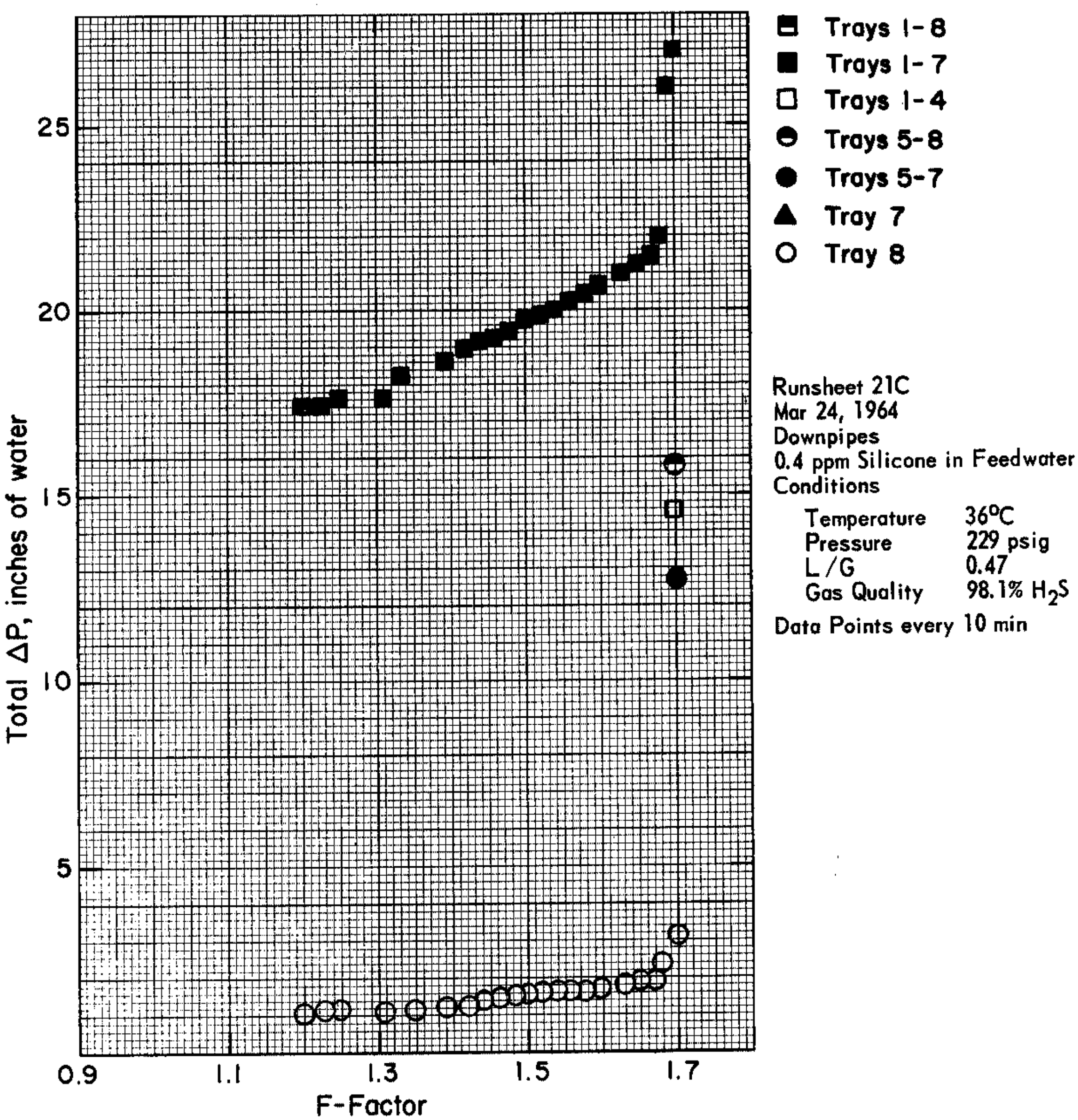

FIG. 15-c REPEAT 15-a, b TESTS WITH SILICONE ANTIFOAM

Figure 16a Synopsis

Runsheet 23

Tray stability limit: F-factor 1.40

Flows were increased every 2 hours, while maintaining process-optimum L/G at cold tower conditions with 0.5 ppm silicone added to the feedwater. Fluorescein was injected during the final hour at each flow level, and tower liquid was sampled and data recorded just before each flow increase.

Trays 1-4 began flooding between F-factors of 1.21 and 1.31 per ΔP data, with no indication of flooding on trays 5-7 until an F-factor of 1.4. Entrainment from tray 3 to tray 4 confirms flooding above an F-factor of 1.31 which indicates that flooding began on the bottom tray and progressed upward. Liquid carryover, returning from tray 13, rapidly increased from 0 to more than 10 gpm at an F-factor of 1.5.

The GS Plant experienced severe carryover the same day.

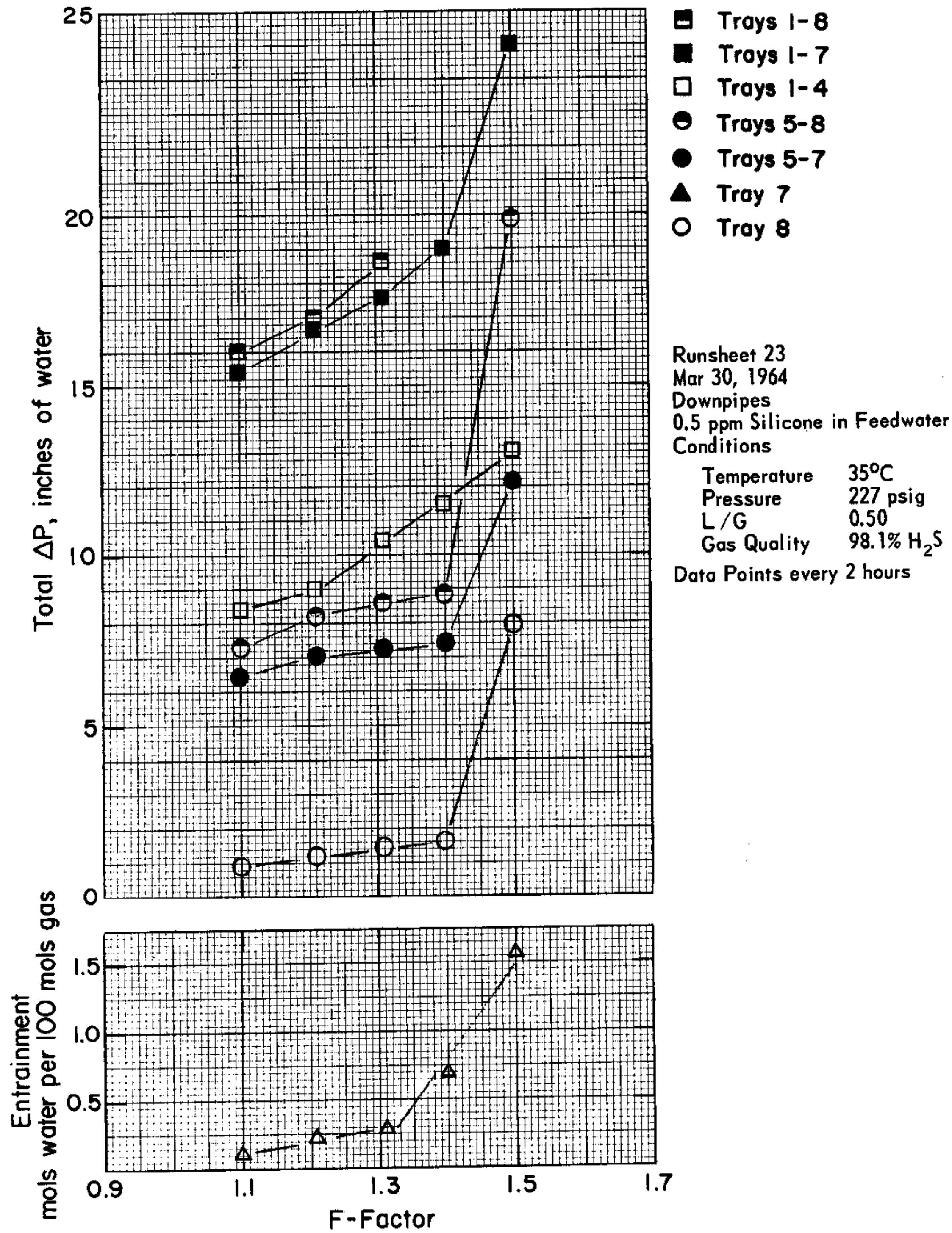

FIG. 16-a SILICONE ANTIFOAM, COLD TOWER CONDITIONS, DOWNPIPES

Figure 16b Synopsis

Runsheet 25

Tray stability limit: F-factor 1.31

This test was conducted the day after the test shown in Figure 16a, and in the same manner, except silicone was not added to the feedwater. Again, but less clearly, ΔP data indicate flooding began on trays 1-4 at a low F-factor (1.2 to 1.3) with no indication of flooding on trays 5-7 until tray 8 ΔP indicated flooding above an F-factor of 1.31.

Poor feedwater quality caused GS Plant carryover the same day.

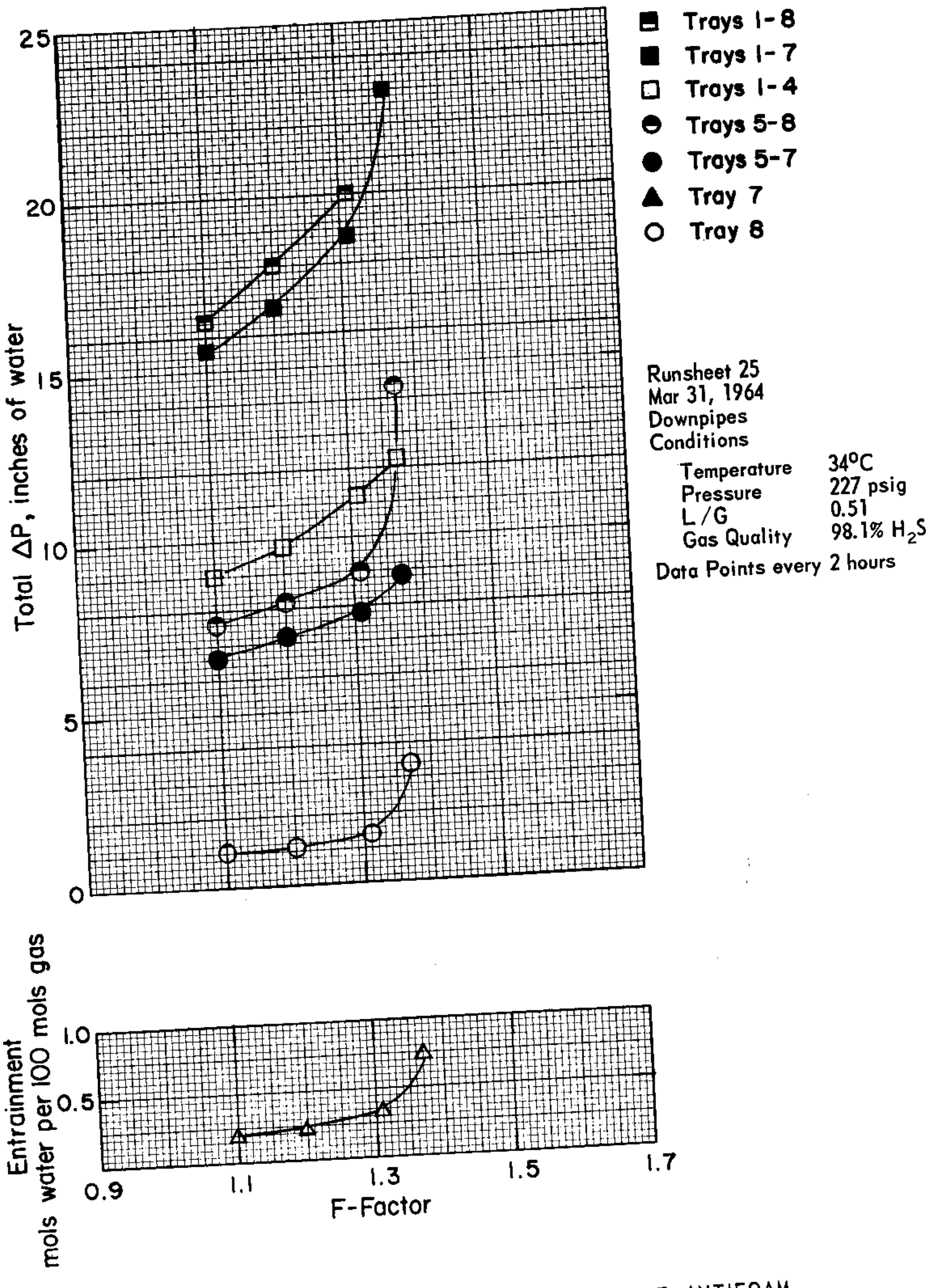

FIG. 16-b REPEAT 16-a WITHOUT SILICONE ANTIFOAM

<u>Figure 17a Synopsis</u>

Runsheet 29

Tray stability limit: F-factor 1.54

This was the first test in the July series and the first test in which tray 7 ΔP could be measured separately (new tap installed below tray 7). Flows were increased every 10 minutes while maintaining process-optimum L/G at cold tower conditions in this test and in the tests covered by the succeeding three figures. Temperatures varied 5°C during the series. Chronologically, several other tests interrupted the series. Entrainment was not measured.

