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PERFORMANCE OF SIEVE TRAYS UNDER GS HEAVY WATER PROCESS CONDITIONS

Part II - High Pressure Operation

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PERFORMANCE OF SIEVE TRAYS UNDER GS HEAVY WATER PROCESS CONDITIONS

PART II - HIGH PRESSURE OPERATION

by

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ABSTRACT

Under GS process conditions in a 6-1/2-ft-diameter tower, tray flooding limited stable operation to a maximum F-factor of 1.8 at 275-280 psig operating pressure. Entrainment over the stable operating range of the trays was less than 0.5 mol liquid per 100 mols gas.

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PART II - HIGH PRESSURE OPERATION

INTRODUCTION

Equipment used and results of preliminary tests at 230 psig, with segmental downcomers and with downpipes, are shown in DP-1025.[1] In December 1965 the pressure at the point of interconnection between the GS Plant and the test unit was increased to 280 psig, and testing was resumed in July 1966.

SUMMARY

At 275 to 280 psig, maximum flow at GS cold tower conditions was limited by tray flooding to an F-factor* of about 1.8. Liquid entrainment at 280 psig was about 0.5 mol water per 100 mols gas, the same as the entrainment at 230 psig. Consequently, tray efficiency should not decrease significantly as flows are increased up to the flooding point. Fluctuating feedwater quality continued to cause wide variations in attainable flow. Trays flooded at F-factors as low as 1.3 during periods of heavy rainfall and high river turbidity. Sporadic carryover, indicative of poor feedwater quality, was experienced in the GS Plant while the high pressure tests were in progress. Silicone antifoam increased attainable flows at least 7% during periods of poor water quality.

TEST RESULTS

Detailed results from each high pressure test are presented in Figures 5 through 23. Individual test conditions are described in a synopsis on the page facing these figures. Downpipes were installed for all high pressure tests, and gas quality was 99.0 to 99.5 mol % H_2S. Criteria for analyzing tray performance are the same as those used with low pressure test data:[1]

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

$$F = v\sqrt{\rho} \quad \text{where } \rho = \text{gas density, lb/cu ft}$$
$$v = \text{gas velocity, ft/sec, based on de-entrainment area.}$$

- 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 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.

Results at Cold Tower Conditions

1. Sieve Tray Capacity. Tests at 280 psig were started on July 13. During initial runs the trays flooded at F-factors of 1.3 to 1.4 (Figures 5 and 7) without silicone antifoam; with 1 ppm of "GE-60"* silicone in the feedwater the trays flooded at F-factors of 1.4 to 1.6 (Figures 6 and 18). Flooding was caused apparently by poor feedwater quality or perhaps by particulate matter (foam nuclei) in the equipment after a two-year shutdown. On July 21, with gas flow constant at an F-factor of 1.82 and increasing water flow, stable operation was maintained up to a liquid flow of 148 gpm (L/G = 0.47) with 1 ppm silicone; flooding began at 152 gpm (L/G = 0.50). Figure 20 shows the ΔP data for this run. On the following day stable operation was maintained, with 1 ppm silicone, up to an F-factor of 1.81; flooding occurred at blower capacity at an F-factor of 1.87 (Figure 9).

Tray-to-tray entrainment at the flooded condition was about 3 mols water per 100 mols of gas. This capacity at GS cold tower conditions was verified with a duplicate run on July 27, following calibration of flow and ΔP instruments. Stable operation was maintained up to an F-factor of 1.77**; flooding occurred at an F-factor of 1.83 (Figure 11).

2. Feedwater Quality. Flooding of the top sieve tray limited flows at high pressure in much the same manner as in the low pressure tests. Figure 1 summarizes the high pressure tests at GS cold tower conditions and illustrates the variation in maximum attainable flows attributed to fluctuations in feedwater quality. The F-factors plotted in this figure correspond to incipient flooding rather than to stable operation of tray 7 because most

* General Electric Company, Schenectady, New York.
**The difference between the F-factors of 1.81 and 1.77, obtained in duplicate runs, is within our accuracy of measuring F-factor.

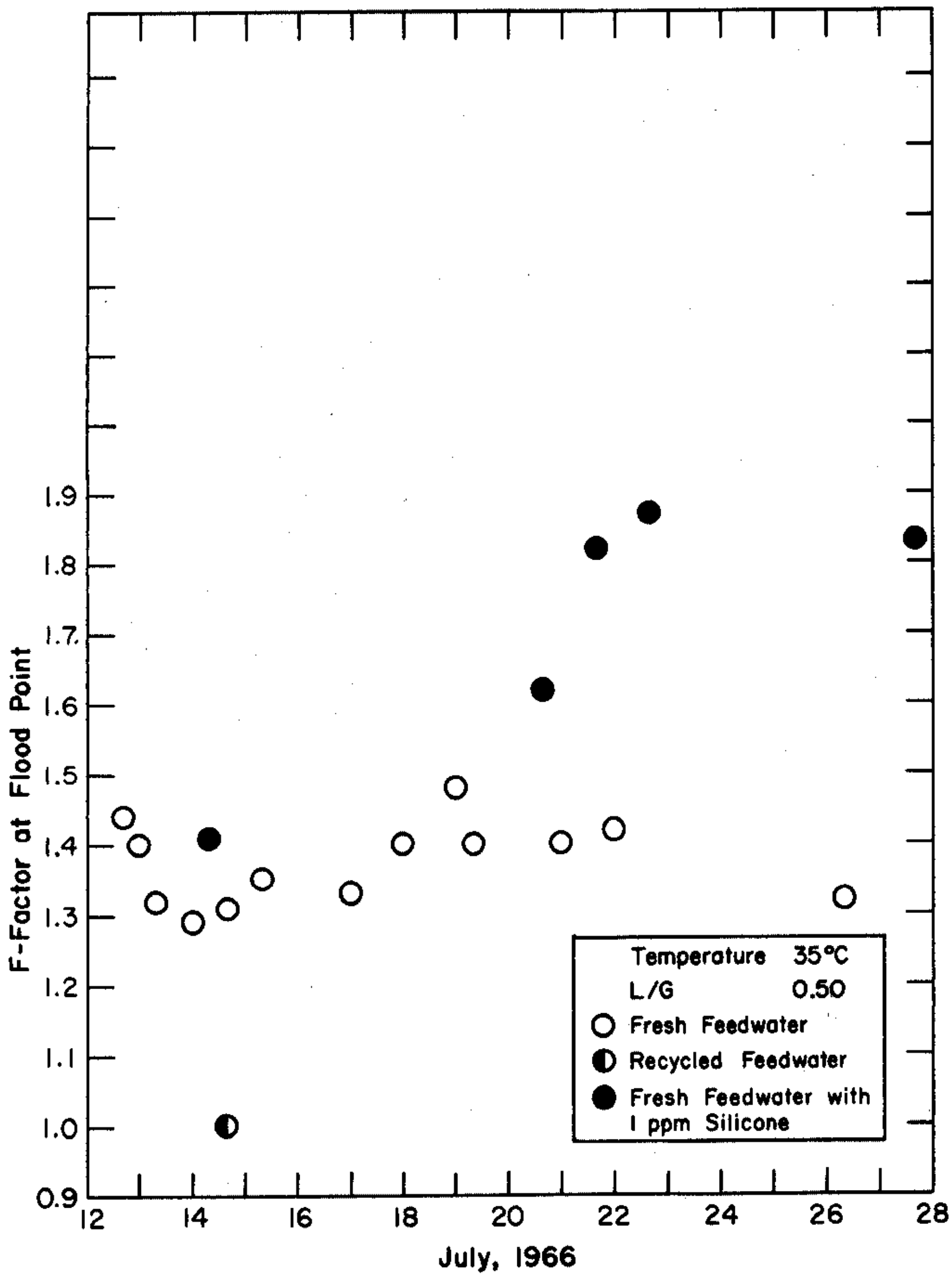

FIG. 1 EFFECT OF VARIATIONS IN FEEDWATER QUALITY

of the data were obtained by brief excursions to high flows without recording intermediate conditions (Figure 7). In those runs where intermediate data were taken, stable operation was maintained at an F-factor about 0.05 below the flood points shown in Figure 1.

For many years, feedwater quality has been a seasonal limitation in the operation of the Savannah River GS Plant where it causes flooding of the first stage cold towers. This flooding causes carryover of liquid into the gas blowers and, if flows are not reduced, loss of process control due to erratic L/G's throughout the tower.

Without silicone antifoam, flows are always limited to some extent by carryover, but during periods when heavy rains overflow surrounding swamps and river turbidity is high, flows must be reduced despite the use of silicone. Turbidity is the only aspect of river water quality that appears to correlate with carryover. River turbidity is usually high when carryover occurs, but carryover occasionally occurs when river turbidity is low. This correlation indicates that turbidity is not the only cause of carryover. Trace quantities of some soluble foam-inducing agent, associated with the turbidity, may also cause carryover.

River turbidity, routinely measured with a Hellige* turbidimeter, is normally about 15 - 20 ppm, with occasional excursions to 50 - 60 ppm following heavy rains. Feedwater turbidity measured on the same instrument never exceeds 1 ppm; however, measurements with a Lumetron** Model 402-EF turbidimeter show variations from 0.5 to >5.0 ppm, consistent with fluctuations in river turbidity (Table I).

TABLE I

River and Feedwater Turbidity

Date, Oct. 1964	Savannah River Turbidity, ppm (Hellige Turbidimeter)	GS Feedwater Turbidity, ppm (Lumetron Turbidimeter)
1[(a)]	59	3.7
2[(a)]	49	4.5
3[(a)]	49	>5.0[(b)]
4[(a)]	42	>5.0[(b)]
8	26	3.1
9	26	3.8
14	25	3.4
15	25	0.7
17	25	0.4
18	25	0.5
21	20	0.4
22	20	0.4

(a) First stage flows reduced due to carryover.
(b) Lumetron upper limit - 5 ppm.

* Hellige, Inc., Garden City, L. I., N. Y.
**Trademark of Photovolt Corp., New York, N. Y.

3. <u>Effect of Silicone Antifoam</u>. The effect of silicone antifoam in suppressing flooding at high pressure 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, July	Silicone, ppm	Maximum F-factor	Flow Increase With Silicone, %
5	13	0	1.32	-
6	14	1	1.41	7
7	21	0	1.40	-
18	20	1	1.62	16
7	22	0	1.42	-
20	21	1	1.82	28

Because each comparative test extended over a 16- to 24-hour period, the possibility of a change in feedwater quality during the test must be considered in evaluating the above data. However, similar tests at low pressure indicated, and these data confirm, a flow increase of at least 7% with silicone antifoam.

4. <u>Recycled Feedwater</u>. An attempt was made to operate the test unit at GS cold tower conditions with recycled effluent water (saturated with H_2S) as feedwater but the trays flooded at the first data point (F-factor 1.0). This confirms low pressure tests where more extensive data showed that stable operation with recycled water was limited to a significantly lower F-factor than that achieved with fresh feedwater on the same day. In this test, as at low pressure, the recycled water was quite turbid but fresh feedwater and associated effluent were visually clear. Turbidity was generated, apparently, when recycled water containing H_2S passed through feed piping and equipment normally exposed to fresh water.

5. <u>Entrainment</u>. Entrainment at high pressure is summarized in Table II and is plotted against F-factor in Figure 2. The poor correlation of entrainment with F-factor is, again, a manifestation of varying feedwater quality. 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 this maximum. The data, plotted this way in Figure 3, correlate better and show maximum entrainment of about 0.5 mol water per 100 mols gas over the stable operating range of the sieve trays. This is in excellent agreement with data from similar tests at low pressure.

TABLE II

Sieve Tray Entrainment at 280 psig-GS Cold Tower Conditions

Correlation With Flood Point

Date, July	Figure No.	F-factor Data Point	F-factor Maximum Stable for Test	F-factor Percent of Maximum Stable Flow	Entrainment mols/100 mols
13	5	1.04	1.27	81.0	0.03
13	5	1.17	1.27	90.9	0.12
13	5	1.27	1.27	100.0	1.20
13	5	1.36	1.27	109.1	1.06
14	6	1.22	1.32	93.1	0.08[a]
14	6	1.32	1.32	100.0	0.86[a]
14	6	1.45	1.32	106.1	5.03[a]
16	12	1.21	-	-	0.14
19	14	1.41	1.41	100.0	0.29
20	18	1.62	1.62	100.0	1.42[a]
21	20	1.82	1.82	100.0	1.56[a]
22	9	1.87	1.81	103.3	2.86[a]
27	11	1.83	1.77	103.4	1.01[a]

(a) Silicone antifoam added.

