Fermilab

TM-971
1650

AN ANALYSIS OF THE COOLDOWN OF THE CENTRAL LIQUEFIER

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June 2, 1980

ABSTRACT

During the recent cooldown of the Central Liquefier some data were logged which can be compared to model calculations of liquefier performance. The cooldown began about midnight on April 18 and continued for approximately 14 hours. During this period, the heat exchangers of the liquefier were cooled at the rate of 2.2×10^{-3} to 3.6×10^{-3}°K/sec. The computer program CENTRAL described in TM-967 was used to simulate the cooldown. In this report, the results of the simulation are compared with the data taken during plant operation.

METHOD OF ANALYSIS

The thermal characteristics of the heat exchangers in the Central Liquefier are summarized in Figure 1. The plant operating data shown in Figures 2 and 3 were used to estimate the cooling rate $\frac{dT}{dt}$ for each heat exchanger. The value of $\frac{dT}{dt}$ during cooldown was used with the mass of each heat exchanger and the specific heat of aluminum to determine time-dependent heat loads at each temperature level. These heat loads are summarized in Figure 4.

Please refer to Figures 1 and 2 of TM-967 for a flow diagram of the liquefier and a drawing which shows the control room instrumentation. The normal flow path of helium through the turboexpanders unbalances the heat exchangers (except HX8) of the liquefier to produce refrigeration for cooldown. Additionally, helium was taken from process point 17 in the plant and returned to compressor suction after heating to room temperature.

The simulation produced TS diagrams for the liquefier. Five of these are shown in Figures 5 through 9. The operating conditions for the plant are given at four-hour intervals beginning two

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hours after the start of the cooldown. The cooling rate used during actual operation of the plant was the input to this simulation. This gives the time dependence of the turbine operating temperatures. The time-dependent heat loads at each temperature level are determined by the heat capacity of the heat exchangers. The computer program CENTRAL was used to calculate temperature values throughout the liquefier and the mass flow at all points in the plant. The program calculated the enthalpy of helium at each process point and these values were part of the program's output.

DISCUSSION OF THE COMPUTER RESULTS

The data taken during plant operation can be compared to the computer output in order to verify that the computer program correctly predicts the liquefier performance. A number of unphysical conditions are evident in the data logged. The recorded inlet temperature of the T1 turbine is lower than the exit temperature beginning at 0630. The same effect is found at 0630 for the T2 turbine. Besides these problems with the instrument readings, the flow of liquid nitrogen was not used very effectively to maintain the temperatures at process points 3 and 4. Generally, the simulated cooldown agrees with the operating data although more frequent sets of readings would be desirable. In the future, the turbine efficiencies can be determined at the operating conditions if the inlet and exit temperatures are measured.

CONCLUSIONS

During the cooldown of April 18, the turboexpanders were not being operated at full capacity so it is evident that the plant could be cooled to helium temperature in less than 14 hours. More computer runs could determine the optimum cooldown procedure; however, it is clear that a more rapid cooldown would result if the compressors were operating at full discharge pressure from the outset.

The heater, used to remove helium at process point 17, is a load on the refrigeration system. Also, because main flow passes through the high pressure side of HX2, taking helium out the heater unbalances HX2 in the wrong direction for rapid cooldown. If manual by-pass valves (HV186, HV187, HV188) are configured properly, the helium flow in the low pressure side of HX8 can be rerouted from process point 16 directly to point 14. This change in operating procedure would speed up the cooldown and would avoid the use of the heater during cooldown.

The simulation results shown in Figure 9 indicate that the plant can make 2919 liters per hour of liquid helium using 768.4 grams per second of compressor flow. On page 5 of the Central Liquefier Log Book II, it appears that this output of liquid helium required 920 grams per second of main flow (a differential pressure of 16.4 inches water corresponding to 11,000 scfm helium). This measured main flow is 20 percent greater than the computed value. An extrapolation to maximum capacity requires assumptions about the performance of the liquefier components at higher mass flow. If the operating efficiencies remain unchanged at higher mass flow, the maximum capacity which can be expected from the Central Liquefier is the design value of 4875 liters per hour multiplied by the ratio 768/920.

The computer program CENTRAL appears to reproduce the behavior of the plant; however, comparisons with data which are taken more systematically would be desirable. The calculations which were made to obtain the data contained in this report required approximately 5 seconds of computer time so a simulated cooldown for study can be completed quickly.