Trays 1-4 started flooding between F-factors of 1.37 and 1.40.

Trays 5-7 started flooding between F-factors of 1.45 and 1.50 (based on shape of the ΔP curve; plus leveling out of 1-4 curve which indicates increase in flow did not reach trays 1-4 because of flooding on upper trays).

Tray 7 flooded between F-factor of 1.54 and 1.58 which prevented increase in flow from reaching trays 5-6 and all those lower.

Tray 8 flooded almost immediately after tray 7 and prevented further flow increase from reaching tray 7. The meter in the drain line from tray 13 increased from zero to maximum at an F-factor of 1.62, showing de-entrainment and return of more than 10 gpm carryover.

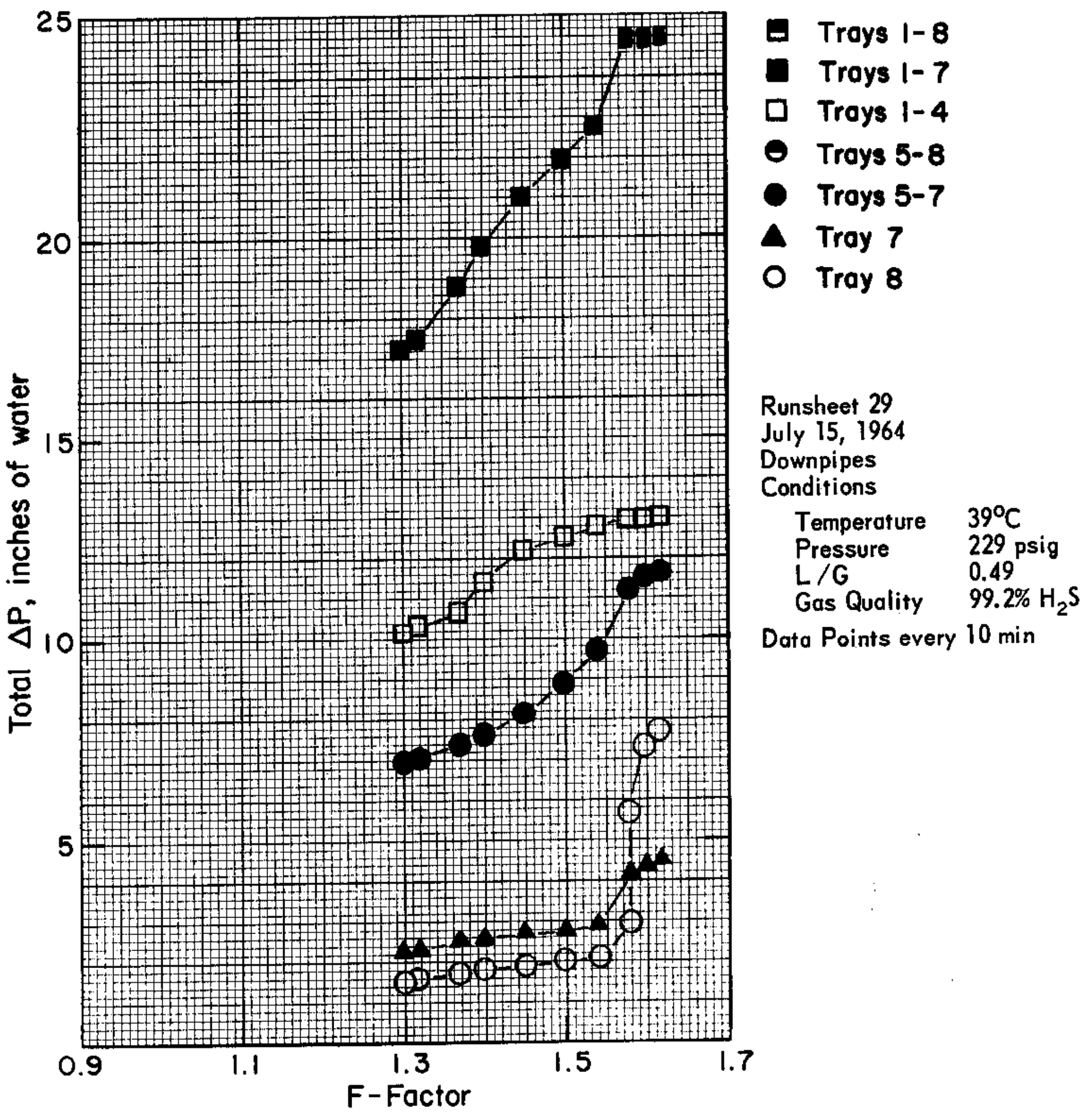

FIG. 17-a COLD TOWER CONDITIONS,
DOWNPIPES, JULY 15

Figure 17b Synopsis

Runsheet 29

Tray stability limit: F-factor 1.50

This second test in the Figure 17 series (cold tower conditions, optimum L/G) was made immediately after the test with recycled feedwater (Figure 18).

Trays 1-4 started flooding between F-factors of 1.28 and 1.33 (probably not flooding at 1.28 since ΔP shows normal 4/3 ratio with trays 5-7 ΔP).

Trays 5-6 started flooding between F-factors of 1.42 and 1.46 and began to level out tray 1-4 curve by withholding flow increases. Tray 7 started flooding between F-factors of 1.46 and 1.50.

Tray 8 flooded almost immediately after tray 7 and prevented further flow increases from reaching tray 7.

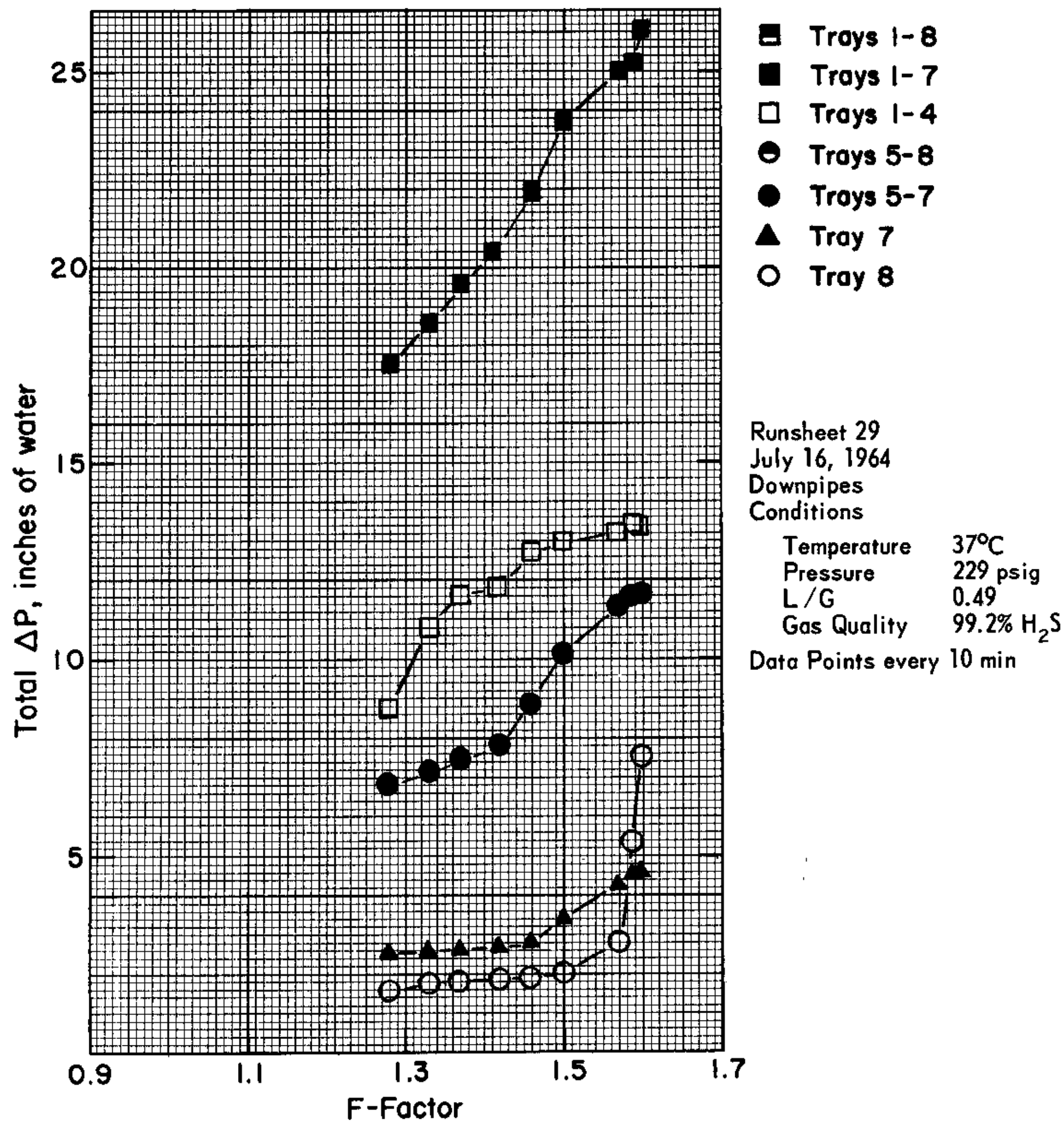

FIG. 17-b REPEAT 17-a ON JULY 16

Figure 17c Synopsis

Runsheet 29

Tray stability limit: F-factor 1.59

See Figure 17a Synopsis.

Trays 1-4 probably did not flood during test.

Trays 5-6 flooded between F-factors of 1.56 and 1.59 and withheld further flow increase from trays below, which leveled out trays 1-4 ΔP curve.

Tray 7 flooded between F-factors of 1.59 and 1.62.

