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CHL LIQUID HELIUM DEWAR / RING INTERFACES AND OPERATION

PREPARED UNDER FERMILAB SUBCONTRACT NO. 94199
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FOR

FERMI NATIONAL ACCELERATOR LABORATORY
BATAVIA, ILLINOIS

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CHL LIQUID HELIUM DEWAR / RING INTERFACES AND OPERATION

The following operating modes may be experienced:

1. CHL operating with forced flow from CHL through ring and left over liquid into 5,000 gal dewar. Pump does not operate.
2. CHL not operational. Liquid helium pumped from dewar into ring. Excess liquid returned to dewar.
3. One or more satellite refrigerators out; CHL operational. Liquid helium pump also operational to supply extra liquid.
4. System down, ring being kept cold and full.
5. System down, ring being kept cold, but drifting up in temperature.
6. One section of ring out; liquid flowing from CHL in two directions around the ring. Excess liquid to 5,000 gal dewar.
7. Tevatron down, with one section being warmed for magnet replacement. CHL down, ring kept cold and full.
8. Verification of CHL performance; ring and tevatron shut off.

To handle all conditions postulated under 1 through 8 above, consider the flow sheet of Figure 1.

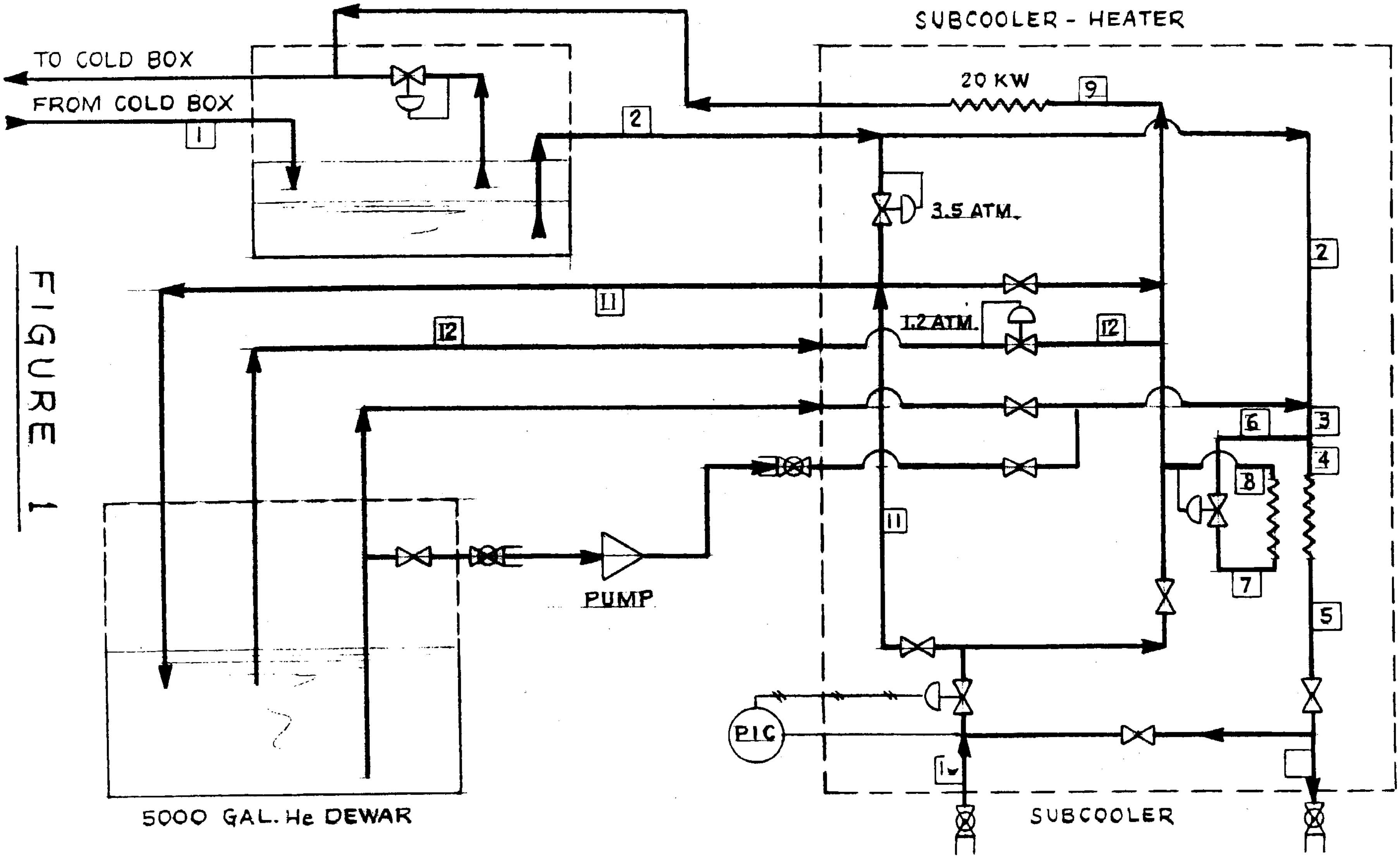


FIGURE 1

CENTRAL LIQUEFIER - CRYOGENIC FLOW SYSTEM

TM-951

Mode 1 (See Figure 2):

a. CHL makes liquid into transfer line.

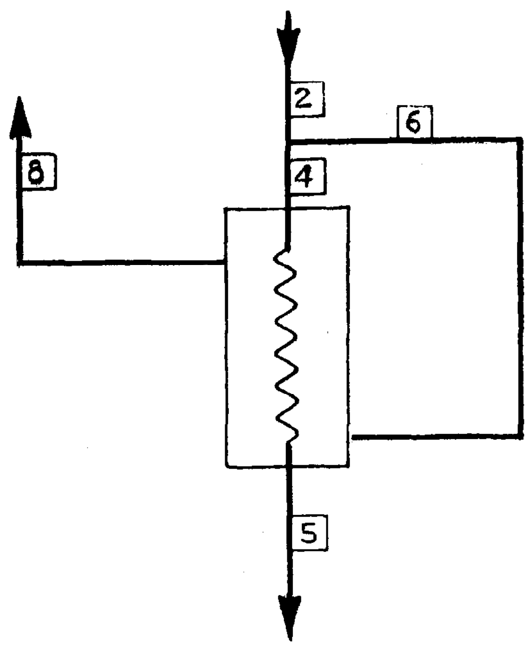
b. Excess flow is deposited in tank.

c. Tank returns vapor to CHL.

PROCESS POINTS

Point	Pres. atm	Temp. °K	Enthalpy J/gr	Flow Rate g/sec
1	11.0	6.14	21.40	311
2	3.5	5.725	21.40	311
3	3.5	5.725	21.40	311
4	3.5	5.725	21.40	148.7
5	3.5	4.6	12.08	148.7
6	3.5	5.725	21.40	162.3
7	1.2	4.42	21.40	162.3
8	1.2	4.42	29.94	162.3
9	1.2			
10	3.5			
11	1.2	4.42		
12	1.2	4.42		

Subcooler Design:



