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M E M O R A N D U M

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STEAM TRANSFER JET TEST RESULTS WITH SIMULATED SLUDGE SLURRIES

Introduction and Summary

In the SRP Waste Removal Program, special long-shafted transfer pumps will be used to pump the sludge layer from old waste tanks. Although the pumps operate well with sludge, they have a high first cost and potential for mechanical problems. Also, maintenance and pump movement between tanks will result in increased radiation exposure to personnel. To eliminate or minimize the above problems, steam transfer jets have been proposed as an alternative for slurry removal. Although jets are used routinely in the tank farm, they have never been used with sludge slurries. As a result, a study was conducted to determine the performance of two jets (designated as D and F) with simulated sludge slurries. The effects of steam pressure, sludge temperature, rheology, and submergence on jet operation were examined. In this report, results from jet performance tests with simulated sludge slurries are presented.

Introduction and Summary (contd)

Characteristic head versus flow curves were developed for each jet and are shown in Figures 3 through 21. Both kaolin clay and synthetic sludge slurries were used with the principal difference being the higher specific gravity of the synthetic sludge (1.4 vs 1.1 sp.g.). Results from tests with kaolin clay suggested the D-jet would meet tank discharge head requirements with a 1.4 sp.g. slurry. It was estimated the jet would develop discharge heads of 60 to 70 feet at 70 to 80 gallons per minute. In attempting to verify these results with 1.4 sp.g. synthetic sludge slurries jet operation was unstable and the above conditions could not be reached. Additional tests showed the upper limit for specific gravity and stable operation to be 1.2. The F-jet was found to operate on the borderline of tank head requirements with kaolin clay and was not tested further with synthetic sludge.

Thus, it is recommended that jets not be used for slurry removal if the specific gravity exceeds 1.25.

Introduction to Discussion

The SRP Waste Removal Program will retire 24 Type I, II, and IV waste tanks from service. As part of this program, the settled sludge layer in the tanks is slurried and transferred to newly built Type III tanks with long-shafted transfer pumps. Although these pumps provide adequate performance, their first cost and associated problems with tank top support and incremental lowering make them costly to use. Also, the high number of between tank transfers of these pumps and their maintenance will result in increased radiation exposure to personnel.

The above problems would be eliminated or reduced if steam transfer jets were substituted for the pumps. Steam jets offer the advantage of no moving parts, are easy to operate, and can be equipped with a telescoping option for incremental lowering. Jets are used on a routine basis in the tank farm for transferring waste between tanks. Because sludge rheology differs from that of other waste (supernate), jet performance could not be predicted from past experience.

Background

Two standard transfer jets (designated as D and F) were selected as the most promising candidates for slurry removal. In addition to developing performance curves, this study investigated three specific areas of jet operation. These were:

- o maximum discharge head
- o performance at low submergence levels, and
- o maximum slurry operating temperature.

Background (contd)

To be used for slurry removal jet performance must meet the minimum requirements of the above areas. The jets should be capable of developing discharge heads in excess of 40 ft. with a 1.4 sp.g. slurry. A discharge head of 40 ft. is needed to meet tank head requirements. Also, they should be capable of pumping the tank level down to a final heel of 1 to 2 inches. Jet performance is very sensitive to the temperature of the liquid being pumped. Therefore, a high slurry operating temperature is desirable. Past experience has shown unsatisfactory jet operation at liquid temperatures above 60°C.

Experimental

The Steam Transfer Jet Test Facility consisted of two process tanks, a rate drum, and associated piping (see Figure 1). When operating, sludge is transferred from the jet tank, through the rate drum, to the receiver tank. A return pump on the receiver tank was used to control the level in the jet tank. Both tanks were equipped with coils for controlling temperature and agitators for mixing. Flowrates were measured with a 40 gallon rate drum which contained viewports at 18 and 36 gallons. Discharge heads were measured with a 0-60 psig pressure gauge located approximatley 16 1/2 feet above the tank bottom (see Figure 2). The tank bottom was selected as an arbitrary reference and all discharge heads were corrected to it. Also, Figure 2 shows the two jet submergence levels (below and above the jet nozzle) that were tested.

A kaolin clay-water slurry was used in most of the tests as a simulant for actual sludge. Kaolin clay was used because its rheology could be easily controlled and it's temperature insensitive. At about 16 wt% kaolin (1.1 sp.g.) the slurry had a yield stress and consistency of 140 dynes/cm^2 and 12 cp, respectively. Results from the kaolin clay tests were adjusted to predict performance with a 1.4 sp.g. slurry. A 1.4 sp.g. synthetic sludge slurry was used to verify predicted jet performance with higher specific gravity materials. The synthetic slurry had a yield stress of 80 dynes/cm^2 and consistency of about 10 cp. Testing was made difficult due to constant slurry dilution and heat-up from steam condensation. Excess water was removed by either decanting or boiling.

Results

Characteristic head versus flow curves for the D and F jets as a function of steam pressure, sludge temperature, rheology, and jet submergence are shown in Figures 3 through 21. In general, the following relationships were seen to hold for both jets.

- o Discharge head is directly related to steam pressure.
- o Flowrate is inversely related to temperature, submergence, and yield stress.

Each figure lists the conditions and slurry characteristics that were tested. Ranges are reported for the yield stress and consistency reflecting slurry dilution from steam condensation as the run progressed. The dotted line portion of the jet curves represents a region of fluctuating performance which preceeds the jet's shutoff pressure.

D-jet Results

Performance curves for the D-jet with kaolin clay slurries are shown in Figures 3 through 17. If this data is adjusted for a 1.4 sp.g. slurry, the jet would be expected to develop 60 to 70 feet of head at flowrates of 70 to 80 gpm. The minimum steam pressure needed to meet tank head requirements was found to be 120 psi. Higher steam pressures (e.g., 130 psi) did not significantly improve jet performance (see Figures 7 through 9). Jet flowrate was found to decrease with increasing slurry temperature as shown in Figure 10. The shutoff temperature with kaolin clay for the jet is approximately 70°C with performance falling off abruptly above 65°C. Therefore, the jet's upper operating temperature is limited to approximately 60°C. Jet flowrate increased about 10% when the jet was submerged above the nozzle (see Figure 11). The jet operated well at all submergence levels, and is capable of pumping the tank level down to 1 to 2 inches. The effect of increasing yield stress is shown in Figures 12 through 17. As the yield stress was increased from 80 to 230 dynes/cm^2, jet flowrate was reduced by about 10%. The reduction in flowrate is attributed to increased suction resistance through the jet's 2 foot (3" diameter) suction leg. Although not determined, the upper yield stress limit is believed to be in the range of 250 to 275 dynes/cm^2. This is estimated from noise in the pressure readings at a yield stress of 230 dynes/cm^2 suggesting a slightly unstable flow. Yield stresses above 200 dynes/cm^2 are believed to exceed those of actual slurried sludge. Steam consumptions averaged approximately 1500 lb/hr at 120 psi. This results in a dilution factor of about 3.5%. For a jet flowrate of 80 gpm about 3 gpm would be water from condensed steam. This compares to a transfer pump water leakrate of 0.5 to 2.0 gpm. (Cooling water is used in the pumps to lubricate the shaft and bearings.)

D-jet Results (contd)

To determine performance with higher specific gravity materials, the D-jet was tested with a 1.4 sp.g. synthetic sludge slurry. These tests were run to verify results obtained from the kaolin clay tests. The increased specific gravity is believed to be the principal difference between the two slurries. No performance curves were developed with the jet and synthetic sludge because flowrates could not be measured. The sludge coated the viewports of the rate drum preventing flowrate measurements. In general, jet performance was poor. The predicted performance from the kaolin clay tests could not be obtained. In addition, the maximum slurry operating temperature was seen to drop to 50°C. Flowrates appeared to be in the range of those (approx. 70 gpm) obtained with kaolin clay. Stable discharge pressures sufficient to meet tank head requirements were not obtained. But, the jet will operate at lower discharge pressures in the range of 30 to 40 feet. Apparently, high discharge pressure and the increased specific gravity place the jet in a region of unstable operation. When the specific gravity of the slurry was reduced to about 1.2, jet operation became stable. This was done by continuously running the jet to dilute the slurry and noting when jet operation became stable.

F-jet Results

Results from tests completed with the F-jet (see Figures 18 through 21) indicated the jet to be on the borderline of meeting tank head requirements. Again, adjusting for a 1.4 sp.g. slurry the jet will deliver head of 40 to 50 feet at flowrates of approximately 150 to 170 gpm. Discharge heads in this range would just satisfy the 40 foot head requirement with relatively no excess head for line losses or safety factor. The shutoff temperature for the jet was found to be 70°C. As with the D-jet, the upper operating temperature is limited to approximately 60°C. The jet is capable of operating at tank levels down to 1 to 2 inches although there is a small decrease in developed head at this level. Steam consumption averaged approximately 2500 lb/hr at 120 psi.

Experimental Error

The major error in these tests was connected with the measurement of jet flowrates. This can be seen from the scatter of data in Figures 3 through 21. Flowrates were measured with a 40 gallon rate drum and a stopwatch. Due to kaolin buildup on the drum viewports, the measurable volume was reduced to 18 gallons. The small volume coupled with errors in visually timing the drum as it filled lead to an estimated error of $\pm$ 4%. For a flowrate of 80 gpm this results in an error of $\pm$ 3 gpm. The steady drop off in flowrate at low discharge heads in many of the figures (for example see Figure 7) is attributed to increasing slurry

Experimental Error (contd)

temperature. Due to poor heat transfer, slurry temperature steadily increased during testing. Temperature was controlled to within ± 5°C of the initial test temperature.

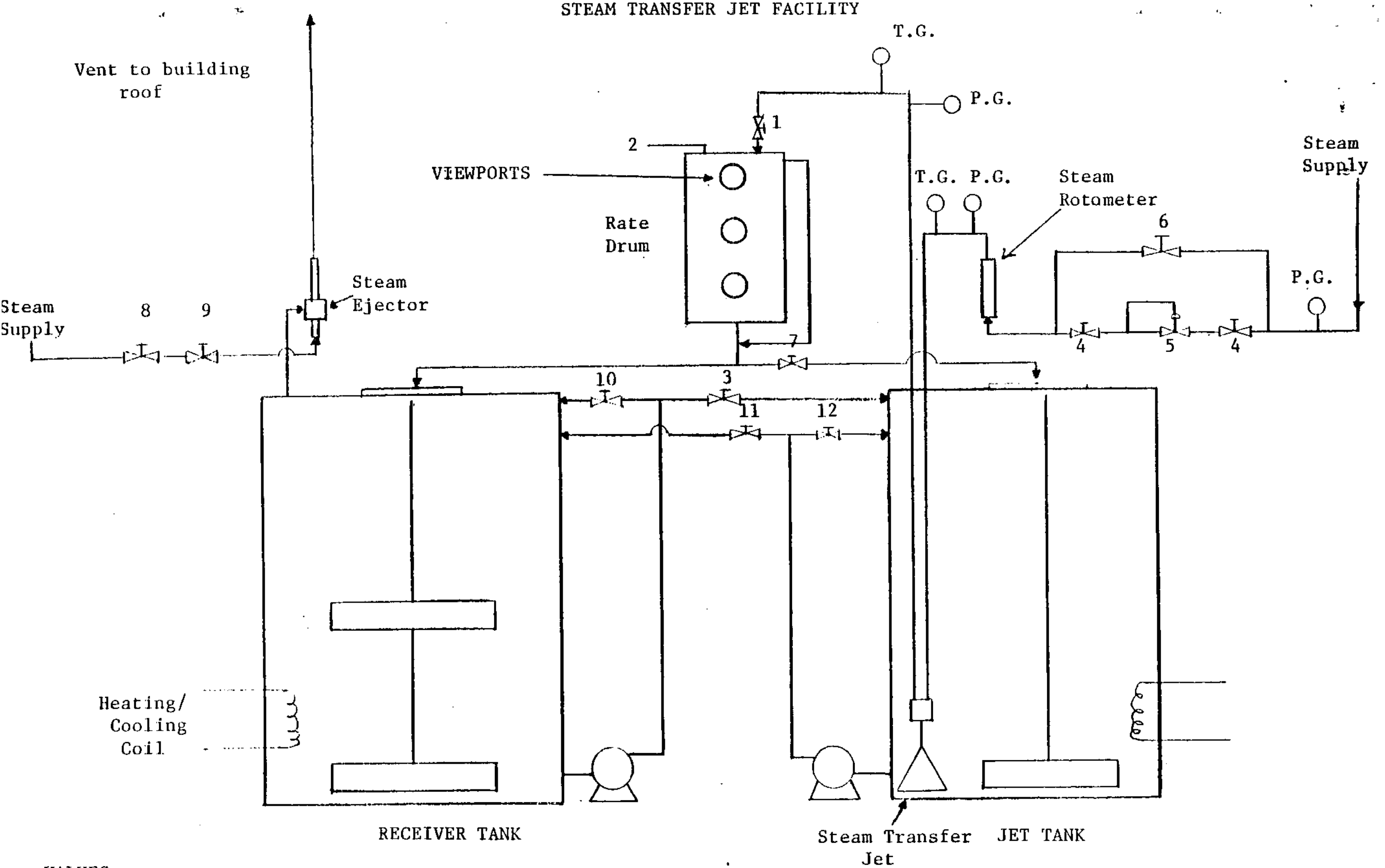
Jet discharge heads were measured with a 0-60 psi pressure gauge. Pressure gauge readings are believed to be accurate to within ± 0.5 psi. This corresponds to a discharge head error of ± 1.0 ft.