Properties of Heat Exchangers

Heat Exchanger Module	Weight (kg)	Heat Exchanger Number	UA (watts/°K)
E16	1950	HX1	98 331
		HX1A	21 576
E17	1996	HX2	94 550
		HX3	8 088
		HX4	75 681
E18	1814	HX5	69 596
		HX6	33 207
E19	726	HX7	29 759
		HX8	6 679

Figure 1.

MAKING LIQUID

Page 1

DATE / TIME	4/18 0030	0130	0230	0630	0915	1345	1715	2200
Cold Box Vac PI-18	10^{-7}	10^{-7}	10^{-7}	10^{-7}	10^{-7}	10^{-7}	10^{-7}	10[illegible]
Cold Box Vac PI-19	50	50	50	50	50	50	50	50
T-1 Speed	38	28	33	—	62,5[illegible]	65,000	62,000	65,[illegible]
T-2 Speed	40	50	44	—	39,5[illegible]	41,000	38,000	38,[illegible]
T-3 Speed	25	30	28	—	26,[illegible]	29,000	25,000	25,000
HIC-1 T-1 In% [illegible]	25%	25	25%	0	30%	30%	30%	35%
HIC-2 T-2 Brake	100%	100	100%	100	100%	32%	99%	90%
HIC-3 T-3 Brake	100%	100 ~~50~~	100%	100	100%	100%	98%	90%
HIC-4 T-3 In	50%	50	50%	0	50%	50%	50%	50%
HIC-5 T-1 Brake	100%	100	80%	100	1[illegible]	100%	100%	100[illegible]
V-5	100%	100	100%	100	100%	100%	100%	100%
TIC-1 JT	M/22/[illegible]	A/21/65%	[illegible]	M/22/20	[illegible]	M 21/15%	[illegible]	M/8.5/[illegible]%
[illegible]C-2 T-2 In	M/45/5[illegible]	A/43/50	[illegible]	M/45/0	[illegible]	M 42/50	[illegible]	M/42/[illegible]%
[illegible]hase Separator Press	A/23/25	A/25/0	A/23/[illegible]	M/17/0	A/20/27%	A 17/100	A/20/35	A/22.5/[illegible]%
Phase Separator Level	M/0/100%	A/23/20	M/0/[illegible]	A/18/0	M/1[illegible]	M 29/20	[illegible]	M/36/[illegible]%
PT-1	7.69	7.69	7.67	6.80	9.5[illegible]	11.27	11.24	11.14
PT-2	1.1	1.09	1.095	1.10	1.12	1.12	1.128	1.12[illegible]
PT-3	7.68	7.67	7.65	6.78	9.57	11.20	11.16	10.99
PT-4	1.1	1.1	1.114	1.09	1.15	1.19	1.184	1.179
PT-5	7.60	7.6	7.59	6.78	9.39	11.03	11.00	10.87
PT-6	1.16	1.14	1.143	1.09	1.26	1.29	1.286	1.2[illegible]
PT-7	6.46	6.94	6.71	6.34	9.99	10.74	10.74	10.8[illegible]
PT-8	4.9	5.96	5.41	6.29	5.30	5.26	5.42	5.54
PT-9	4.87	5.99	5.42	1.24	5.25	5.20	5.34	5.4[illegible]
PT-10	1.289	1.29	1.245	1.23	1.33	1.36	1.364	1.367
PT-11	6.85	6.84	6.54	6.01	9.[illegible]	10.32	10.26	10.12
PT-12	1.294	1.26	1.213	1.10	1.31	1.350	1.346	1.348
PT-13	4.70	5.79	5.26	1.08	5.03	5.03	5.16	5.2[illegible]
PT-14	1.334	1.3	1.241	1.07	1.28	1.313	1.314	1.31[illegible]
[illegible]T-15	8.53	852	8.53	7.78	10.35	12.13	12.09	12.12
PT-16	1.324	1.34	1.272	1.09	1.326	1.368	1.369	1.37[illegible]

(continued)

Figure 2.