Stream 2 is 311 g/sec
Stream 4 is (311 - X)
Streams 6, 8 is X

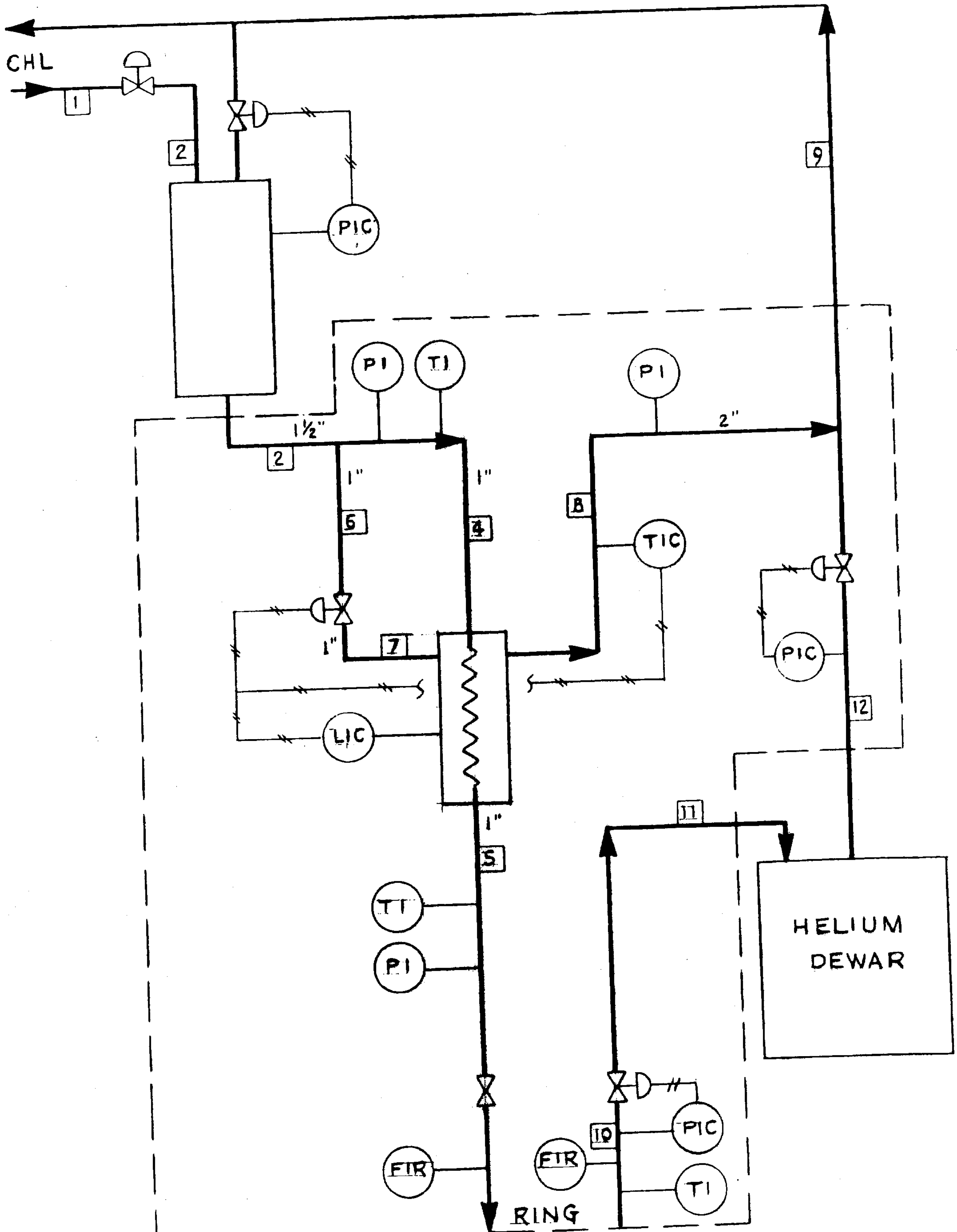


FIGURE 2, MODE 1 FLOWSHEET

Balance

(311) (21.40) = (X) (29.94) + (311 - X) (12.08)

$$X = \frac{21.40 - 12.08}{29.94 - 12.08} (311) = 162.3 \text{ g/sec}$$

The CHL will not produce the flow rate of 311 g/sec at stipulated condition, unless return stream [9] is at 4.4°K. The subcooler, therefore, should operate as a liquid level controlled device.

Duty of cooler is: (148.7) (21.4 - 12.08) =

= 1,386 W = 4,753.6 Btu/hr

$$\Delta T_m = \frac{(5.725 - 4.42 - (4.6 - 4.42)}{\ln \frac{1.3}{.18}} \times 1.8 = 1.02°F$$

$$\text{We need UA} = \frac{47536}{1.02} = 4,660$$

Design for UA = 8,000

Use finned tubing, and let liquid boil on the finned side.

COOLING CURVE

T	H	ΔH	ΔT_m	Q	UA
5.72	21.40				
5.6	19.38	2.02	2.23	1030.2	462
5.5	18.17	3.23	2.03	617.2	304
5.4	17.17	4.23	1.85	510.0	276
5.3	16.31	5.09	1.67	438.6	263
5.2	15.55	5.85	1.49	387.6	260
5.1	14.80	6.60	1.31	382.5	292
5.0	14.13	7.27	1.13	341.7	302
4.6	12.08	9.32	.68	1045.5	1537.5
				4753.3	3696.5

Calculate heat transfercoefficients in tube for 3.5 atm flow rate. M = 1,179 lb/hr in three parallel tubes.