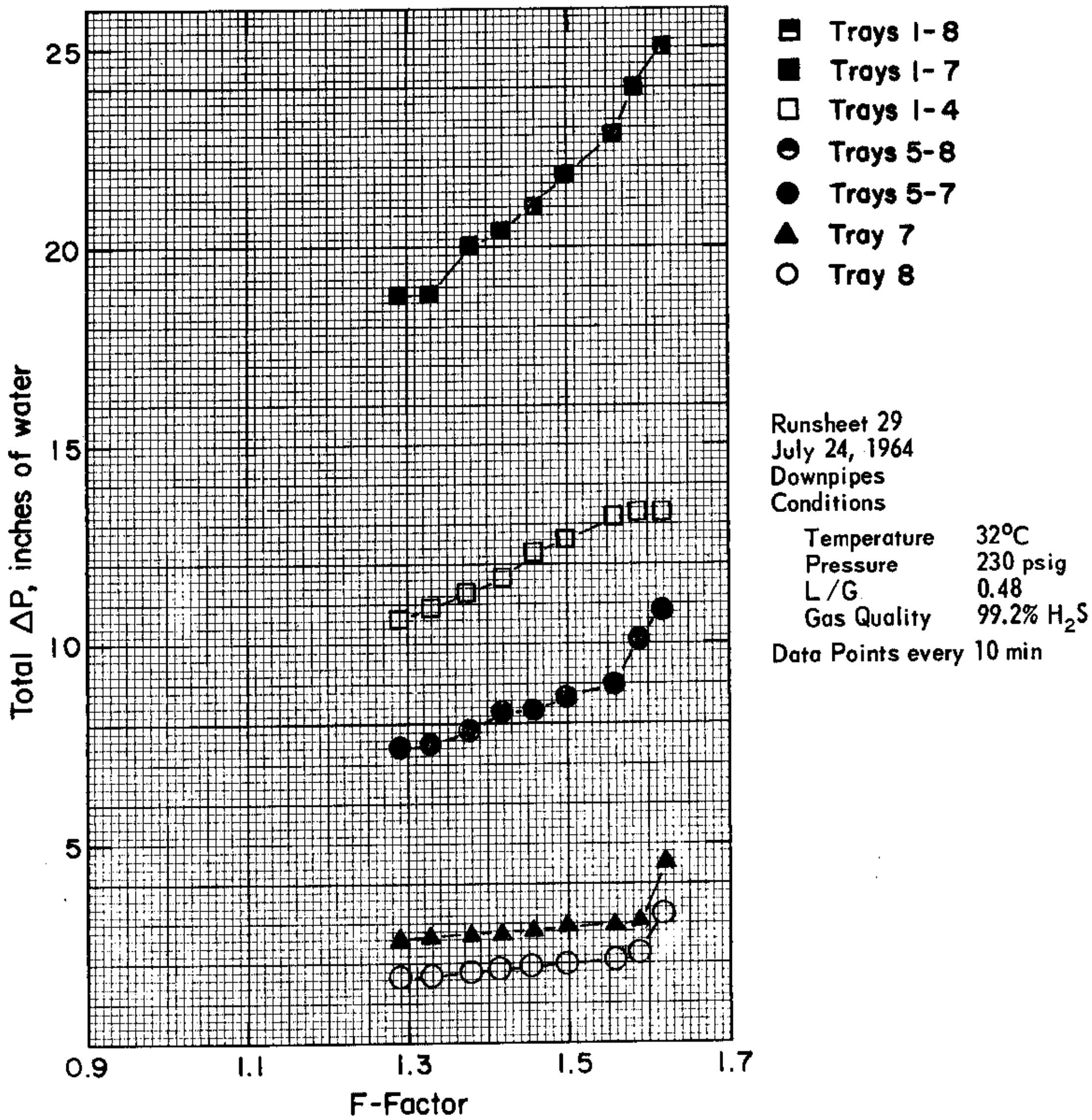

FIG. 17-c REPEAT 17-a, 17-b ON JULY 24

Figure 17d Synopsis

Runsheet 34

Blower capacity limit: F-factor 1.65

This test was similar to others in the Figure 17 series (optimum L/G, cold tower conditions) except that 0.5 ppm silicone was added to the feedwater. No flooding was experienced. Maximum blower capacity was reached for the first time during the sieve tray tests at optimum L/G, cold tower conditions.

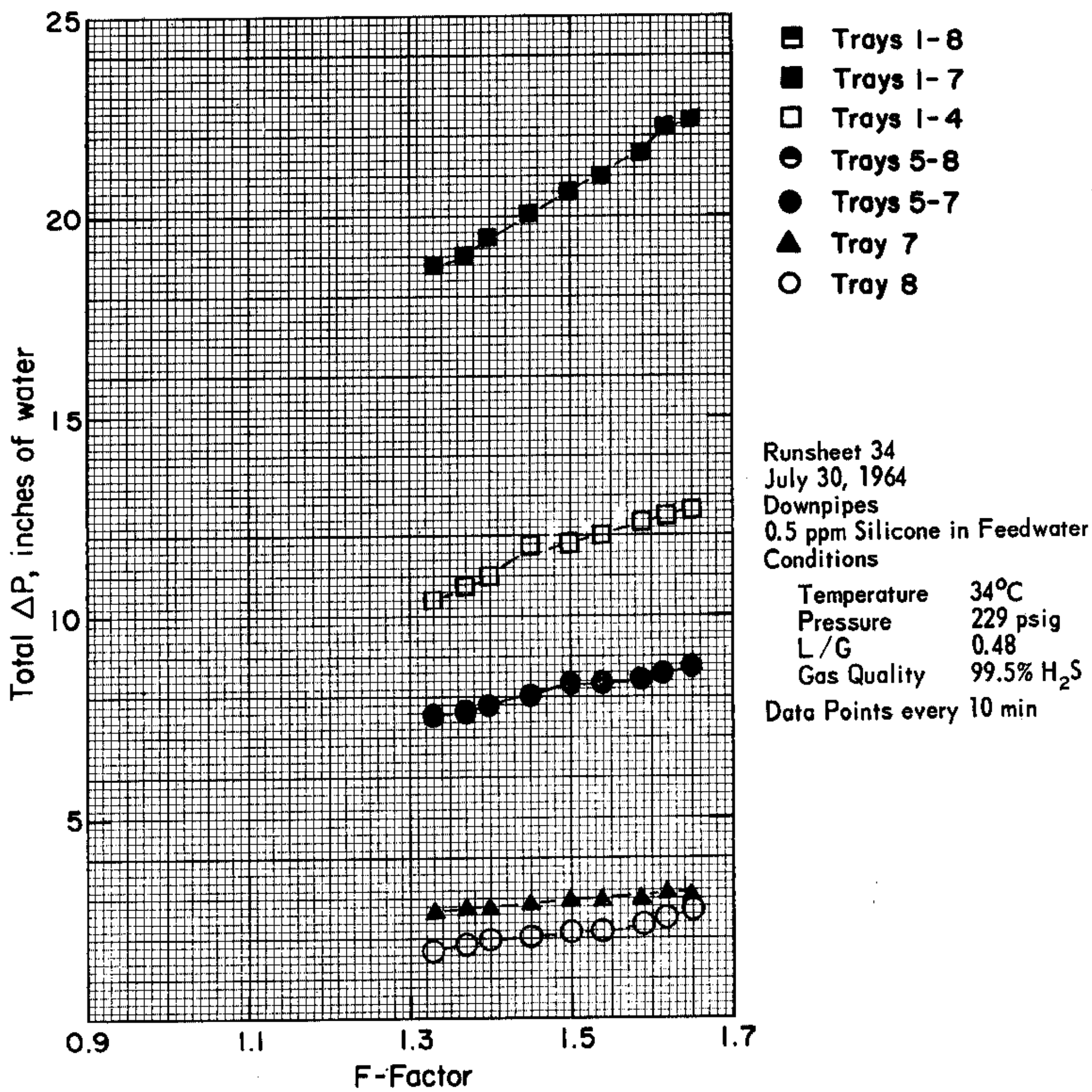

FIG. 17-d REPEAT 17-a, b, c WITH SILICONE ANTIFOAM, JULY 30

Figure 17e Synopsis

Runsheet 34

Tray stability limit: F-factor 1.54

See Figure 17a Synopsis.

This test was made to evaluate water quality immediately after a similar test with silicone addition to feedwater (Figure 17d).

Trays 5-6 (and probably 7) flooded at an F-factor of 1.54. Tray 7 was definitely flooding at an F-factor of 1.58. Tray 7 flooding partially prevented liquid flow increase from reaching trays 5-6.

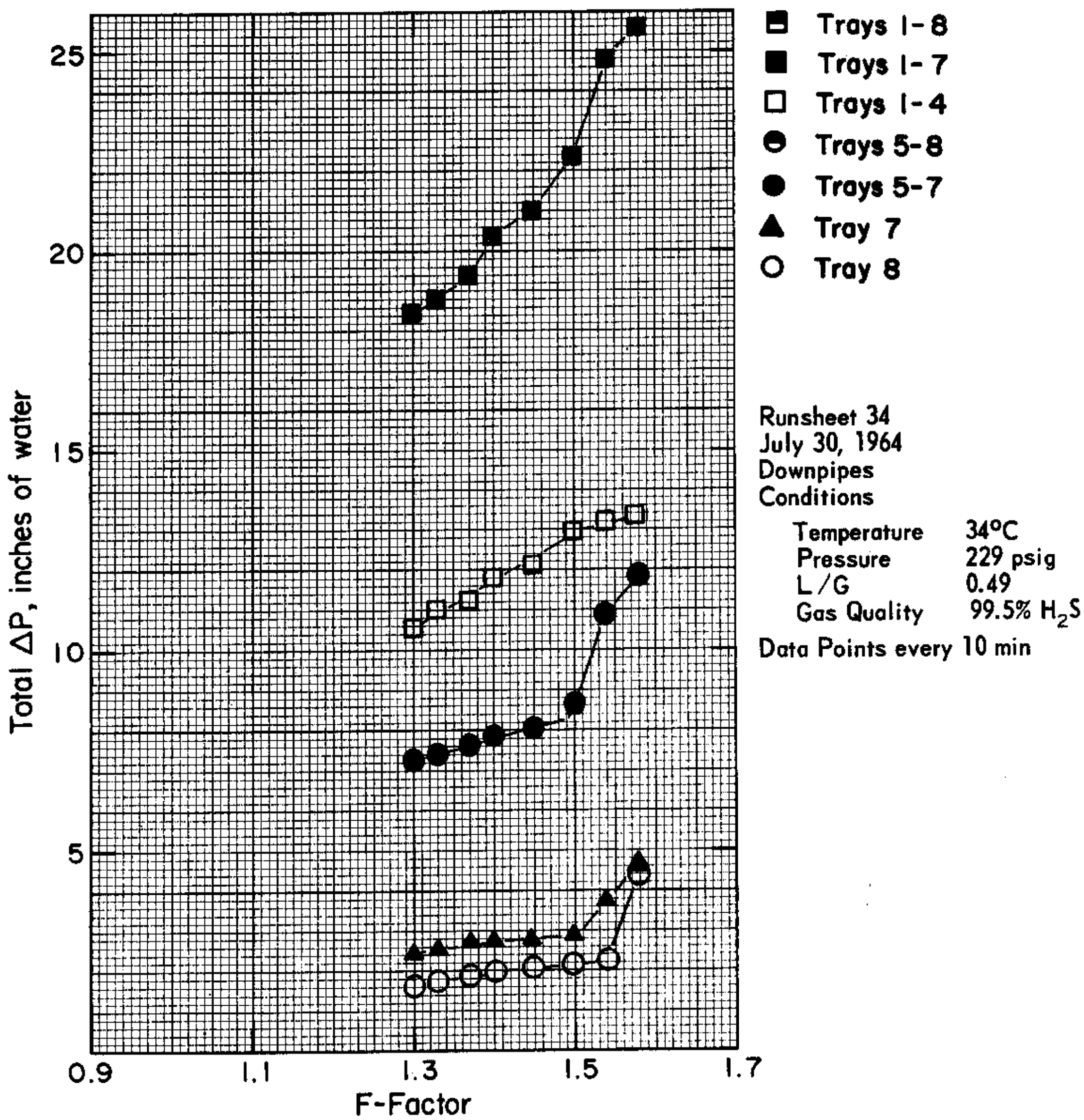

FIG. 17-e REPEAT 17-d WITHOUT SILICONE ANTIFOAM, JULY 30

Figure 18 Synopsis

Runsheet 31

Tray stability limit: F-factor 1.17

Effluent liquid was recycled as feed to CT-2B (see Figure 11 for similar test with segmental downcomers). Flows were increased every 10-20 minutes while holding process-optimum L/G at cold tower conditions. Entrainment could not be measured.

ΔP's indicate tray 7 flooded first which kept the liquid flow increase from reaching the lower trays (very little change in trays 1-4 and 5-6 ΔP's).

Samples of recycled feedwater were black and turbid whereas fresh feedwater and associated effluent during other tests were visually clear.