DATE TIME								
PT17	1.729	1.78	1.222	1.15	1.21	1.343	1.364	1.44[illegible]
PT18	1.442	1.39	1.315	1.11	1.37	1.404	1.404	[illegible]
PT20	7.72	7.66	7.63	6.81	9.41	11.05	11.03	10.93
PT21	4.83	5.90	5.32	5.39	5.16	5.12	5.27	5.36
TT1	296.3	288.5	286.5	293.9	[illegible]	298.2	[illegible]	[illegible]
TT2	290.5	284.9	283.3	305.9	[illegible]	283.7	277.5	270.6
TT3	278.0	113.1	77.0	219.7	195.7	114.3	86.7	78.0
TT4	79.3	106.1	76.8	213.4	201.1	111.4	85.0	76.6
TT5	269.6	217.5	115.1	109.4	53.5	19.3	18.2	17.5
TT6	269.9	224.3	117.1	96.7	51.4	18.3	18.1	16.3
TT7	248.9	93.6	81.7	91.1	44.3	18.1	18.3	16.2
TT8	241.8	91.5	77.9	149.4	90.9	36.5	29.7	23.5
TT9	268.4	211.9	113.0	87.4	55.9	21.4	19.9	19.2
TT10	244.8	186.3	97.0	94.6	47.7	17.0	15.9	15.2
TT11	272.5	246.4	166.0	69.3	39.2	10.5	10.7	10.4
TT12	272.4	245.8	170.3	67.0	33.3	9.8	9.9	9.5
TT13	266.8	241.2	151.9	90.9	33.2	11.6	11.4	11.1
TT14	256.4	229.2	143.5	85.3	32.0	8.3	8.0	7.6
TT15	263.6	239.7	162.9	63.5	31.5	6.4	6.1	5.9
TT16	263.9	237.6	166.7	110.0	29.7	6.5	6.5	6.0
TT17	264.1	240.2	163.6	64.3	33.1	4.3	4.8	4.9
TT18	267.2	243.2	168.2	107.7	44.3	4.3	4.3	4.3
TT19	280.0	268.7	274.7	281.1	281.7	69.4	261.9	253.7
FT1	—				520	980	1070	[illegible]
FT2					2100 2300	930	1340	115.1
FT3	—	266	345		502	920	1020	[illegible]
FT4		227	296		163	450	602	516
FT5		38	77		59	155	200	210
FT6		118	242		273	495	533	[illegible]
ON-OFF N_2 Precool	ON	ON	ON	OFF	ON	ON	ON	ON
E34 Oil -1 Pump	ON	ON	ON	OFF	ON	ON	on	ON
E10 Oil T2 & T3 Pump	ON	ON	ON	OFF	ON	ON	on	ON

Figure 3.

Simulation Input

Heat Exchanger	$\frac{dT}{dt}$ (°K/sec)	Heat Loads during Cooldown (kW)			
		0200 HRS	0600 HRS	1000 HRS	1400 HRS
HX1	2.2×10^{-3}	3.80	3.67	3.51	3.13
HX2	3.4×10^{-3}	1.82	1.60	1.19	0.48
HX3	3.2×10^{-3}	1.50	1.22	0.60	0.20
HX4	3.4×10^{-3}	1.65	1.30	0.64	0.20
HX5	3.2×10^{-3}	2.05	1.52	0.82	0.10
HX6	3.4×10^{-3}	2.18	1.62	0.65	0.10
HX7	3.4×10^{-3}	0.87	0.52	0.05	0.05
HX8	3.6×10^{-3}	0.92	0.62	0.10	0.10

