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SIMULATION PROGRAM FOR CENTRAL HELIUM LIQUEFIER

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ABSTRACT

The computer program described here analyzes the performance of Fermilab Central Helium Liquefier (CHL) and predicts the values of the plant thermodynamic variables at all process points in the plant. To simulate CHL, this program is modified from the prototype program which was developed by Hitachi Ltd. a couple of years ago. This program takes care of only the steady state simulation and takes account of the change of the turbine efficiency, the pressure drops and the UA values of the heat exchangers. How to use the program is shown in Appendix A.

PROGRAM DESCRIPTION

The principal program SHEREL is approximately 2000 FORTRAN statements including comments. SHEREL contains the main program and the subprograms, each of which takes care of the calculation for the corresponding component; i.e., the heat exchanger, the expansion turbine, the valve, the phase separators, etc. Figure 1 shows the flow diagram for CHL and the numbering used in the program. The components are connected by the linkage points. The main program controls the sequence of the calculation and manages the data at each linkage point and each flow path. Each component subprogram calculates the outlet process condition from the inlet process condition of its component at each iteration. Through the iteration the temperature values of the process points are changing automatically, and the iteration stops when it converges to the appropriate distribution which satisfies the heat and mass balance of the system and the restrictions demanded by the components.

In the subprogram for the heat exchanger, the differential equation for steady state heat transfer is solved by finite-difference method. The average value of helium specific heat is used at each flow path for reducing the calculation time. To prevent inaccuracy caused by this approximation, some heat exchangers are divided into a couple of smaller heat exchangers along the flow path.

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The capacity of the heat exchanger is the product of the overall heat transfer coefficient U and the area A, available for heat transfer. At the heat exchanger, A is constant and U mainly depends on the mass flow M. In the program the following expression is used for estimating the value of UA.[1,2]

$$UA = (UA)_o \ (\dot{M}/\dot{M}_o)^{0.7}$$

Here, the suffix o means the design condition.

The pressure drop in the heat exchanger, ΔP, also depends on the mass flow M. The following similar expression is used in the program.

$$\Delta P = (\Delta P)_o \ (\dot{M}/\dot{M}_o)^{1.8}$$

In the subprogram for the valves, the following expressions about the coefficient of the valve C_V are used for calculating the relationship between the mass flow M and the pressure P.

$$\dot{M} = C_V \frac{\sqrt{P_1{}^2 - P_2{}^2}}{\sqrt{T}} \quad \text{at } P_2 \geq 0.5\ P_1$$

$$\dot{M} = C_V \frac{P_1}{\sqrt{T}} \frac{\sqrt{3}}{2} \quad \text{at } P_2 \leq 0.5\ P_1$$

(units: g/s, atm. K)

Here, T is the temperature and the suffix 1 and 2 represent the inlet and the outlet of the valve.

The program takes account of the change of the expansion turbine efficiency. A typical tendency of the expansion turbine efficiency corresponding to the velocity ratio is shown in Fig. 2.[3] In the program, this diagram is approximated by the following expression.

$$\eta = \eta_{max} \cos(u/C_o - \alpha)$$

Here, η is the efficiency of the expansion turbine, u is the rotor tip speed, C_o is the velocity equivalent of the adiabatic head and α is the value of u/C_o where the efficiency reaches the maximum.

The basis for the design of the plant is the TS diagram shown in Fig. 3. A total of approximately 1.0 g/s of helium flows out of the process through the labyrinth seals of the expansion turbines. The program neglects this flow which amounts to 0.07% of the design value of the compressor discharge.

APPLICATIONS

A sample of output from the program is shown in Appendix D. This output corresponds to the design condition. The output is displayed in the order of the sequence number of the components shown in Fig. 1. The linkage point number LN and the flow path number NF correspond to the numbers on Fig. 1.

As the first application, the influence on the J-T valve open rate is analyzed and the results are shown in Figs. 4-6. Figures 4 and 5 show the tendency of the flow rates at several flow paths and Fig. 6 shows the tendency of the temperature at several points corresponding to the open rate of the J-T valve. The C_V value corresponding to the design condition is about 90. The liquid helium production and liquid nitrogen consumption take maxima at around the design point.

As the second application, the performance of CHL is analyzed on the condition that the discharge pressure of the compressor is the same as design condition, 11.9 atm, and that the open rates of the J-T valve and the turbine #1 (T-1) inlet valve are changed. The J-T valve and T-1 valve are two main control valves in this system. The results are shown in Fig. 7. The curve A shows the helium production corresponding to the discharge flow rate of the compressor on the condition that the open rate of the T-1 inlet valve is constant and the open rate of J-T valve is changed. The other curves similar to curve A show the results in the case of the corresponding open rates of the T-1 inlet valve. The curve B shows the maximum helium production corresponding to the discharge flow rate of the compressor; that is the performance curve for CHL on this condition.

Another performance curve on condition that the discharge pressure of the compressor is 9.9 atm is shown in Fig. 8. From the comparison between Figs. 7 and 8, it is the best way to keep up the discharge flow rate of the compressor for producing the most liquid helium at the reduced operation mode.

The performance curve for another reduced operation is shown in Fig. 9. In this case, the discharge pressure is 11.9 atm, the design pressure, but the turbine #2 inlet valve is closed or the turbine #2 is isolated from the process line. The liquid helium production decreases remarkably.

ACKNOWLEDGEMENTS

I would like to thank Drs. R.Walker, G.Mulholland, H.Barton, W.Fowler and R.Yamada for their advice on this work and the hospitality extended during my stay at Fermilab.

REFERENCE

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2. Barton, H.R., J.E.Nichols, and G.T.Mulholland; "Satellite I: Model for the Satellite Mode Refrigerator," TM-984, 1980.

3. Haselden, G.G.; "Cryogenic Fundamentals," Academic Press, London, 1971.

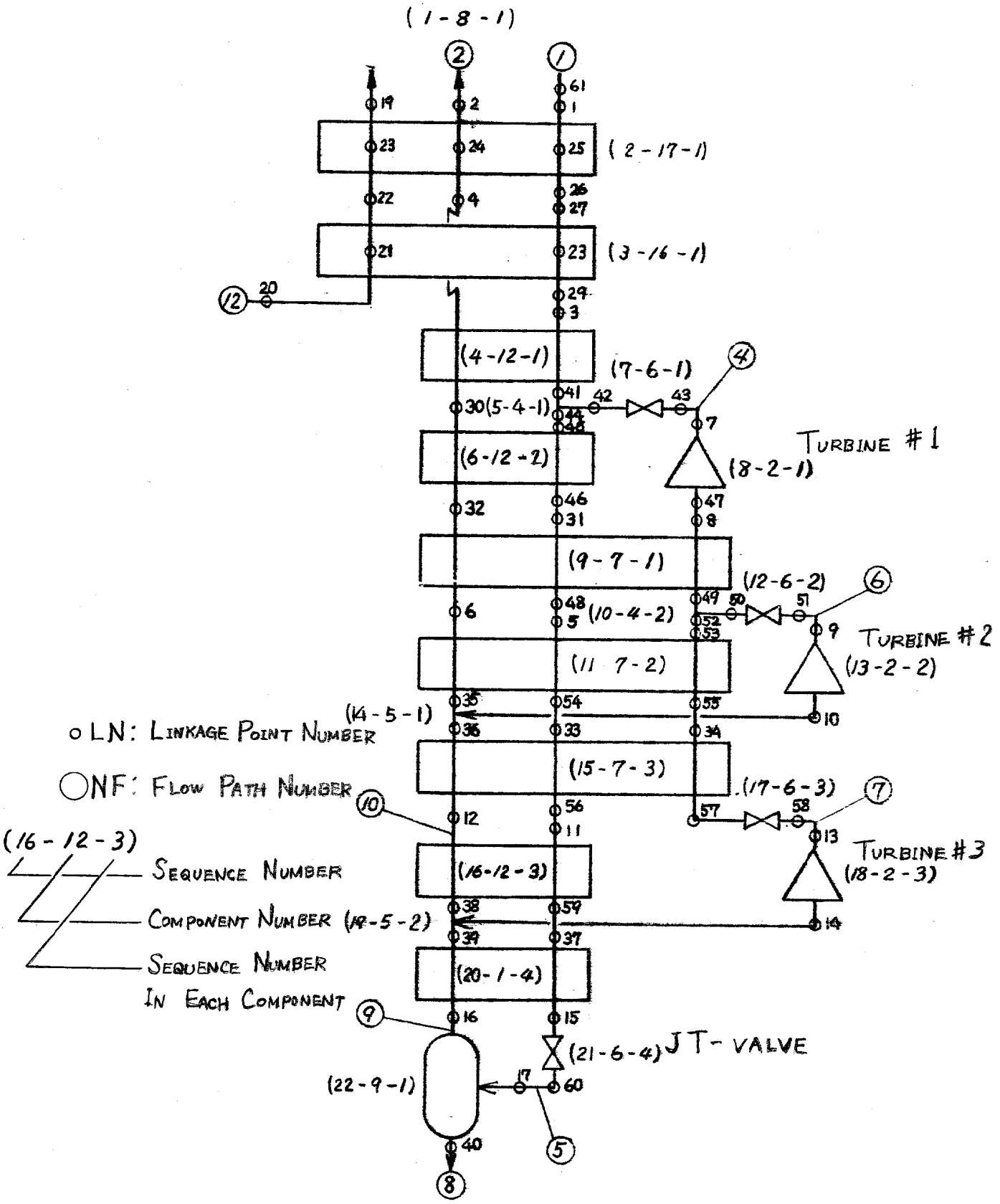
(1-8-1)
(2-17-1)
(3-16-1)
(4-12-1)
(7-6-1)
(5-4-1)
(6-12-2)
(8-2-1)
TURBINE #1
(9-7-1)
(12-6-2)
(10-4-2)
(11 7-2)
(13-2-2)
TURBINE #2
(14-5-1)
(15-7-3)
(17-6-3)
(16-12-3)
(18-2-3)
TURBINE #3
(20-1-4)
(21-6-4) JT-VALVE
(22-9-1)
o LN: LINKAGE POINT NUMBER
ONF: FLOW PATH NUMBER
(16-12-3)
SEQUENCE NUMBER
COMPONENT NUMBER (12-5-2)
SEQUENCE NUMBER
IN EACH COMPONENT