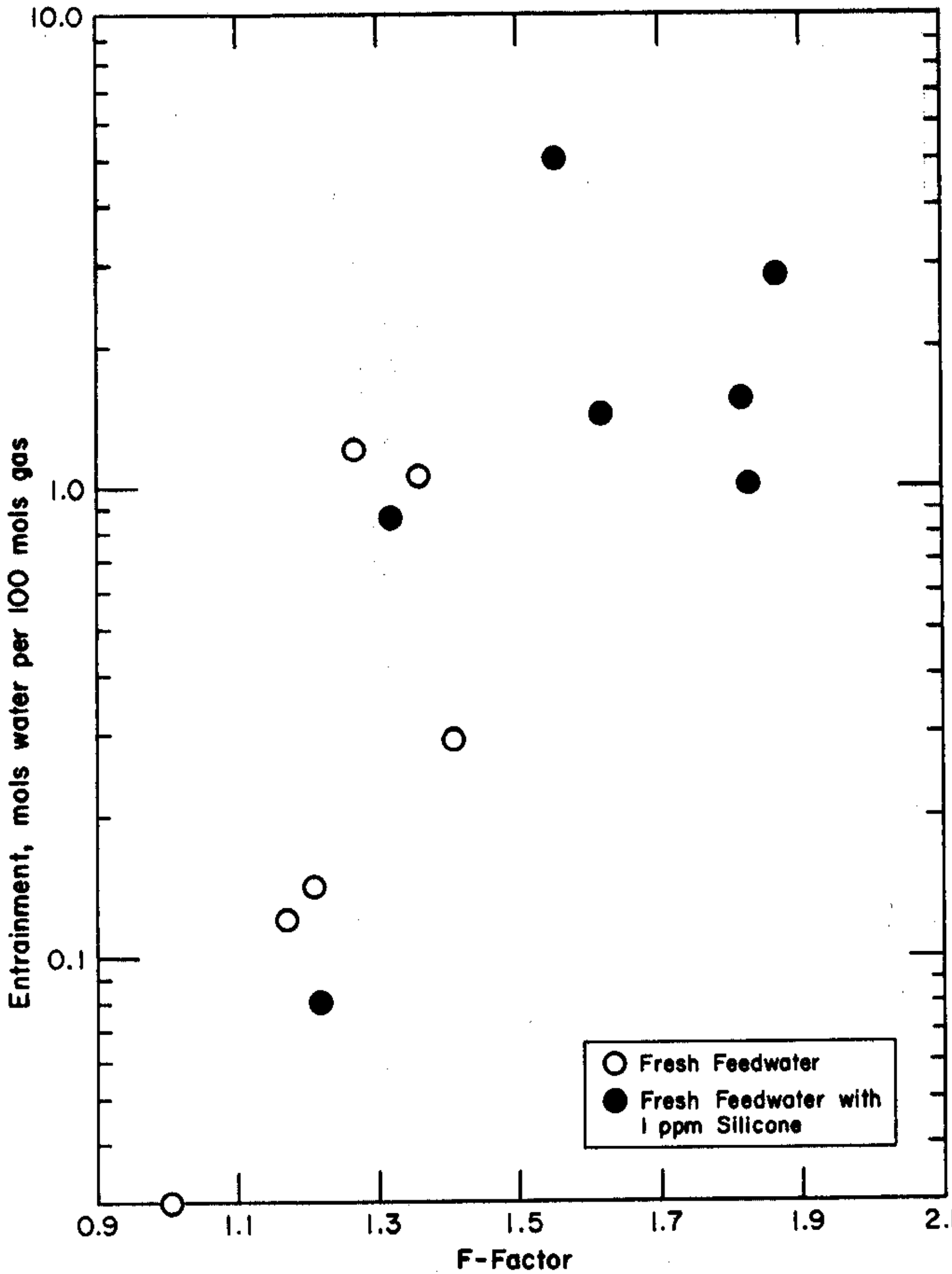

FIG. 2 ENTRAINMENT VERSUS F-FACTOR, GS COLD TOWER CONDITIONS

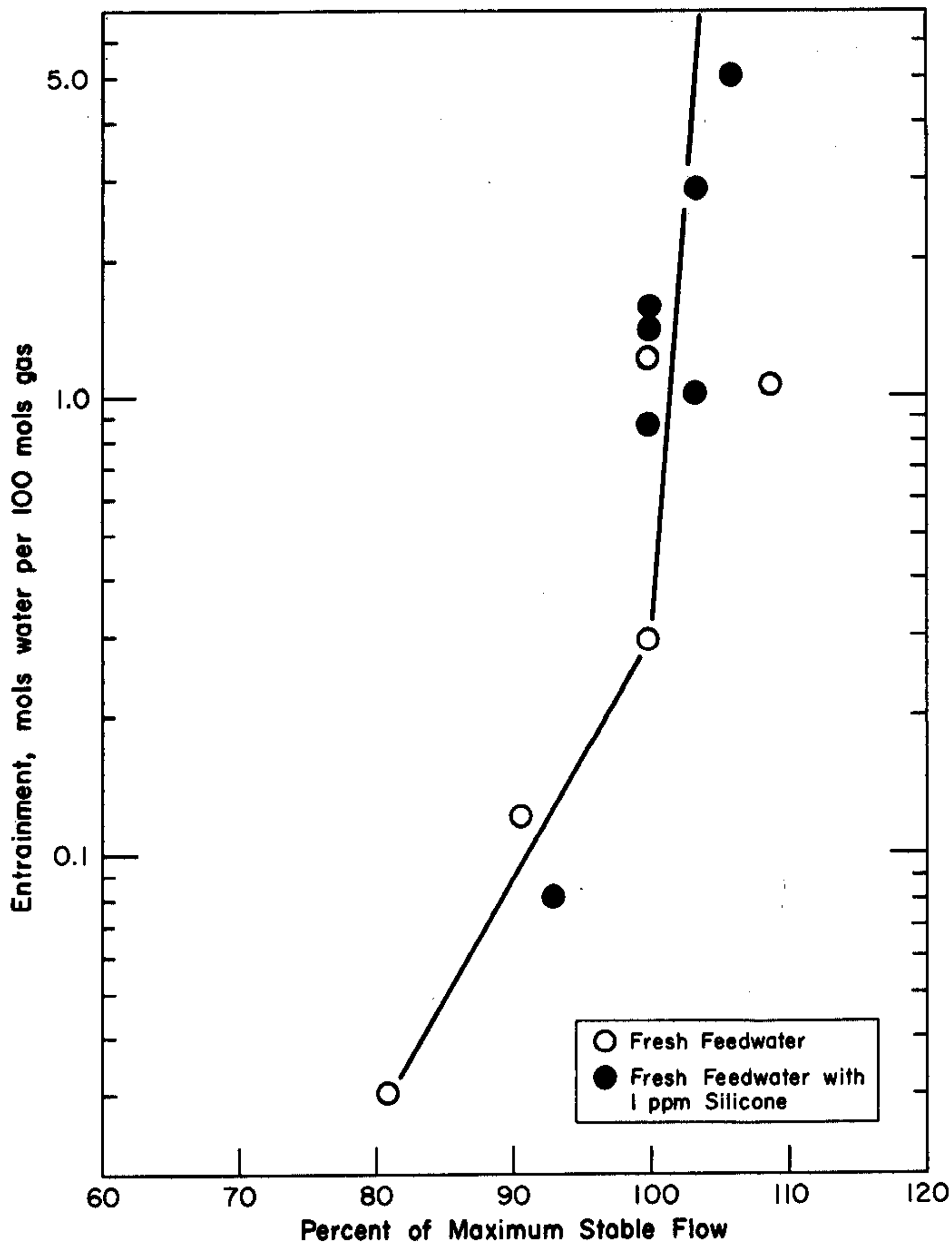

FIG. 3 ENTRAINMENT VERSUS PERCENT OF MAXIMUM STABLE FLOW

6. Application to New Design. Maximum flow capacities during normal and test operation at the two U. S. plants — Dana and Savannah River[2,3] — are summarized in Table III. In all cases, except the SRP sieve tray test at 280 psig, equipment other than trays limited flow. Proctor and Thayer[4] based future plant capacity on the Dana Plant sieve tray test. The SRP test shows the possibility of 20% more capacity, provided high quality feed-water is used. River turbidity, while not the only contributing factor, provides the best correlation with GS feedwater quality. The quality of Savannah River water is probably not unique, and at the high flows being considered, water from almost any source would probably limit throughput similarly. Designers of new GS plants should carefully consider their water treatment facilities.

TABLE III

Maximum Flows Previously Demonstrated

F-factors in this report are based on the tower de-entrainment area, i.e., the full circular area less the area of one downcomer. Dana Plant values were recalculated from previous publications to this same basis. Dana and SRP F-factors and mass velocities are based on a first stage cold tower de-entrainment area of 86.5 sq ft. The full circular area of these towers is 95.2 sq ft. Sieve tray test F-factors and mass velocities are based on a second stage cold tower de-entrainment area of 31.9 sq ft. The full circular area of this tower is 33.2 sq ft.

		Maximum Gas Flow		Tower Exit Pressure,	Temp,	
Bubble-Cap Trays	Date	F-factor	lb/hr/sq ft	psig	°C	Limitation
Dana GS Plant	1956	1.35	6400	245	35	Pumps
SRP GS Plant	Mar 1965	1.35	6200	225	32	
	Aug 1965	1.45	6900	245	33	Blowers
	Feb 1963	1.65	8300	275	34	
	Aug 1966	1.55	7900	275	34	
Sieve Trays						
Dana GS Plant	Aug 1956 - Mar 1957	1.50	7200	245	35	Pumps
SRP Unit 18[a]	Aug 1957	1.60	8100	270	33	Condensate Separators
Sieve Tray Test	July 1964	1.65	7500	230	34	Blower and Tray Stability
	July 1966	1.80	9200	280	36	Tray Stability

(a) Test operation with sieve trays in only first stage cold tower and bottom ten trays of first stage hot tower (humidifier).

Results at Hot Tower Conditions

At GS process-optimum L/G and hot tower conditions, stable operation was maintained up to an F-factor of 1.34, and negligible entrainment was measured (Figure 23). Malfunction of the gas flow-control valve forced termination of this run before achieving blower capacity at this temperature (F-factor about 1.6). No further tests were made at hot tower conditions since this test, along with low pressure data and GS plant experience, indicated that the trays would be stable at blower capacity.

Other Results at Abnormal L/G

Several runs were made, with and without silicone, by holding gas flow constant and increasing the liquid flow (Figures 12 through 20). Two runs were made with silicone by holding liquid flow constant and increasing the gas flow (Figures 21 and 22). These runs at abnormal L/G's were used to establish a profile of stable flows for the sieve trays at 280 psig and 35°C. Such a profile is shown in Figure 4, along with a similar curve constructed from earlier data at 230 psig. Stable operation of the sieve trays has been demonstrated to the left of and below the two pressure curves. The numbers along the 280 psig curve refer to Figure numbers of this report that are the source of the data points shown. The numbers at the data points for the 230 psig curve refer to Figure numbers in DP-1025.[1] Due to limitations of test equipment and feedwater quality, data at abnormal L/G's are insufficient to define the curves more accurately. However, such plant-scale curves may be useful in predicting sieve tray performance at other operating conditions.

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1. M. P. Burgess, R. G. Garvin, and W. C. Scotten. Performance of Sieve Trays Under GS Heavy Water Process Conditions. Part I - Low Pressure Operation. USAEC Report DP-1025. E. I. du Pont de Nemours & Co., Aiken, S. C. (June 1966).

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

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

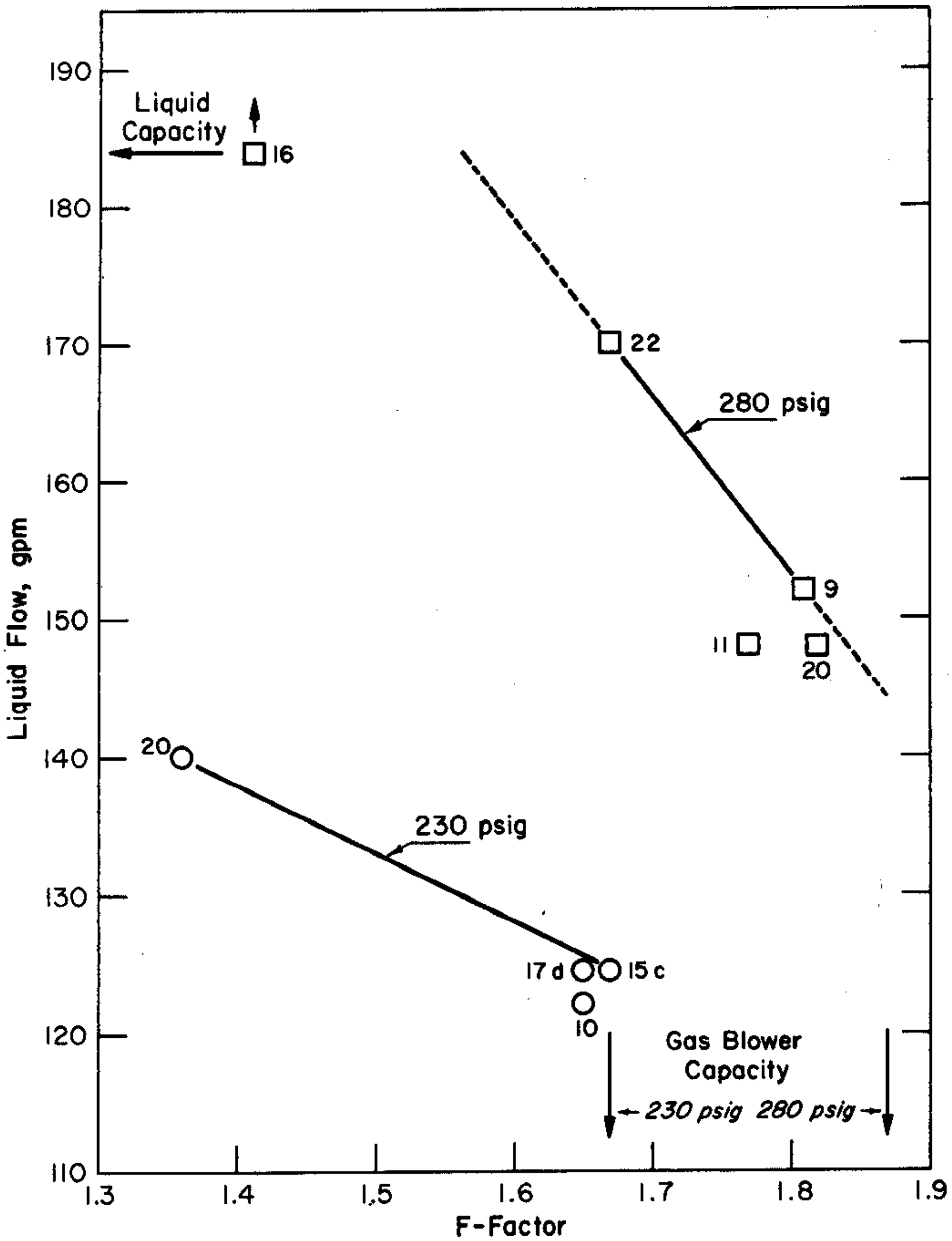

FIG. 4 STABLE OPERATING PROFILES FOR SIEVE TRAYS, 35°C

Figure 5 Synopsis

Runsheet 50

Tray stability limit: F-factor of 1.21

Flows were increased every two hours while maintaining process-optimum L/G at cold tower conditions. Fluorescein was injected continuously. At steady state, just before increasing flows to next set of conditions, effluent liquid from trays 3 and 4 was sampled for dye analysis and ΔP's were recorded. ΔP's and entrainment from tray 3 to 4 show flooding above an F-factor of 1.21.