Figure 4

4/18/80 0200 HRS

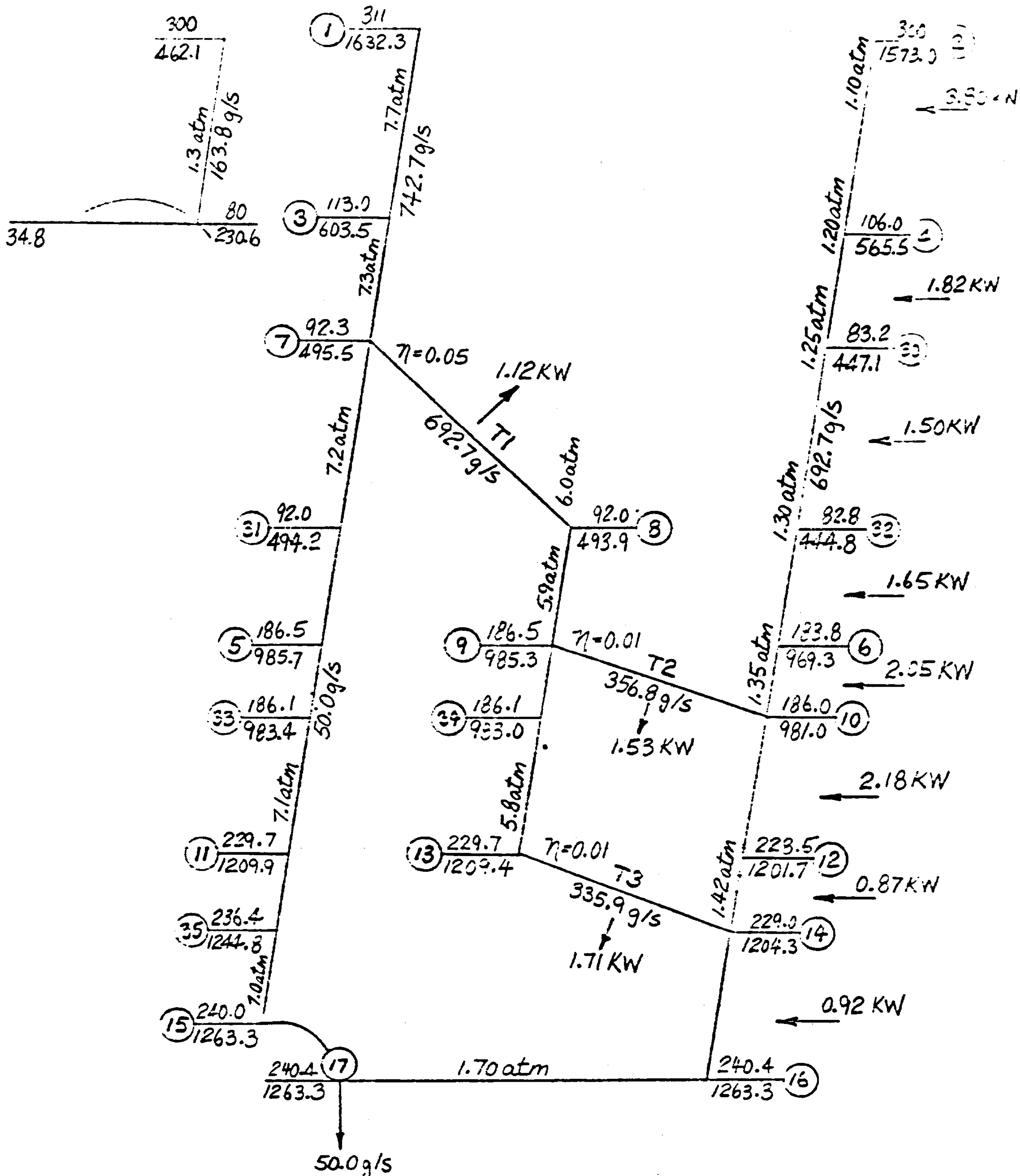


Figure 5.