FIGURE 1

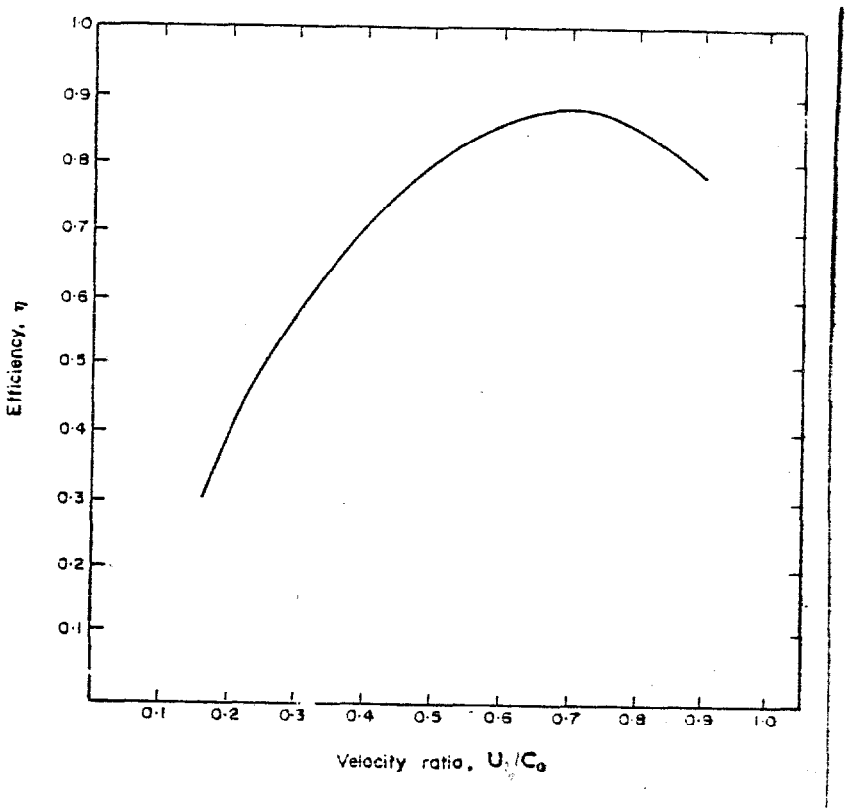
1·0
0·9
0·8
0·7
0·6
0·5
0·4
0·3
0·2
0·1
Efficiency, η
0·1
0·2
0·3
0·4
0·5
0·6
0·7
0·8
0·9
1·0
Velocity ratio, U₁/C₀

FIGURE 2

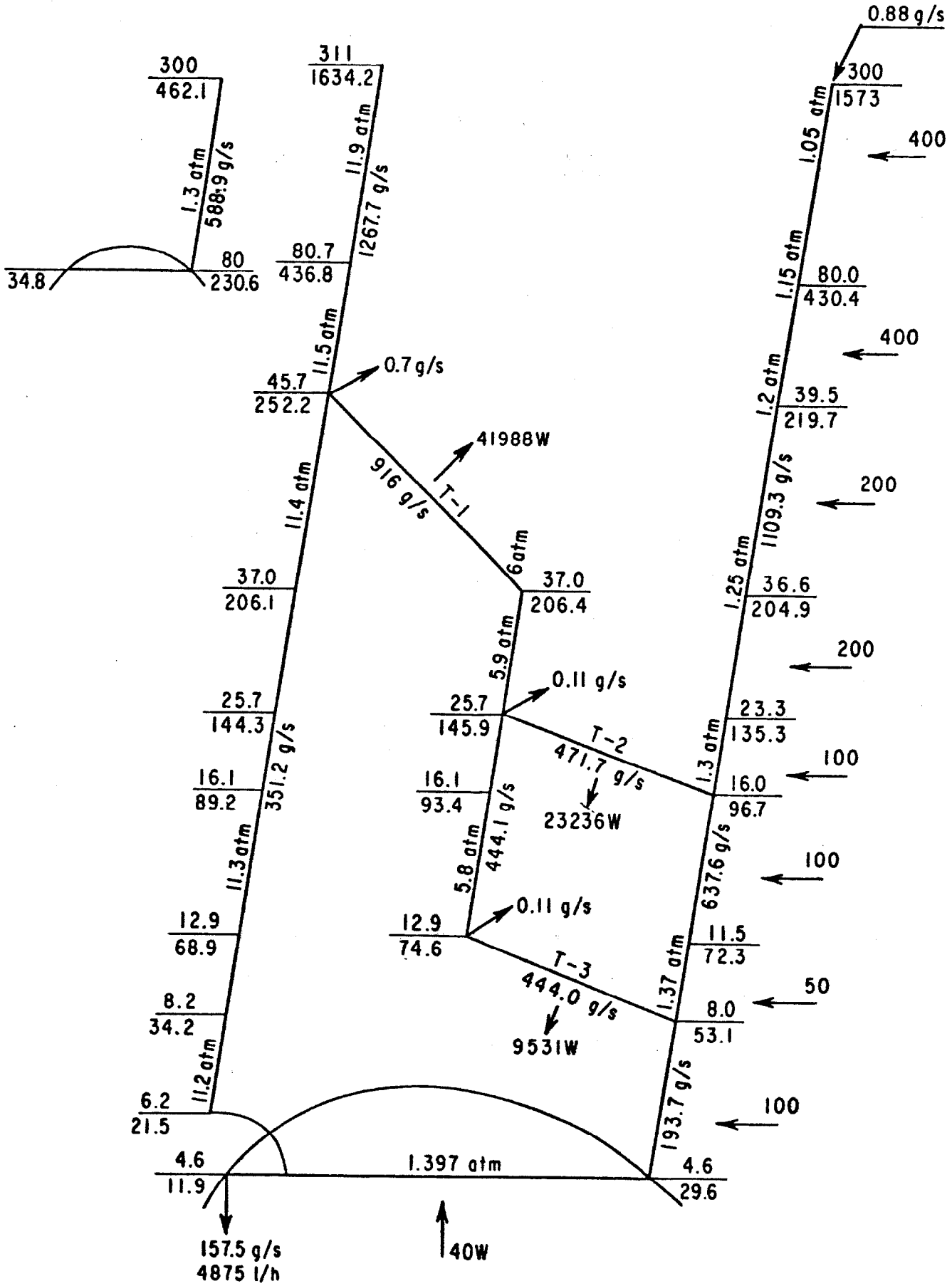
0.88 g/s
300
1573
1.05 atm
400
1.15 atm
80.0
430.4
400
1.2 atm
39.5
219.7
200
1109.3 g/s
1.25 atm
36.6
204.9
200
23.3
135.3
1.3 atm
100
16.0
96.7
637.6 g/s
100
11.5
72.3
1.37 atm
50
8.0
53.1
193.7 g/s
100
4.6
29.6
1.397 atm
300
462.1
1.3 atm
588.9 g/s
80
230.6
34.8
311
1634.2
11.9 atm
1267.7 g/s
80.7
436.8
11.5 atm
0.7 g/s
45.7
252.2
41988W
916 g/s
T-1
6 atm
37.0
206.4
11.4 atm
37.0
206.1
5.9 atm
0.11 g/s
25.7
145.9
T-2
471.7 g/s
23236W
25.7
144.3
351.2 g/s
16.1
93.4
16.1
89.2
5.8 atm
444.1 g/s
11.3 atm
0.11 g/s
12.9
74.6
T-3
444.0 g/s
9531W
12.9
68.9
8.2
34.2
11.2 atm
6.2
21.5
4.6
11.9
157.5 g/s
4875 l/h
40W