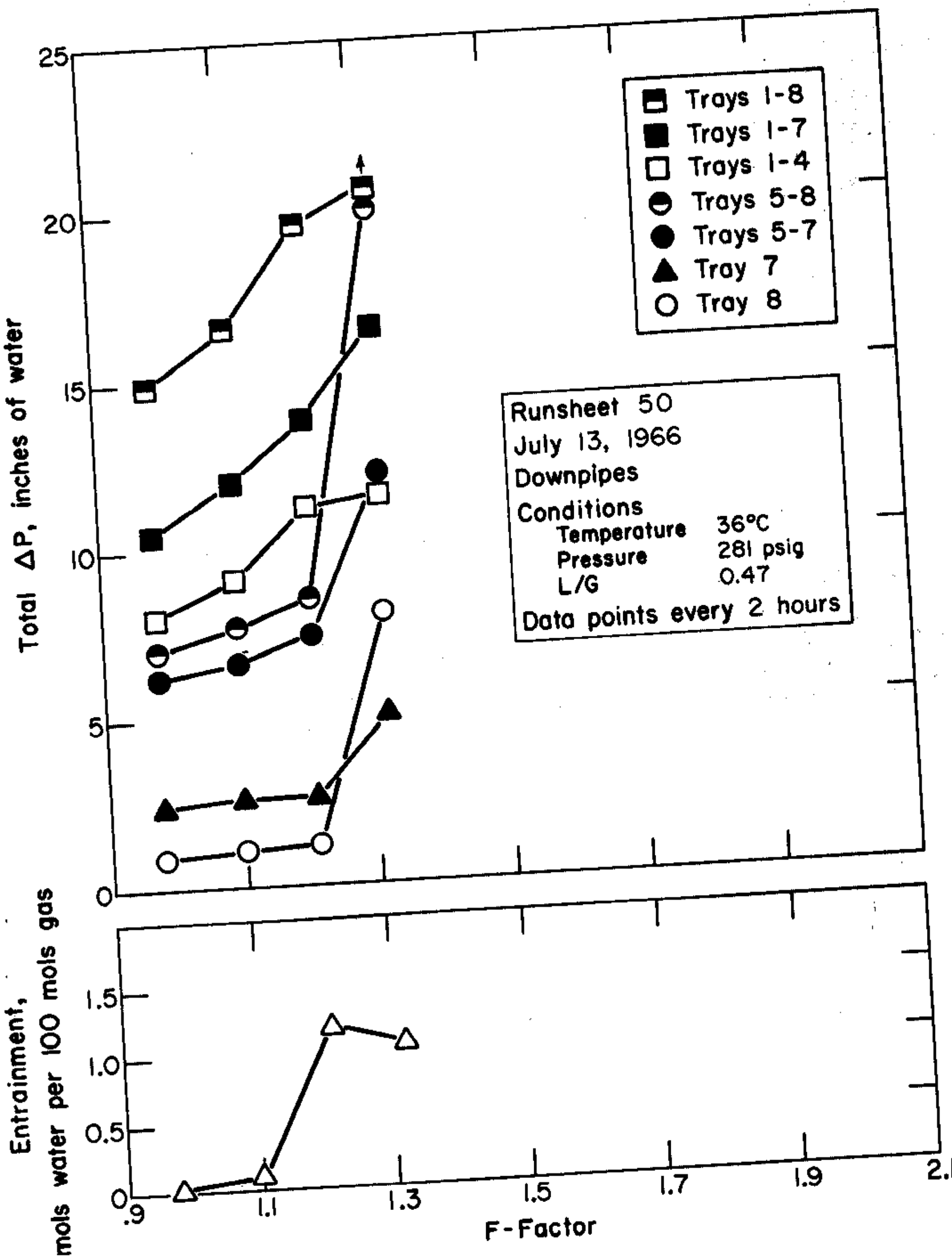

FIG. 5 COLD TOWER CONDITIONS WITHOUT SILICONE ANTIFOAM

Figure 6 Synopsis

Runsheet 50S

Tray stability limit: F-factor of 1.32

The test shown in Figure 5 was repeated on the following day with 1 ppm silicone added to the feedwater. Flooding occurred at flows above an F-factor of 1.32. Entrainment from tray 3 to tray 4 at flooding — 5.0 mols water per 100 mols gas — was the highest recorded throughout the high pressure tests.

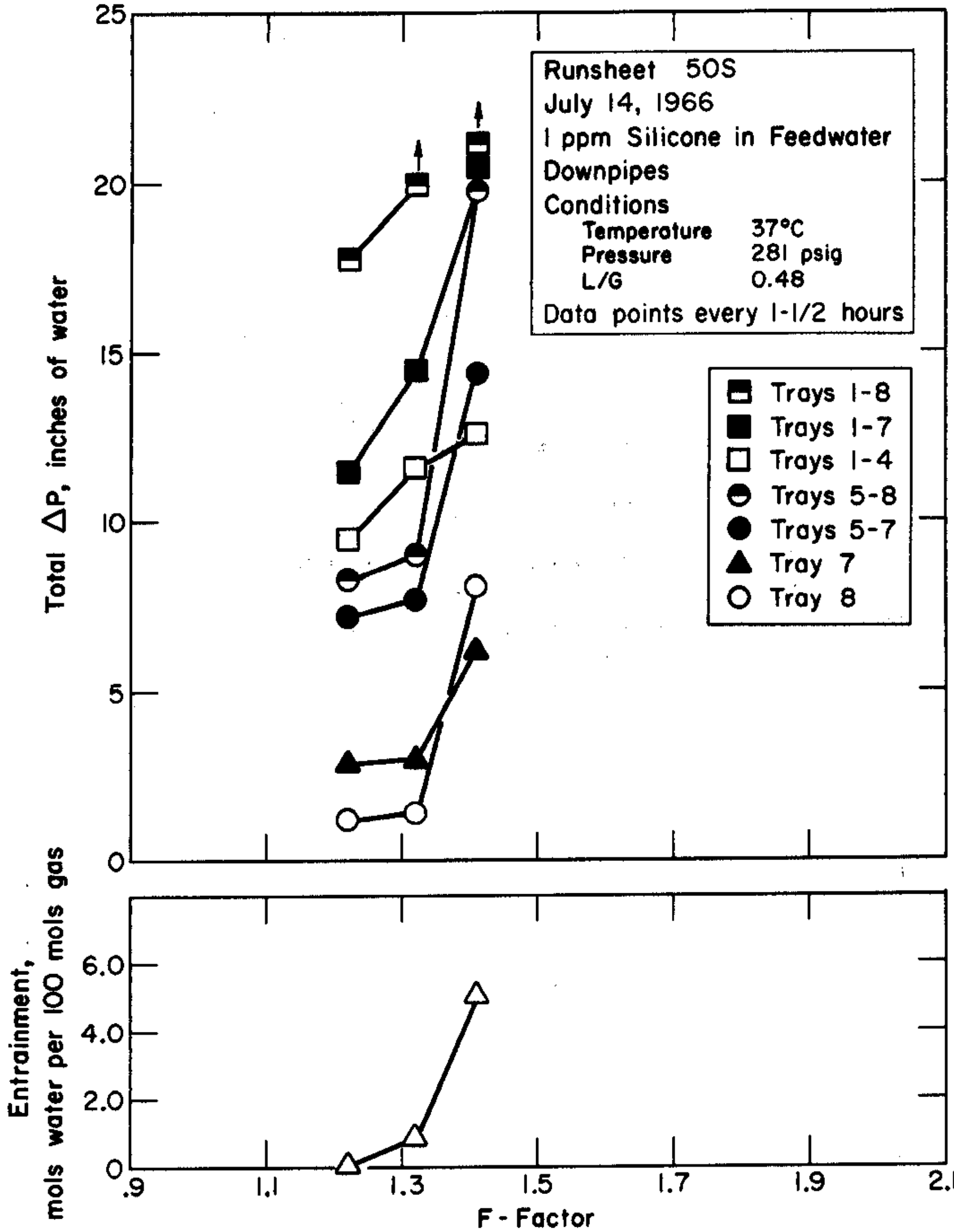

FIG. 6 COLD TOWER CONDITIONS WITH SILICONE ANTIFOAM

Figure 7 Synopsis

General Runsheet 68

During shifts when scheduled tests were not in progress, flows were increased every five minutes, while maintaining process-optimum L/G at cold tower conditions, until tray 8 ΔP increased above three inches of water.

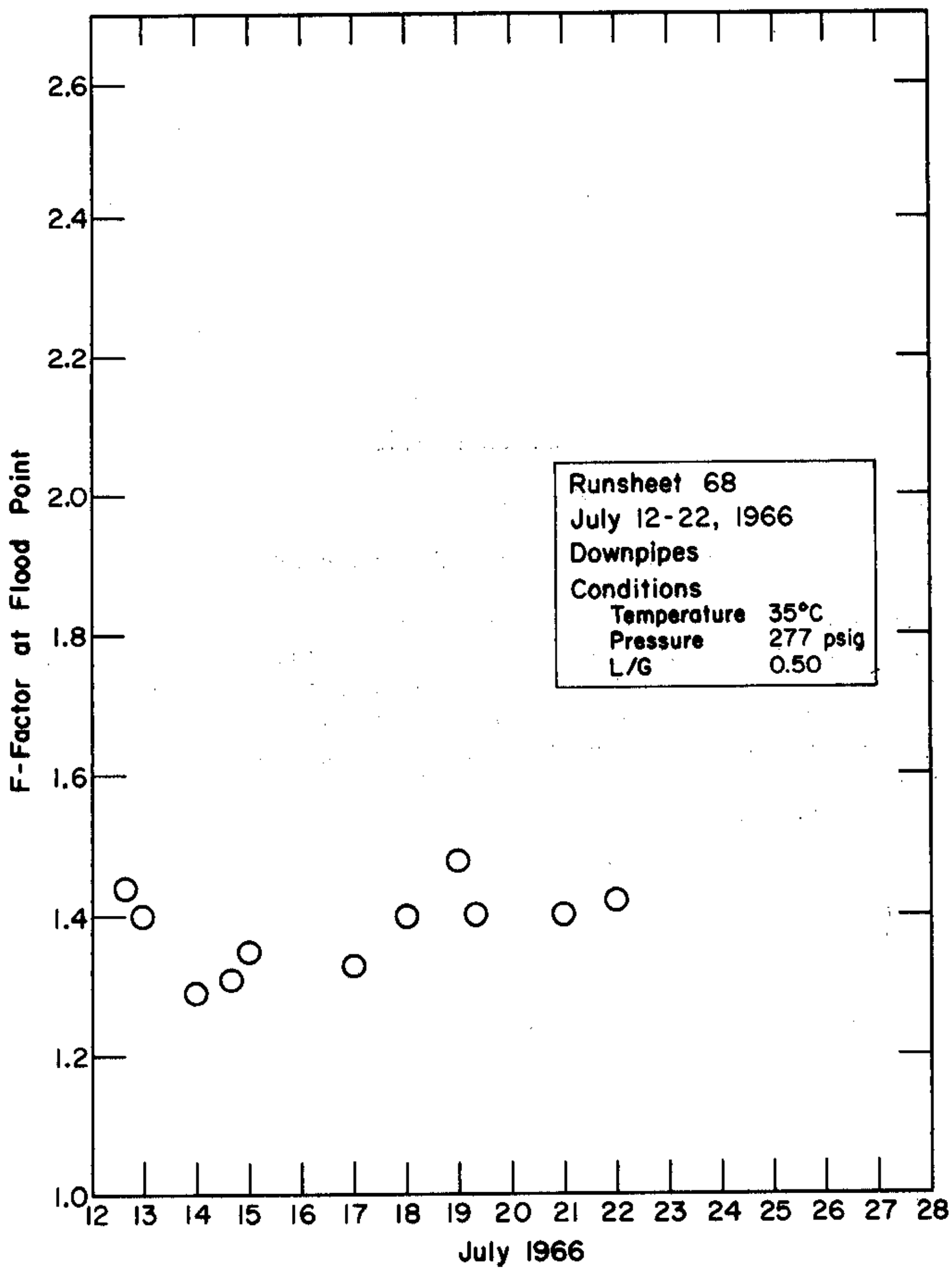

FIG. 7 PERIODIC CHECKS OF FLOODPOINT WITHOUT SILICONE ANTIFOAM

Figure 8 Synopsis

Runsheet 69

Tray stability limit: F-factor of 1.22

The test shown in Figure 5 was repeated about ten days later. No entrainment measurements were made. The last two data points (F-factors of 1.22 and 1.33) were taken three days after the first two points. Calibrations of the gas and water flowmeters and two ΔP transmitters were verified during this period. Agreement with the data shown in Figure 5 is excellent over the stable operating range of the trays.