4/18/80 0600 HRS

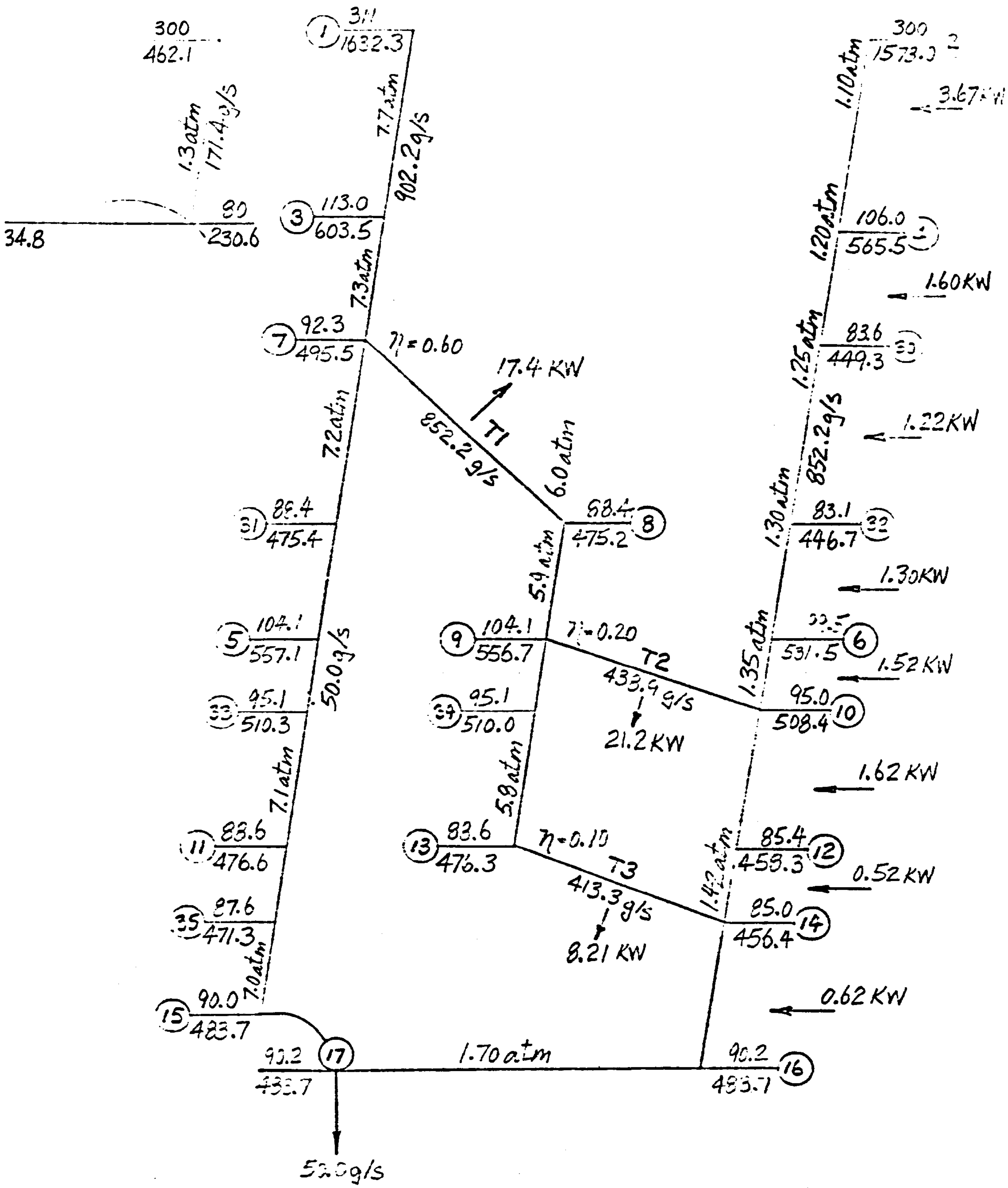


Figure 6.