FIGURE 3

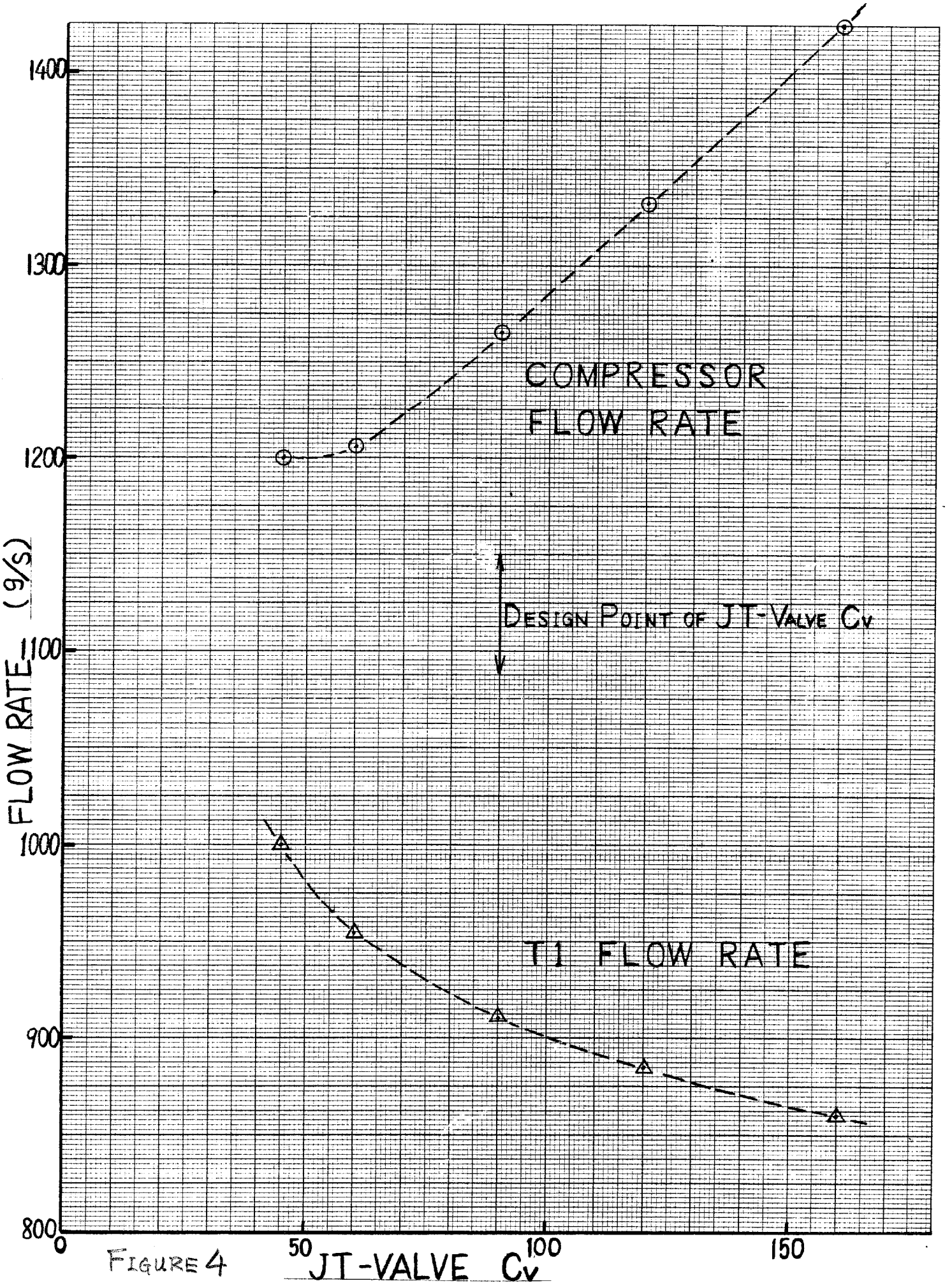
1400
1300
1200
1100
1000
900
800
FLOW RATE (g/s)
0
50
100
150
JT-VALVE Cv
COMPRESSOR
FLOW RATE
DESIGN POINT OF JT-VALVE Cv
T1 FLOW RATE

FIGURE 4

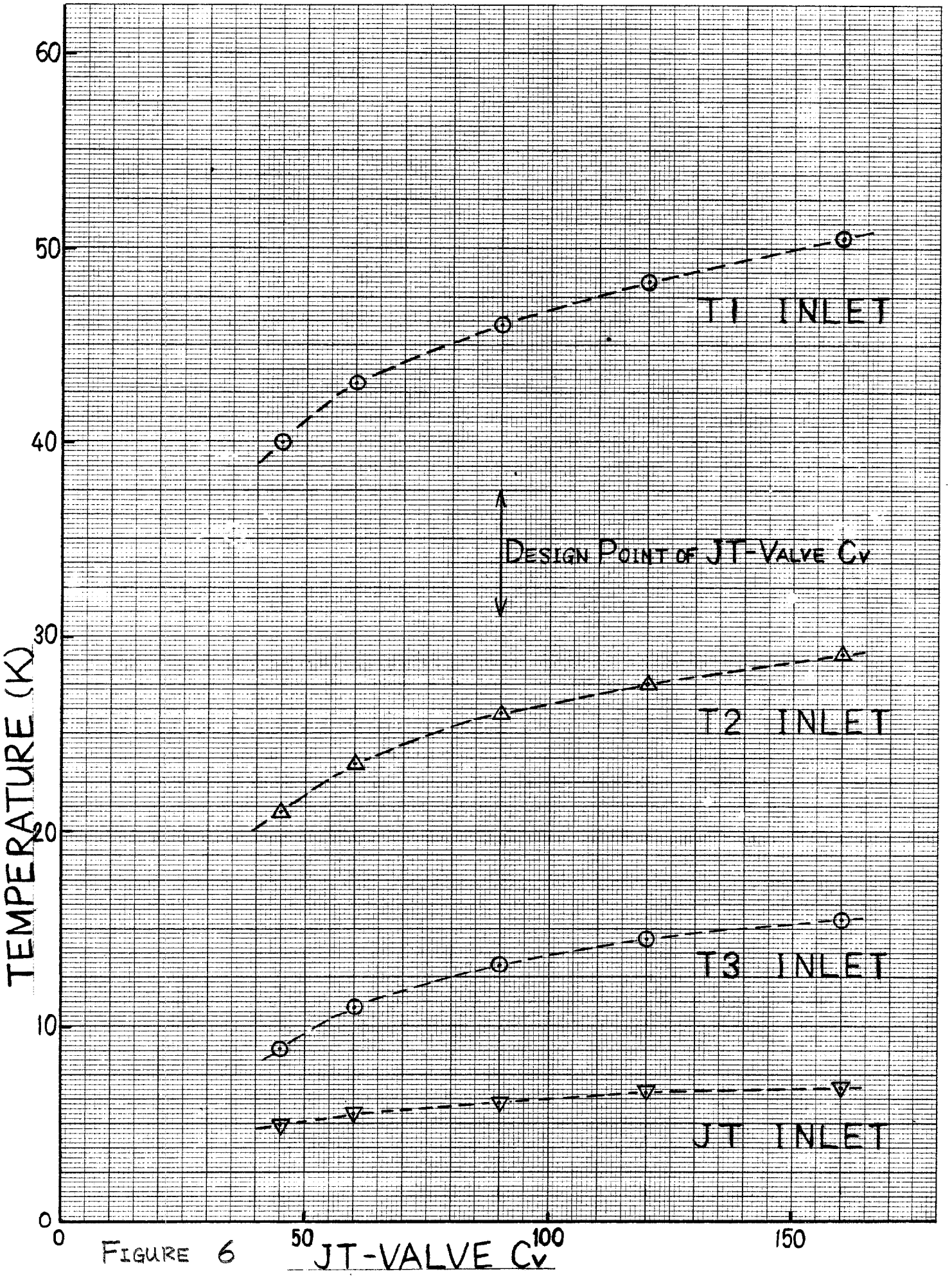
60
50
40
30
20
10
0
TEMPERATURE (K)
T1 INLET
DESIGN POINT OF JT-VALVE Cv
T2 INLET
T3 INLET
JT INLET
0
50
100
150
JT-VALVE Cv