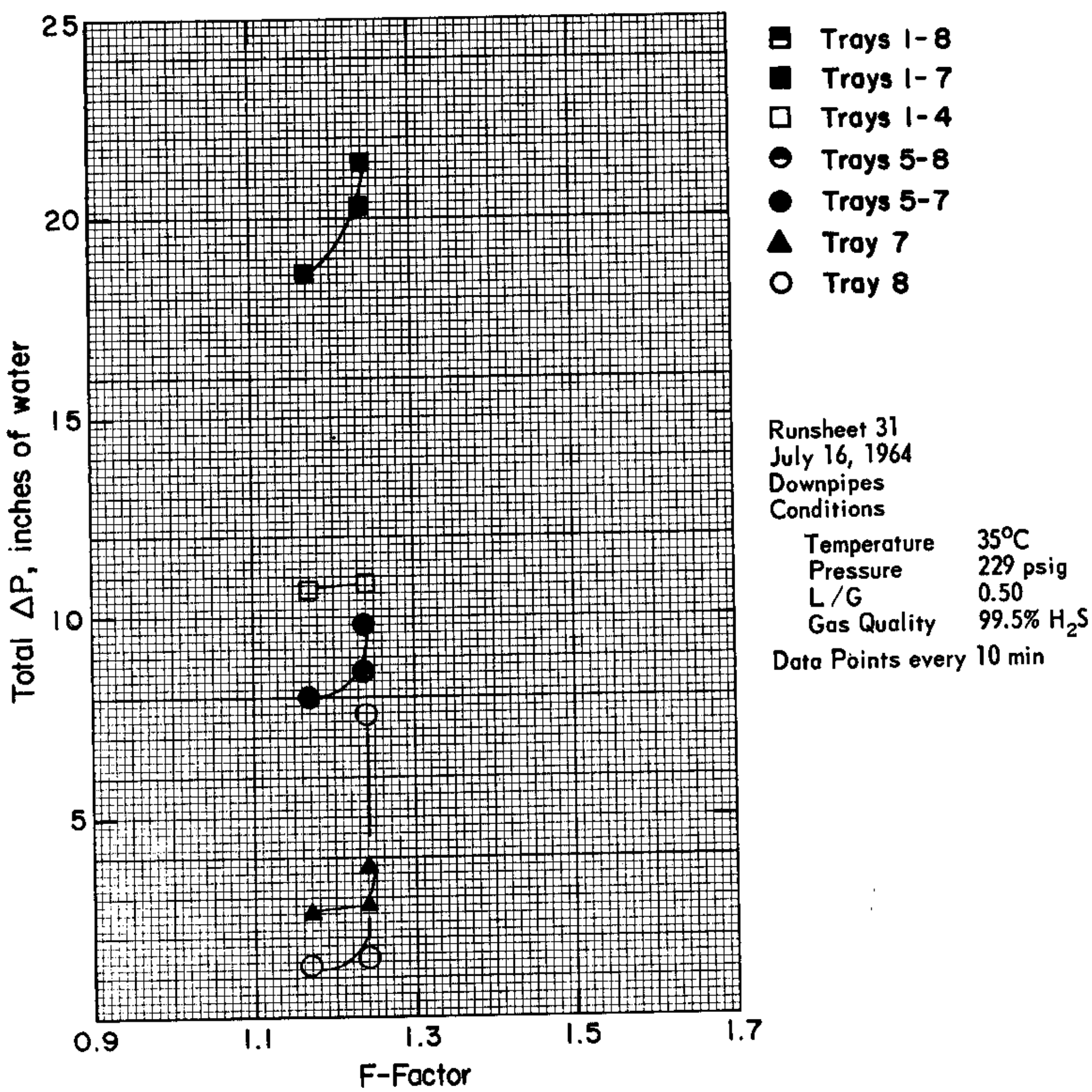

FIG. 18 RECYCLED FEEDWATER, DOWNPIPES

Figure 19a Synopsis

Runsheets 13 and 14

Entrainment was not measured. Liquid flow was held constant at 106 gpm as gas flow was increased every 30 minutes to an F-factor of 1.70, maximum blower capacity, with no pronounced evidence of tray instability. At this gas flow, liquid flow was increased to 112 gpm before the trays flooded; liquid carryover, returned from tray 13, rapidly increased from 0 to 9 gpm. The dip in trays 5-7 ΔP below an F-factor of 1.5 cannot be explained (changing water quality would probably have affected trays 1-4, also).

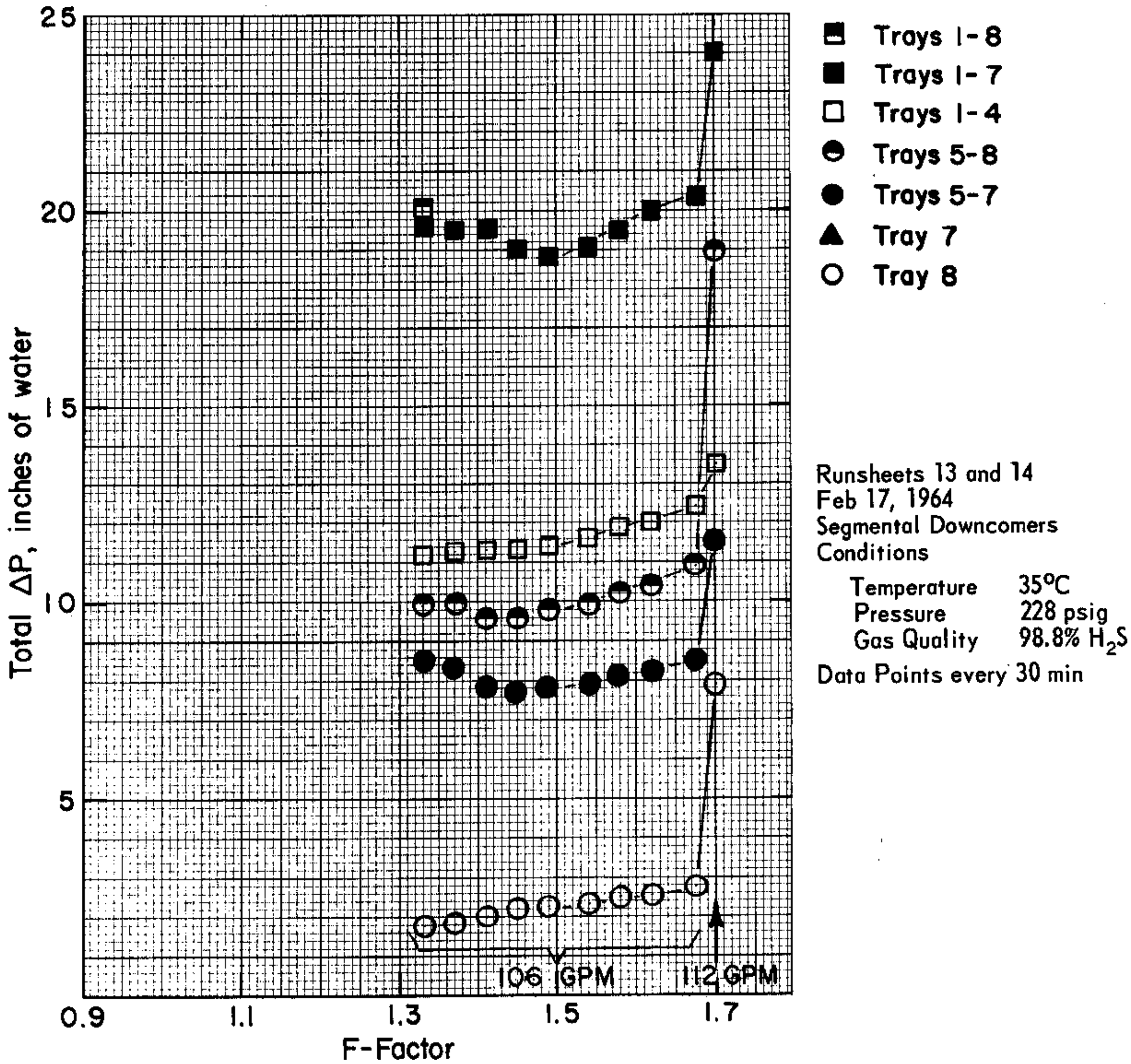

FIG. 19-a GAS FLOW CAPACITY, SEGMENTAL DOWNCOMERS, 35°C

Figure 19b Synopsis

Runsheet 15

Blower capacity limit: F-factor 1.72

Figure 19a test (Runsheets 13 and 14) was repeated to measure entrainment for stable operation at blower capacity. Liquid flow was held constant at 106 gpm. After recording initial data at F-factor 1.41, gas flow was gradually increased over a 5-1/2-hour period until maximum blower capacity was reached at F-factor 1.72, the maximum F-factor attained during all sieve tray tests. Tower operation was stable at this point and no liquid carryover was draining from tray 13, but the L/G was abnormally low for cold tower conditions. Samples taken after injecting fluorescein for 75 minutes showed entrainment from tray 3 to tray 4 of 0.4 mols water per 100 mols gas.

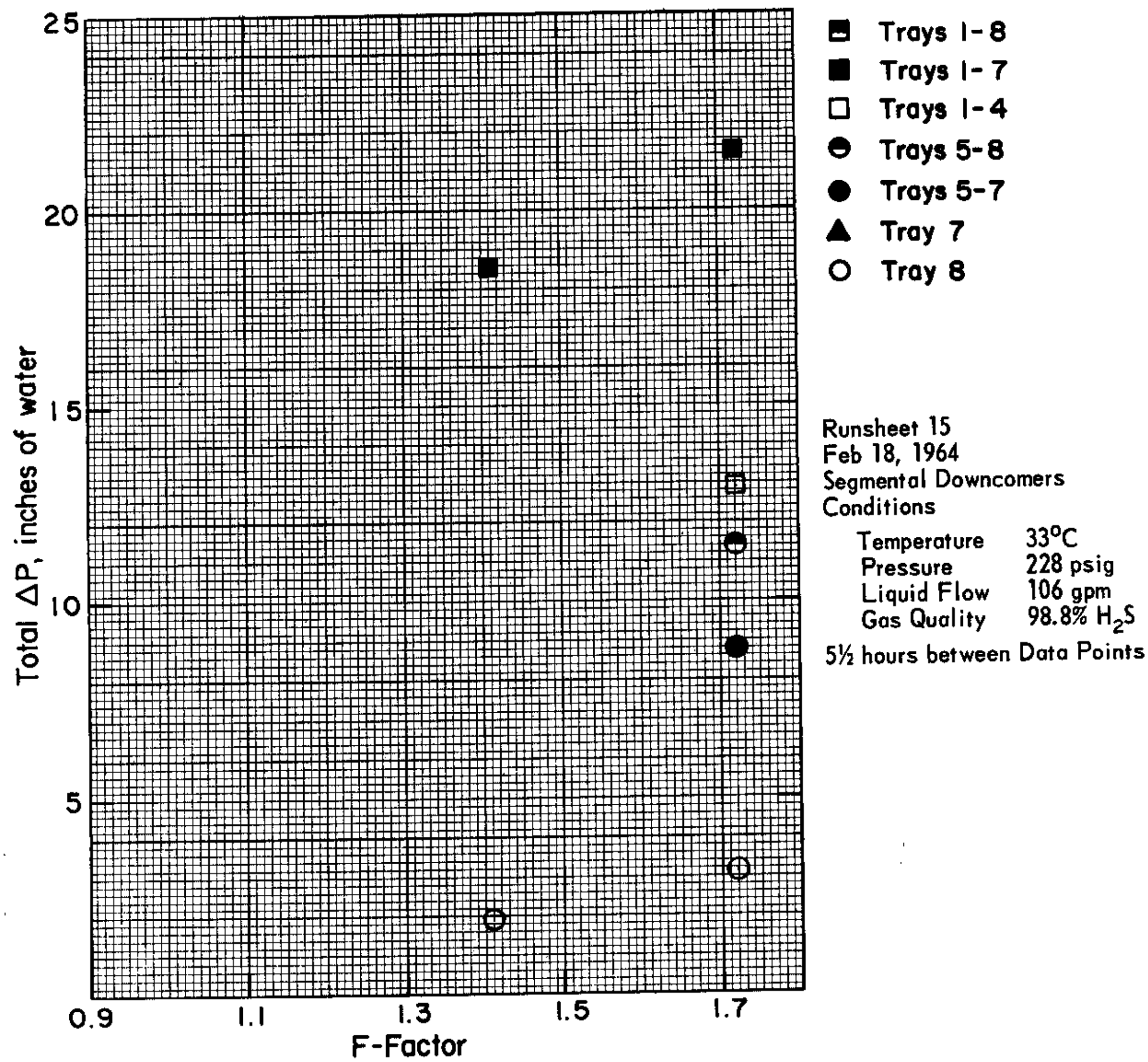

FIG. 19-b REPEAT 19-a TEST AT 33°C

Figure 20 Synopsis

Runsheets 7, 8, and 9

Tray stability limit: 140 gpm (33°C)

Gas flow was held constant at an F-factor of 1.36 and temperature of 33°C while increasing liquid flow every 45 minutes. Entrainment was not measured. Calculations neglected an increasingly greater loss of H_2S in effluent so F-factor cited is low by about 2% at maximum liquid flow.