Summary

The purpose of this report was to present results obtained from tests to determine if steam jets could be used for slurry removal from waste tanks. Testing was done with both kaolin clay and synthetic sludge slurries. The effects of steam pressure, yield stress, temperature, and submergence on jet performance were examined. Of the two jets tested the D-jet was found to be a higher head jet and, therefore, more suitable for use in the waste tanks. But, the D-jet performed poorly with 1.4 sp.g. synthetic sludge slurries. Discharge heads sufficient to meet tank head requirements could not be maintained. When the slurry specific gravity was reduced to 1.2, jet operation became stable. At a slurry specific gravity of 1.2, the D-jet will meet the necessary operating conditions for use in the waste tanks. Therefore, jets should not be used for slurry removal if the specific gravity exceeds 1.25.

MAS:tks

STEAM TRANSFER JET FACILITY



VALVES

1. Rate Drum Flow Control
2. Rate Drum Plunger
3. Tank E-8 Level Control
4. Jet Steam Supply - On/Off
5. Steam Supply - Self-Regulating
6. Steam Supply Manual Operation
7. Rate Drum Return to E-8
8. Vent System - On/Off
9. Vent System - Control
10. Tank A-9 Recirculation
11. Tank A-9 Level Control
12. Tank E-8 Recirculation

FIGURE 1

EXPERIMENTAL TEST JET

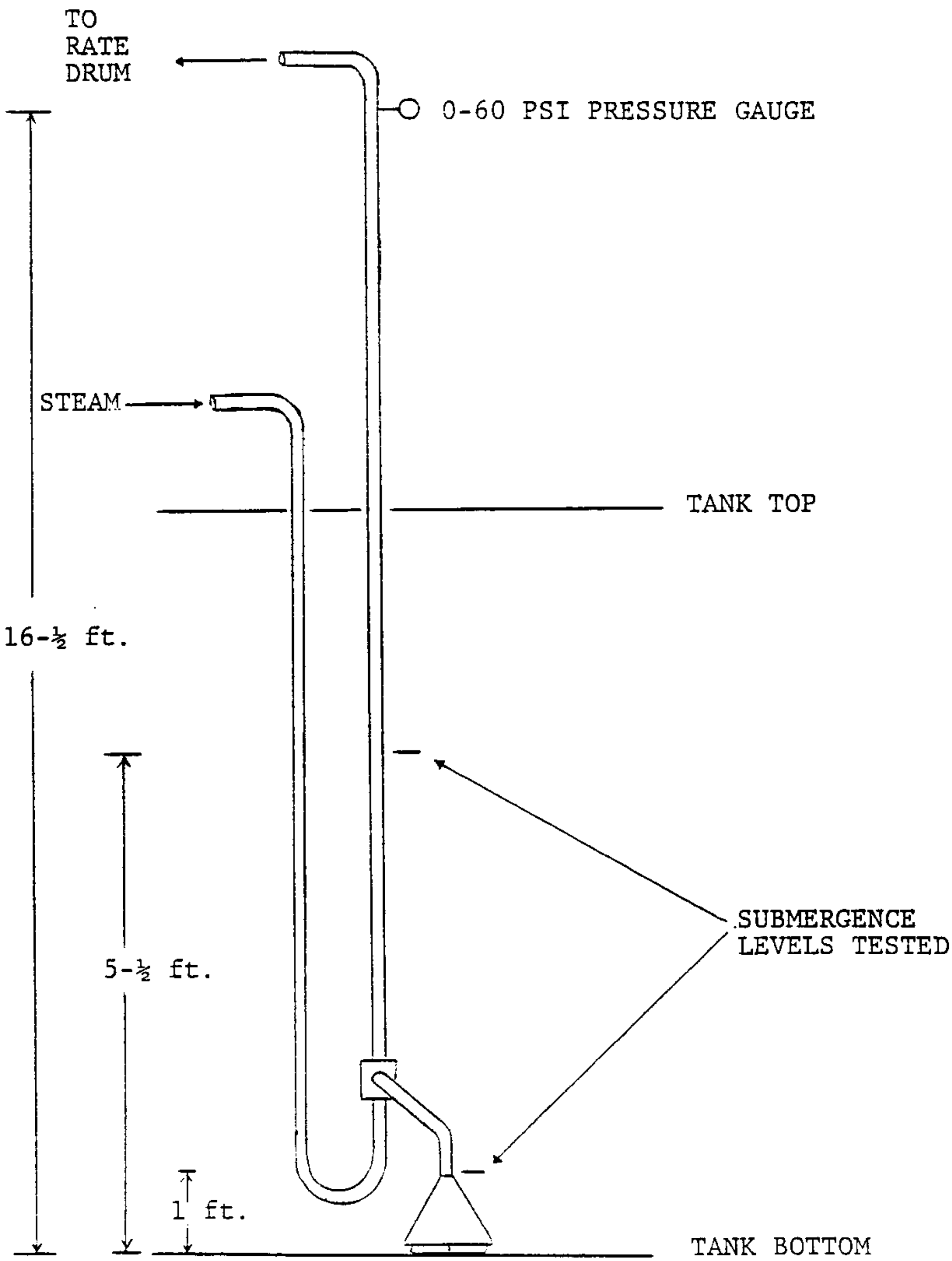


FIGURE 2

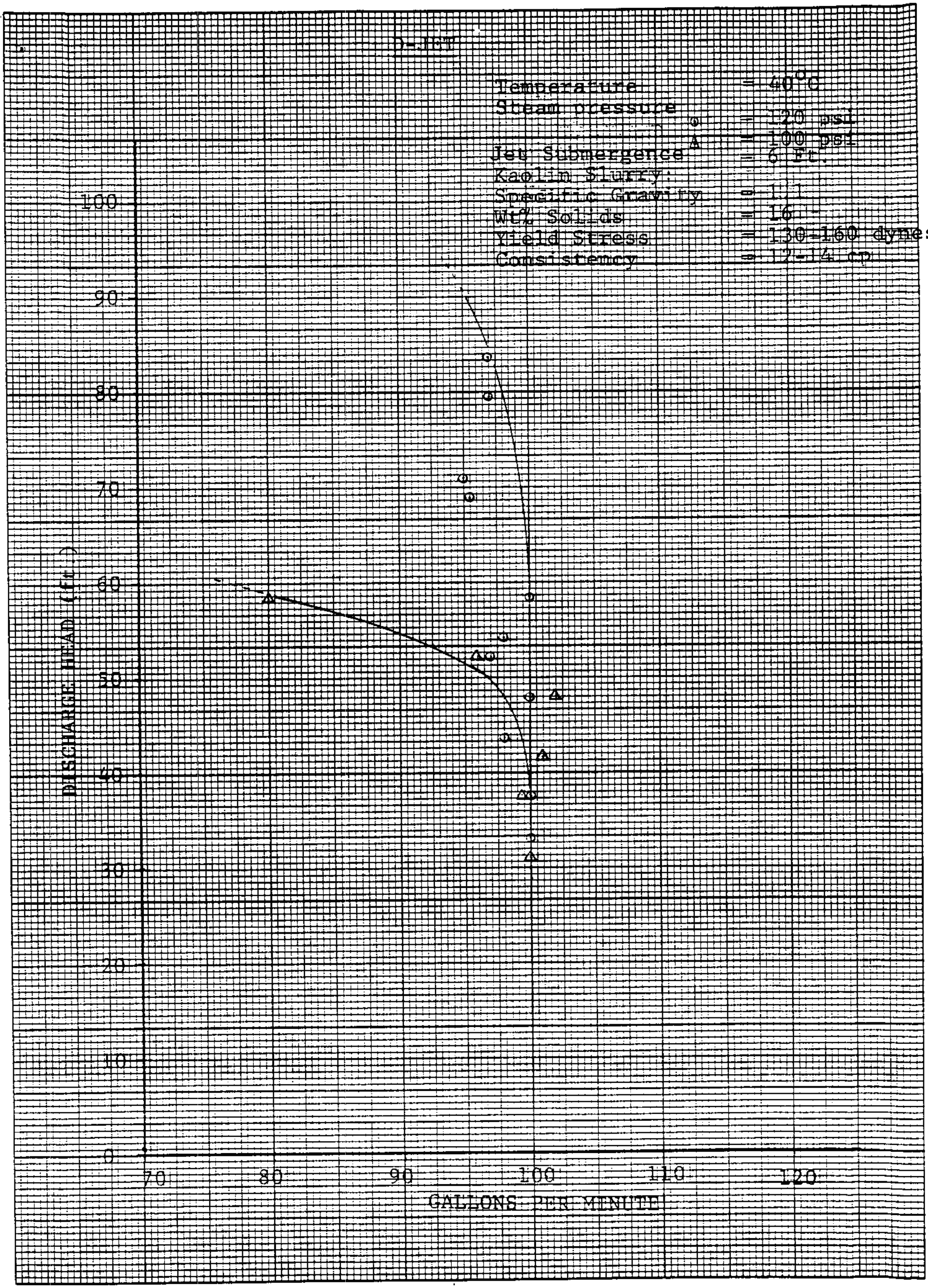
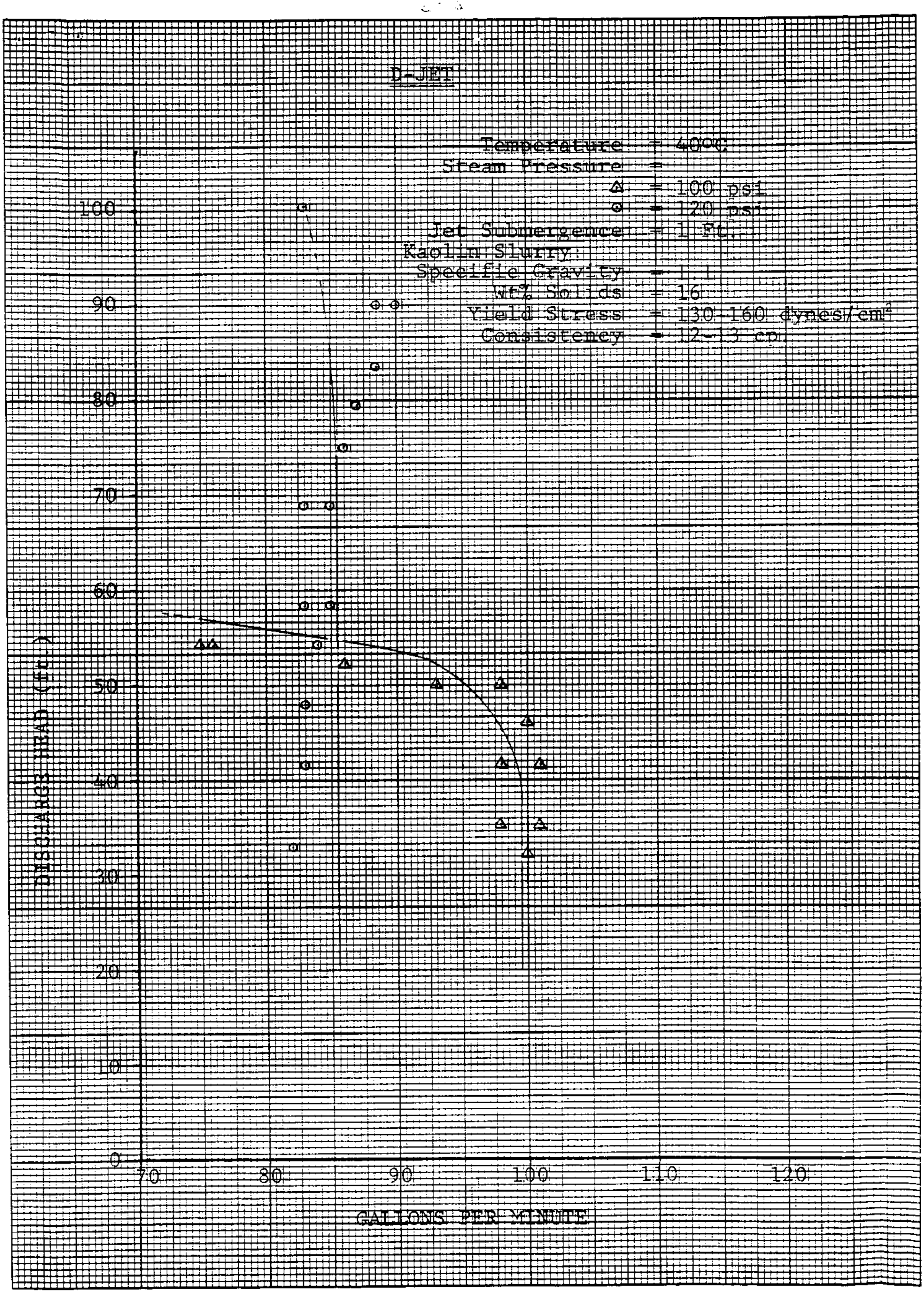
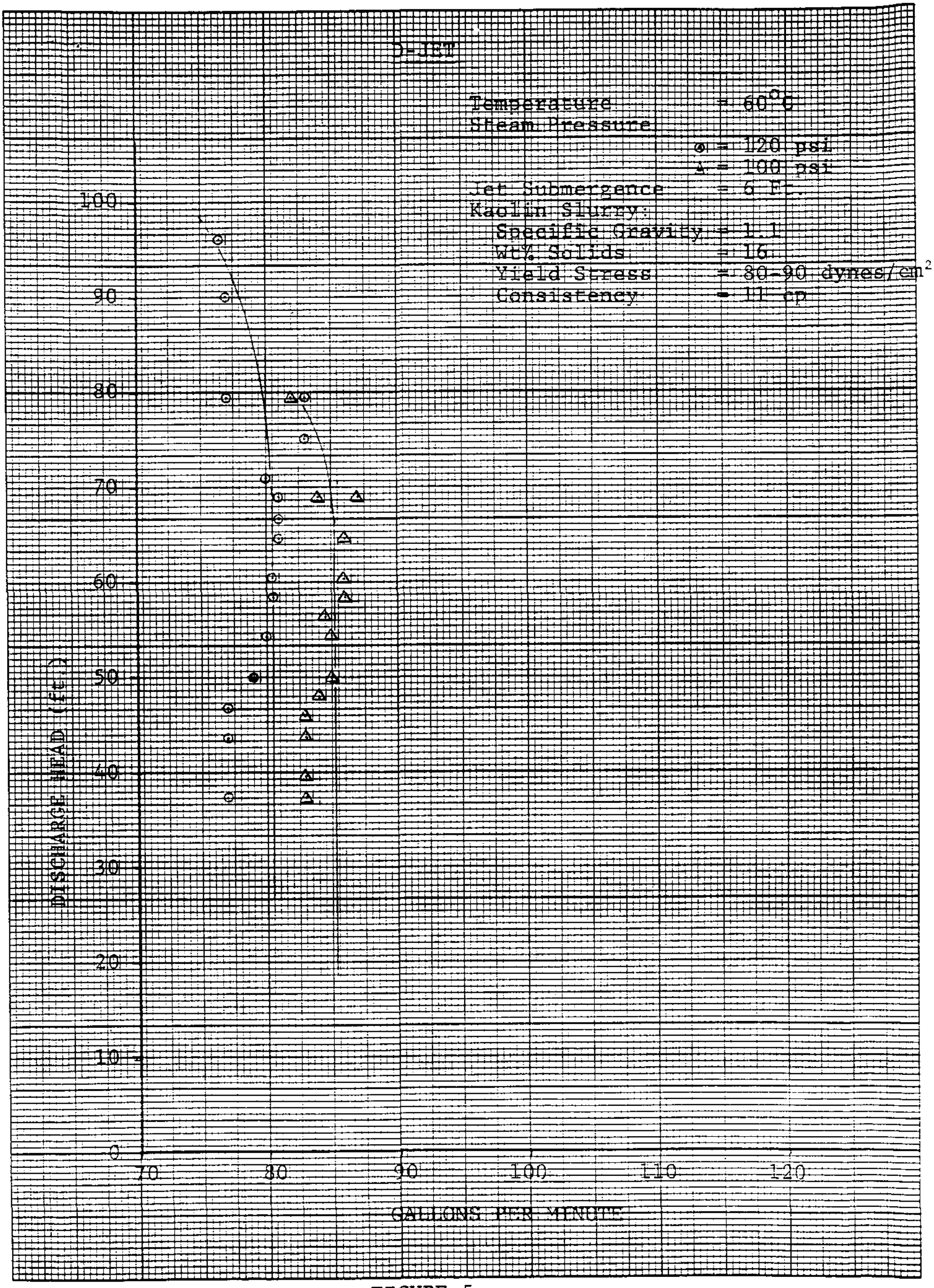