FIGURE 6

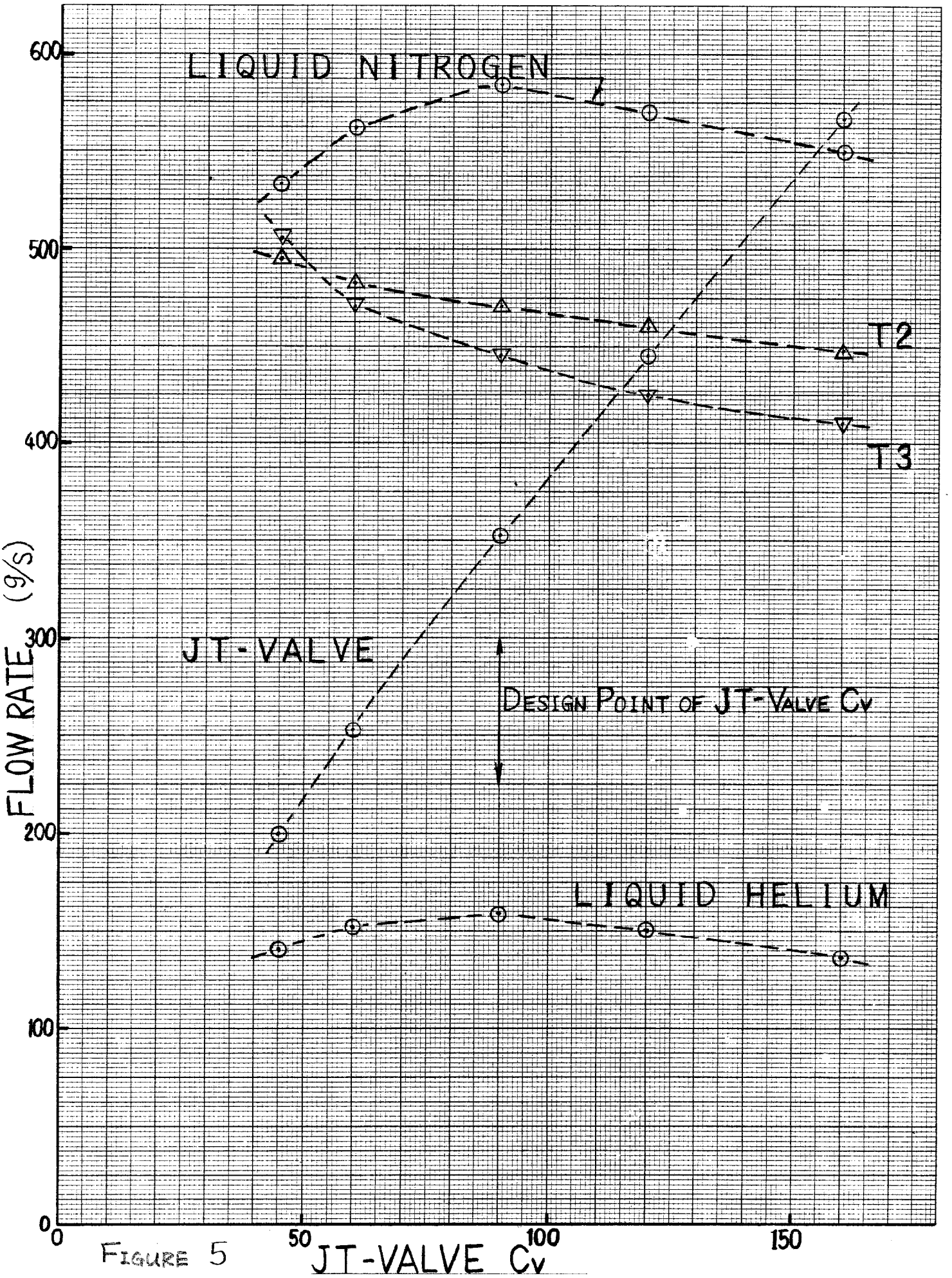
LIQUID NITROGEN
T2
T3
JT-VALVE
DESIGN POINT OF JT-VALVE Cv
LIQUID HELIUM
FLOW RATE (g/s)
JT-VALVE Cv
0
100
200
300
400
500
600
50
150