ΔP's indicate that tray 7 began flooding between 140 and 144 gpm although trays 5-6 probably began flooding 90 minutes earlier at 136 gpm. Increases in liquid flow above 144 gpm did not reach trays 1-4. When flow was increased to 156 gpm — the last recorded point — liquid carryover, returned from tray 13, increased from 0 to greater than 10 gpm.

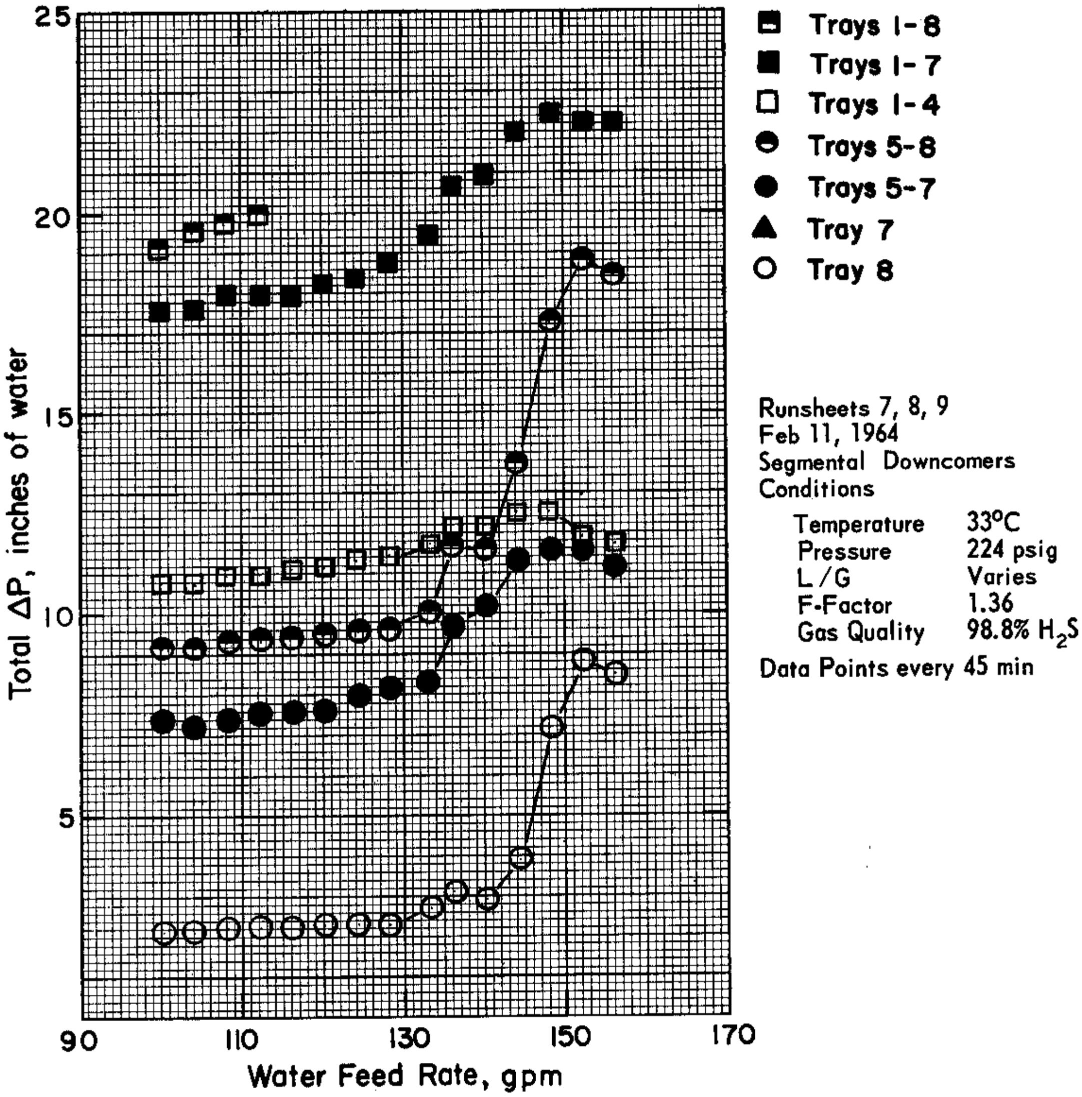

FIG. 20 LIQUID FLOW CAPACITY, SEGMENTAL DOWNCOMERS, 33°C

Figure 21a Synopsis

Runsheet 30

Tray stability limit: 124 gpm (32°C)

Gas flow was held constant* at a mass flow of 200,000 lb/hr while liquid flow was increased every 10 minutes in this and the two succeeding tests, Figures 21b and 21c. Entrainment was not measured.

In this test, temperature was 32°C.

Per ΔP data, trays 1-4 began flooding between 116 and 120 gpm and trays 5-6 and 7 at 124 gpm. Per tray 8 ΔP, tray 7 was flooded at 128 gpm. Flow increase to 128 gpm was not entirely reflected by trays 5-6 ΔP due to tray 7 flooding.

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* Gas flow changed about 2% because of dissolved H_2S.

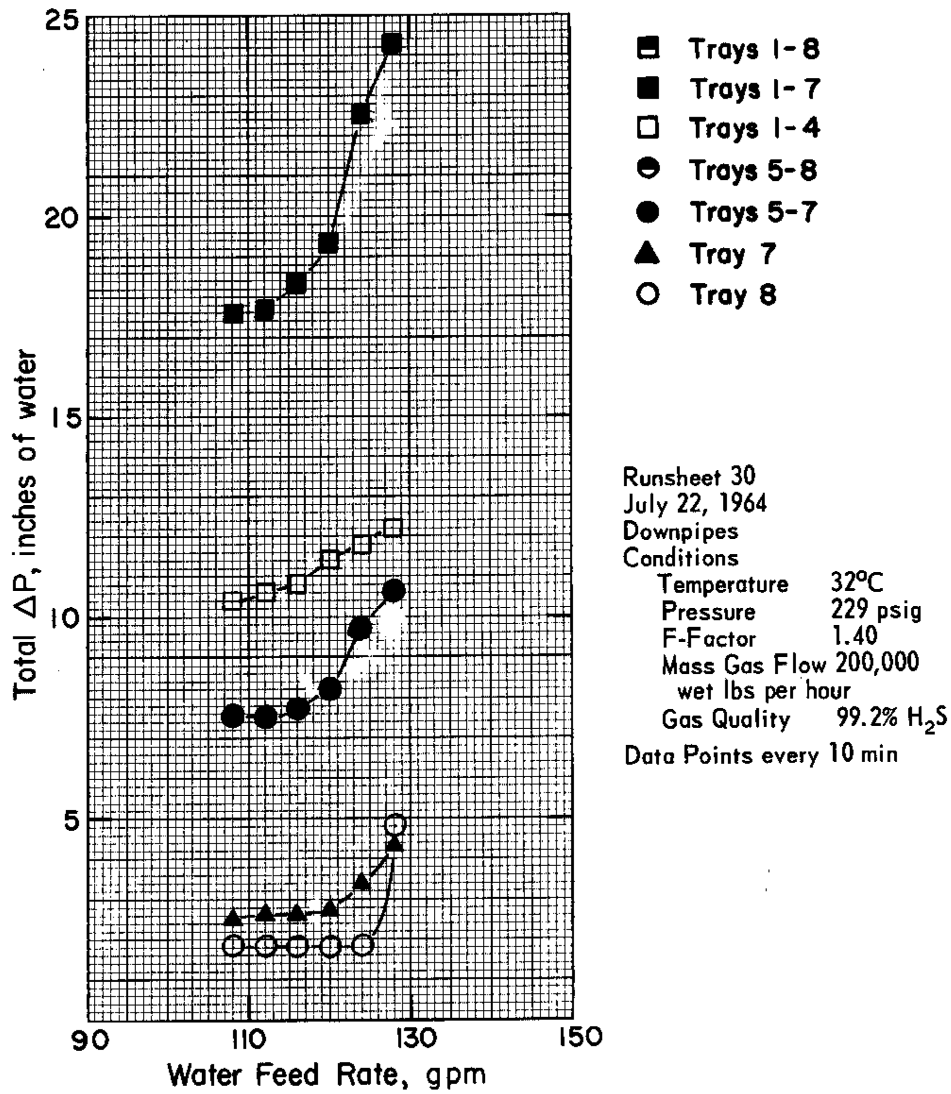

FIG. 21-a LIQUID FLOW CAPACITY, DOWNPIPES, CONSTANT MASS GAS FLOW, 32°C

Figure 21b Synopsis

Runsheet 30

Tray stability limit: 128 gpm (54°C)

See Figure 21a Synopsis.

In this test, temperature was 54°C.

For ΔP data, trays 1-4 began flooding between 116 and 120 gpm, trays 5-6 at 124 gpm, and tray 7 at 128 gpm. Tray 7 was flooded at 132 gpm per tray 8 ΔP. Flow increase to 137 gpm was not entirely reflected by ΔP's across trays 1-4, 5-6, and 7 because of flooding on tray 8.

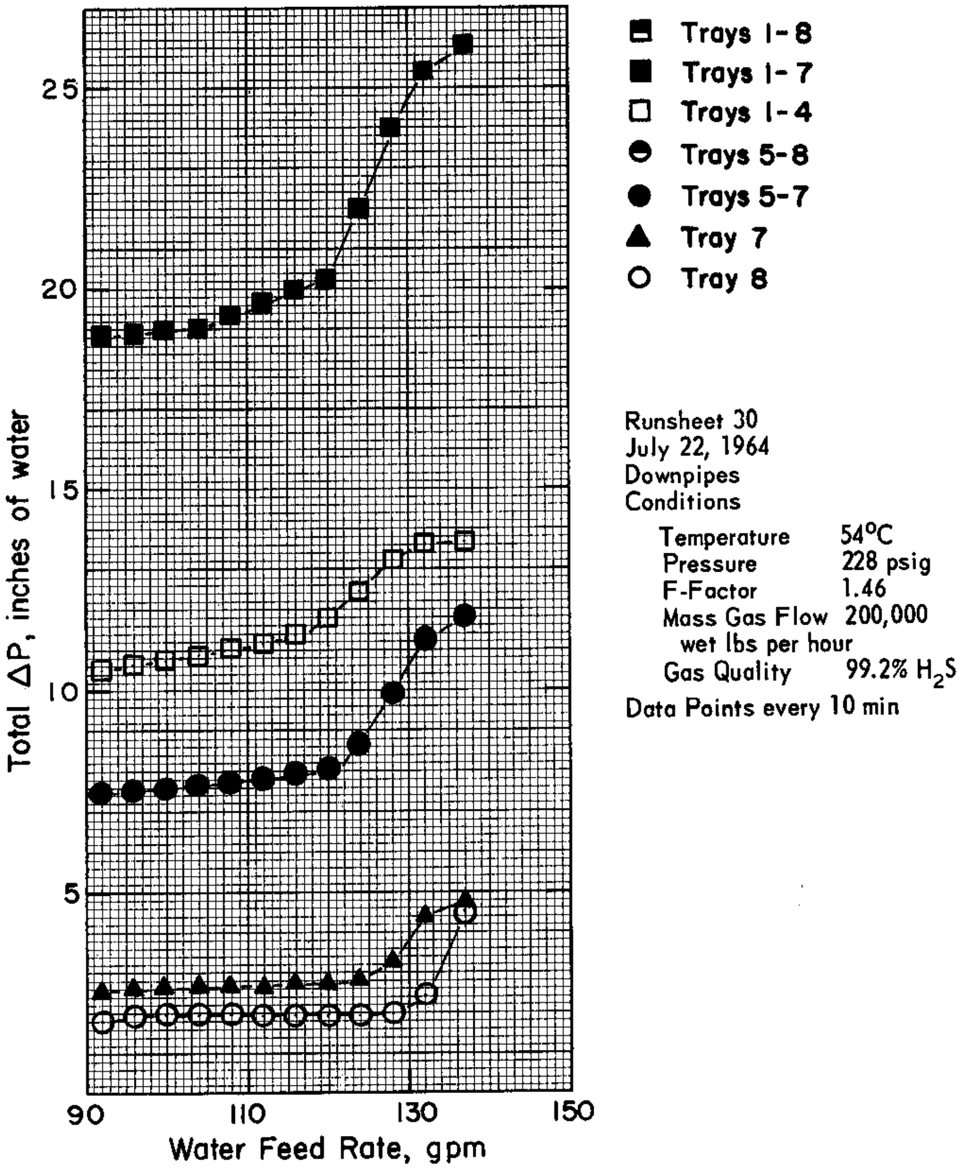

FIG. 21-b REPEAT 21-a AT 54°C

Figure 21c Synopsis

Runsheet 30

Tray stability limit: greater than 199 gpm (84°C)

See Figure 21a Synopsis.