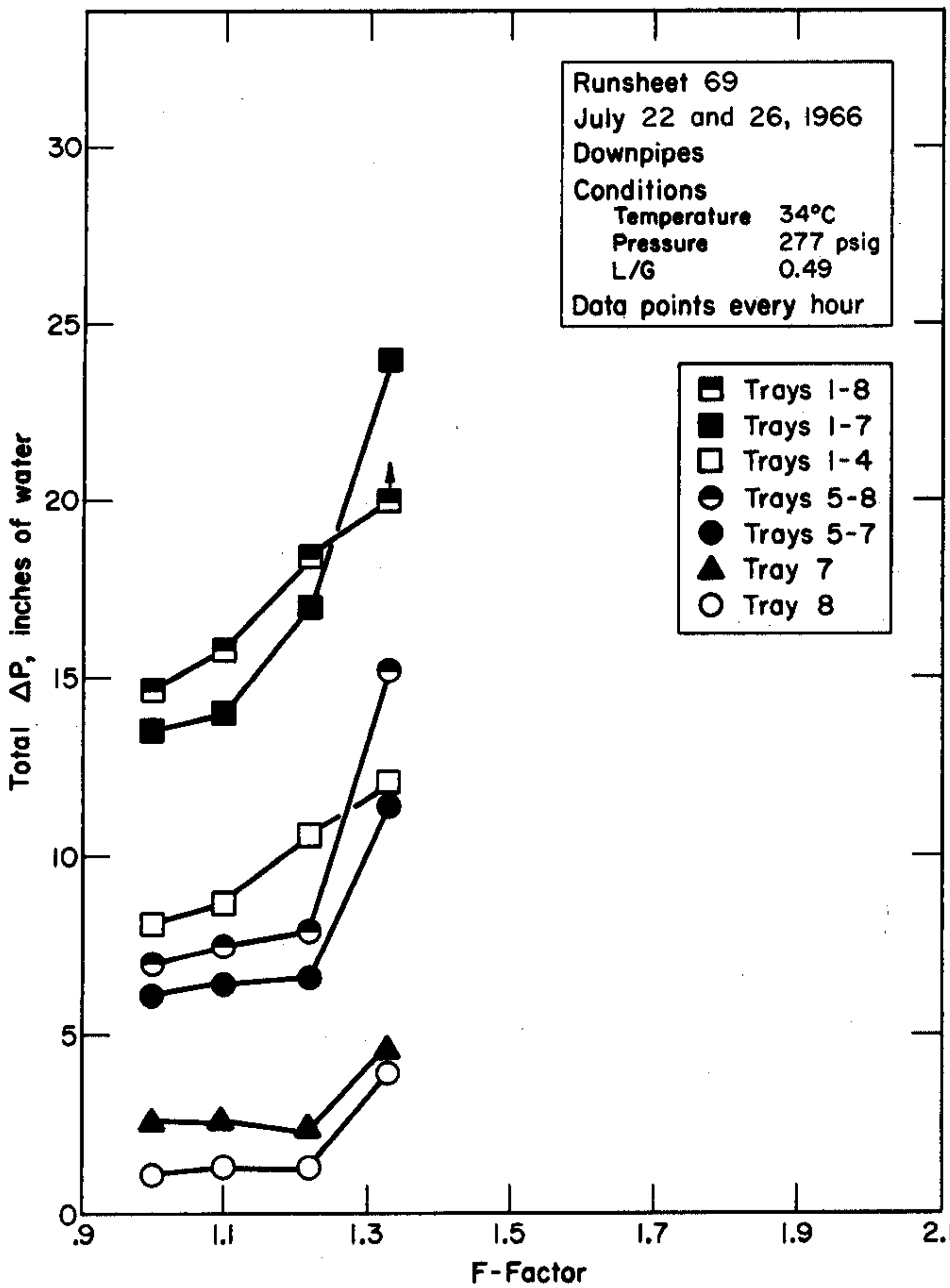

FIG. 8 COLD TOWER CONDITIONS WITHOUT SILICONE ANTIFOAM

Figure 9 Synopsis

Runsheets 71S and 72S

Tray stability limit: F-factor of 1.81

The test shown in Figure 6 was repeated eight days later when feedwater quality, though erratic, was beginning to improve. Flooding occurred as flows were increased above an F-factor of 1.81. At flooded conditions (an F-factor of 1.87) entrainment from tray 3 to tray 4 was 2.86 mols water per 100 mols gas.

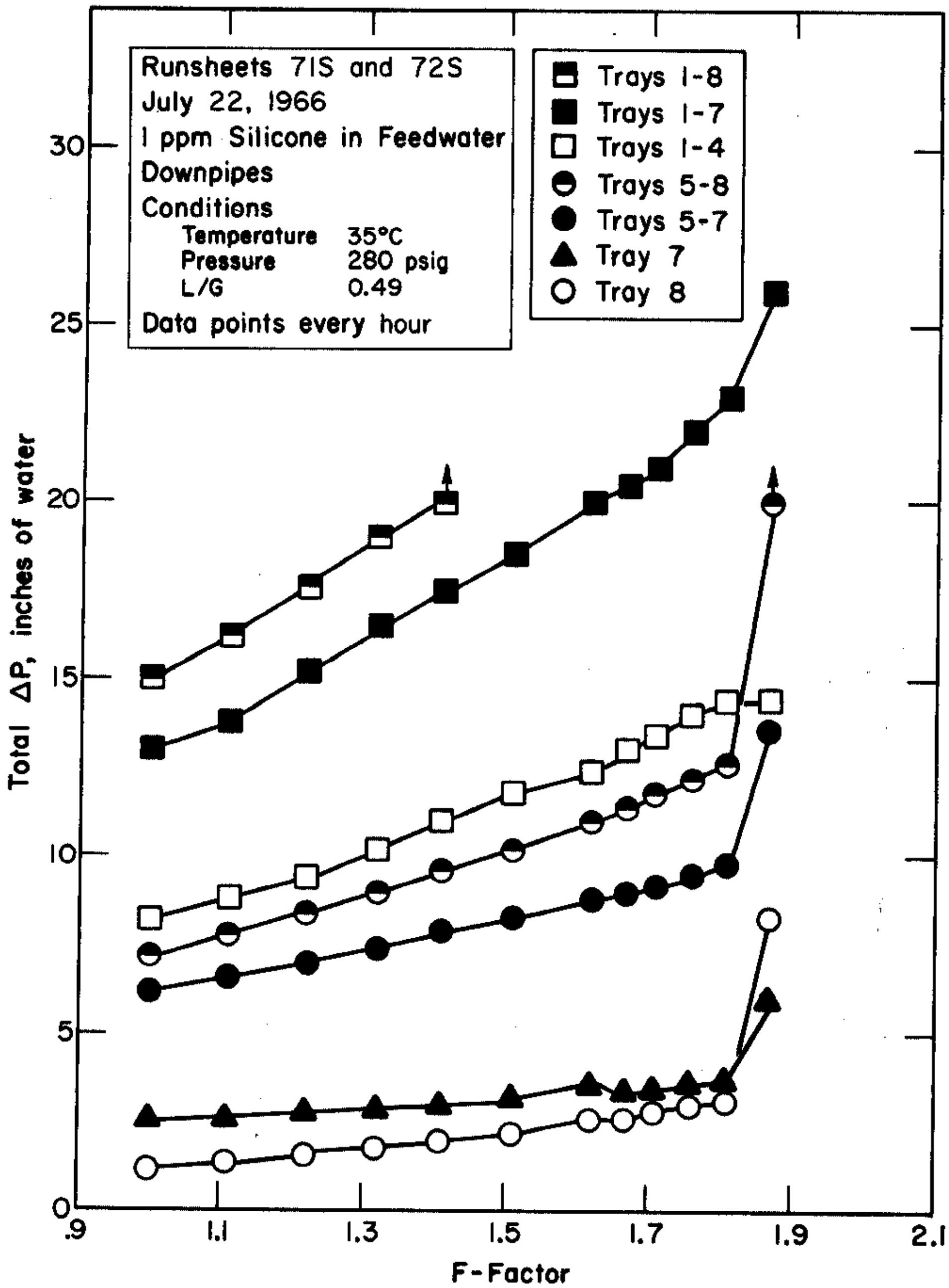

FIG. 9 COLD TOWER CONDITIONS WITH SILICONE ANTIFOAM

Figure 10 Synopsis

Runsheet 69S

The test shown in Figures 6 and 9 was repeated. No limit had been reached when the test was stopped at the end of the shift. The test was repeated on the following day (Figure 11).

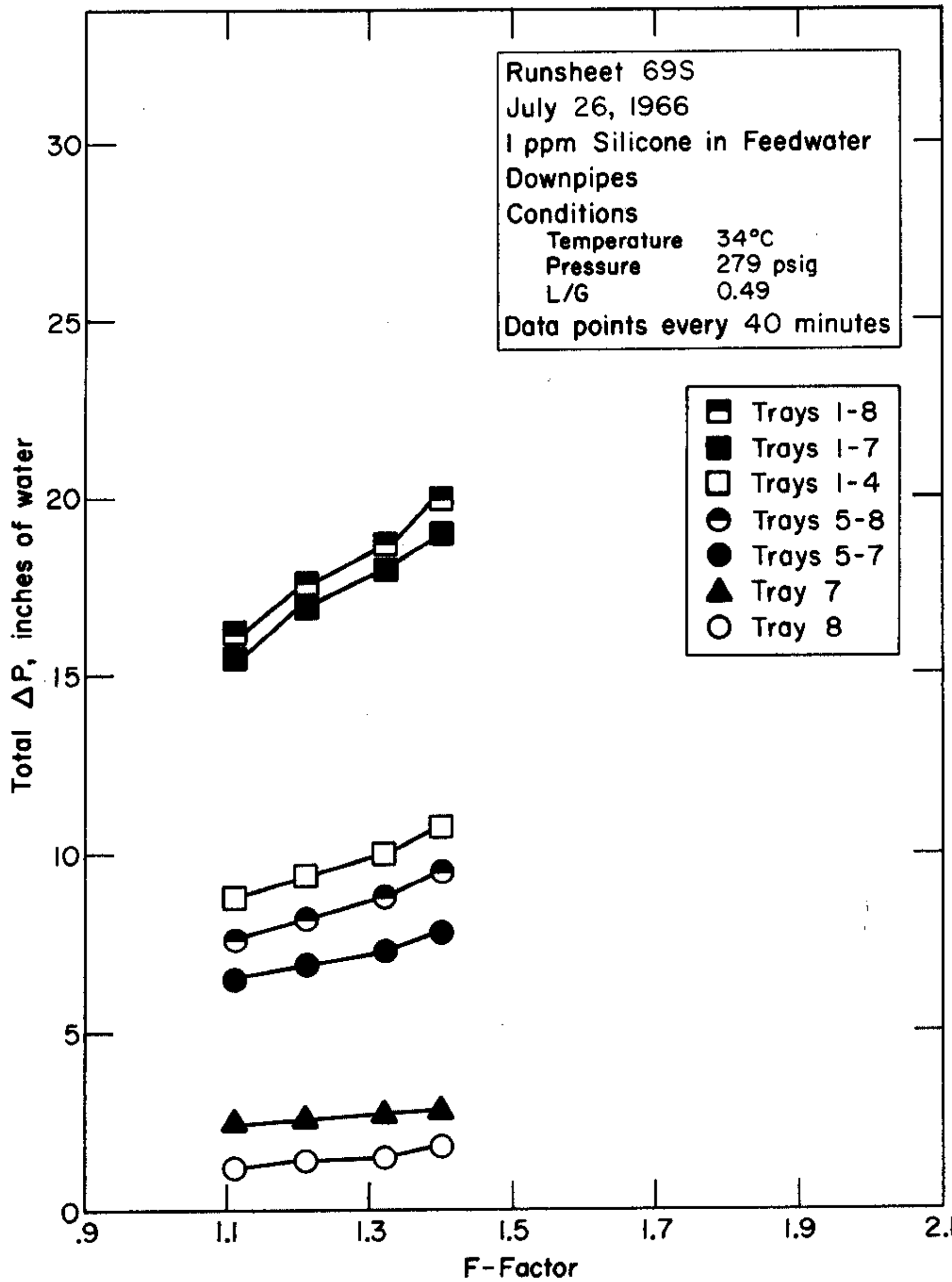

FIG. 10 COLD TOWER CONDITIONS WITH SILICONE ANTIFOAM

Figure 11 Synopsis

Runsheets 69-1/2S and 70-1/2S

Tray stability limit: F-factor of 1.77

The test shown in Figures 6 and 9 was repeated. Calibrations of gas and liquid flowmeters and ΔP instruments had been verified during the time between the test shown in Figure 9 and this test. Agreement with the data shown in Figure 9 is excellent, indicating reproducible stable operation at GS cold tower conditions up to an F-factor of about 1.8. At flooded conditions, F-factor of 1.83, entrainment was 1.01 mols water per 100 mols gas.