FIGURE 5

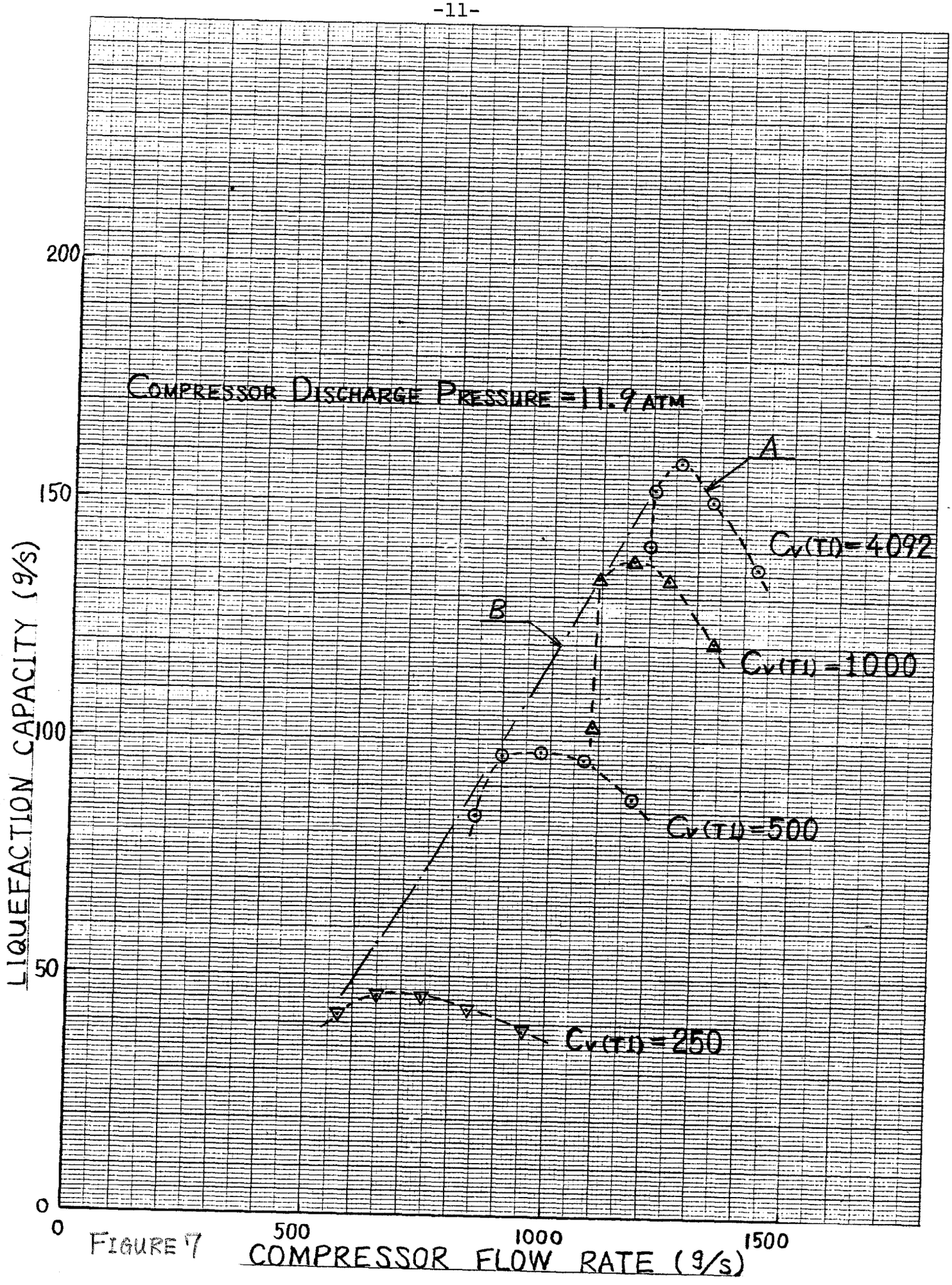
COMPRESSOR DISCHARGE PRESSURE = 11.9 ATM
A
B
$C_v(T1) = 4092$
$C_v(T1) = 1000$
$C_v(T1) = 500$
$C_v(T1) = 250$
LIQUEFACTION CAPACITY (g/s)
COMPRESSOR FLOW RATE (g/s)
0
50
100
150
200
500
1000
1500

FIGURE 7

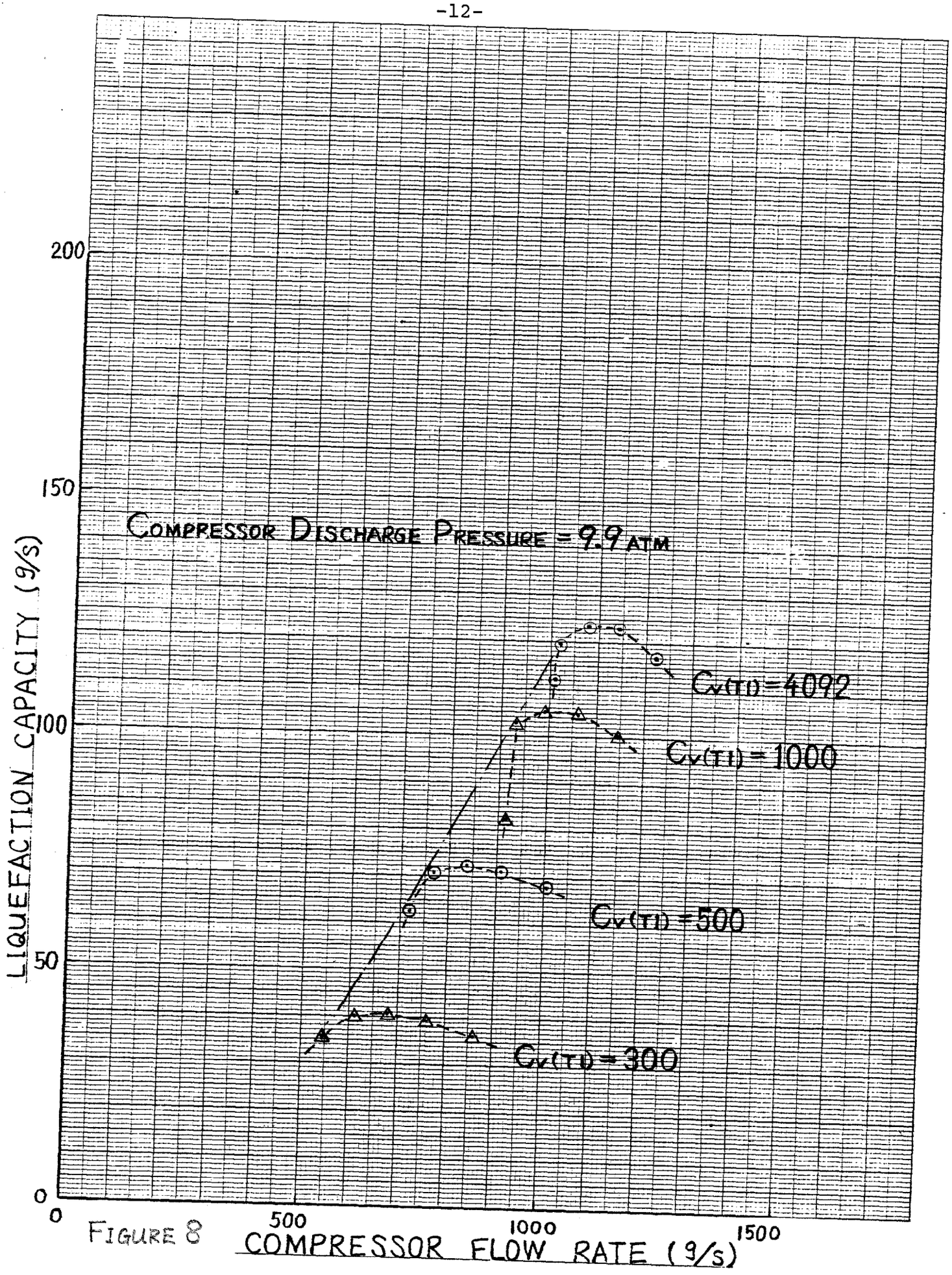
COMPRESSOR DISCHARGE PRESSURE = 9.9 ATM
$C_{v(T1)}$ = 4092
$C_{v(T1)}$ = 1000
$C_{v(T1)}$ = 500
$C_{v(T1)}$ = 300
LIQUEFACTION CAPACITY (g/s)
COMPRESSOR FLOW RATE (g/s)
0
50
100
150
200
0
500
1000
1500