D-JET
Temperature = 40°C
Steam pressure ⊙ = 120 psi
Δ = 100 psi
Jet Submergence = 6 Ft.
Kaolin Slurry:
Specific Gravity = 1.1
Wt% Solids = 16
Yield Stress = 130-160 dynes/c
Consistency = 12-14 cp
DISCHARGE HEAD (ft.)
0
10
20
30
40
50
60
70
80
90
100
70
80
90
100
110
120
GALLONS PER MINUTE

FIGURE 3



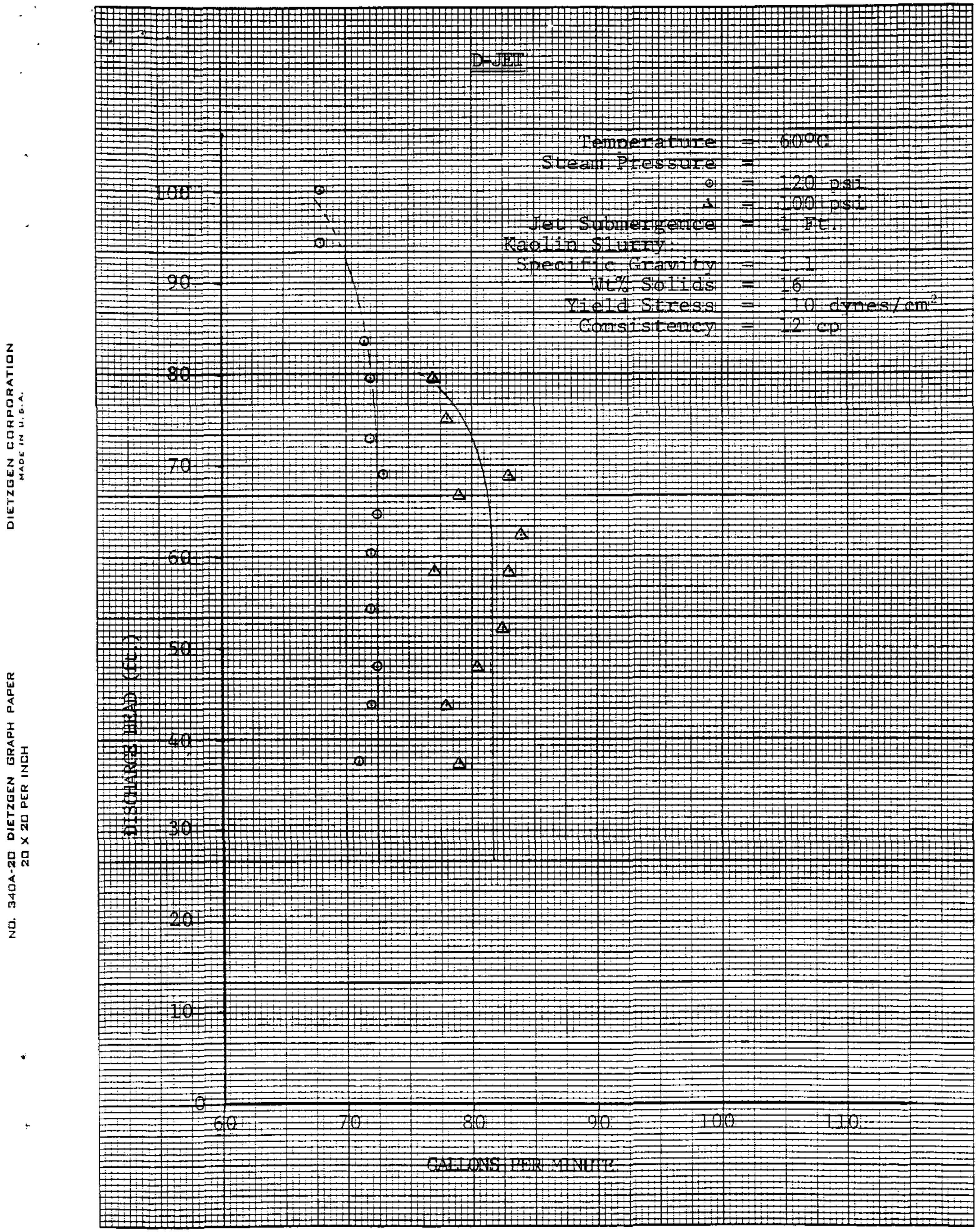
D-JET
Temperature = 40°C
Steam Pressure =
Δ = 100 psi
⊙ = 120 psi
Jet Submergence = 1 Ft.
Kaolin Slurry
Specific Gravity = 1.1
Wt% Solids = 16
Yield Stress = 130-160 dynes/cm²
Consistency = 12-13 cp.
DISCHARGE HEAD (ft.)
0
10
20
30
40
50
60
70
80
90
100
70
80
90
100
110
120
GALLONS PER MINUTE

FIGURE 4



D-JET
Temperature = 60°C
Steam Pressure
⊙ = 120 psi
△ = 100 psi
Jet Submergence = 6 Ft.
Kaolin Slurry:
Specific Gravity = 1.1
Wt% Solids = 16
Yield Stress = 80-90 dynes/cm²
Consistency = 11 cp
DISCHARGE HEAD (ft.)
0
10
20
30
40
50
60
70
80
90
100
70
80
90
100
110
120
GALLONS PER MINUTE

FIGURE 5



D-JET
Temperature = 60°C
Steam Pressure =
⊙ = 120 psi
Δ = 100 psi
Jet Submergence = 1 Ft.
Kaolin Slurry:
Specific Gravity = 1.1
Wt% Solids = 16
Yield Stress = 110 dynes/cm²
Consistency = 12 cp
DISCHARGE HEAD (Ft.)
0
10
20
30
40
50
60
70
80
90
100
60
70
80
90
100
110
GALLONS PER MINUTE