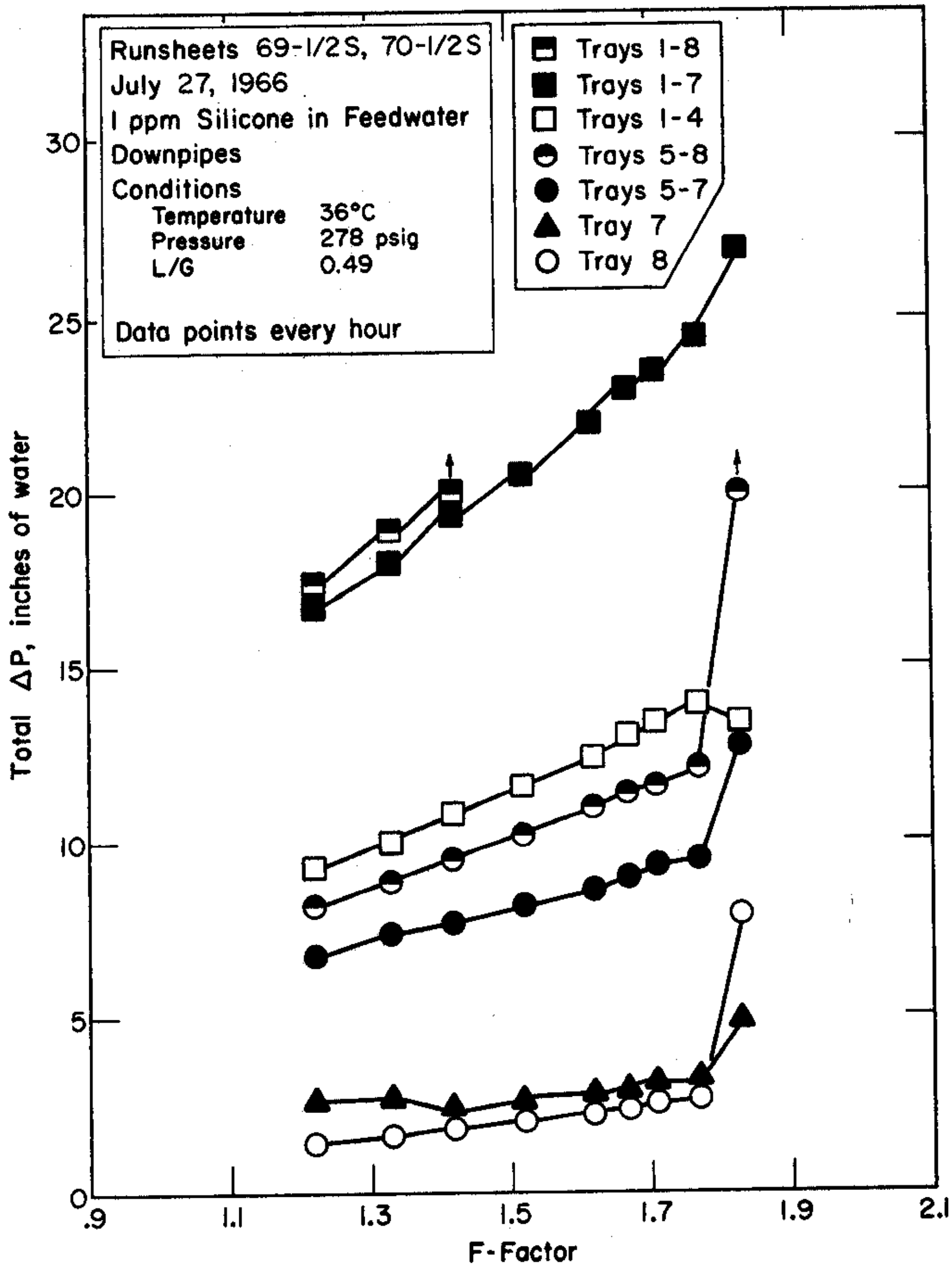

FIG. 11 COLD TOWER CONDITIONS WITH SILICONE ANTIFOAM

Figure 12 Synopsis

Runsheet 56

Tray stability limit: 110 gpm

Gas flow was held constant at an F-factor of 1.22 and temperature of 36°C while increasing liquid flow every 1-1/2 hours. Entrainment at 102 gpm (L/G = 0.49) was 0.14 mol water per 100 mols gas. Entrainment at flooding (114 gpm, L/G = 0.55) was 0.63 mol water per 100 mols gas.

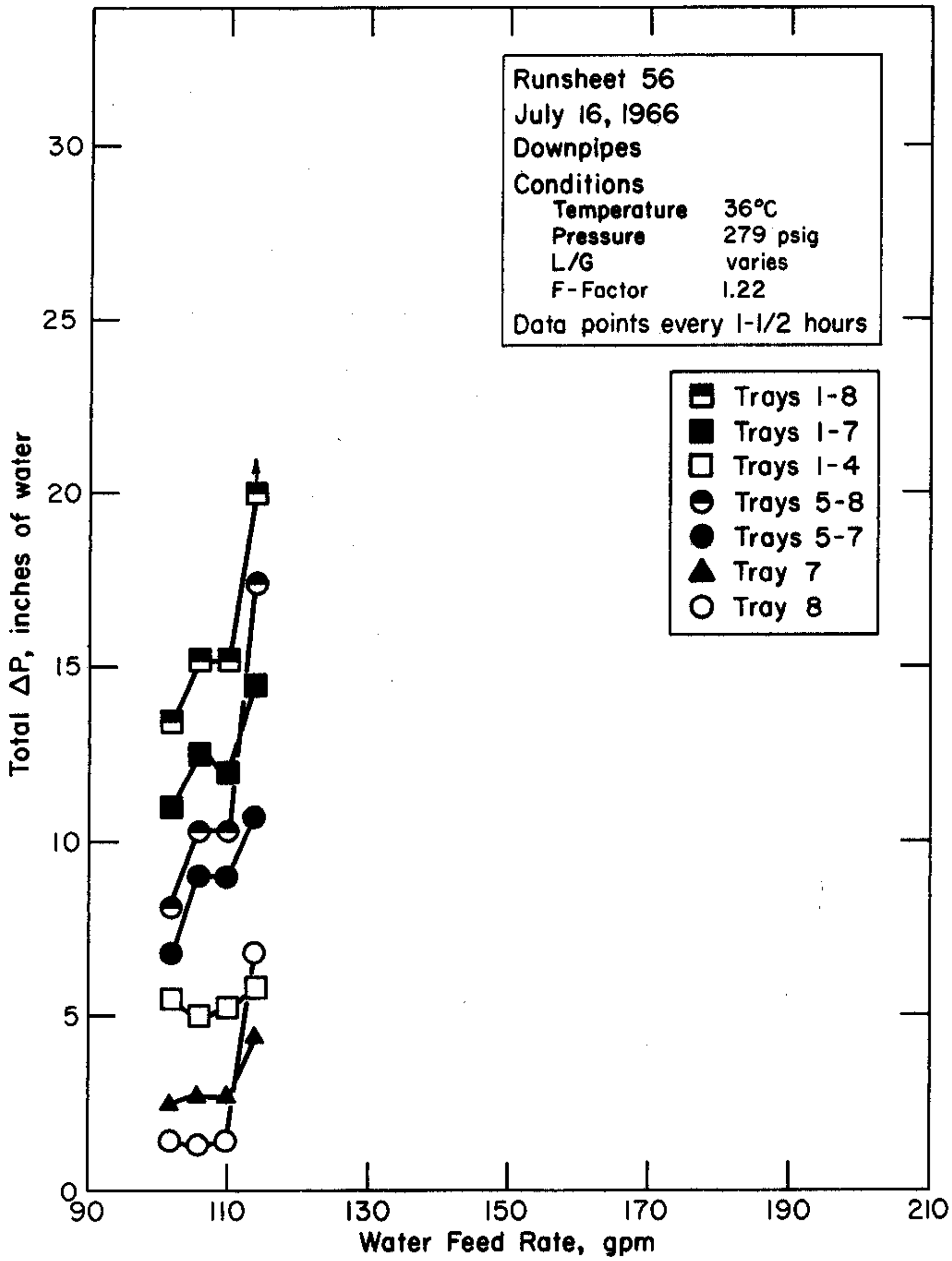

FIG. 12 LIQUID FLOW CAPACITY AT F-FACTOR 1.22
WITHOUT SILICONE ANTIFOAM

Figure 13 Synopsis

Runsheets 56S, 57S, and 58S

Liquid flow capacity: 178 gpm

This test was similar to that shown in Figure 12 (increasing liquid flow with the F-factor constant at 1.22 and temperature constant at 36°C) except that 1 ppm silicone was added to the feedwater. No flooding occurred. Liquid flow capacity was limited by the 1-1/2" control valve (LRC-7) in the 3" effluent water line. Entrainment was not measured. The increase in stable flow over that attainable in Figure 12 (Runsheet 56) is attributed to the silicone addition and an improvement in feedwater quality during the 24-hour interval between the two tests.

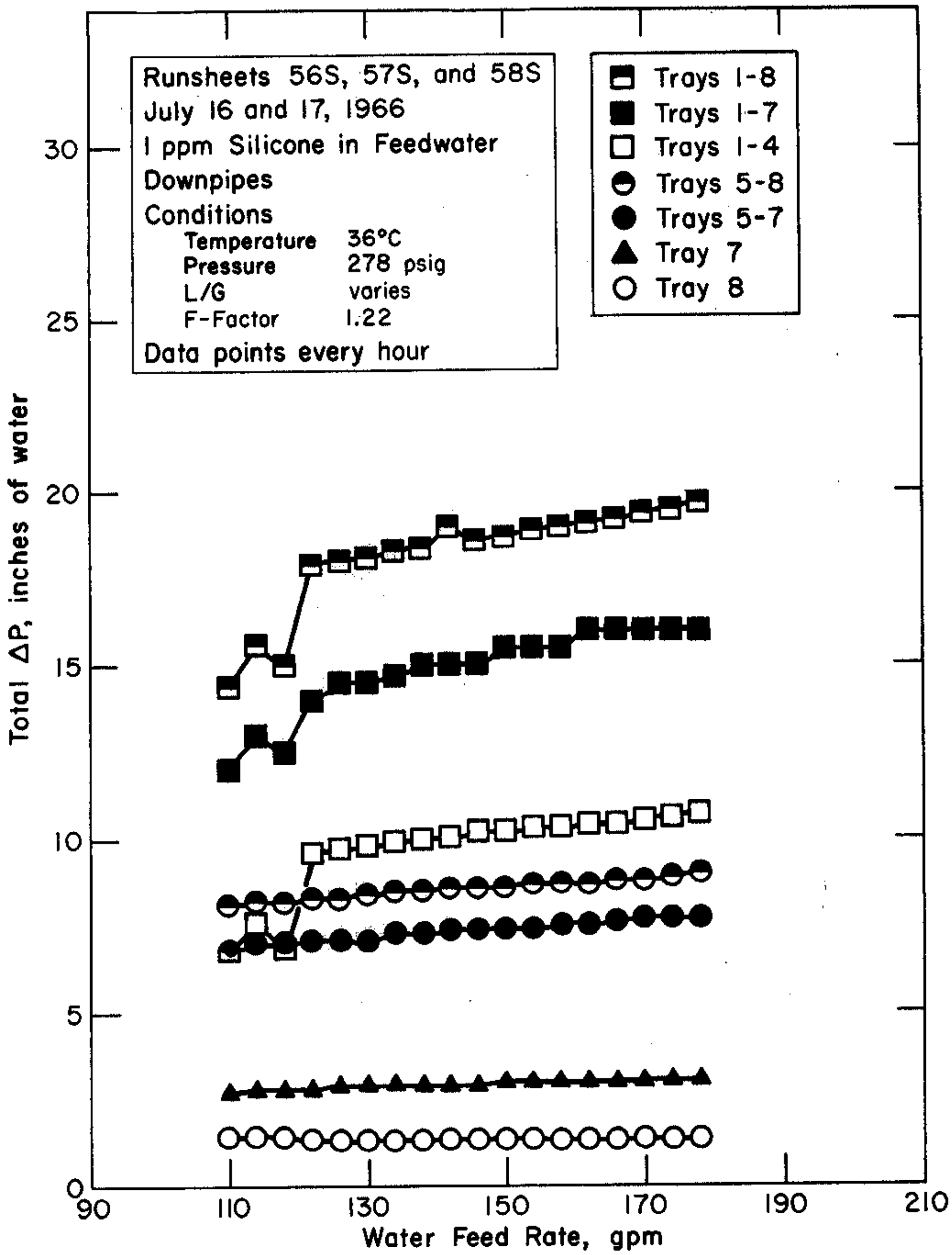

FIG. 13 LIQUID FLOW CAPACITY AT F-FACTOR 1.22
WITH SILICONE ANTIFOAM

Figure 14 Synopsis

Runsheets 59 and 60

Tray stability limit: 116 gpm

Gas flow was held constant at an F-factor of 1.40 and temperature of 33°C while increasing liquid flow every hour. Entrainment at flooding (120 gpm, L/G = 0.49) was 0.29 mol water per 100 mols gas.