FIGURE 8

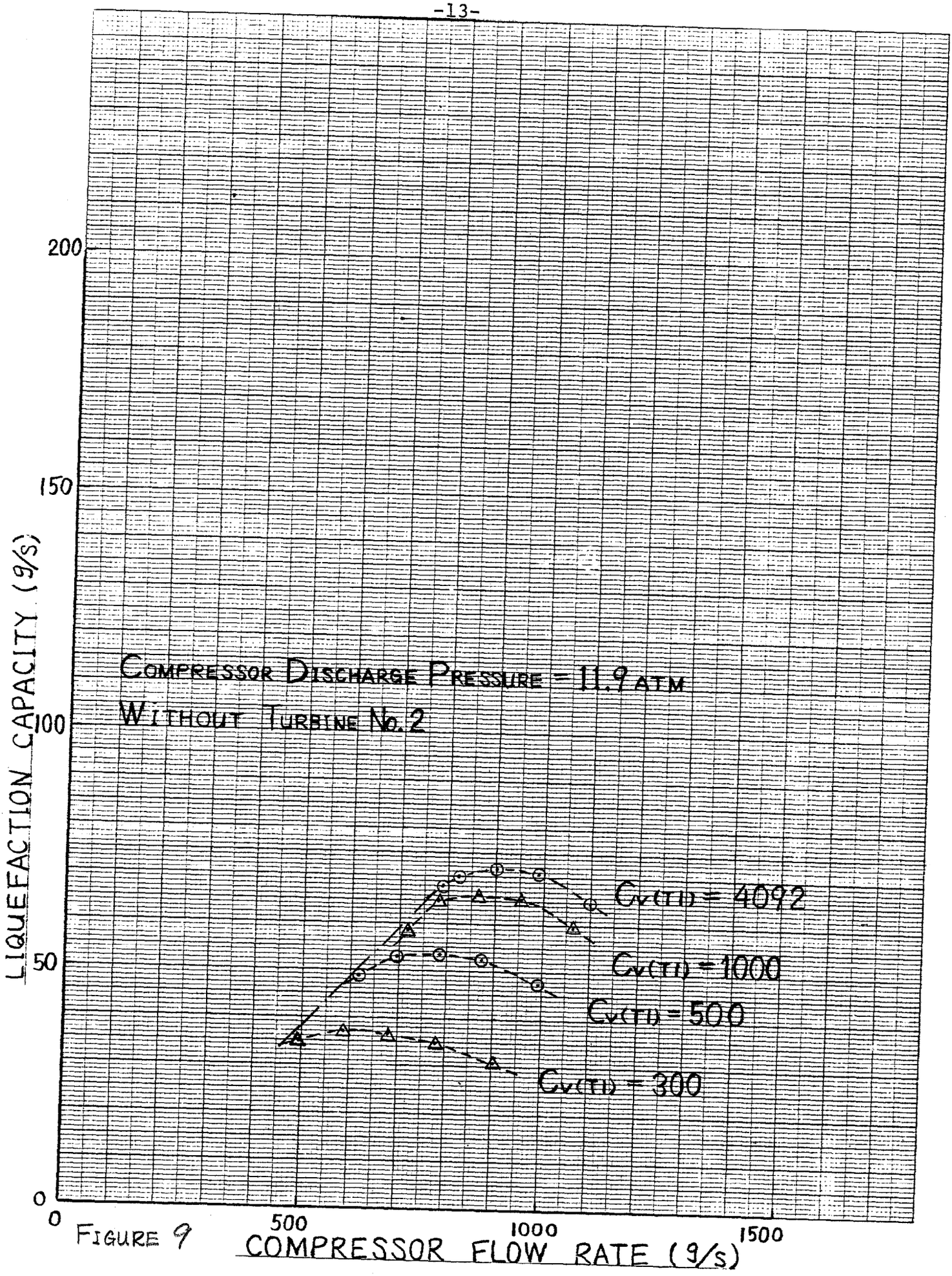
COMPRESSOR DISCHARGE PRESSURE = 11.9 ATM
WITHOUT TURBINE No. 2
Cv(TI) = 4092
Cv(TI) = 1000
Cv(TI) = 500
Cv(TI) = 300
LIQUEFACTION CAPACITY (g/s)
COMPRESSOR FLOW RATE (g/s)
0
50
100
150
200
500
1000
1500

FIGURE 9

APPENDIX A

HOW TO USE THE SIMULATION PROGRAM FOR CHL

1. Starting up.

   a. Log in.

   b. Type the following commands:

```
/GET,HEREF/UN=V3055
/GET,ELMDATA/UN=V3055
/GET,INTDATA/UN=V3055
/HEREF
```

HEREF is a procedure program which contains the commands for transferring the permanent files to the local files, compiling, linking and executing the several kinds of programs. ELMDATA contains information about the refrigeration equipment and the linkage relationship among the equipment. A sample ELMDATA is shown in Appendix B. INTDATA contains the initial data of pressure, temperature, and enthalpy at each linkage point and the data of flow rate at each flow path. A sample INTDATA is shown in Appendix C. It takes a few minutes to start the calculation.

2. Printing the results.

When the calculation is completed without errors, "NORMAL END" appears on the terminal. The result of the calculation is written in a local file called ROUTPUT. To print ROUTPUT, type

```
/R, ROUTPUT
/ROUTE,ROUTPUT,DC=PR
```

3. Rerun.

To rerun the program with the same INTDATA that was used at the previous run, type

```
/HEREFR
```

4. Continuation of the run.

When the number of repetition of the calculation reaches the specified limit (default: 100 cycles) but the temperature distribution does not converge, the following message appears on the screen:

"THE CALCULATION IS NOW ON THE REPETITION LIMIT. PLEASE TYPE (HEREFC) TO CONTINUE THE CALCULATION."

To continue the calculation, type

```
/HEREFC
```

5. Time limit.

When the program does not get to the end in the time limit specified by the computer "TIME LIMIT" appears on the screen. To terminate the run, type

/"CTRL" + T

then reduce the number of repetition limit of the local file ELMDATA. To rerun the program, type

/HEREFR

6. Post-mortem dump.

In case of a fatal computation error, a post-mortem dump will be generated on the file PMDUMP. To examine this dump, type

/R,PMDUMP
/C,PMDUMP

7. Change ELMDATA and/or INTDATA.

To edit the data of ELMDATA and/or INTDATA, use ICE.

APPENDIX B

```
ELMDATA
24          100         0           2
0.01        0.6         0.7         1.8
8           1
1267.7      1.05        0.04        11.9        311.0       0.0         0.0         0.0
2           61
2           1
4           6           1           2           1           43
6           6           2           2           2           51
7           6           3           2           3           58
11          0           6           0           7           0
5           6           4           0           0           0
1           0           4           0           5           0
9           0           5           -1          8           0
10          0           7           0           9           0
2           0           6           0           10          0
0           0           0           0           0           0
17          1
300.0       9309.0      89022.0     588.9       1109.3      1267.7      0.0         0.06
0.1
19          22          2           4           1           26          61          23
24          25
12          2           1
16          1
100.0       21576.0     588.9       1267.7      0.0         0.1
22          20          27          29          26          21          28
12          1
12          1
400.0       93849.0     1109.3      1267.7      0.05        0.2
4           30          3           41          29
2           1
0           65
4           1
0.0
41          42          44
1           4           5
12          2
200.0       8238.0      1109.3      351.2       0.          0.1
30          32          45          46          44
2           5
0           75
6           1
0.0         4092.00     0.0         0.0         0.0         0.0         0.0         0.0
42          43
4
2           1
0.829       638.83      0.7         0.0         0.0         0.0         0.0         42195.7
233.135     0.829       229.44      270.93
7           47          43
4
7           1
200.0       0.0         22045.2     54432.5     1109.3      351.2       916.0       0.05
0.1         0.1
32          6           31          48          8           49          46          47
2           5           4
4           2
0.0
49          50          52
11          6           7
7           2
100.0       0.0         31126.7     36425.2     1109.3      351.2       444.0       0.05
0.          0.1
6           35          5           54          53          55          48          52
2           5           7
```

```
6          2
0.0        2210.75    0.0        0.0        0.0        0.0        0.0        0.0
50         51
6
2          2
0.821      476.07     0.7        0.0        0.0        0.0        0.0        23470.3
244.2      0.821      231.38     305.23
9          10         51
6
5          1
0.0
35         10         36
2          6          10
7          3
100.0      0.0        14478.0    18367.2    637.6      351.2      444.0      0.0
0.         0.
36         12         33         56         34         57         54         55
10         5          7
12         3
50.0       29759.0    637.6      351.2      0.06       0.1
12         38         11         59         56
10         5
1          85
6          3
0.0        1487.06    0.0        0.0        0.0        0.0        0.0        0.0
57         58
7
2          3
0.813      323.05     0.7        0.0        0.0        0.0        0.0        9525.1
161.1      0.81       129.12     255.49
13         14         58
7
5          2
0.0
38         14         39
10         7          9
12         4
100.0      6679.0     193.7      351.2      0.038      0.0
39         16         37         15         59
9          5
1          95
6          4
0.0        90.157     0.0        0.0        0.0        0.0        0.0        0.0
15         60
5
9          1
40.0       0.0        0.0        0.0
16         17         40         60
9          5          8
18         1
300.0      1.0        0.5        0.5        0.         0.         0.         0.
19         2          8          12
18         2
4.0        -0.005     -0.001     -0.001     0.         0.         0.         0.
11         3          1          47
```