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20 X 20 PER INCH

FIGURE 6

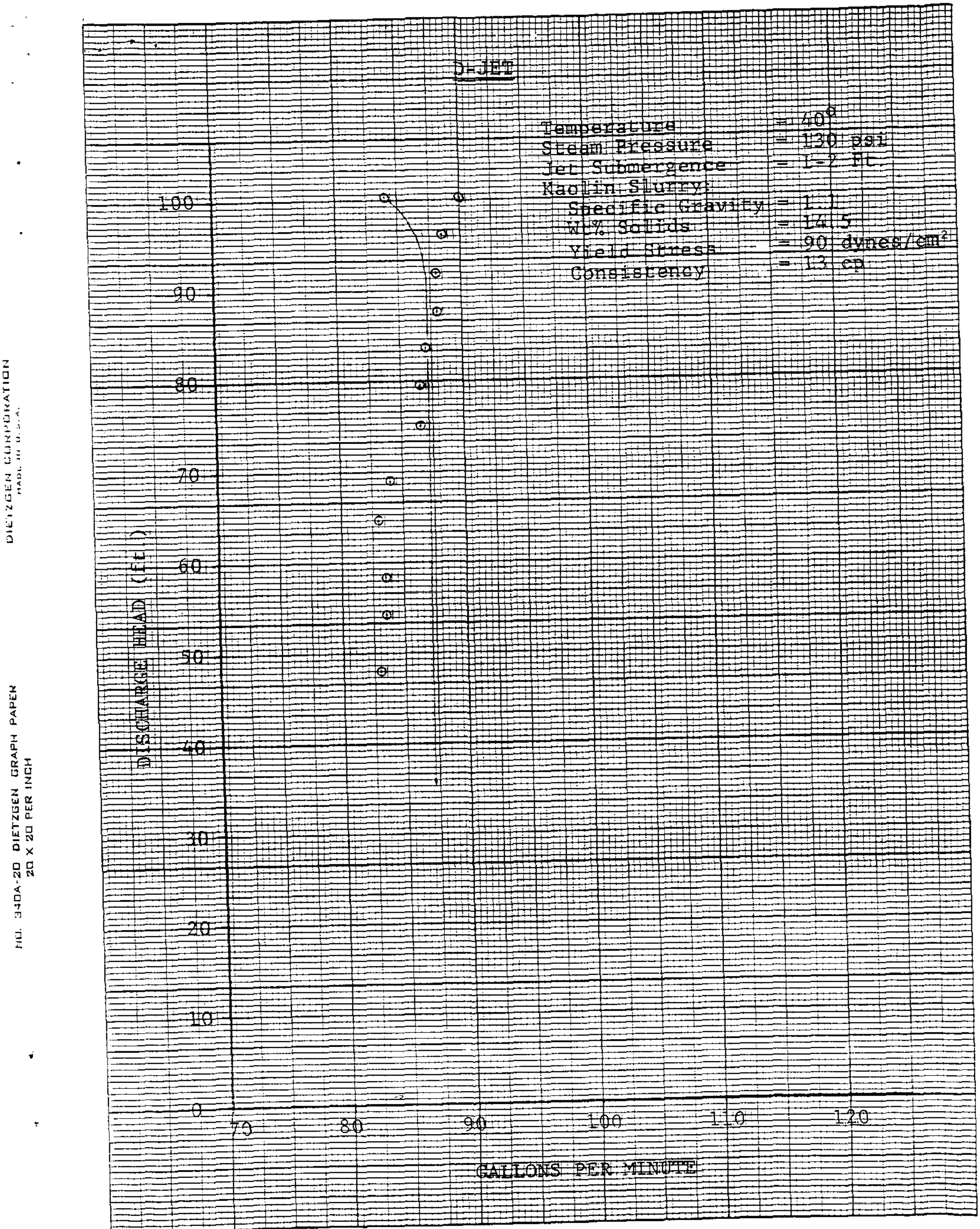

D-JET
Temperature = 40°
Steam Pressure = 130 psi
Jet Submergence = 1-2 Ft.
Kaolin Slurry:
Specific Gravity = 1.1
Wt% Solids = 14.5
Yield Stress = 90 dynes/cm²
Consistency = 13 cp
DISCHARGE HEAD (Ft)
100
90
80
70
60
50
40
30
20
10
0
70
80
90
100
110
120
GALLONS PER MINUTE
DIETZGEN CORPORATION
MADE IN U.S.A.
NO. 340A-20 DIETZGEN GRAPH PAPER
20 X 20 PER INCH

FIGURE 7

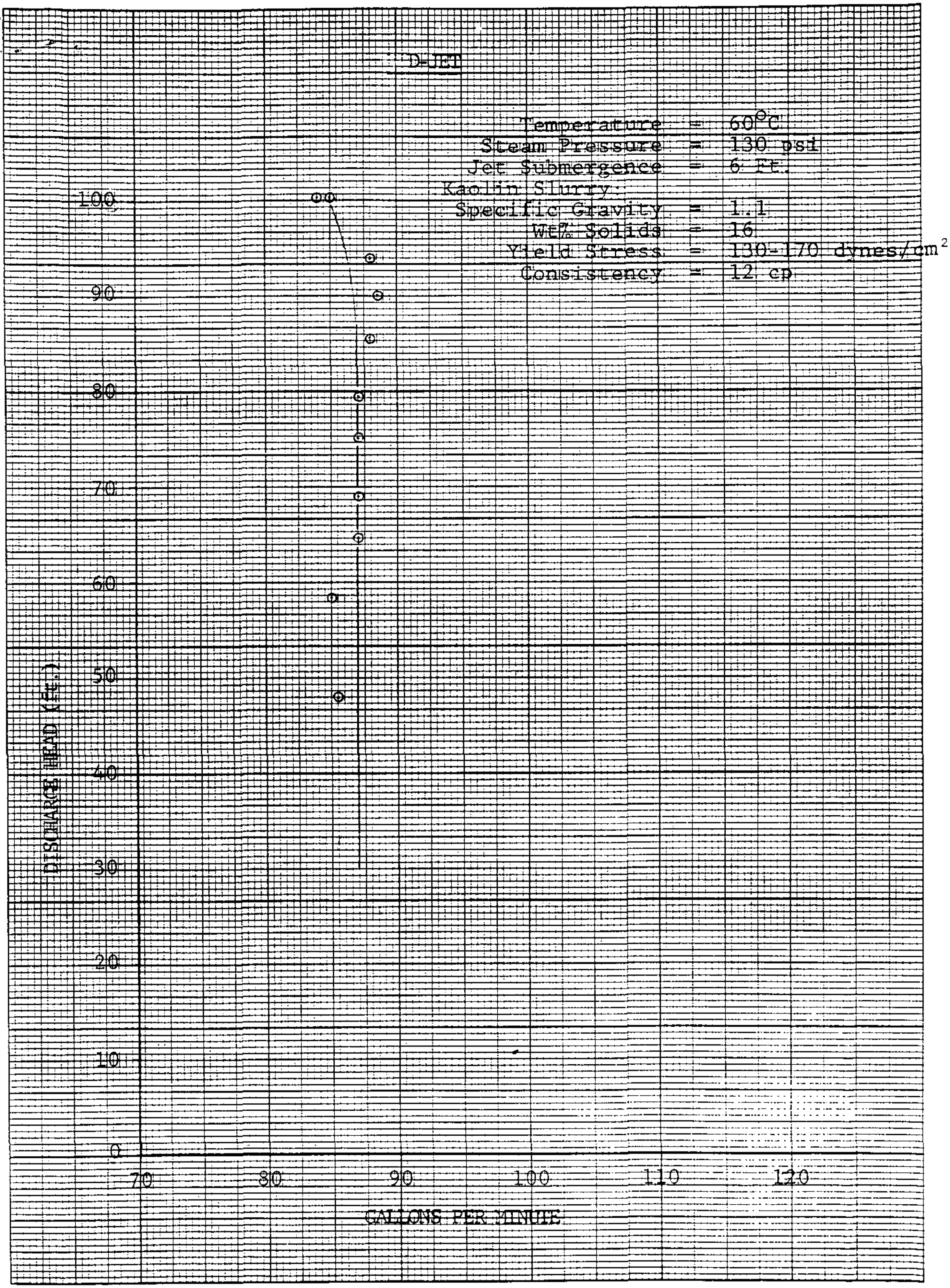

D-JET
Temperature = 60°C
Steam Pressure = 130 psi
Jet Submergence = 6 Ft.
Kaolin Slurry
Specific Gravity = 1.1
Wt% Solids = 16
Yield Stress = 130-170 dynes/cm²
Consistency = 12 cp
DISCHARGE HEAD (Ft.)
0
10
20
30
40
50
60
70
80
90
100
70
80
90
100
110
120
GALLONS PER MINUTE

FIGURE 8

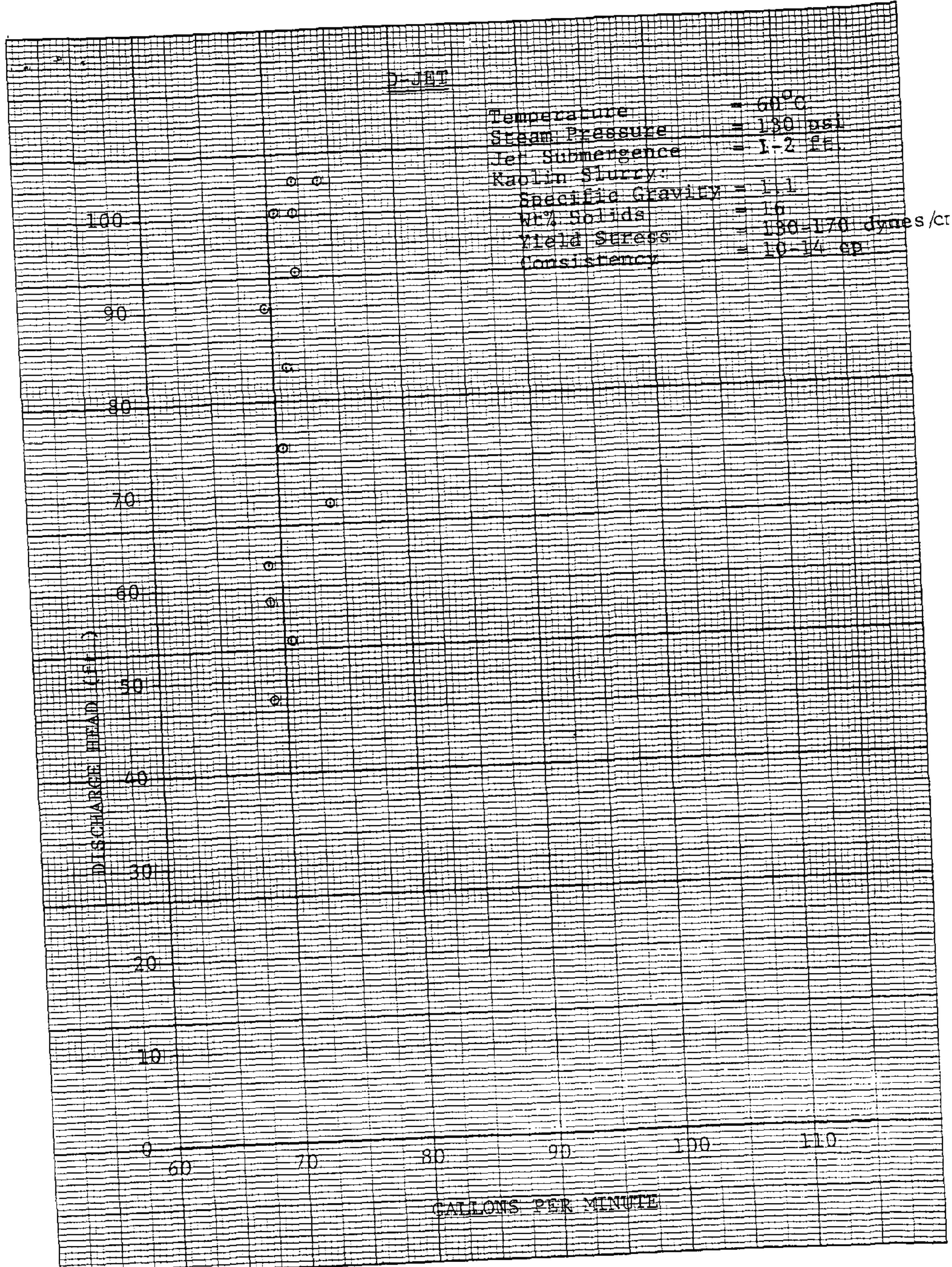

D-JET
Temperature = 60°C
Steam Pressure = 130 psi
Jet Submergence = 1-2 ft.
Kaolin Slurry:
Specific Gravity = 1.1
Wt% Solids = 16
Yield Stress = 130-170 dynes/cm
Consistency = 10-14 cp
DISCHARGE HEAD (FT.)
100
90
80
70
60
50
40
30
20
10
0
60
70
80
90
100
110
GALLONS PER MINUTE
NO. 340A-20 DIETZGEN GRAPH PAPER
20 X 20 PER INCH
DIETZGEN CORPORATION
MADE IN U.S.A.