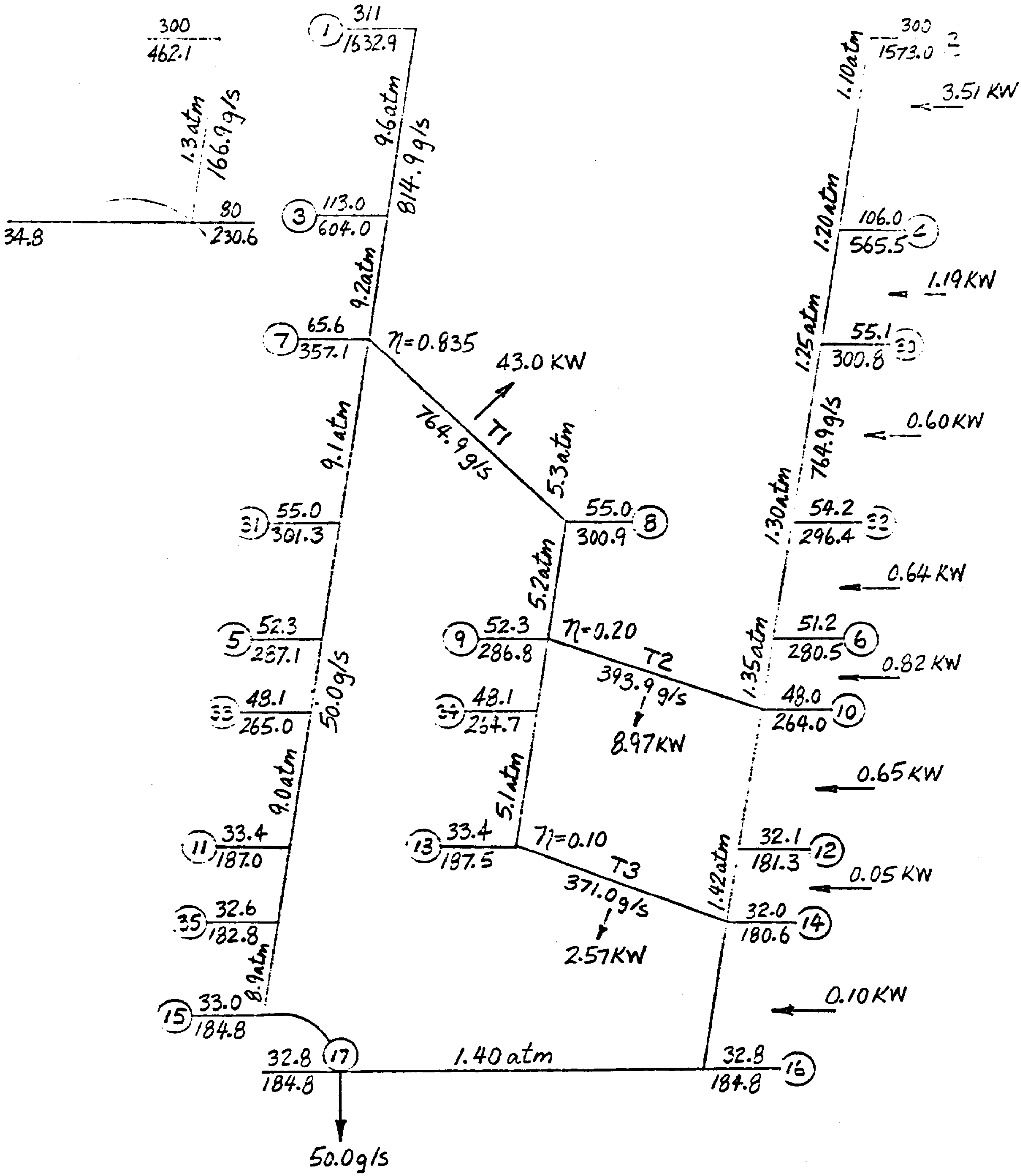
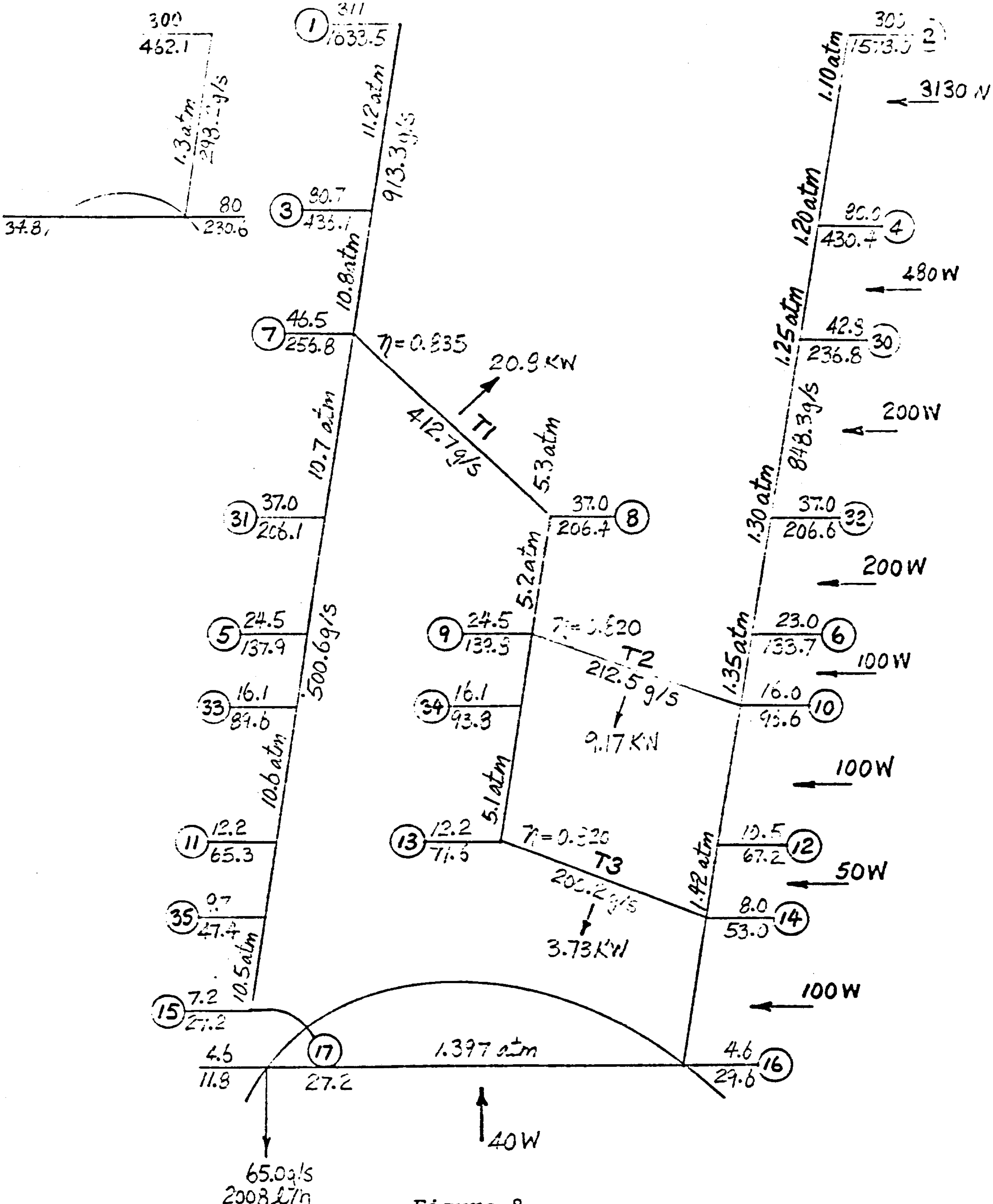