In this test, temperature was 84°C.

No flooding was encountered up through the maximum flow possible of 199 gpm.

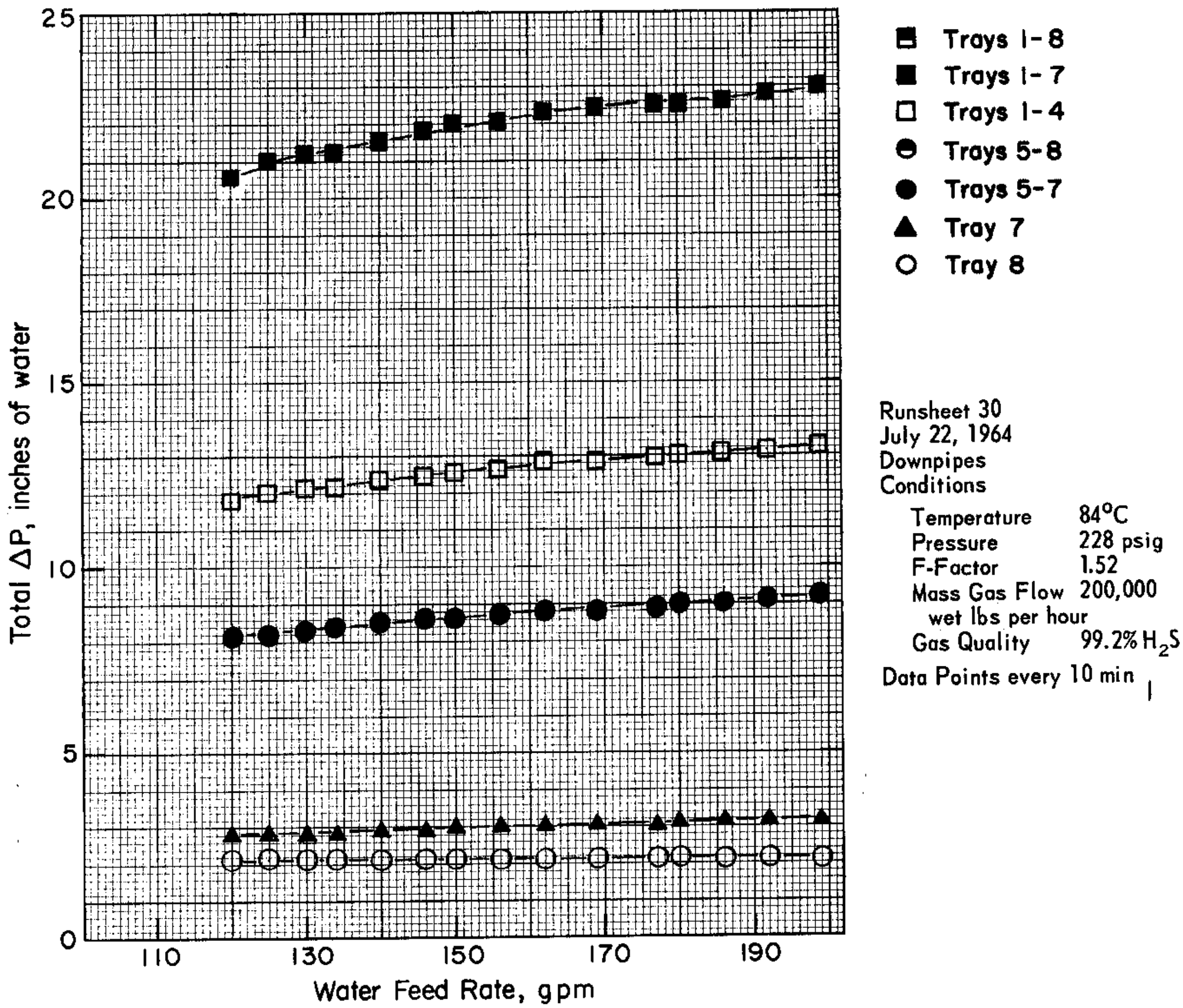

FIG. 21-c REPEAT 21-a AT 84°C

Figure 22a Synopsis

Runsheet 33

Tray stability limit: 100 gpm (32°C)

This and the three succeeding tests covered by Figures 22b, c, and d were performed in the same fashion as the Figure 21 series, i.e., constant* mass gas flow of 200,000 lb/hr at various test temperatures.

In this specific test, temperature was held at 32°C.

Trays 5-6 and 7 flooded on the second liquid flow increase from 100 gpm to 104 gpm. At 104 gpm, L/G was near optimum for cold tower conditions. Flooding at such low F-factor indicated poor feedwater quality. On this date the GS plant experienced slight carryover (one unit out of eight).

* Gas flow changed about 2% because of dissolved H_2S.

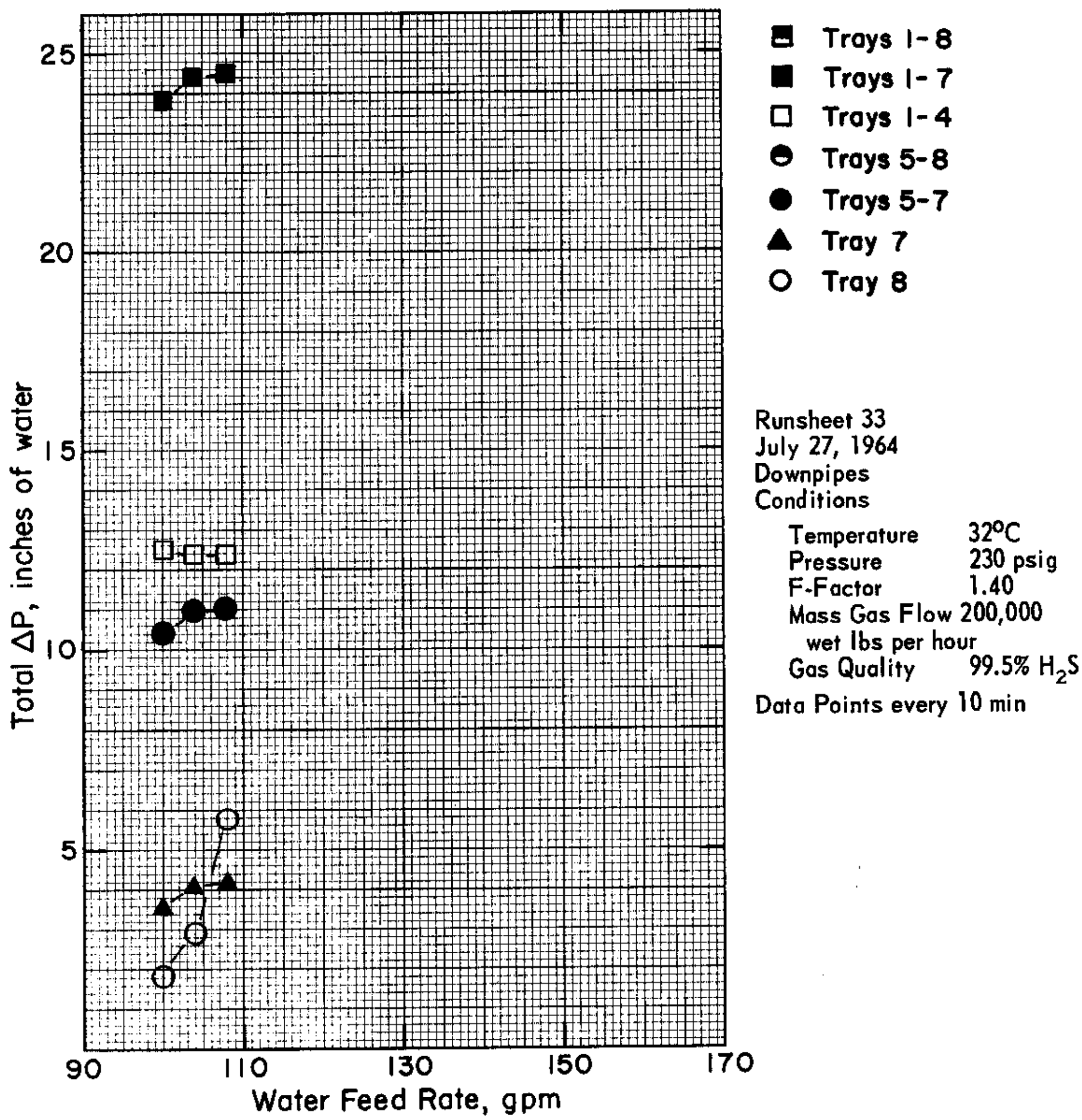

FIG. 22-a REPEAT 21 SERIES 32°C

Figure 22b Synopsis

Runsheet 33

Tray stability limit: 116 gpm (44°C)

See Figure 22a Synopsis.

In this test, temperature was held at 44°C.

Trays 1-4 were probably flooding early in test. Flooding of trays 5-6 at 116 gpm prevented flow increase from reaching trays 1-4. Per tray 8 ΔP, tray 7 flooded at 120 gpm.