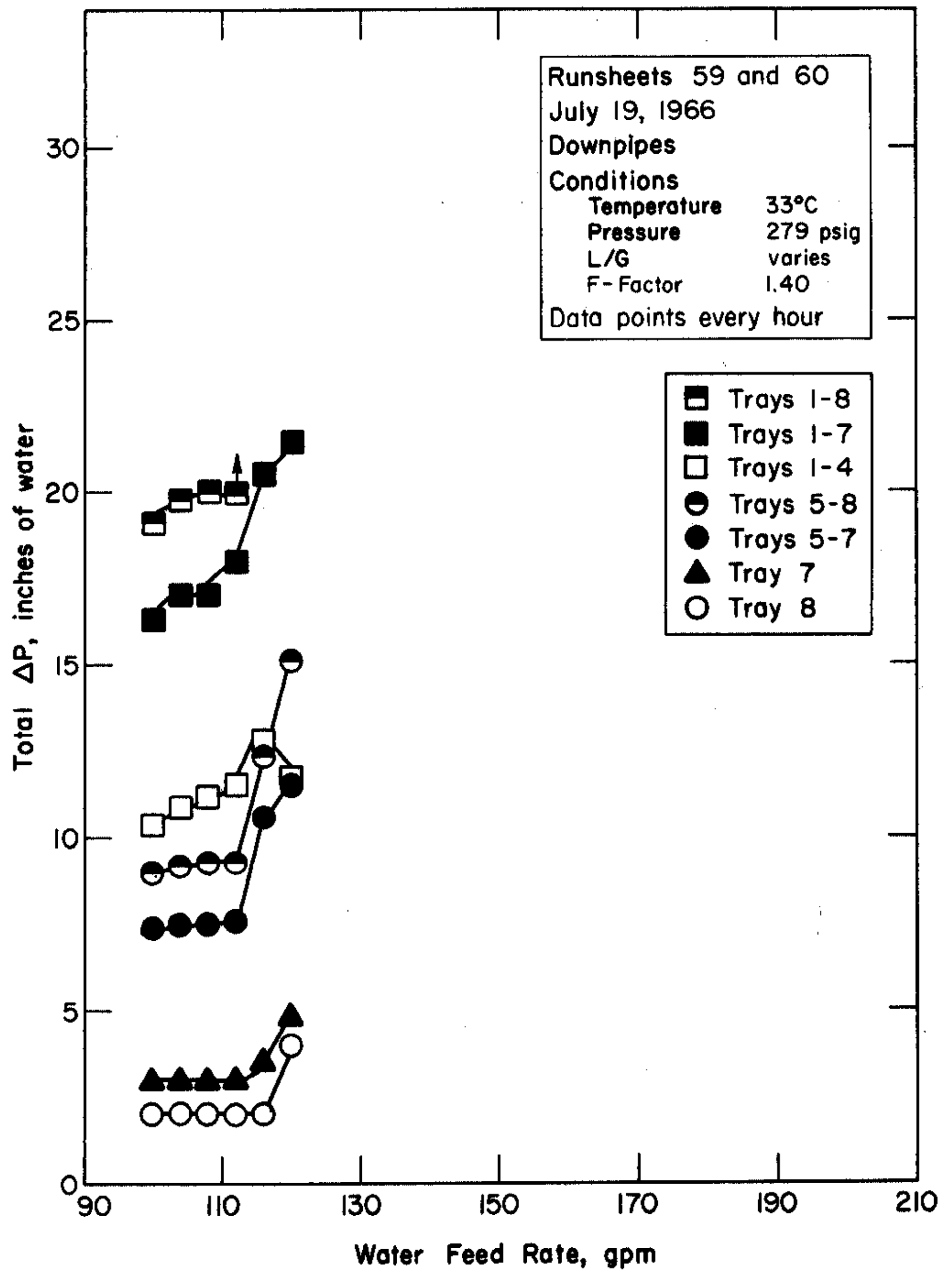

FIG. 14 LIQUID FLOW CAPACITY AT F-FACTOR 1.40
WITHOUT SILICONE ANTIFOAM

Figure 15 Synopsis

Runsheets 59S and 60S

Tray stability limit: 128 gpm

This test was made immediately after the one shown in Figure 14 (Runsheets 59 and 60). The two tests were similar except that in this test 1 ppm silicone was added to the feedwater. The 12 gpm increase in liquid capacity is attributed to the silicone antifoam. Entrainment at flooding (132 gpm, L/G = 0.57) was 1.63 mols water per 100 mols gas.

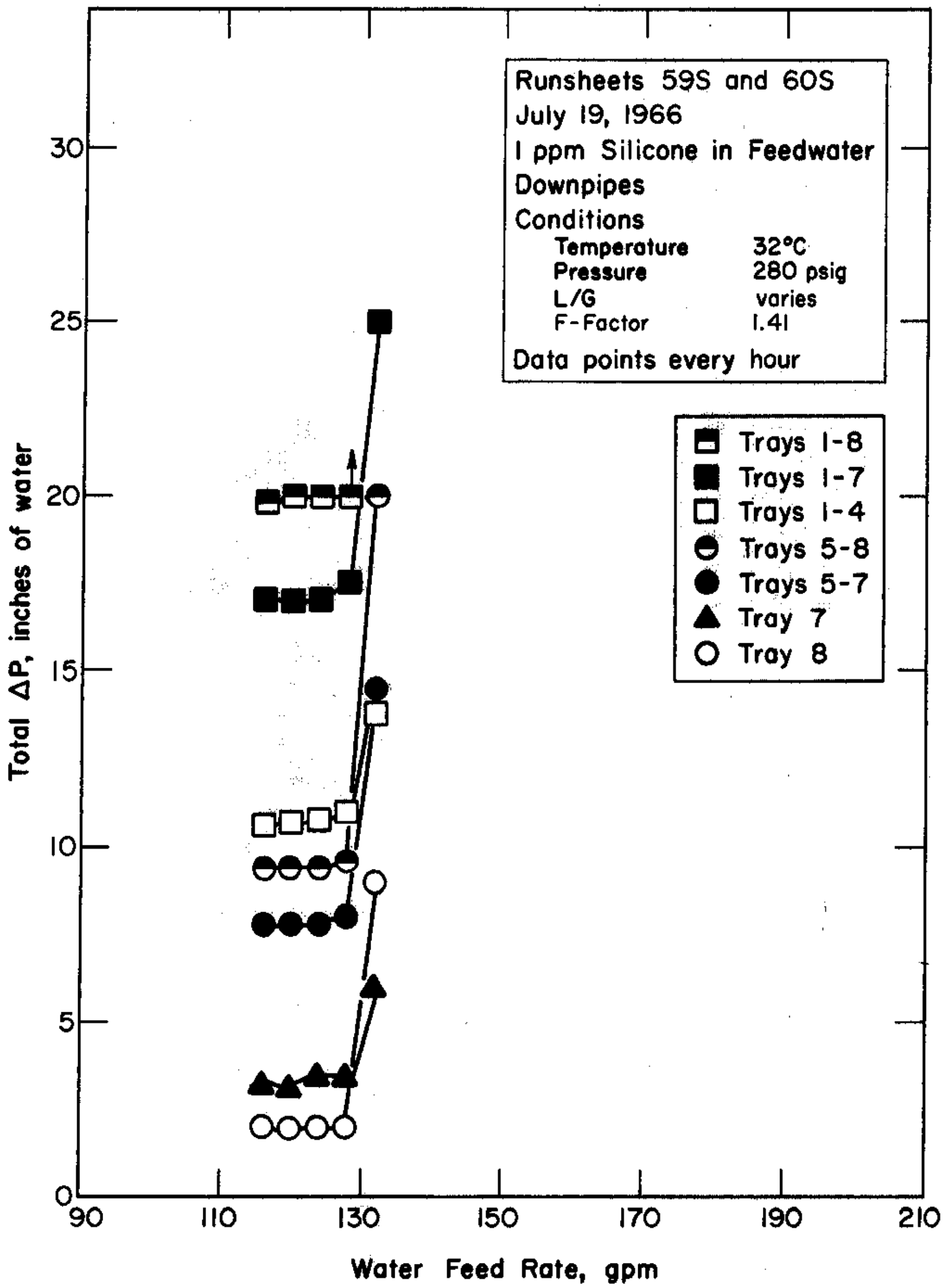

FIG. 15 LIQUID FLOW CAPACITY AT F-FACTOR 1.41 WITH SILICONE ANTIFOAM

Figure 16 Synopsis

Runsheet 59-1/2S

Liquid flow capacity: 184 gpm

This test was a repeat of the test shown in Figure 15 (Runsheets 59 S and 60 S) made 10 days later after feedwater quality had improved. In this test, tray capacity was not attained because liquid flow was limited by the effluent control valve as in Figure 13. The agreement between the liquid capacity demonstrated in this test and in Figure 13 (178 gpm) is within the accuracies of the liquid flowmeter and effluent control valve.

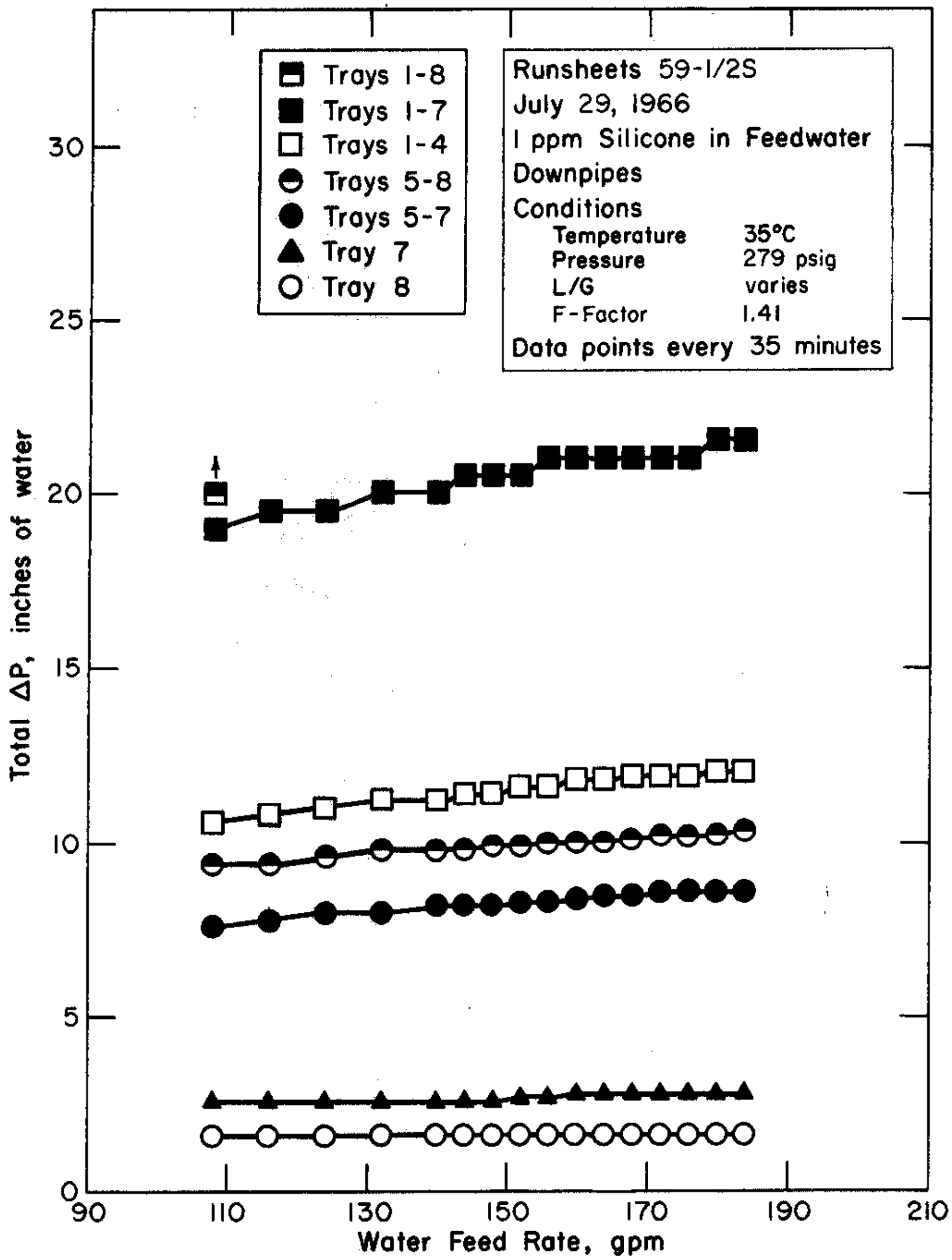

FIG. 16 LIQUID FLOW CAPACITY AT F-FACTOR 1.41 WITH SILICONE ANTIFOAM

Figure 17 Synopsis

Runsheet 62

Tray stability limit: 104 gpm

Gas flow was held constant at an F-factor of 1.62 and temperature of 34°C while increasing liquid flow every 1-1/2 hours. Entrainment at flooding (108 gpm, L/G = 0.39) was 1.07 mols water per 100 mols gas. Flooding began when liquid flow was first increased to 108 gpm, but subsided before final ΔP and entrainment measurements were taken.

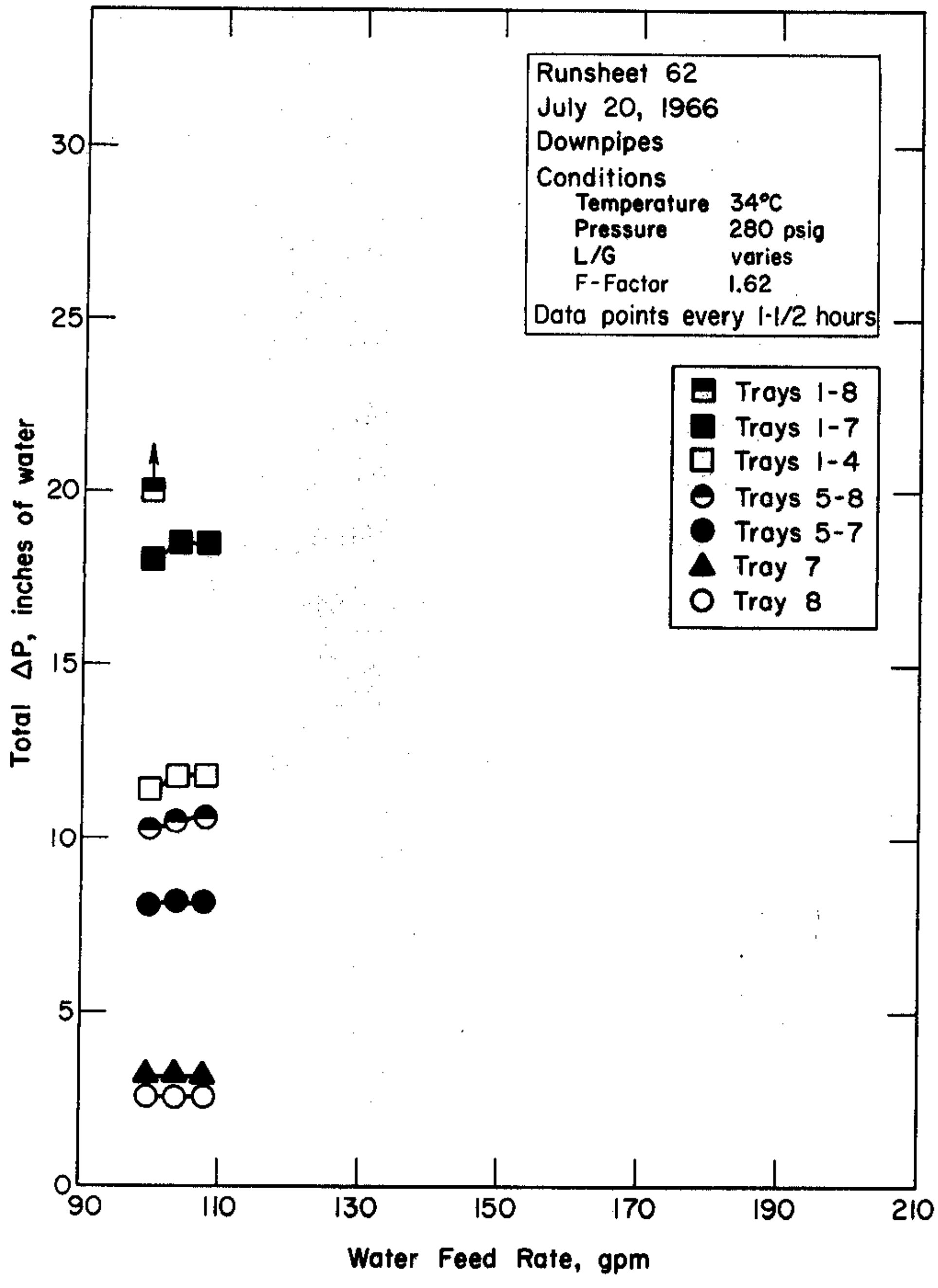

FIG. 17 LIQUID FLOW CAPACITY AT F-FACTOR 1.62
WITHOUT SILICONE ANTIFOAM

Figure 18 Synopsis

Runsheets 62S and 63S

Tray stability limit: 132 gpm

This test was made immediately after the one shown in Figure 17. The two tests were similar except that in this one, 1 ppm silicone was added to the feedwater. The 28 gpm increase in maximum stable liquid flow is attributed to the silicone antifoam and a possible improvement in feedwater quality. Entrainment at flooding (136 gpm, L/G = 0.49) was 1.42 mols water per 100 mols gas.