APPENDIX C

```
INTDATA
1
11.9        311.0       1634.2
2
1.05        300.0       1573.C
3
11.7        80.7        436.8
4
1.15        80.0        430.4
5
11.4        25.7        144.3
6
1.3         23.3        135.3
7
11.5        45.7        252.2
8
6.0         37.0        206.4
9
5.9         25.7        145.9
10
1.3         16.0        96.7
11
11.3        12.9        68.9
12
1.37        11.5        72.3
13
5.8         12.9        74.6
14
1.37        8.0         53.1
15
11.2        6.2         21.5
16
1.397       4.6         29.6
17
1.397       4.6         21.5
18
0.0         0.0         0.0
19
1.3         300.0       311.1
20
1.3         79.66       -116.62
21
1.3         79.66       78.934
22
1.3         79.66       78.934
23
1.3         79.66       78.934
24
1.15        80.0        430.4
25
11.8        98.09       526.66
26
11.8        98.09       526.66
27
11.8        98.09       526.66
28
11.8        98.09       526.66
29
11.7        80.7        436.8
30
1.2         39.5        219.7
31
11.4        37.0        205.1
32
1.25        36.6        204.9
33
11.3        16.1        89.2
34
5.8         16.1        93.4
35
1.3         16.0        96.7
36
1.3         16.0        96.7
37
11.2        8.2         34.2
38
1.37        8.0         53.1
39
1.37        8.0         53.1
40
1.397       4.6         11.9
41
11.5        45.7        252.2
42
11.5        45.7        252.2
43
11.5        45.7        252.2
44
11.5        45.7        252.2
45
11.5        45.7        252.2
46
11.4        37.0        206.1
47
6.0         37.0        206.4
48
11.4        25.7        144.3
49
5.9         25.7        145.9
50
5.9         25.7        145.9
51
5.9         25.7        145.9
52
5.9         25.7        145.9
53
5.9         25.7        145.9
54
11.3        16.1        89.2
55
5.8         16.1        93.4
56
11.3        12.9        68.9
57
5.8         12.9        74.6
58
5.8         12.9        74.6
59
11.2        8.2         34.2
60
1.397       4.6         21.5
61
11.9        311.0       1634.2
0
1
1267.7
2
1109.3
3
0.0
4
916.0
5
351.2
6
471.7
7
444.0
8
157.5
9
193.7
10
637.6
11
916.0
12
588.9
0
```

```
        NORMAL END

   ELMDATA= ELMDATA              INTDATA=INTDATA
REPETITION NO.=    33                  SUMMATION OF DELT.TEMP.=     .00923
DMIT= .01000       RAMD= .60000       AUEXP= .70000       DPEXP=1.80000

NO= 1    8(FLOW CONT ) NO= 1
  FLOW.MAX     PRESS.SUC       DP.SUC  PRESS.DISCH  TEMP.DISCH
  1267.70000     1.05000       .04000    11.90000   311.00000      0.00000      0.00000      0.00000


NO= 2  17(NX21        ) NO= 1
     QL          AU13D        AU23D          F1D          F2D          F3D          DP1D         DP2D
   300.00000  9309.00000  89022.00000    588.90000  1109.30000  1267.70000      0.00000       .06000

     DP3D         AU13          AU23          DP1          DP2          DP3
     .10000  9281.07798  88863.65654      0.00000       .05969       .09960

        NO    FLOW NO    FLOW RATE      **************  HOT  END  **************      **************  COLD END  **************
                           F(G/S)          LN        P(ATM)         T(K)       H(J/G)          LN        P(ATM)         T(K)       H(J/G)
         1        12     585.1657          19        1.3000     300.0053    311.0913          22        1.3000      99.9317     101.3978
         2         2    1106.1049           2        1.0900     300.2517   1574.2584           4        1.1497      80.2342     431.5442
         3         1    1264.9116           1       11.9000     311.0000   1634.2000          26       11.8004     100.2373     538.1763

NO= 3  16(NX11        ) NO= 1
     QL          AU13D         F1D          F2D          DP1D         DP2D         AU13         DP1
   100.00000 21576.00000    588.90000  1267.70000      0.00000       .10000 21511.28354      0.00000

     DP2
     .09960

        NO    FLOW NO    FLOW RATE      **************  HOT  END  **************      **************  COLD END  **************
                           F(G/S)          LN        P(ATM)         T(K)       H(J/G)          LN        P(ATM)         T(K)       H(J/G)
         1        12     585.1657          22        1.3000      99.9317    101.3978          20        1.3000      79.4269    -116.8717
         2         1    1264.9116          27       11.8004     100.2373    538.1763          29       11.7008      80.8957     437.2751

NO= 4  12(HX11-DIV   ) NO= 1
     QL          AU13          F1D          F2D          DP1D         DP2D         AU13         DP1
   400.00000 93849.00000  1109.30000  1267.70000       .05000       .20000 93682.07075       .04974

     DP2
     .19921

     NO.DIV      LNSTART
          0           65

        NO    FLOW NO    FLOW RATE      **************  HOT  END  **************      **************  COLD END  **************
                           F(G/S)          LN        P(ATM)         T(K)       H(J/G)          LN        P(ATM)         T(K)       H(J/G)
         1         2    1106.1049           4        1.1497      80.2342    431.5442          30        1.1994      40.0804     222.7608
         2         1    1264.9116           3       11.7008      80.8957    437.2751          41       11.5016      46.1921     255.0114

NO= 5    4(FLOW SEPR ) NO= 1
     0.00000

NO= 6  12(HX11-DIV   ) NO= 2
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   QL          AU13          F1D          F2D          DP1D         DP2D         AU13         DP1
 200.00000  8238.00000  1109.30000   351.20000      0.00000       .10000  8256.48852      0.00000

   DP2
   .10169

   NO.DIV      LNSTART
       0           75

      NO   FLOW NO   FLOW RATE      ************** HOT  END **************      ************** COLD END **************
                       F(G/S)        LN       P(ATM)        T(K)       H(J/G)        LN       P(ATM)        T(K)       H(J/G)
       1         2   1106.1049        30       1.1994      40.0804     222.7608        32       1.1994     37.2117     207.8180
       2         5    354.4869        45      11.5016      46.1921     255.0114        46      11.3999     37.5451     208.9271

NO= 7   6(VALVE      ) NO= 1
   QL          CV                                  BETA1        BETA2       PRESS.IN
  0.00000  4092.00000     0.00000      0.00000  2041.88056   602.07631    11.50158      0.00000

      NO   FLOW NO   FLOW RATE      ************** HOT  END **************      ************** COLD END **************
                       F(G/S)        LN       P(ATM)        T(K)       H(J/G)        LN       P(ATM)        T(K)       H(J/G)
       1         4    910.4247        42      11.5016      46.1921     255.0114        43      11.4017     46.1813     255.0114

NO= 8   2(TURBINE    ) NO= 1
   EFFIC.D       CV          (U/CO)D  DELT.ENTH.    WORK          BETA2       PRESS.IN      WORK.D
    .82900   638.83000        .70000    45.83060 41725.30655     94.00525    11.40174 42195.70000

      U.D       EFFIC.        U.LOW       U.HIGH
 233.13500       .82900    229.44000    270.93000

      NO   FLOW NO   FLOW RATE      ************** HOT  END **************      ************** COLD END **************
                       F(G/S)        LN       P(ATM)        T(K)       H(J/G)        LN       P(ATM)        T(K)       H(J/G)
       1         4    910.4247         7      11.4017      46.1813     255.0114        47       6.0171     37.5243     209.1744

NO= 9   7(HX12       ) NO= 1
   QL2          QL3         AU13D        AU14D         F1D          F3D          F4D          DP1D
 200.00000     0.00000 22045.20000 54432.50000  1109.30000   351.20000   916.00000       .05000

   DP3D         DP4D         AU13         AU14         DP1          DP3          DP4
    .10000       .10000 22094.67598 54261.46965       .04974       .10169       .09891

      NO   FLOW NO   FLOW RATE      ************** HOT  END **************      ************** COLD END **************
                       F(G/S)        LN       P(ATM)        T(K)       H(J/G)        LN       P(ATM)        T(K)       H(J/G)
       1         2   1106.1049        32       1.1994      37.2117     207.8180         6       1.2492     23.7189     137.3468