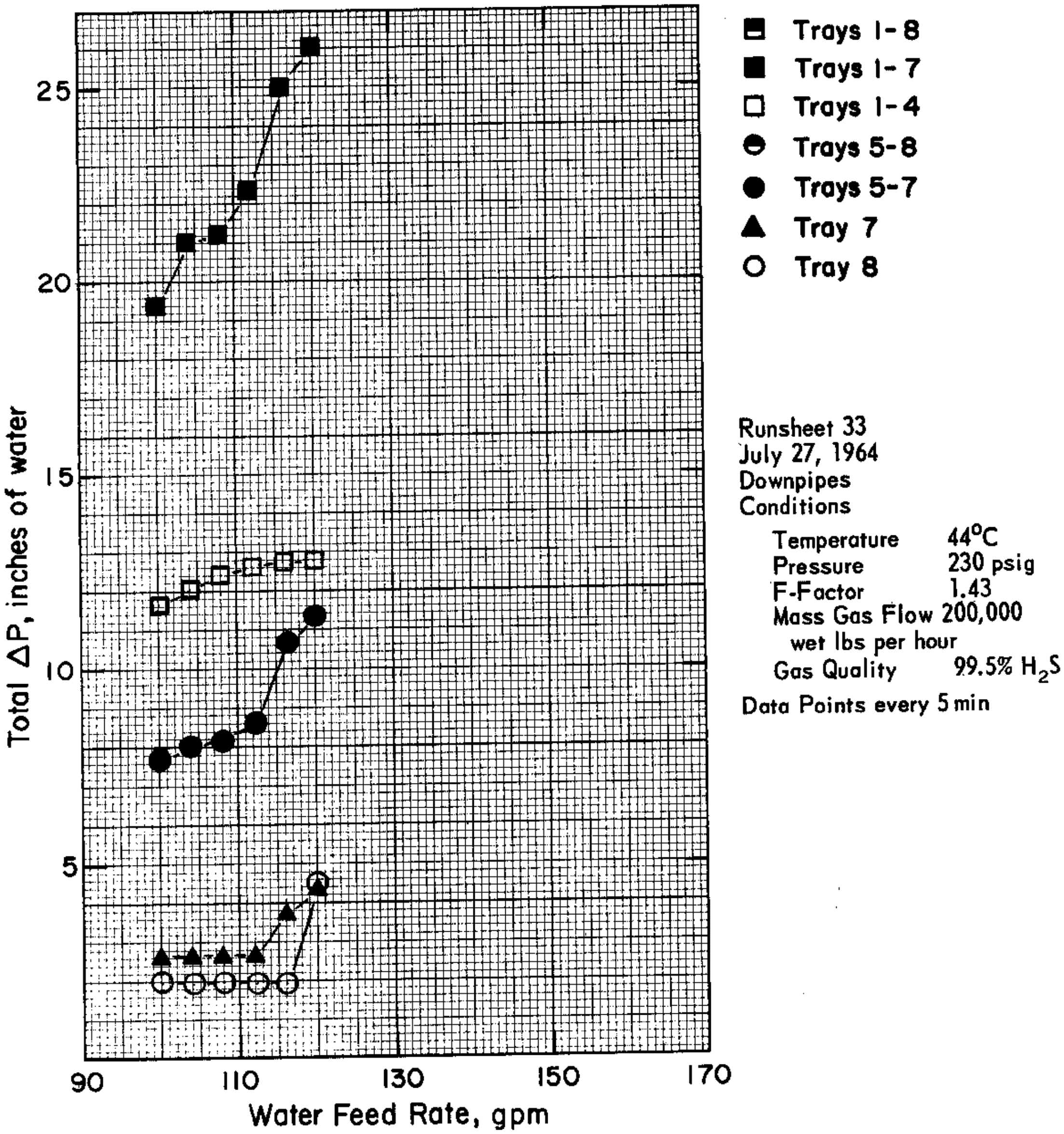

FIG. 22-b REPEAT 22-a AT 44°C

<u>Figure 22c Synopsis</u>

Runsheet 33

Tray stability limit: 128 gpm (58°C)

See Figure 22a Synopsis.

In this test, temperature was held at 58°C.

All trays began flooding at about 121 gpm. Per tray 8 ΔP, tray 7 was flooded at 132 gpm.

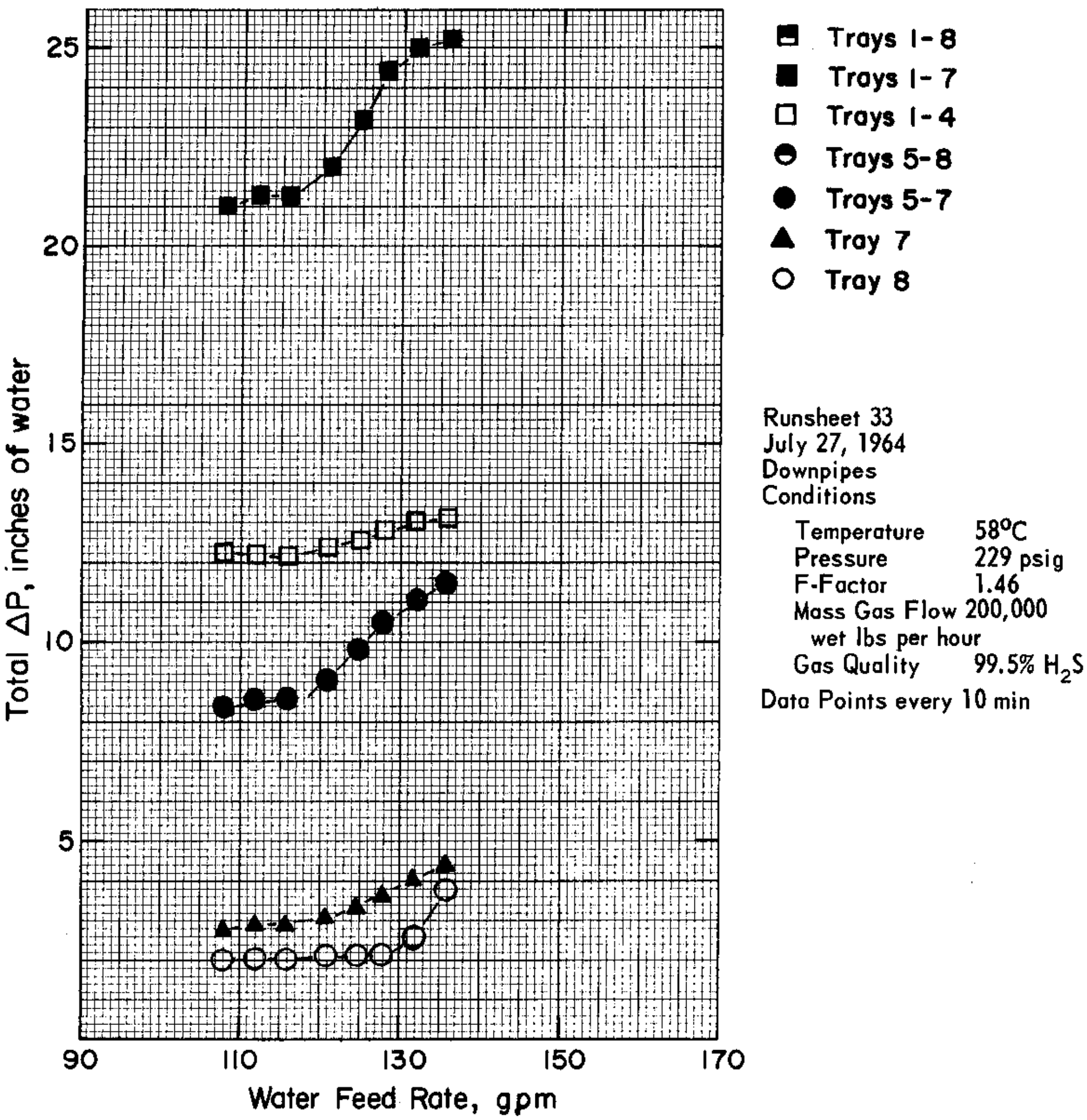

FIG. 22-c REPEAT 22-a AT 58°C

Figure 22d Synopsis

Runsheet 33

Tray stability limit: 160 gpm (74°C)

See Figure 22a Synopsis.

In this test, temperature was held at 74°C.

Tray 1-4 and 5-6 all appeared to start flooding at 152 gpm; tray 7 began flooding at 160 gpm, and per tray 8 ΔP, was completely flooded at 164 gpm.

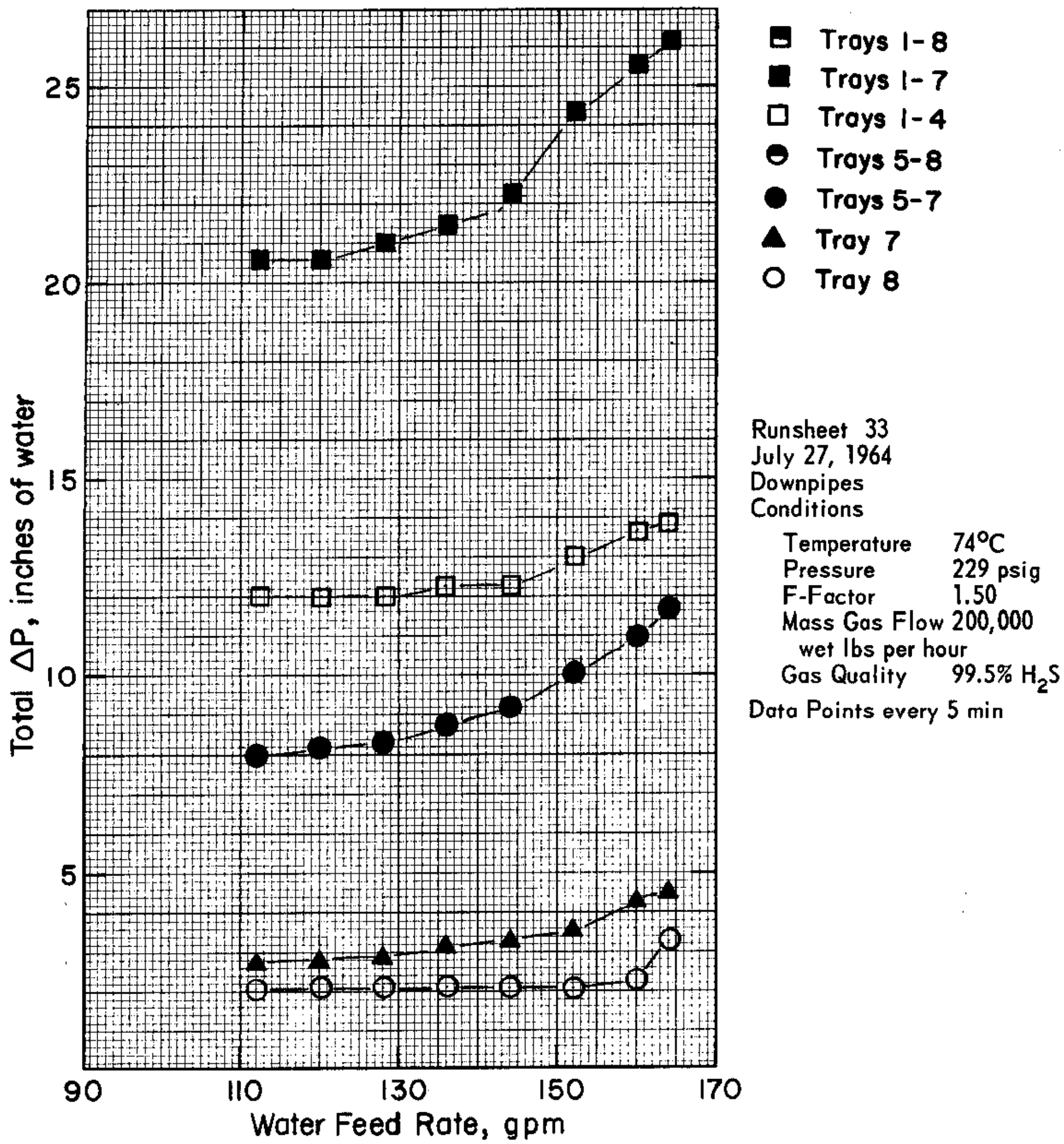

FIG. 22-d REPEAT 22-a AT 74°C

Figure 23a Synopsis

Runsheet 27

Tray stability limit: 112 gpm (36°C)

Gas flow was held nearly constant at an F-factor near 1.4 (see Figure 20 Synopsis) while increasing liquid flow every 15 minutes. Fluorescein was injected during tray 7 flooding at maximum liquid flow of 116 gpm. Tower liquid was sampled 60 minutes after injection began. Analyses showed entrainment of 1.0 mols water per 100 mols gas.

Per ΔP data, trays 1-4 were probably flooding at start, trays 5-6 probably flooded between 104 and 108 gpm, followed by flooding of tray 7 above 112 gpm. Liquid flow increases above 104 gpm did not entirely reach trays 1-4 because of flooding on trays 5-7. Similarly, tray 8 flooding appeared to keep flow increases from reaching tray 7. Return of liquid carryover from tray 13 rapidly increased from 0 to 10 gpm at a liquid flow of 116 gpm.

Note quantitative and qualitative similarity in ΔP data between this test and that shown by Figure 22b, 4 months apart, with intervening shutdown.