300
462.1
1.3 atm
166.9 g/s
34.8
80
230.6
1
311
1632.9
9.6 atm
814.9 g/s
3
113.0
604.0
9.2 atm
7
65.6
357.1
η = 0.835
43.0 KW
764.9 g/s
T1
5.3 atm
9.1 atm
31
55.0
301.3
55.0
300.9
8
5.2 atm
5
52.3
287.1
50.0 g/s
33
48.1
265.0
9
52.3
286.8
η = 0.20
T2
393.9 g/s
8.97 KW
34
48.1
264.7
9.0 atm
5.1 atm
11
33.4
187.0
13
33.4
187.5
η = 0.10
T3
371.0 g/s
2.57 KW
35
32.6
182.8
8.9 atm
15
33.0
184.8
32.8
17
184.8
1.40 atm
50.0 g/s
300
1573.0
1.10 atm
3.51 KW
1.20 atm
106.0
565.5
1.19 KW
1.25 atm
55.1
300.8
764.9 g/s
0.60 KW
1.30 atm
54.2
296.4
0.64 KW
51.2
280.5
6
1.35 atm
0.82 KW
48.0
264.0
10
0.65 KW
32.1
181.3
12
1.42 atm
0.05 KW
32.0
180.6
14
0.10 KW
32.8
184.8
16

Figure 7.