FIGURE 9

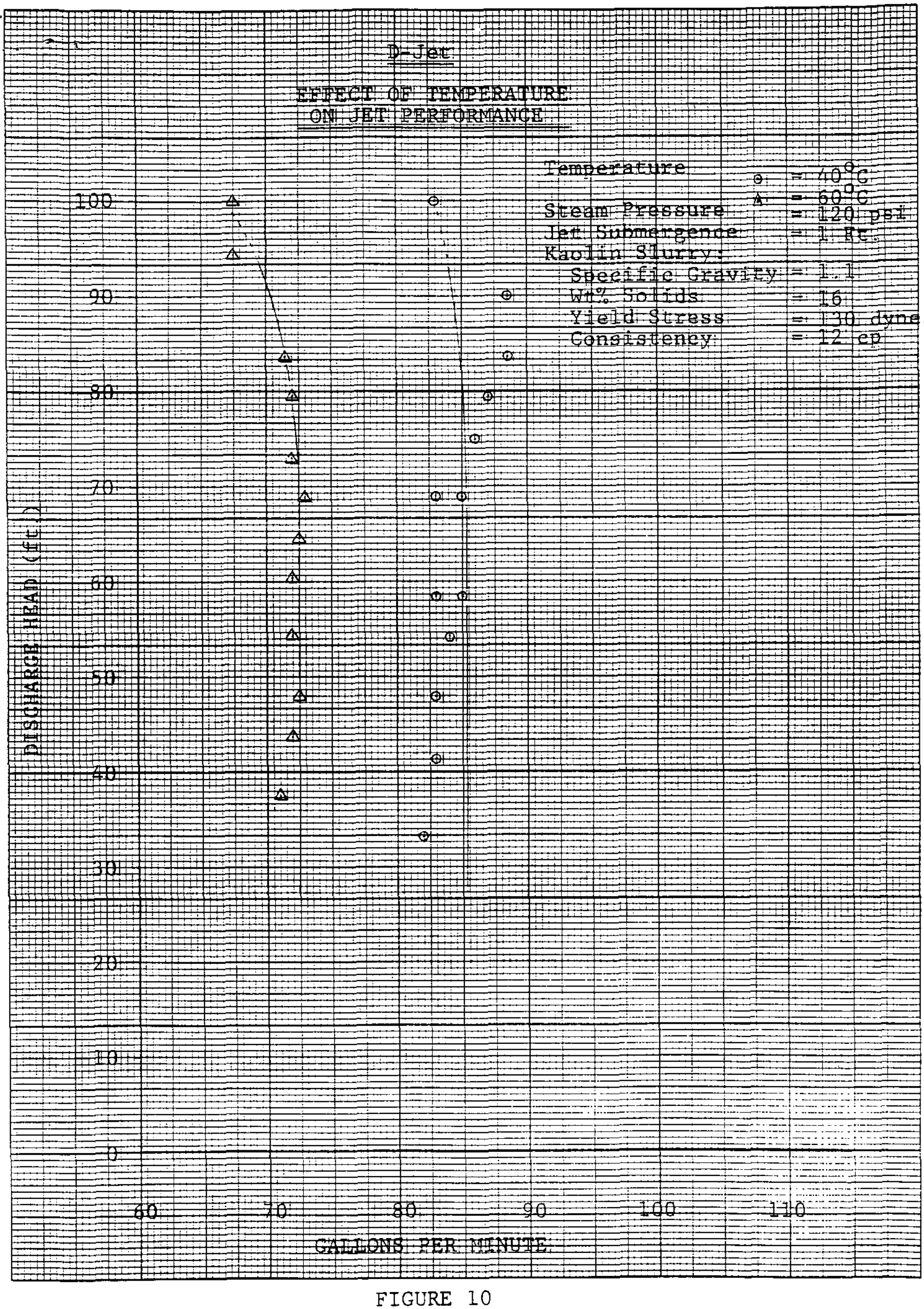

D-Jet
EFFECT OF TEMPERATURE
ON JET PERFORMANCE
Temperature ⊙ = 40°C
△ = 60°C
Steam Pressure = 120 psi
Jet Submergence = 1 Ft.
Kaolin Slurry:
Specific Gravity = 1.1
Wt% Solids = 16
Yield Stress = 130 dynes/cm
Consistency = 12 cp
DISCHARGE HEAD (ft.)
0
10
20
30
40
50
60
70
80
90
100
60
70
80
90
100
110
GALLONS PER MINUTE

FIGURE 10

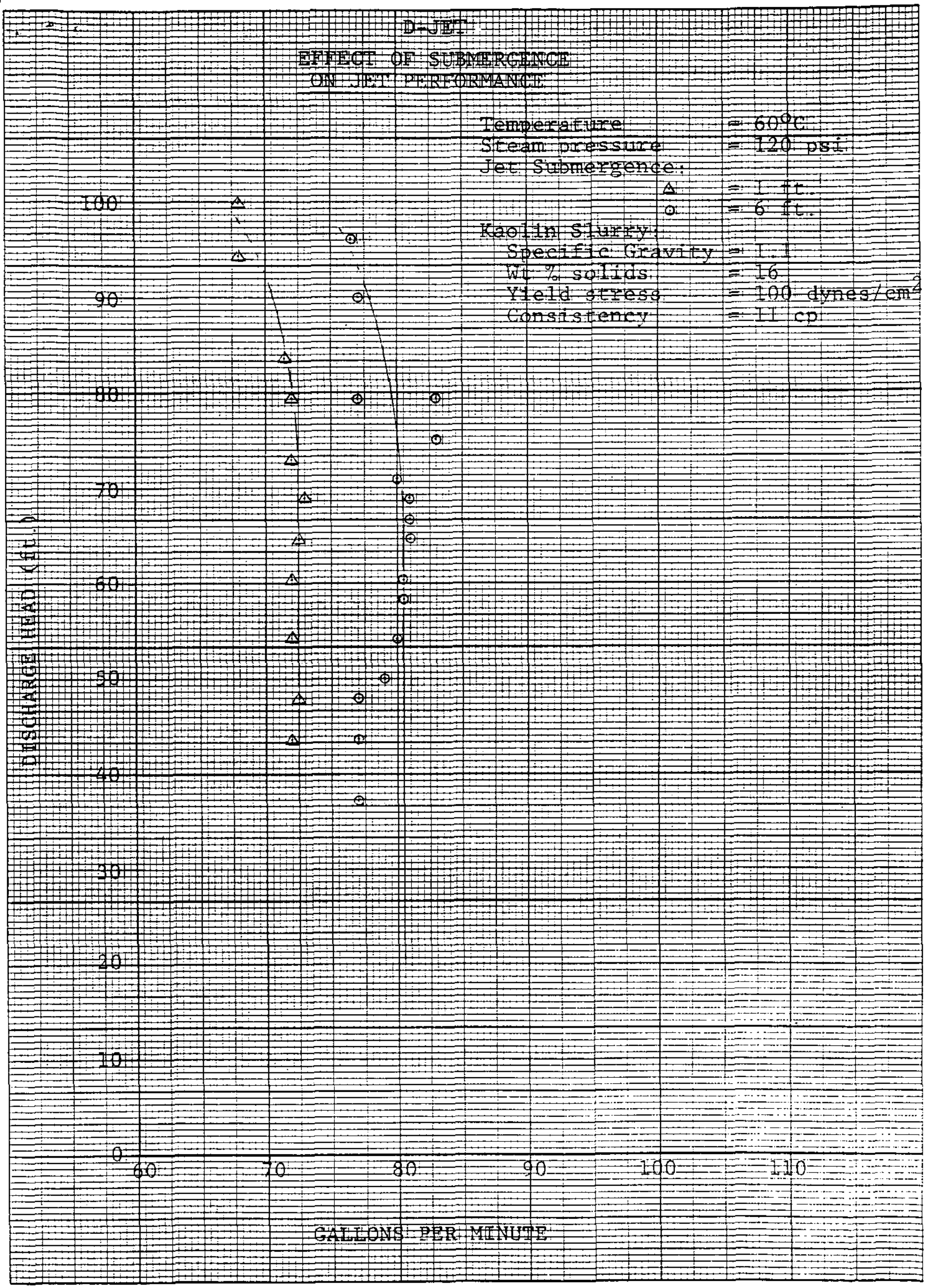

D-JET
EFFECT OF SUBMERGENCE
ON JET PERFORMANCE
Temperature = 60°C
Steam pressure = 120 psi
Jet Submergence:
△ = 1 ft.
⊙ = 6 ft.
Kaolin Slurry:
Specific Gravity = 1.1
Wt % solids = 16
Yield stress = 100 dynes/cm²
Consistency = 11 cp
DISCHARGE HEAD (ft.)
0
10
20
30
40
50
60
70
80
90
100
60
70
80
90
100
110
GALLONS PER MINUTE

FIGURE 11

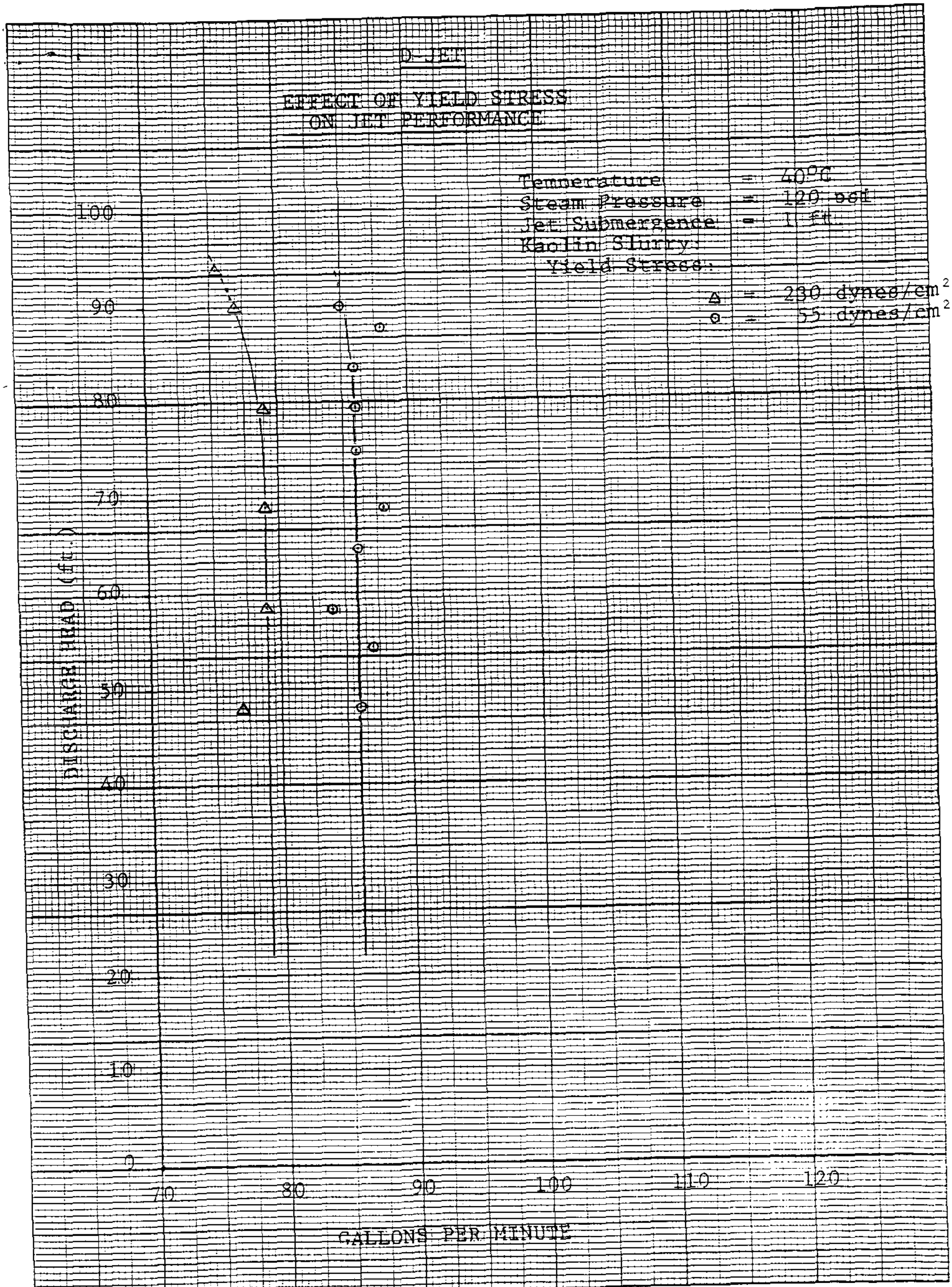

D-JET
EFFECT OF YIELD STRESS ON JET PERFORMANCE
Temperature = 40°C
Steam Pressure = 120 psi
Jet Submergence = 1 ft
Kaolin Slurry:
Yield Stress:
△ = 230 dynes/cm²
⊙ = 55 dynes/cm²
DISCHARGE HEAD (ft.)
100
90
80
70
60
50
40
30
20
10
0
70
80
90
100
110
120
GALLONS PER MINUTE