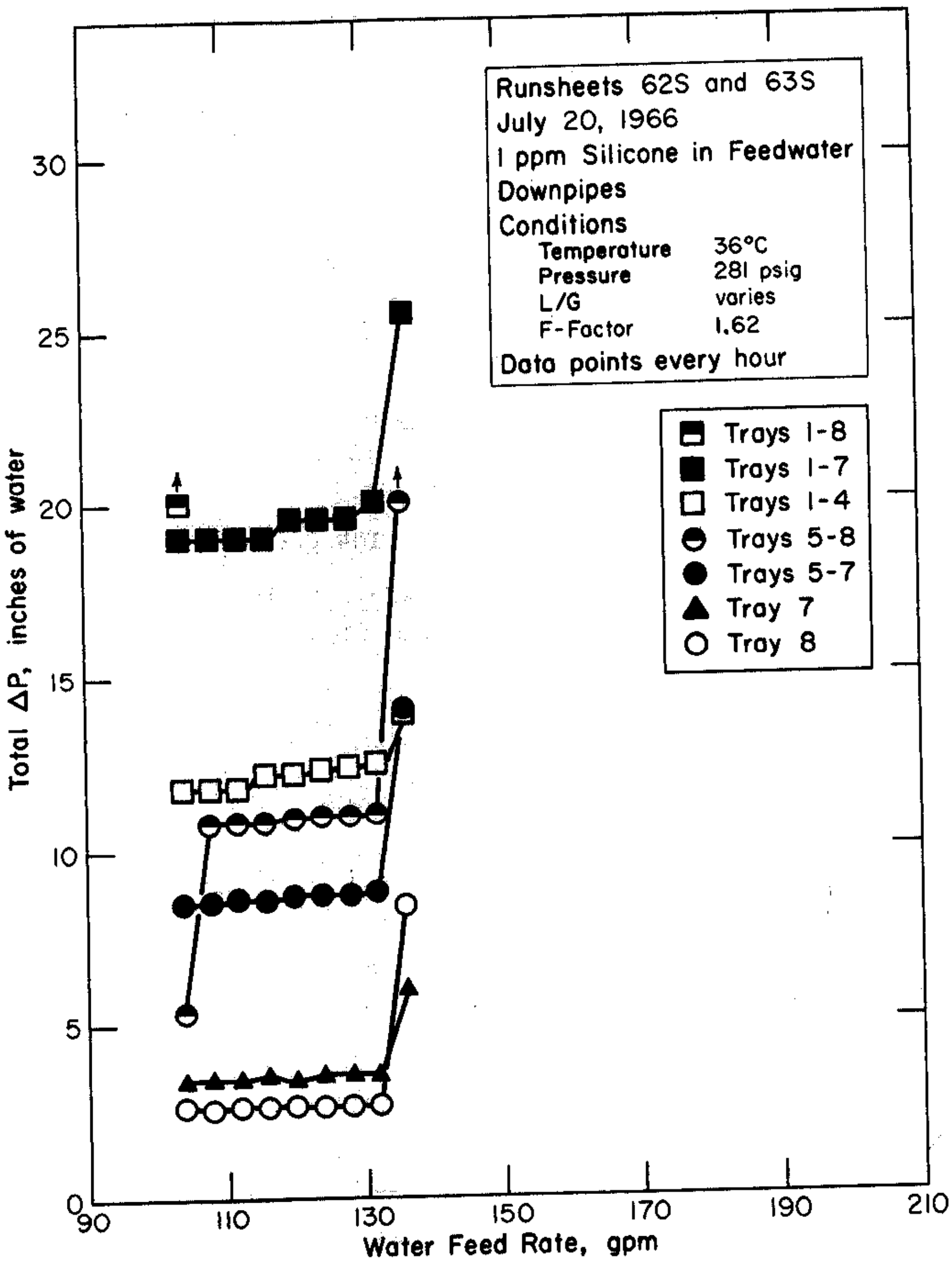

FIG. 18 LIQUID FLOW CAPACITY AT F-FACTOR 1.62 WITH SILICONE ANTIFOAM

Figure 19 Synopsis

Runsheet 65

Tray stability limit: 104 gpm

Gas flow was held constant at an F-factor of 1.81 and temperature at 34°C while increasing liquid flow every hour. Entrainment was not measured.

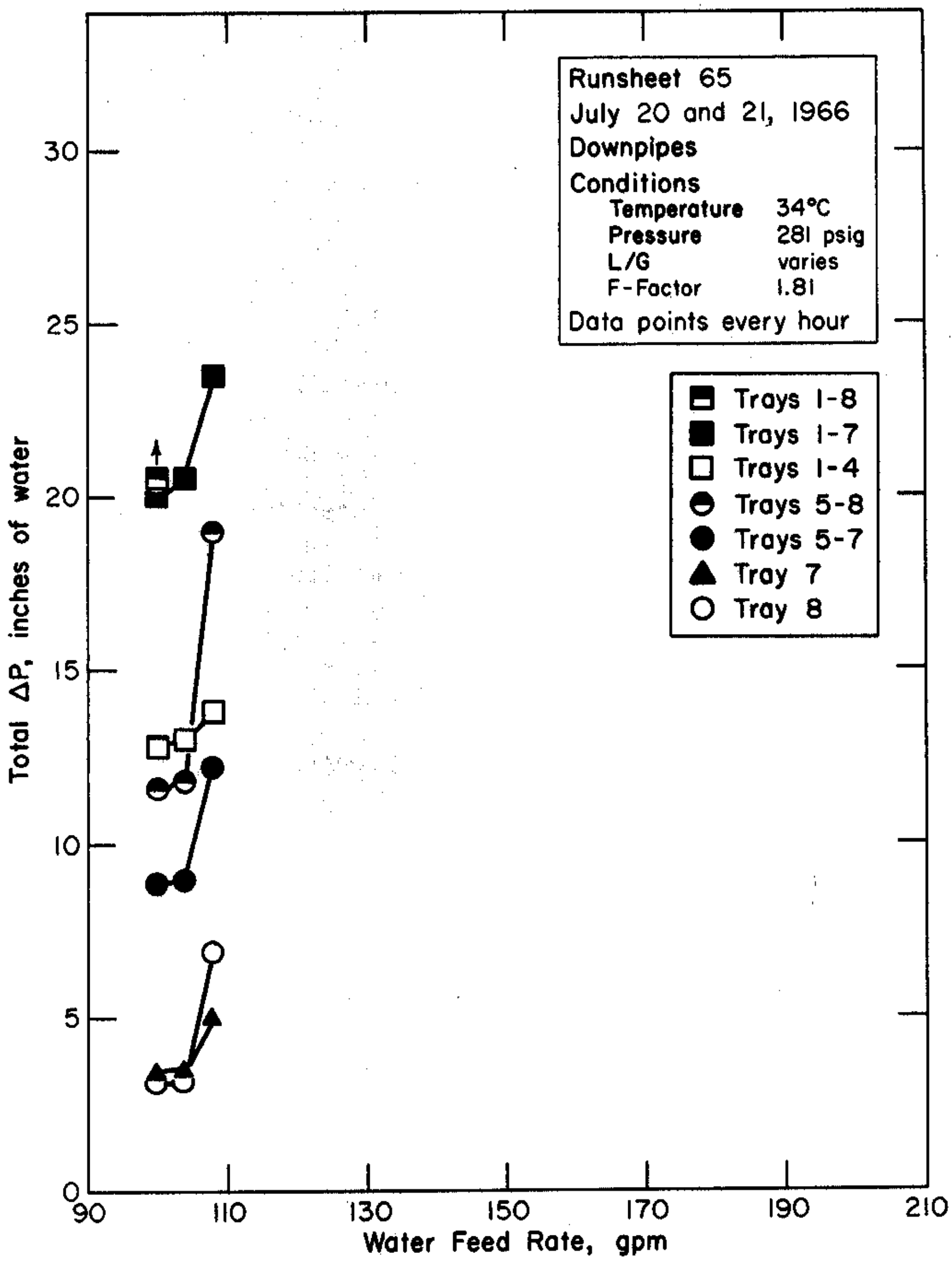

FIG. 19 LIQUID FLOW CAPACITY AT F-FACTOR 1.81 WITHOUT SILICONE ANTIFOAM

Figure 20 Synopsis

Runsheets 65S, 66S, and 67S

Tray stability limit: 148 gpm

The test shown in Figure 19 was repeated immediately with 1 ppm silicone in the feedwater. The 44 gpm increase in maximum stable liquid flow is attributed to the silicone antifoam and an improvement in feedwater quality over the 12-hour period of the test. Stable operation was maintained up to a liquid flow of 148 gpm (L/G = 0.47); flooding occurred at a liquid flow of 152 gpm (L/G = 0.49). This was the first indication that stable operation could be maintained at GS cold tower conditions (L/G about 0.50) at F-factors around 1.8. Entrainment at flooding was 1.56 mols water per 100 mols gas.

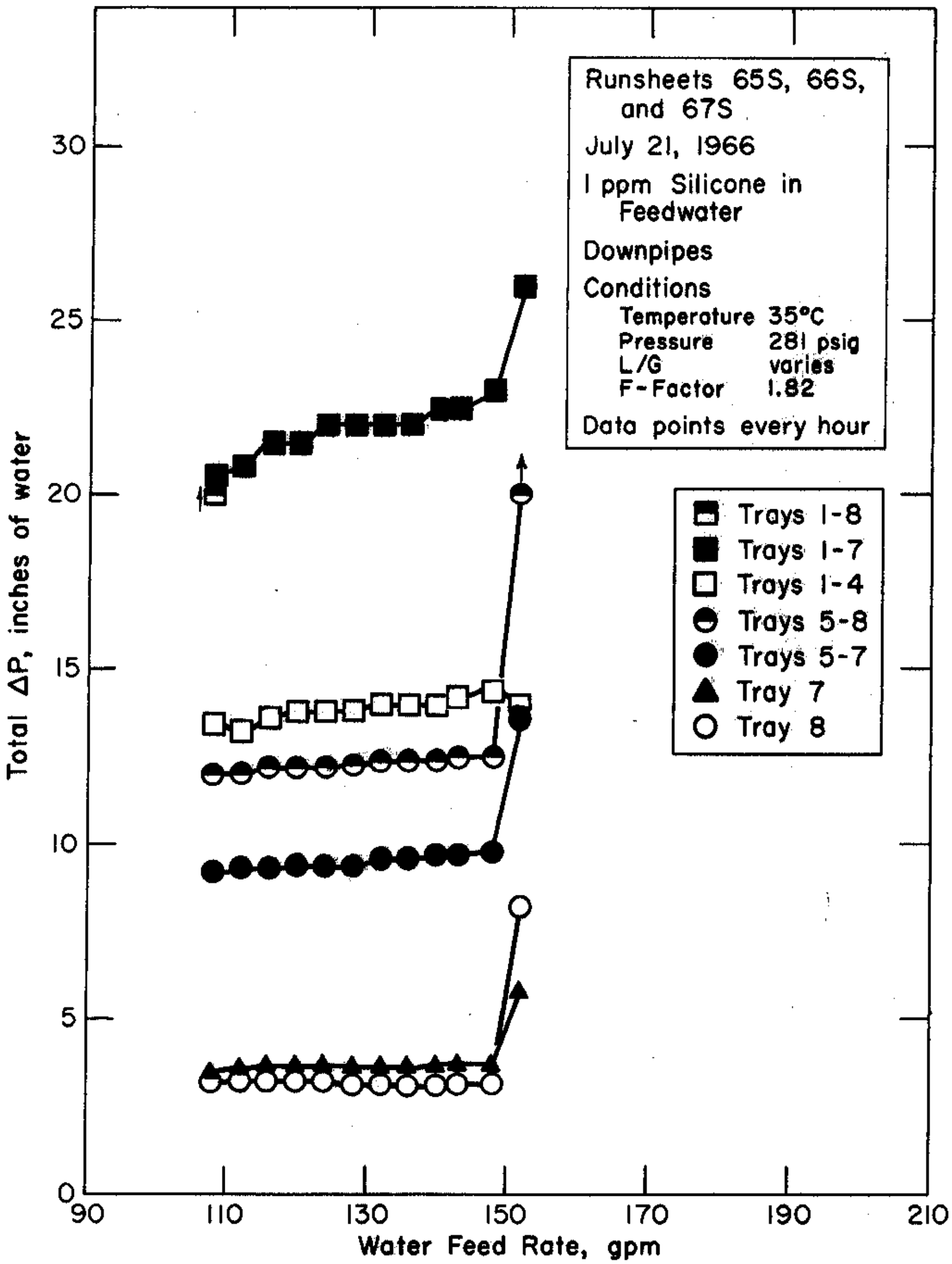

FIG. 20 LIQUID FLOW CAPACITY AT F-FACTOR 1.82 WITH SILICONE ANTIFOAM

Figure 21 Synopsis

Runsheets 73S and 74S

Tray stability limit: F-factor of 1.50

Liquid flow was held constant at 160 gpm and temperature at 36°C while increasing gas flow every hour. One ppm silicone was added to the feedwater. ΔP's were measured before each flow increase. Entrainment was not measured. Stable operation was maintained up to an F-factor of 1.50 ($L/G = 0.60$).