       2         5    354.4869        31      11.3999      37.5451     208.9271        48      11.2982     26.0191     146.2987
       3         4    910.4247         8       6.0172      37.5243     209.1744        49       5.9183     26.0684     148.1515

NO=10   4(FLOW SEPR ) NO= 2
   0.00000

NO=11   7(HX12       ) NO= 2
   QL2          QL3         AU13D        AU14D         F1D          F3D          F4D          DP1D
 100.00000     0.00000 31126.70000 36425.20000  1109.30000   351.20000   444.00000       .05000

   DP3D         DP4D         AU13         AU14         DP1          DP3          DP4
   0.00000       .10000 31196.55756 36286.90554       .04974      0.00000       .09857

      NO   FLOW NO   FLOW RATE      ************** HOT  END **************      ************** COLD END **************
                       F(G/S)        LN       P(ATM)        T(K)       H(J/G)        LN       P(ATM)        T(K)       H(J/G)
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     1         2   1106.1049        6      1.2492     23.7189    137.3468        35      1.2989     16.2805     98.1517
     2         5    354.4869        5     11.2982     26.0191    146.2987        54     11.2982     16.3500     90.6409
     3         7    440.4713       53      5.9183     26.0684    148.1515        55      5.8197     16.3518     94.7369
NO=12   6(VALVE      ) NO= 2
    QL          CV                                   BETA1       BETA2      PRESS.IN
  0.00000  2210.75000     0.00000     0.00000  1053.36573   432.99427     5.91826     0.00000

      NO   FLOW NO   FLOW RATE      ************** HOT  END **************      ************** COLD END **************
                       F(G/S)          LN       P(ATM)        T(K)       H(J/G)        LN       P(ATM)        T(K)       H(J/G)
      1         6    469.9579         50       5.9183     26.0684    148.1515        51       5.8179     26.0513    148.1515
NO=13   2(TURBINE    ) NO= 2
    EFFIC.D       CV          (U/CO)D  DELT.ENTH.     WORK          BETA2      PRESS.IN      WORK.D
     .82100   476.07000       .70000     49.95467 23476.59172    93.27310     5.81792 23470.30000

      U.D       EFFIC.       U.LOW       U.HIGH
  244.20000      .82100   231.38000   305.23000

      NO   FLOW NO   FLOW RATE      ************** HOT  END **************      ************** COLD END **************
                       F(G/S)          LN       P(ATM)        T(K)       H(J/G)        LN       P(ATM)        T(K)       H(J/G)
      1         6    469.9579          9       5.8179     26.0513    148.1515        10       1.2989     16.2885     98.1940
NO=14   5(FLOW SUM   ) NO= 1
    0.00000

NO=15   7(HX12       ) NO= 3
    QL2          QL3        AU13D        AU14D         F1D          F3D          F4D          DP1D
  100.00000     0.00000 14478.00000 18367.20000   637.60000   351.20000   444.00000     0.00000
    DP3D         DP4D         AU13         AU14         DP1          DP3          DP4
    0.00000      0.00000 14513.56838 18301.32051     0.00000      0.00000      0.00000

      NO   FLOW NO   FLOW RATE      ************** HOT  END **************      ************** COLD END **************
                       F(G/S)          LN       P(ATM)        T(K)       H(J/G)        LN       P(ATM)        T(K)       H(J/G)
      1        10    636.1470         36       1.2989     16.2748     98.1214        12       1.2989     11.9110     74.8114
      2         5    354.4869         33      11.2982     16.3500     90.6409        56      11.2982     13.3058     71.6516
      3         7    440.4713         34       5.8197     16.3518     94.7369        57       5.8197     13.2219     76.5787
NO=16  12(HX11-DIV   ) NO= 3
    QL          AU13          F1D          F2D          DP1D         DP2D         AU13         DP1
  50.00000 29759.00000   637.60000   351.20000       .06000       .10000 29832.10952       .05975
    DP2
    .10169

    NO.DIV      LNSTART
        1           85

      NO   FLOW NO   FLOW RATE      ************** HOT  END **************      ************** COLD END **************
                       F(G/S)          LN       P(ATM)        T(K)       H(J/G)        LN       P(ATM)        T(K)       H(J/G)
      1        10    636.1470         12       1.2989     11.9110     74.8114        38       1.3288      8.1576     54.0909
      2         5    354.4869         11      11.2982     13.3058     71.6516        59      11.2474      8.2646     34.6072
NO=17   6(VALVE      ) NO= 3
    QL          CV                                   BETA1       BETA2      PRESS.IN
  0.00000  1487.06000     0.00000     0.00000   986.57624   408.96003     5.81969     0.00000
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        NO   FLOW NO   FLOW RATE      **************  HOT  END  **************      **************  COLD END  **************
                          F(G/S)          LN       P(ATM)        T(K)       H(J/G)          LN       P(ATM)        T(K)       H(J/G)
         1          7    440.4713         57       5.8197      13.2219      76.5787          58       5.7192      13.1958      76.5787

NO=18   2(TURBINE    ) NO= 3
     EFFIC.D        CV          (U/CO)D  DELT.ENTH.     WORK          BETA2       PRESS.IN       WORK.D
      .81300    323.05000       .70000    22.46045  9893.18191     88.93075      5.71918   9525.10000

        U.D       EFFIC.        U.LOW       U.HIGH
   161.10000       .81293    129.12000    255.49000

        NO   FLOW NO   FLOW RATE      **************  HOT  END  **************      **************  COLD END  **************
                          F(G/S)          LN       P(ATM)        T(K)       H(J/G)          LN       P(ATM)        T(K)       H(J/G)
         1          7    440.4713         13       5.7192      13.1958      76.5787          14       1.3288       8.1623      54.1178

NO=19   5(FLOW SUM   ) NO= 2
     0.00000

NO=20  12(HX11-DIV   ) NO= 4
     QL          AU13          F1D          F2D          DP1D         DP2D         AU13         DP1
   100.00000  6679.00000   193.70000   351.20000       .03800      0.00000  6724.65451       .03870

      DP2
     0.00000

      NO.DIV      LNSTART
          1           95

        NO   FLOW NO   FLOW RATE      **************  HOT  END  **************      **************  COLD END  **************
                          F(G/S)          LN       P(ATM)        T(K)       H(J/G)          LN       P(ATM)        T(K)       H(J/G)
         1          9    195.6758         39       1.3288       8.1469      54.0305          16       1.3481       4.5555      29.7113
         2          5    354.4869         37      11.2474       8.2646      34.6072          15      11.2474       6.1371      21.4649

NO=21   6(VALVE      ) NO= 4
     QL          CV                                  BETA1        BETA2       PRESS.IN
     0.00000    90.15700     0.00000     0.00000   122.05187    36.39311     11.24735     0.00000

        NO   FLOW NO   FLOW RATE      **************  HOT  END  **************      **************  COLD END  **************
                          F(G/S)          LN       P(ATM)        T(K)       H(J/G)          LN       P(ATM)        T(K)       H(J/G)
         1          5    354.4869         15      11.2474       6.1371      21.4649          60       1.3481       4.5555      21.4649

NO=22   9(LIQ SEPRT  ) NO= 1
     QL          QRD          QR        FLOW.LIQ
    40.00000     0.00000     0.00000   158.81112


NO=23  18(CONTROLLER) NO= 1
          NO      MEASUR.  CNTRL.ELM          NO.
          19       TEMP.      FLOW             12

    TARGET       P-COEFF.     I-COEFF.     D-COEFF.     1-BEFORE     2-BEFORE     3-BEFORE     4-BEFORE
   300.00000      1.00000       .50000       .50000       .00529       .00537       .00542       .00542


NO=24  18(CONTROLLER) NO= 2
          NO      MEASUR.  CNTRL.ELM          NO.
          11         FLOW     PRESS.           47
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TARGET	P-COEFF.	I-COEFF.	D-COEFF.	1-BEFORE	2-BEFORE	3-BEFORE	4-BEFORE
4.00000	-.00500	-.00100	-.00100	.00452	.00521	.00594	.00654