FIGURE 12

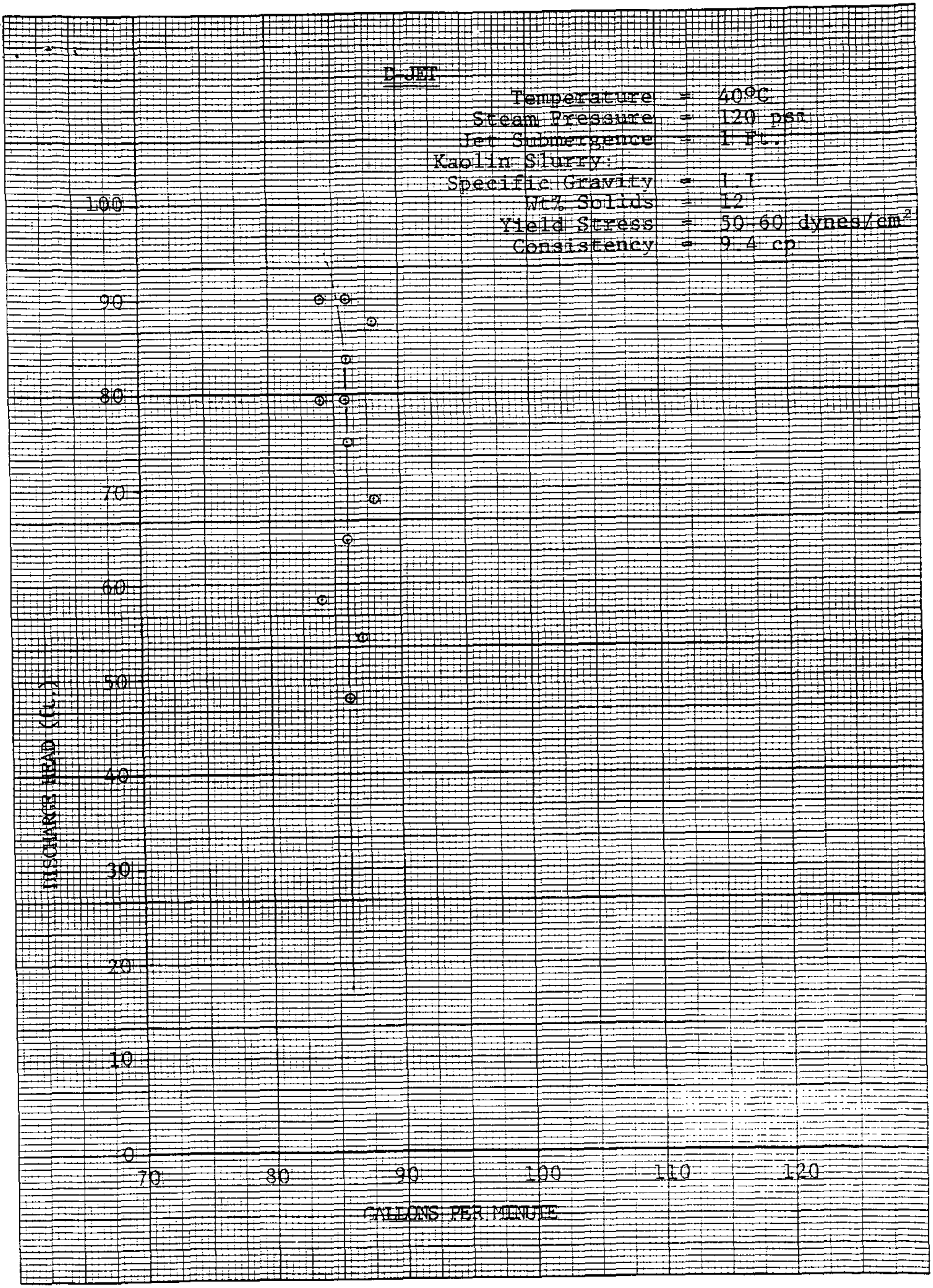

D-JET
Temperature = 40°C
Steam Pressure = 120 psi
Jet Submergence = 1 Ft.
Kaolin Slurry:
Specific Gravity = 1.1
Wt% Solids = 12
Yield Stress = 50-60 dynes/cm²
Consistency = 9.4 cp
DISCHARGE HEAD (ft.)
0
10
20
30
40
50
60
70
80
90
100
70
80
90
100
110
120
GALLONS PER MINUTE

FIGURE 13

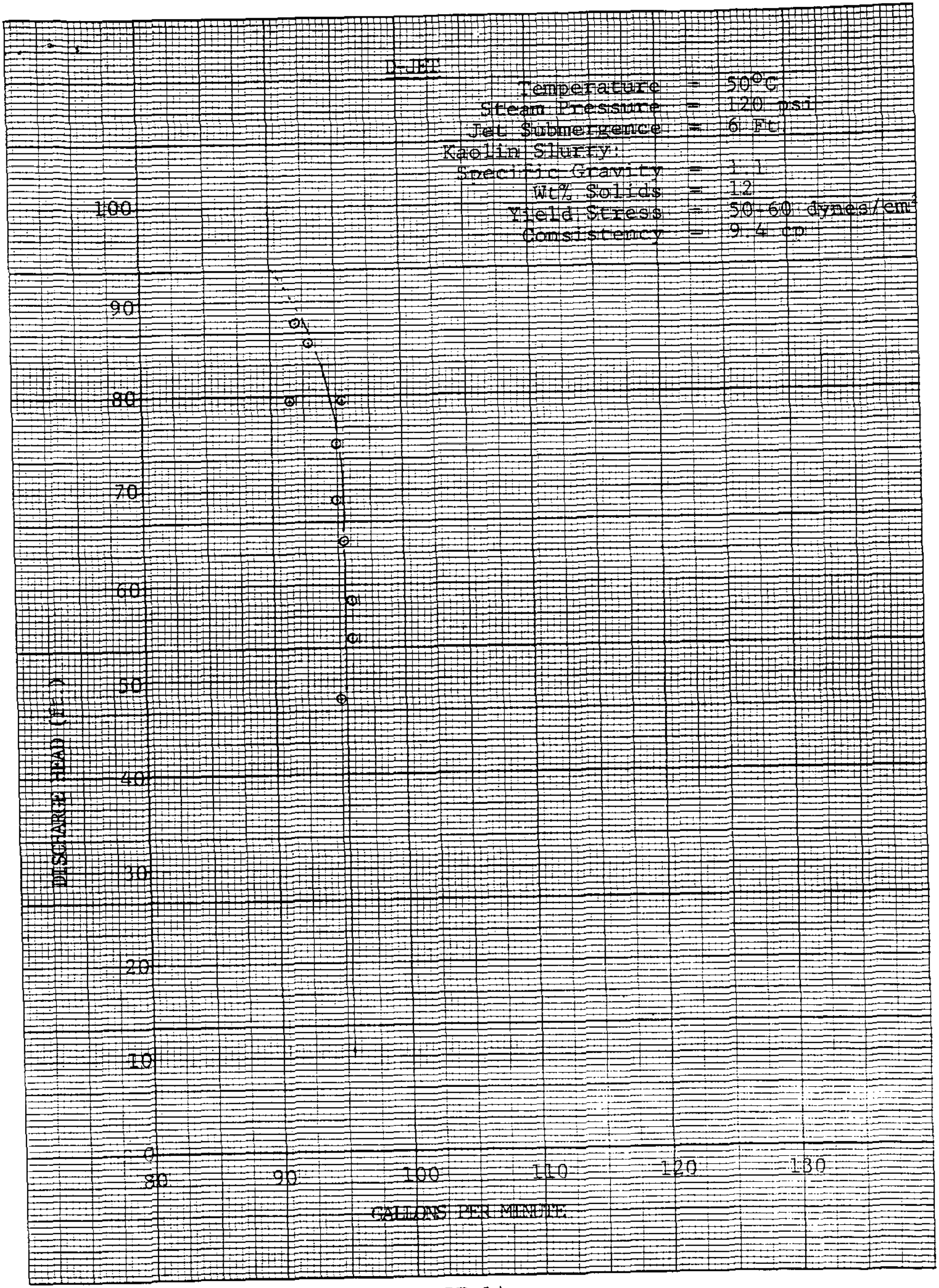

D-JET
Temperature = 50°C
Steam Pressure = 120 psi
Jet Submergence = 6 Ft.
Kaolin Slurry:
Specific Gravity = 1.1
Wt% Solids = 12
Yield Stress = 50-60 dynes/cm²
Consistency = 9.4 cp
DISCHARGE HEAD (Ft.)
0
10
20
30
40
50
60
70
80
90
100
80
90
100
110
120
130
GALLONS PER MINUTE

FIGURE 14

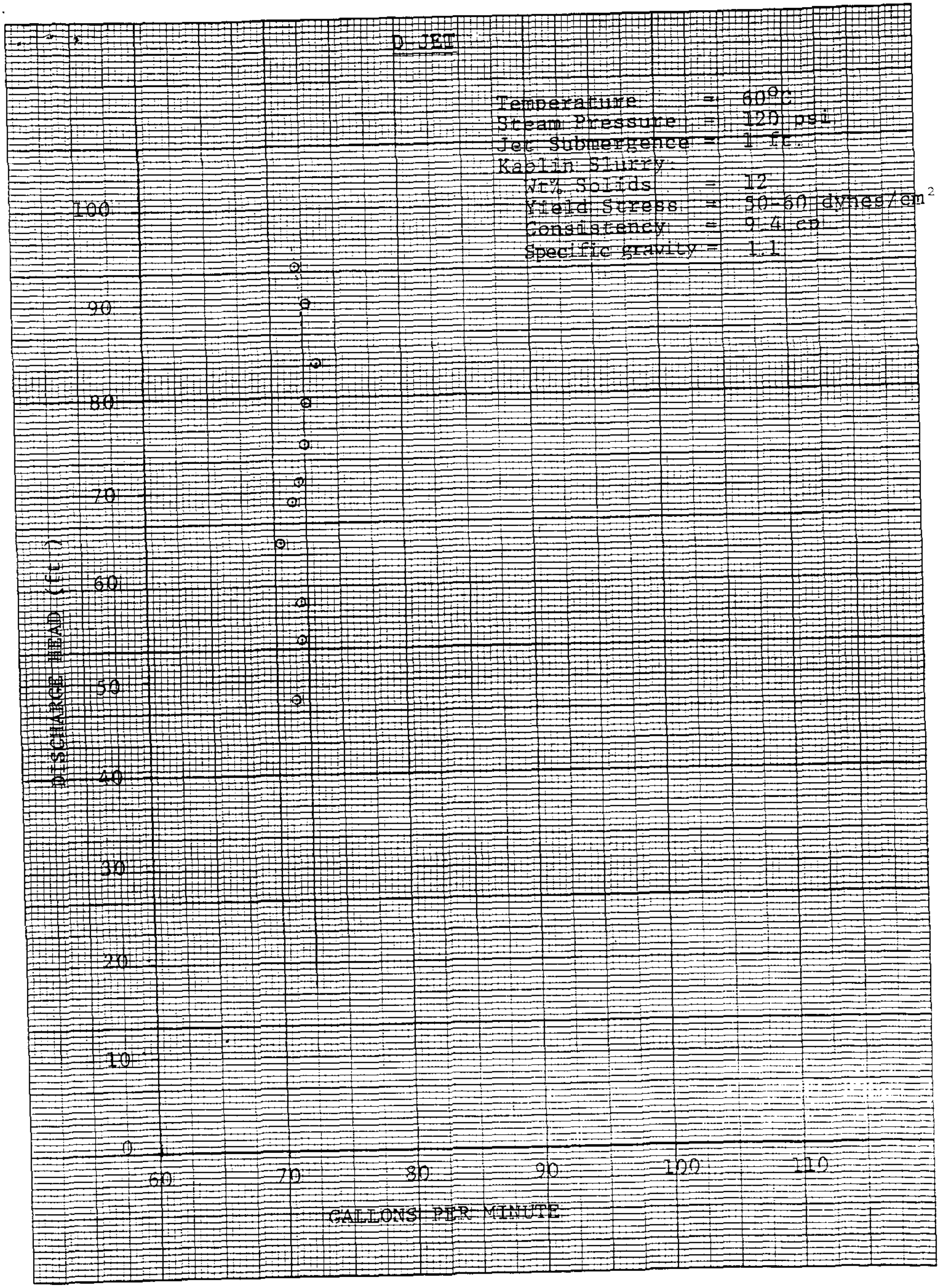

D-JET
Temperature = 60°C
Steam Pressure = 120 psi
Jet Submergence = 1 ft.
Kaolin Slurry
Wt% Solids = 12
Yield Stress = 50-60 dynes/cm²
Consistency = 9.4 cp
Specific gravity = 1.1
DISCHARGE HEAD (ft)
100
90
80
70
60
50
40
30
20
10
0
60
70
80
90
100
110
GALLONS PER MINUTE