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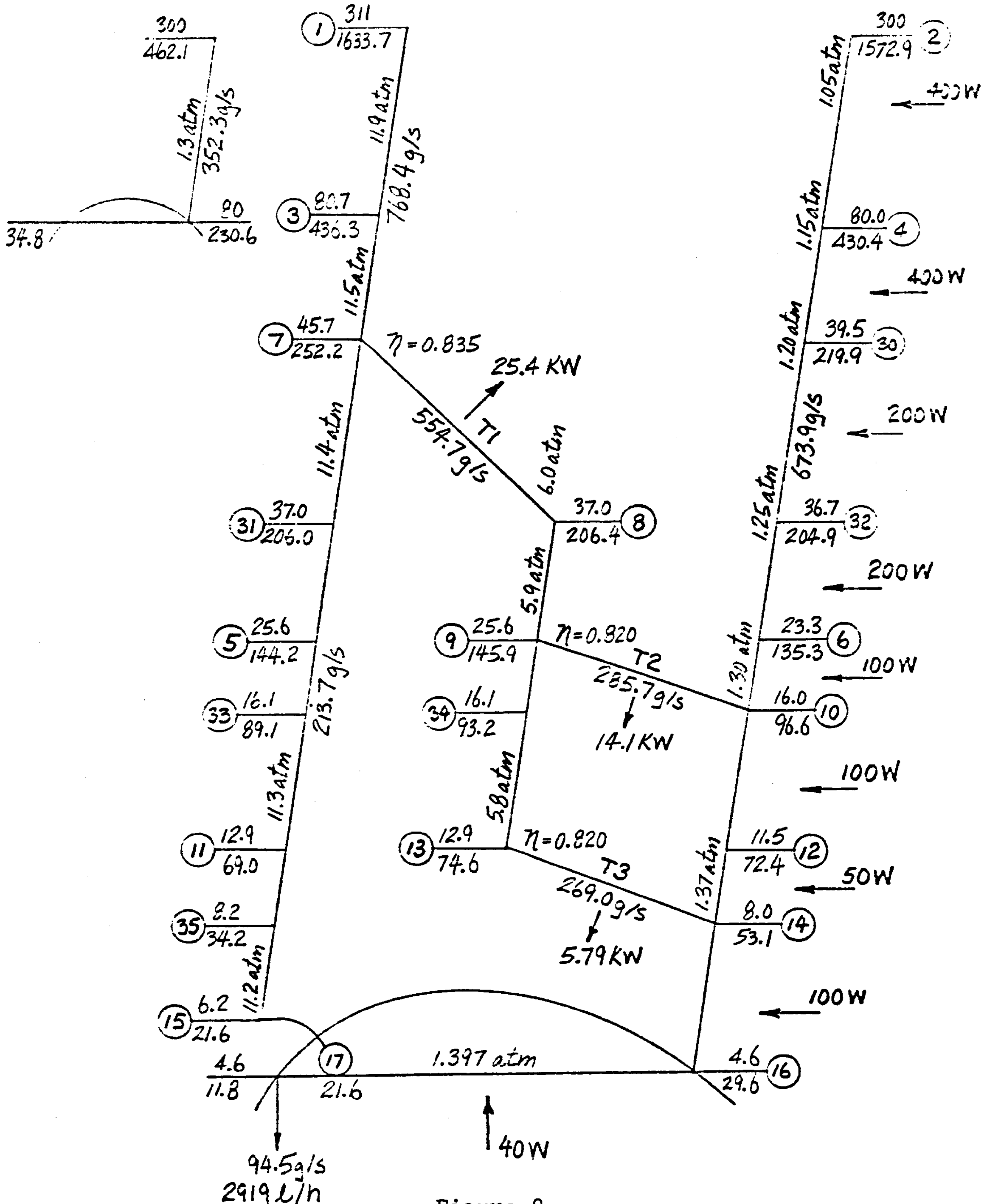
300
462.1
1.3atm
352.3g/s
80
230.6
34.8
1
311
1633.7
11.9atm
768.4g/s
3
80.7
436.3
11.5atm
7
45.7
252.2
η = 0.835
25.4 KW
T1
554.7g/s
6.0atm
11.4atm
31
37.0
206.0
8
37.0
206.4
5.9atm
5
25.6
144.2
213.7g/s
33
16.1
89.1
11.3atm
11
12.9
69.0
35
8.2
34.2
11.2atm
15
6.2
21.6
9
25.6
145.9
η=0.820
T2
285.7g/s
14.1KW
34
16.1
93.2
5.8atm
13
12.9
74.6
η=0.820
T3
269.0g/s
5.79KW
2
300
1572.9
1.05atm
400W
4
80.0
430.4
1.15atm
400W
30
39.5
219.9
1.20atm
673.9g/s
200W
32
36.7
204.9
1.25atm
200W
6
23.3
135.3
1.30atm
100W
10
16.0
96.6
100W
12
11.5
72.4
1.37atm
50W
14
8.0
53.1
100W
17
4.6
11.8
21.6
1.397 atm
16
4.6
29.6
40W
94.5g/s
2919 l/h

Figure 9.