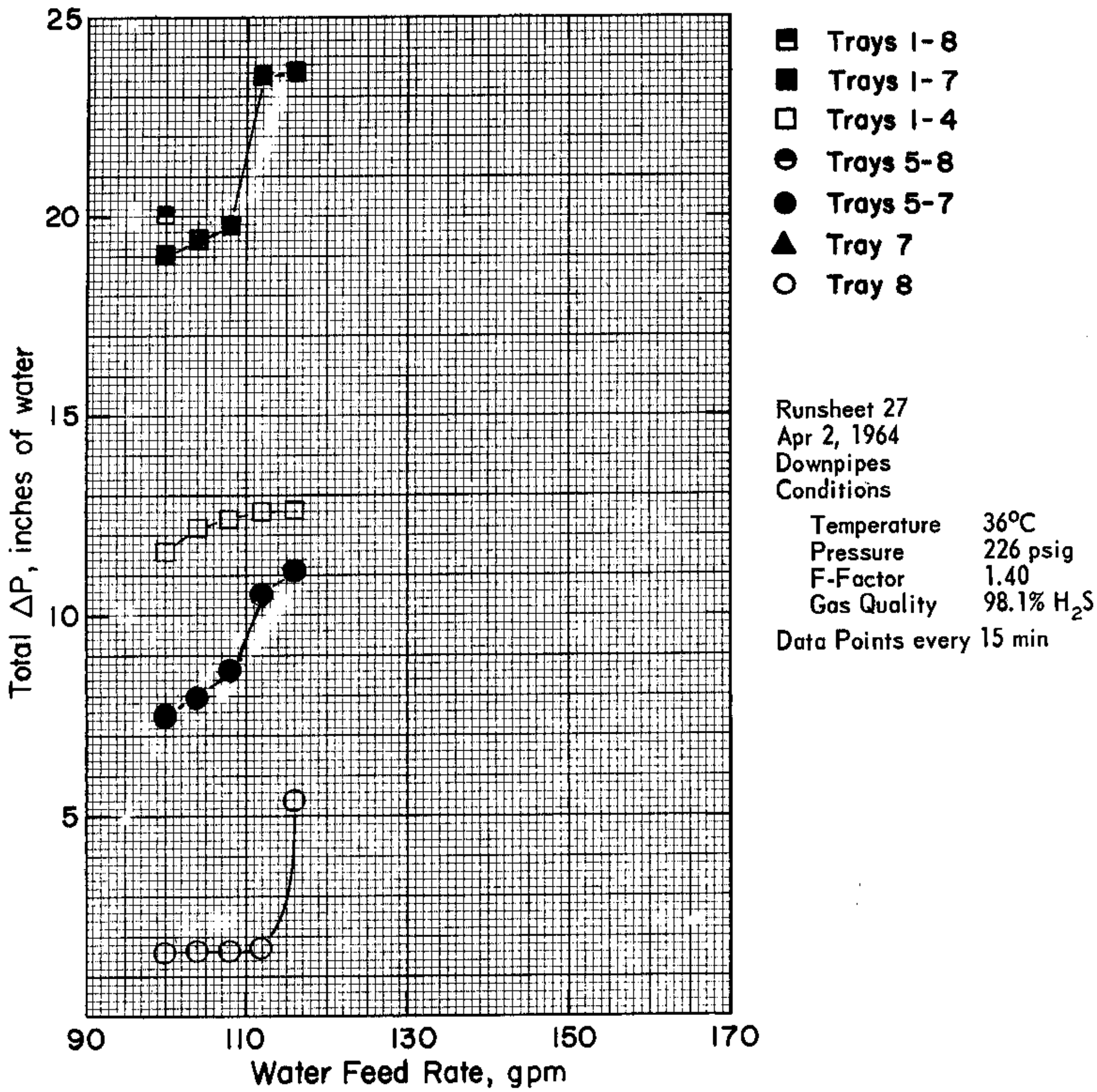

FIG. 23-a LIQUID FLOW CAPACITY, DOWNPIPES, CONSTANT F-FACTOR, 36°C

Figure 23b Synopsis

Runsheet 32

Tray stability limit: 150 gpm (66°C)

See Figure 23b Synopsis. No entrainment data were taken. Test temperature was 66°C.

Per ΔP data, trays 1-4 began to flood first between 120 and 130 gpm followed by trays 5-6 and 7 between 130 and 140 gpm. Tray 7 flooded at 160 gpm based on tray 8 ΔP.

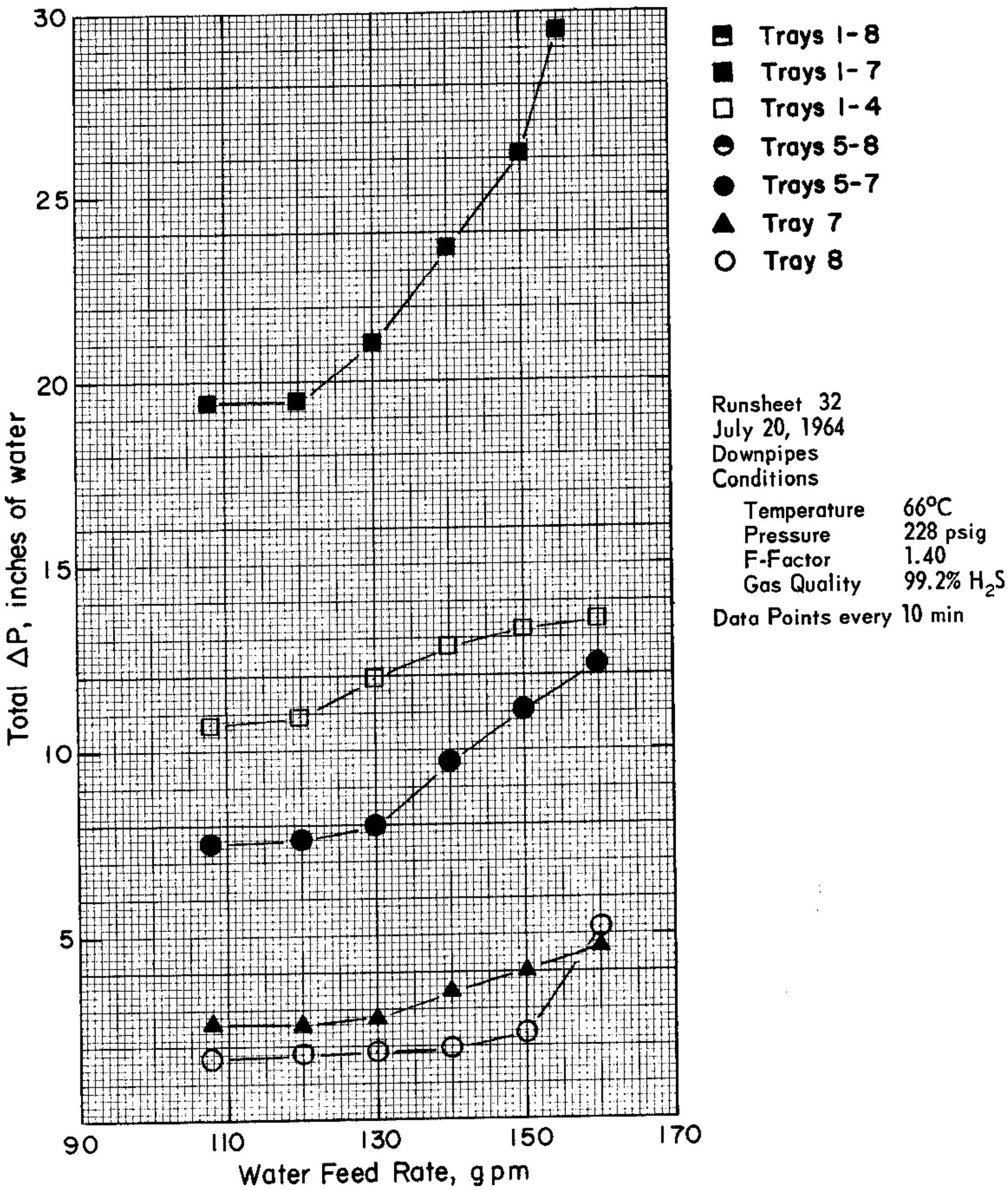

FIG. 23-b REPEAT 23-a AT 66°C

Figure 23c Synopsis

Runsheet 28

Maximum possible flow: 198 gpm (117°C)

See Figure 23a Synopsis. Test temperature was 117°C.

First signs of flooding were reached at maximum available flow of 198 gpm but tray 7 did not flood, per tray 8 ΔP. Entrainment at maximum flow was only 0.2 mols water per 100 mols gas.

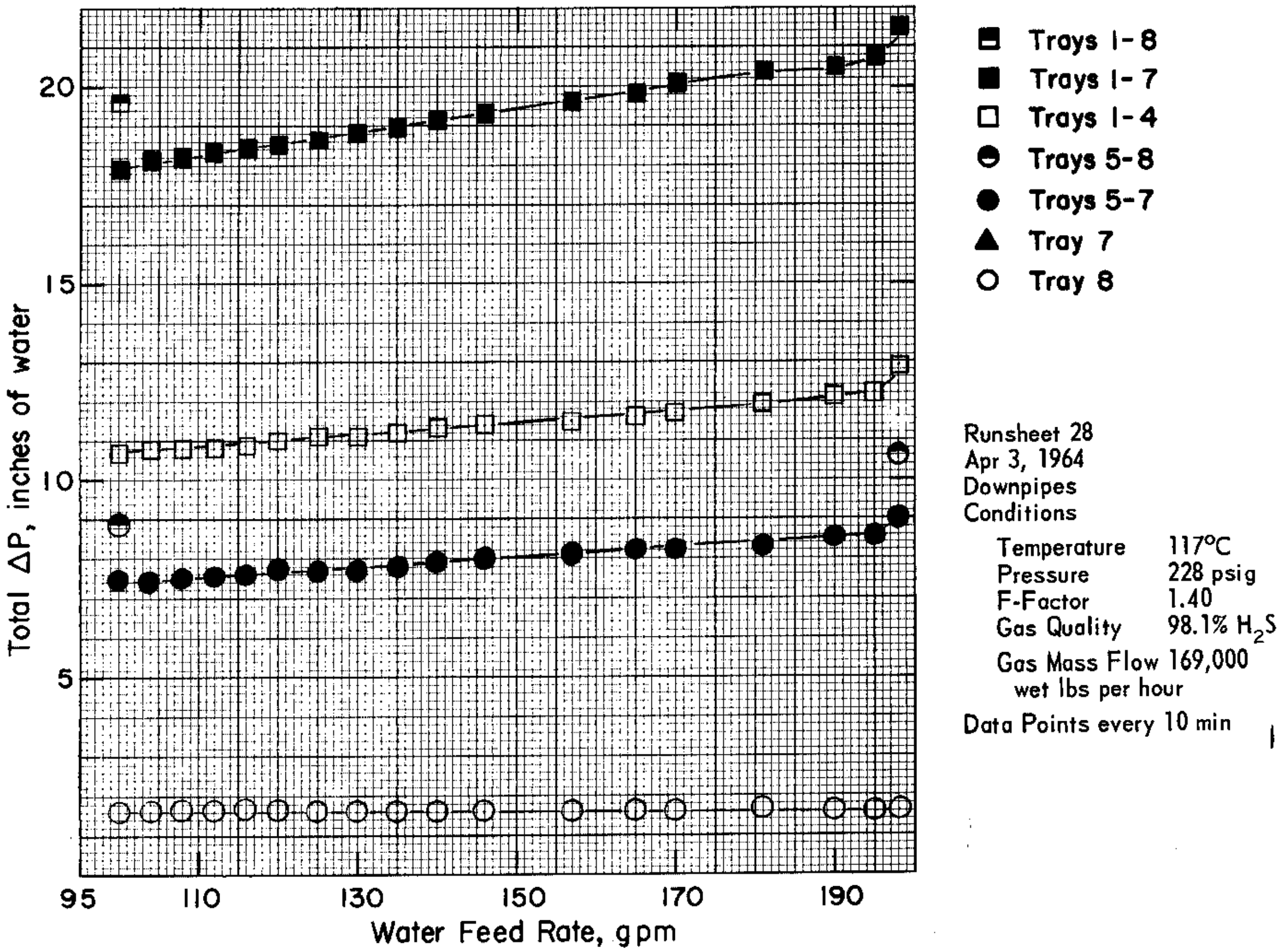

FIG. 23-c REPEAT 23-b AT 117°C

EXTERNAL RELEASE OF TECHNICAL INFORMATION

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