FIGURE 15

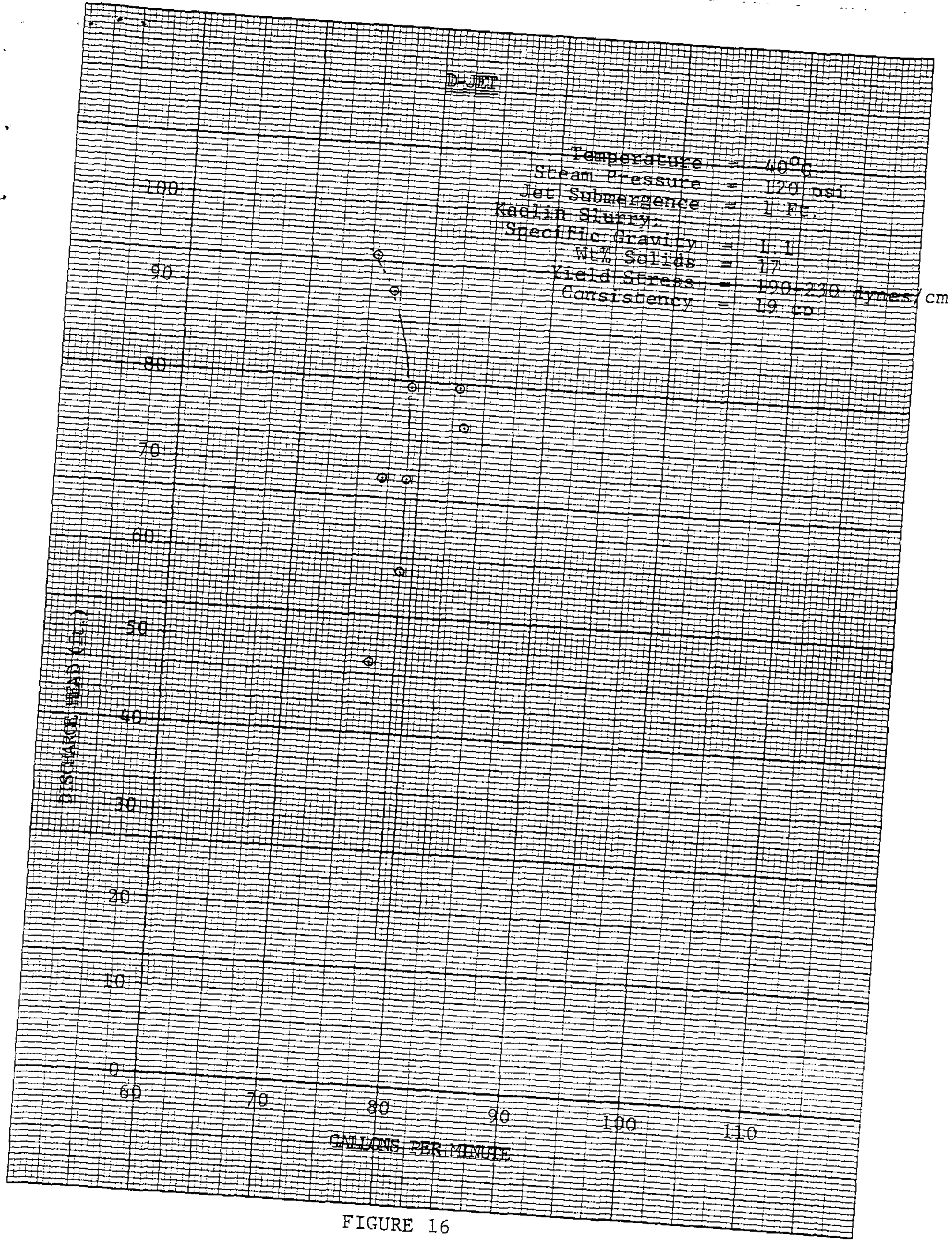

D-JET
Temperature = 40°C
Steam Pressure = 120 psi
Jet Submergence = 1 Ft.
Kaolin Slurry:
Specific Gravity = 1.1
Wt% Solids = 17
Yield Stress = 190-230 dynes/cm
Consistency = 19 cp
100
90
80
70
60
50
40
30
20
10
0
60
70
80
90
100
110
DISCHARGE HEAD (Ft.)
GALLONS PER MINUTE

FIGURE 16

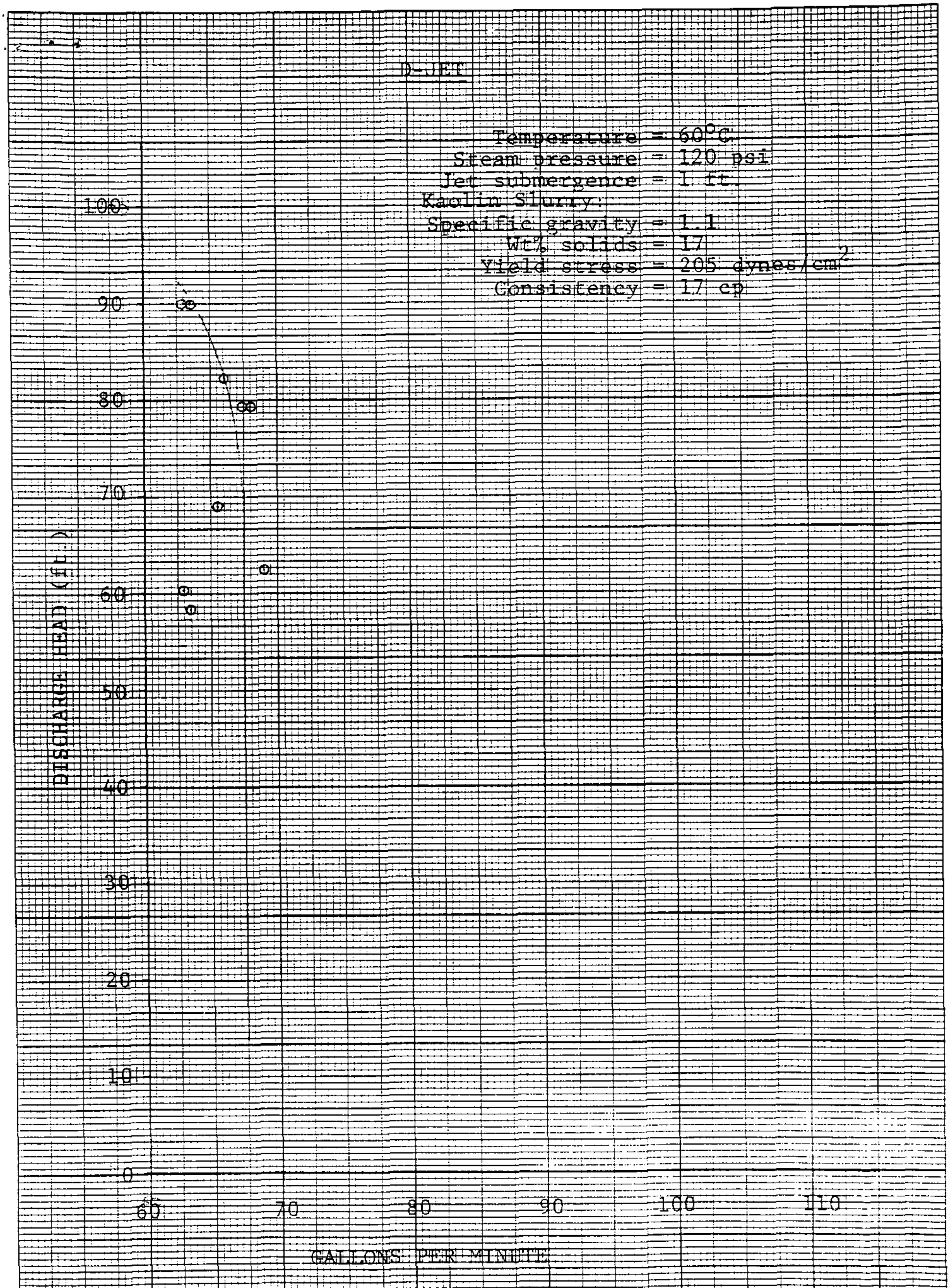

D-JET
Temperature = 60°C
Steam pressure = 120 psi
Jet submergence = 1 ft.
Kaolin Slurry:
Specific gravity = 1.1
Wt% solids = 17
Yield stress = 205 dynes/cm2
Consistency = 17 cp
DISCHARGE HEAD (ft.)
100
90
80
70
60
50
40
30
20
10
0
60
70
80
90
100
110
GALLONS PER MINUTE

FIGURE 17

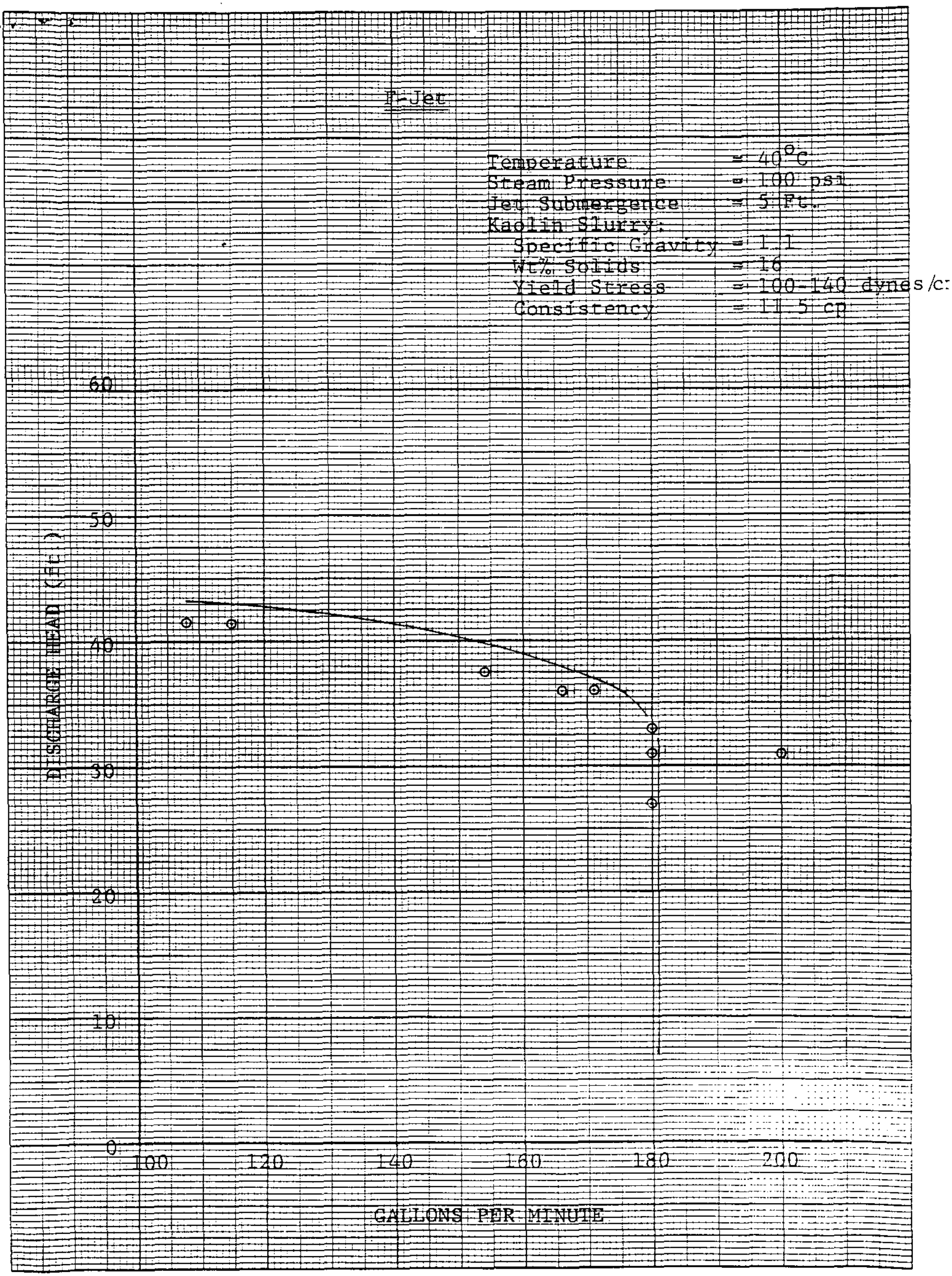

T-Jet
Temperature = 40°C
Steam Pressure = 100 psi
Jet Submergence = 5 Ft.
Kaolin Slurry:
Specific Gravity = 1.1
Wt% Solids = 16
Yield Stress = 100-140 dynes/c
Consistency = 11.5 cp
DISCHARGE HEAD (Ft.)
0
10
20
30
40
50
60
100
120
140
160
180
200
GALLONS PER MINUTE