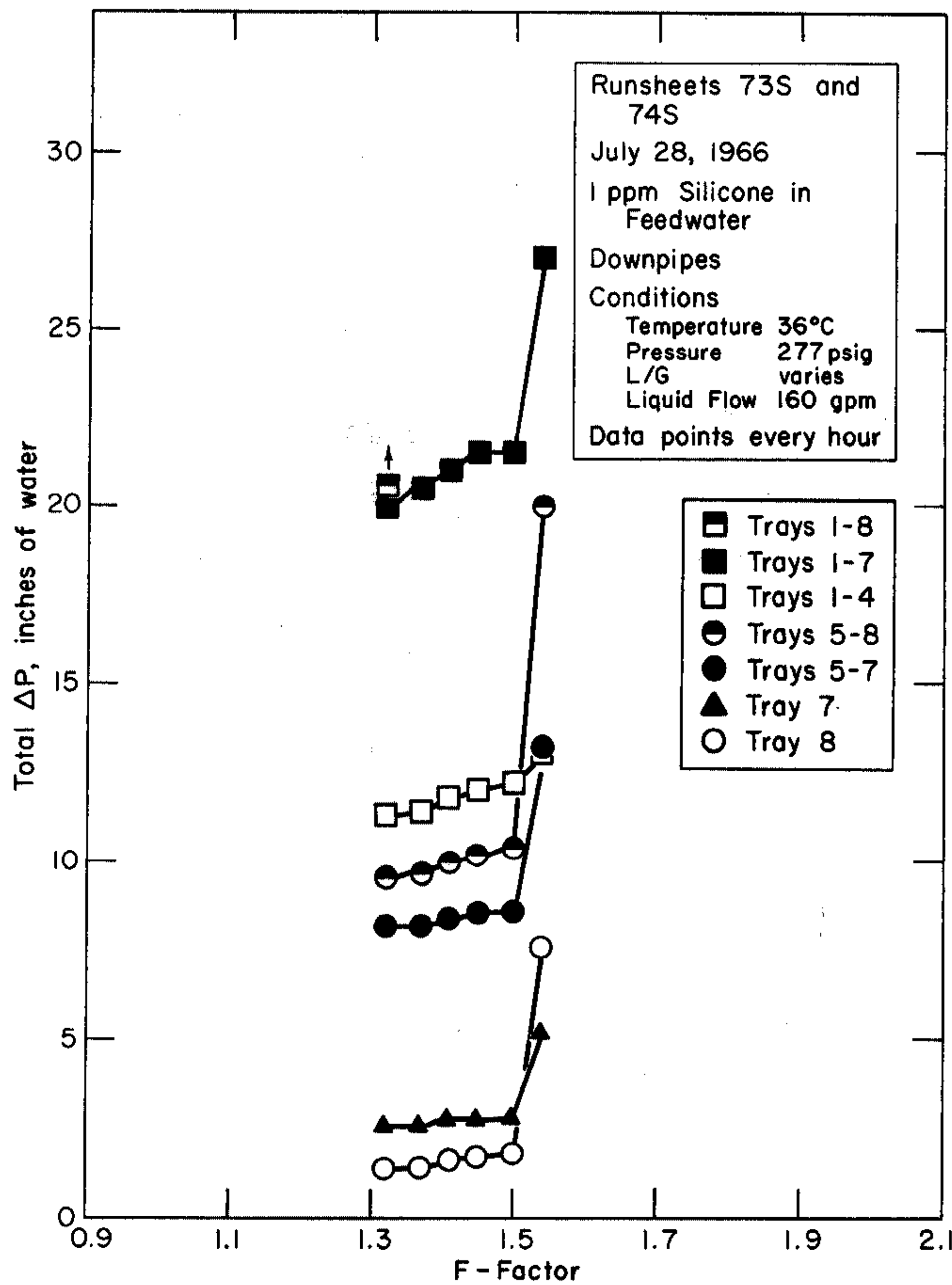

FIG. 21 GAS FLOW CAPACITY, 160 gpm LIQUID FLOW WITH SILICONE ANTIFOAM

Figure 22 Synopsis

Runsheets 76S and 77S

Tray stability limit: F-factor of 1.67

Liquid flow was held constant at 170 gpm and temperature at 36°C while gas flow was increased every 35 minutes. One ppm silicone was added to the feedwater. ΔP's were measured before each flow increase. Entrainment was not measured. Stable operation was maintained up to an F-factor of 1.67 (L/G = 0.58).

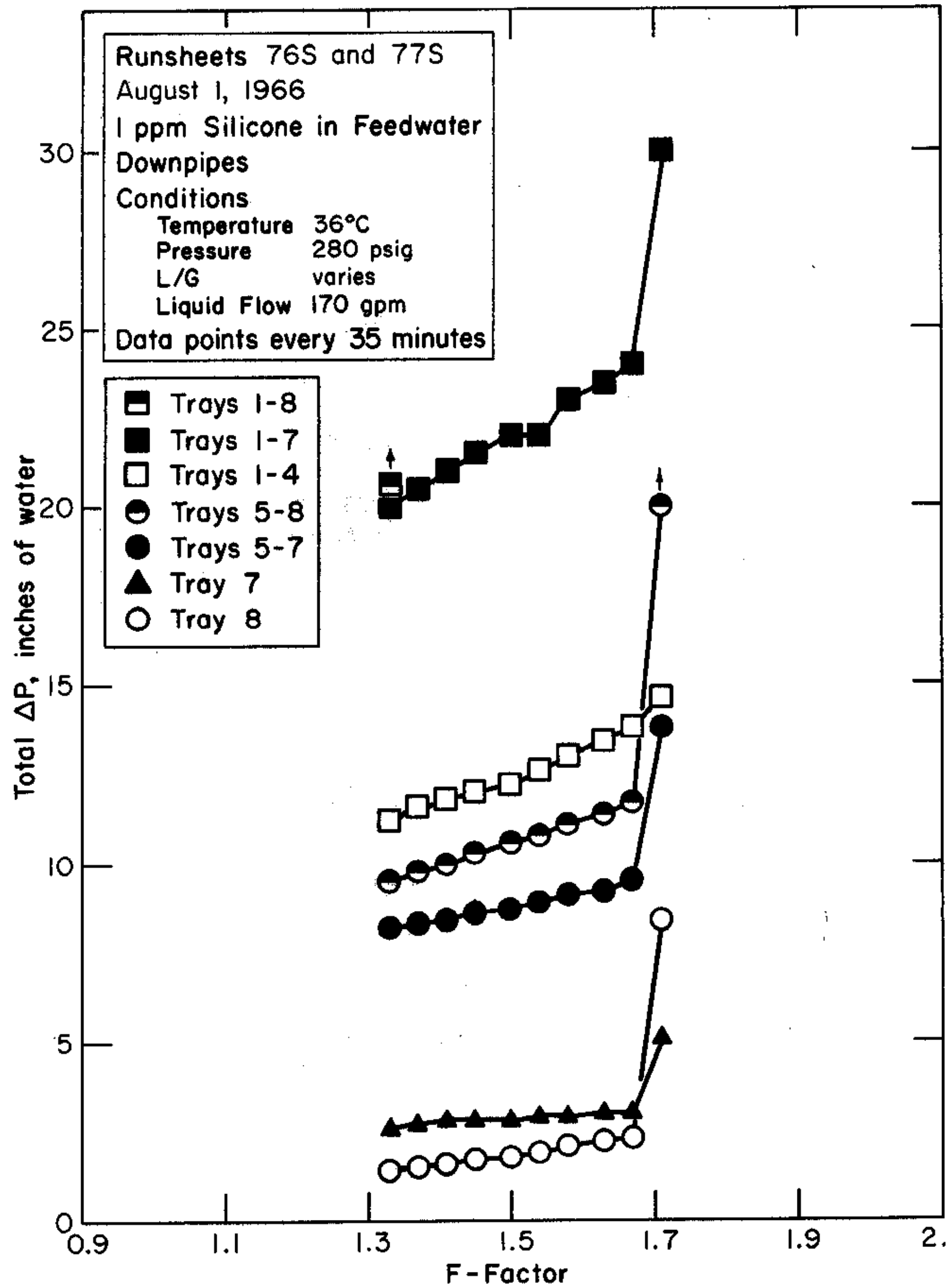

FIG. 22 GAS FLOW CAPACITY, 170 gpm LIQUID FLOW WITH SILICONE ANTIFOAM

Figure 23 Synopsis

Runsheet 52

Flows were increased every two hours while maintaining process-optimum L/G at hot tower conditions. Fluorescein was injected continuously. Effluent liquid from trays 3 and 4 was sampled for dye analysis and ΔP's were recorded just before increasing flows to the next set of conditions. The run was terminated because the gas flow control valve (FRCp-2) would not open completely. Based on previous data, blower capacity at an F-factor of about 1.6 was expected at this temperature and pressure.

Both ΔP instruments (trays 1-7 on one; trays 1-4, 5-7, 5-8, 8, and 7 on the other) confirmed the decrease in ΔP across trays 1-4 as flows increased. Because a sticking gas flow control valve terminated the run prematurely, it is possible that gas flows were erratic throughout this particular test.

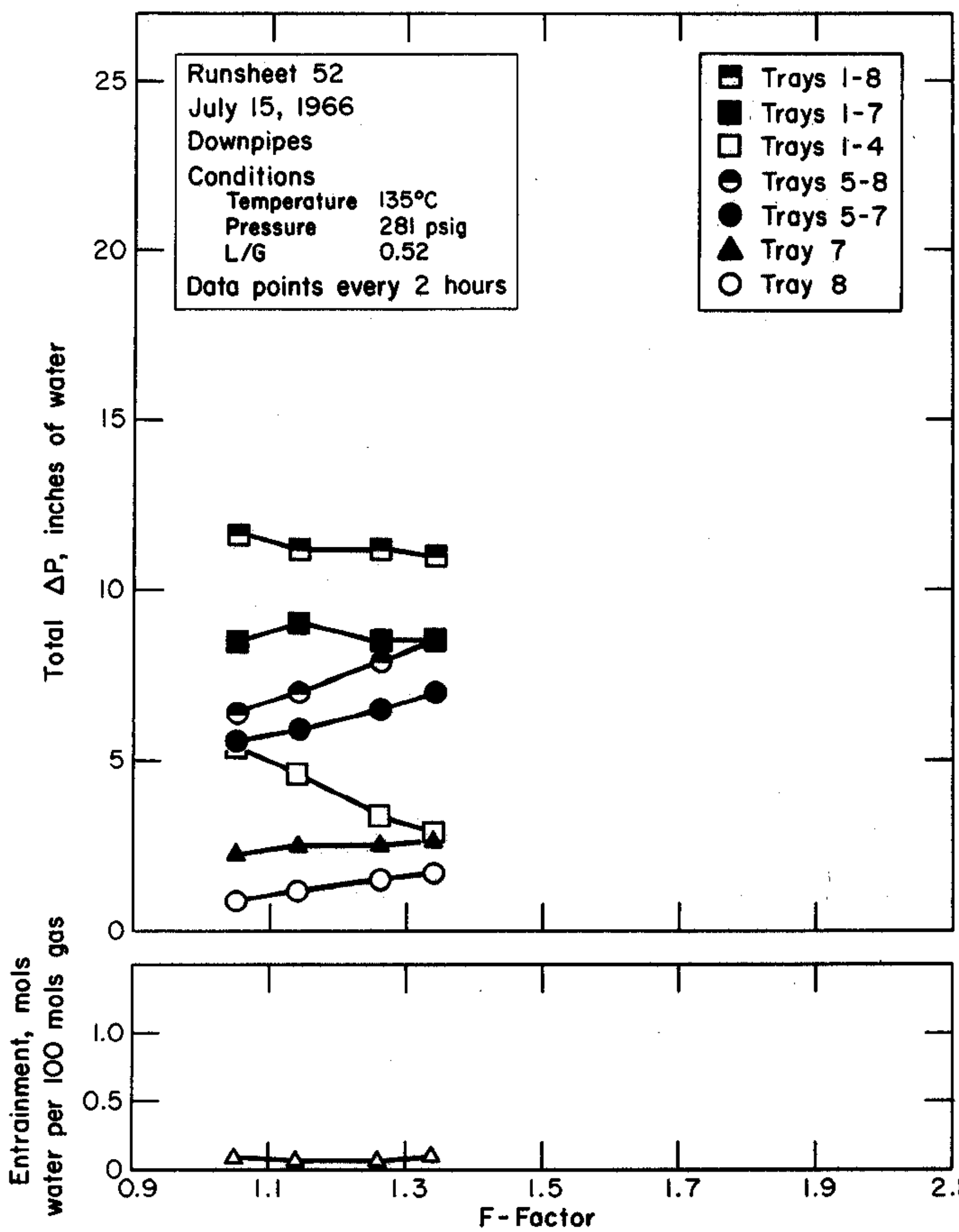

FIG. 23 HOT TOWER CONDITIONS WITHOUT SILICONE ANTIFOAM