FIGURE 18

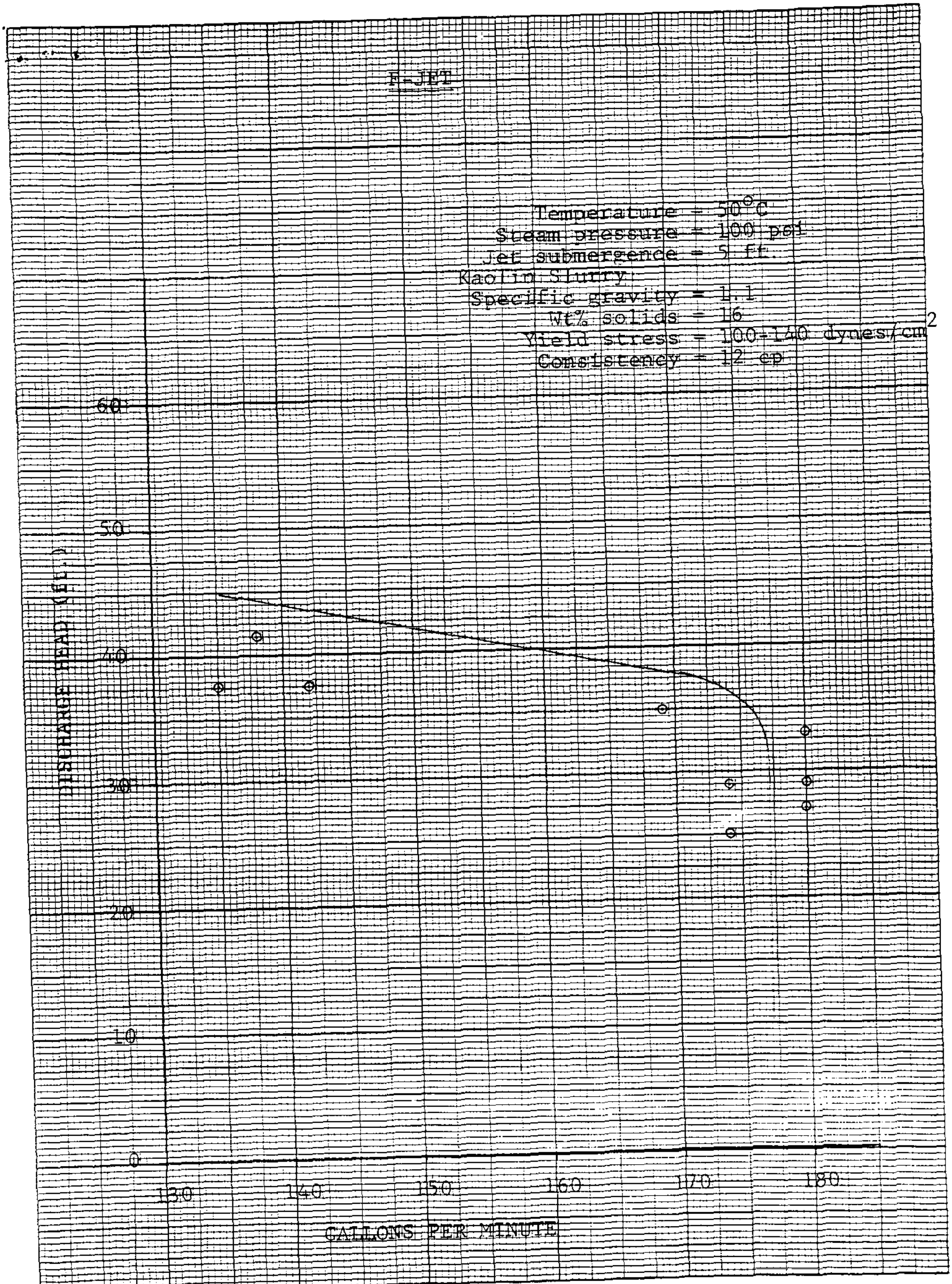
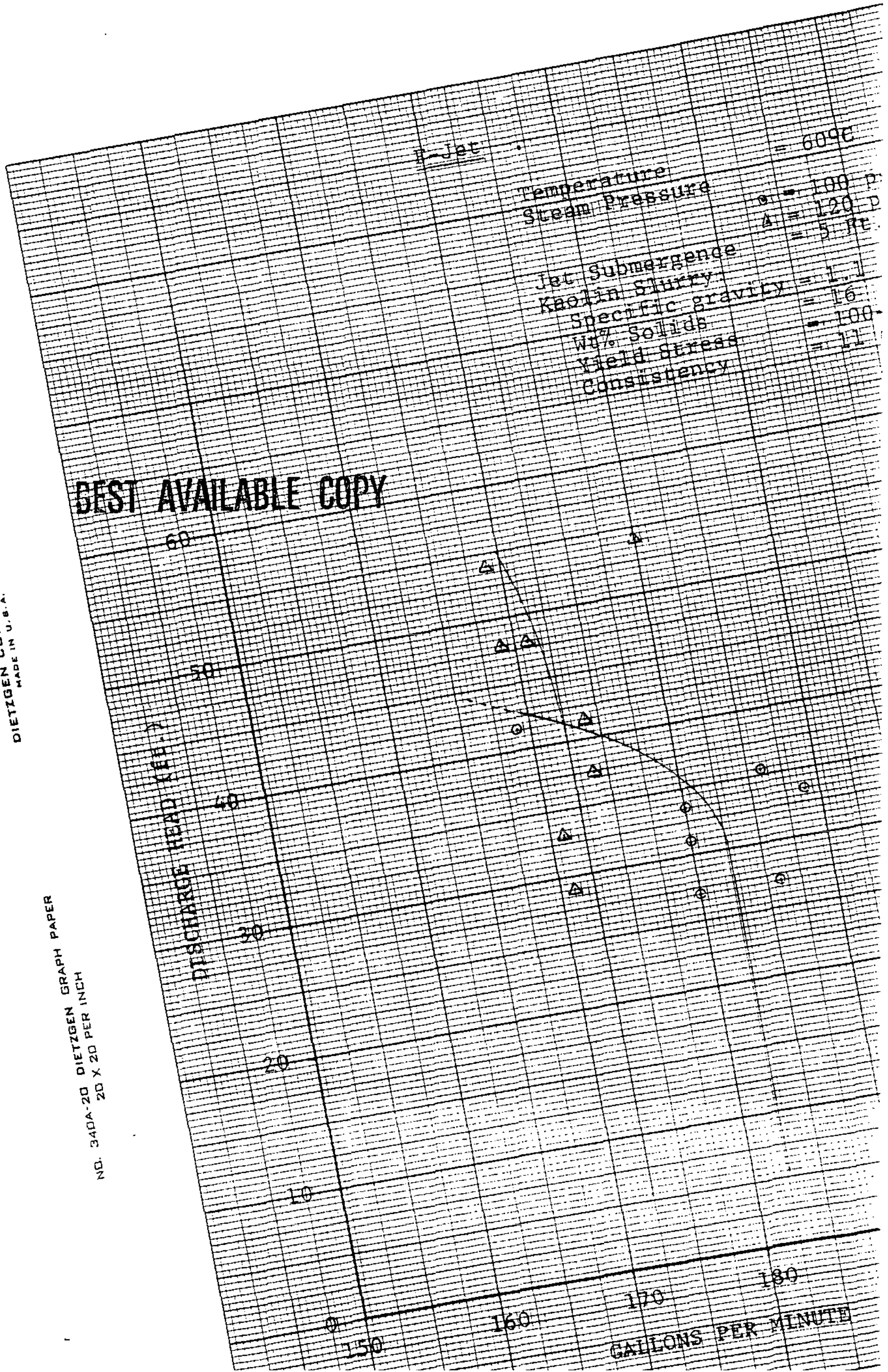

F-JET
Temperature = 50°C
Steam pressure = 100 psi
Jet submergence = 5 ft.
Kaolin Slurry:
Specific gravity = 1.1
Wt% solids = 16
Yield stress = 100-140 dynes/cm2
Consistency = 12 cp
DISCHARGE HEAD (FT.)
60
50
40
30
20
10
0
130
140
150
160
170
180
GALLONS PER MINUTE

FIGURE 19



Temperature = 60°C
Steam Pressure
Jet Submergence = 5 ft
Kaolin Slurry:
Specific gravity = 1.1
Wt% Solids = 16
Yield Stress
Consistency
DISCHARGE HEAD (ft.)
60
50
40
30
20
10
0
150
160
170
180
GALLONS PER MINUTE

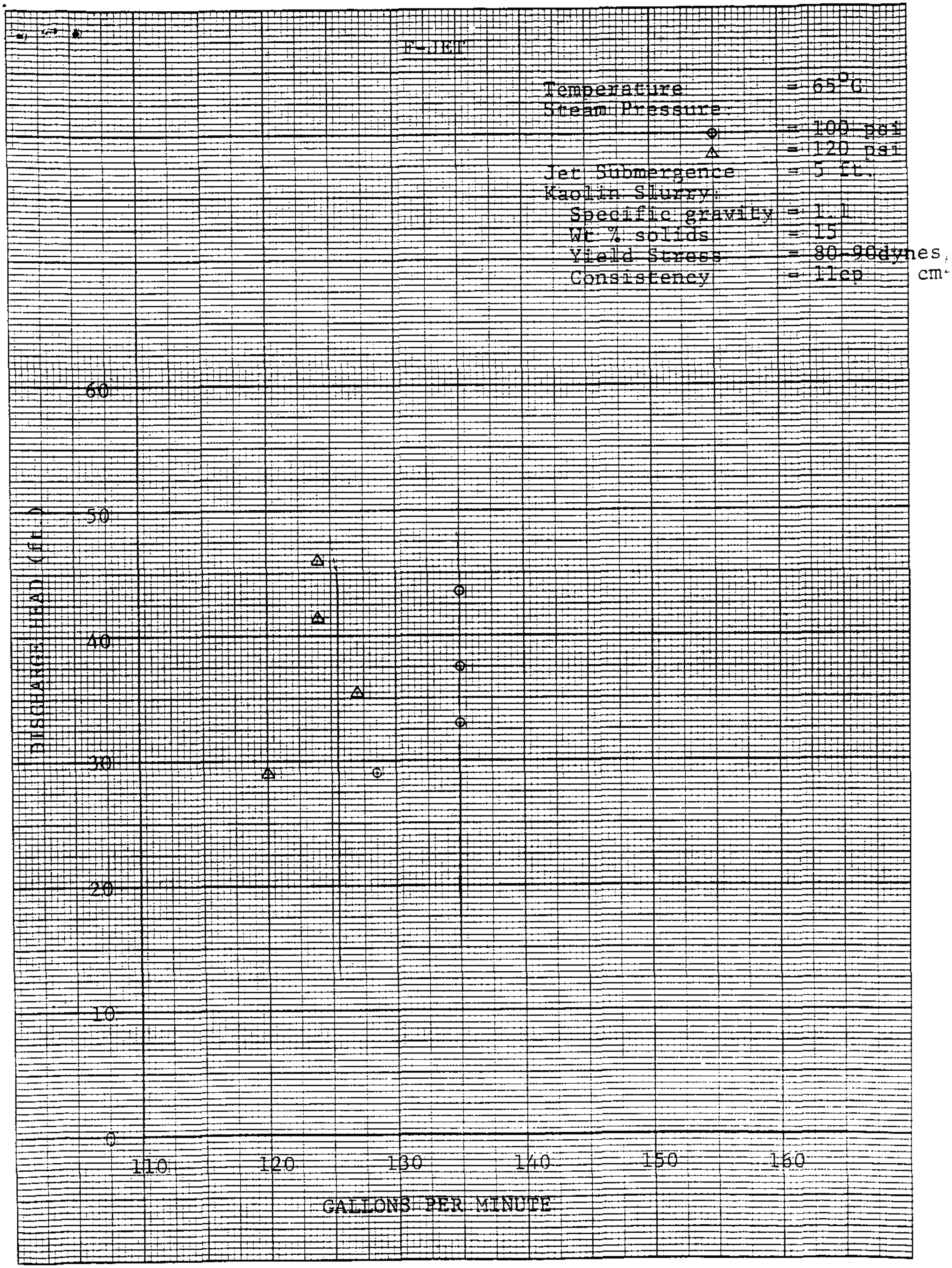

F-JET
Temperature = 65°C
Steam Pressure
⊕ = 100 psi
△ = 120 psi
Jet Submergence = 5 ft.
Kaolin Slurry:
Specific gravity = 1.1
Wt % solids = 15
Yield Stress = 80-90dynes/cm²
Consistency = 11cp
DISCHARGE HEAD (ft.)
0
10
20
30
40
50
60
110
120
130
140
150
160
GALLONS PER MINUTE

FIGURE 21