T	5.7	5.1	4.6
μ	.00627	.00765	.00862
d_h	.43"	.43"	.43"
d_h	.0358'	.0358	.0358
G	393,040	393,040	393,040
Re	2.24×10^6	1.84×10^6	1.63×10^6
j	.0012345	.001285	.001316
f	.002469	.00257	.002632
C_p	4.14	1.585	1.12
Pr	2.06	.967	.746
$Pr^{2/3}$	1.618	.978	.823
ρ	5.57	7.38	8.12
h_1	1,241	818	704
h_2	50	50	50

Divide exchanger in three sections:

Section	1	2	3
Temp. Span:	5.72 - 5.3	5.3 - 5.0	5.0 - 4.6
UA	1,305	854	1,538
U	554	450	413
A (ft^2)	2.36	1.90	3.73
A per Tube	.79	.63	1.24
L per Tube	7.05	5.62	11.07

Total length per tube = 23.74 ft

Make tubes 40 ft long each. Then calculate pressure drop:

T	5.7	5.1	4.6
$\frac{\Delta P}{L}$	.0637	.0500	.0466
ΔP (psig)	.363	.255	.516

For first 23.76 ft ΔP = 1.134 psig

For next 36.26 ft ΔP = 36.26 x .0466 = 1.69 psig

ΔP_{Total} = 2.82 psig

Pressure drop is a little high. Change to four parallel tubes as follows:

T	5.7	5.1	4.6
μ	.00627	.00765	.00862
d_h	.43"	.43"	.43"
d_h	.0358'	.0358'	.0358
G	294,780	294,780	294,780
Re	2.24×10^6	1.84×10^6	1.63×10^6
j	.00131	.00136	.00139
f	.00262	.00272	.00278
C_p	4.14	1.585	1.12
Pr	2.06	.967	.746
$Pr^{2/3}$	1.618	.978	.823
ρ	5.57	7.38	8.12
h_1	987	650	559
h_2	50	50	50

Temp. Span:	5.72 - 5.3	5.3 - 5.0	5.0 - 4.6
UA	1,305	854	1,538
U	496	394	358
A (ft^2)	2.63	2.17	4.29
A per Tube	.66	.54	1.07
L per Tube	5.87	4.84	9.57

Total length per tube = 20.28.

Make tubes 40 ft long each. Then calculate pressure drop:

T	5.7	5.1	4.6
$\frac{\Delta P}{L}$	.0381	.0298	.0277
ΔP (psig)	.223	.144	.265

For first 20.28 ft ΔP = .632 psig

For next 19.78 ft ΔP = .548

ΔP_{Total} = 1.180 psig

The heat exchanger will be made of four parallel 1/2 in. OD tubes of 40 ft long each.

Line Sizes In and Out of Subcooler

Line	Flow Rate g/sec	Flow Rate lb/hr	ρ lb/cft	Sch 10 Size IPS	Area ft^2	G lb/hr ft^2	Vel. ft/sec	d_h ft
2	311	2,466	5.57	1-1/2"	.0154	159,895	8.0	.140
4	148.7	1,179	5.57	1"	.00656	179,726	9.0	.0914
5	148.7	1,179	8.12	1"	.00656	179,726	6.15	.0914
6	162.3	1,287	5.57	1"	.00656	196,189	9.8	.0914
7	162.3	1,287	-	1"	.00656	196,189	-	.0914
8	162.3	1,287	1.25	2"	.02536	50,742	11.3	.1798

Mode 2 (See Figure 3):

a. CHL not operational.

b. Liquid helium pump operational.

c. Excess flow deposited in storage tank.

Pump Process

In	Out (Ideal)	Out (Real)
P = 1.2 atm	P = 3.5 atm	P = 3.5 atm
T = 4.42°K	T = 4.724	T = 4.883
H = 10.80	H = 12.71	H = 13.53
S = 3.667	S = 3.667	S =
V_s = 8.28	V_s =	V_s = 8.097
ΔH = 1.91	τ = .7	ΔH = 2.73

On first approximation, maintain same flow rate to ring. Then subcooler balance is as follows:

$$(148.7)\ (13.53 - 12.08) = (X)\ (29.94 - 13.53)$$

$$X = 148.7\ \frac{1.45}{16.41} = 13.14 \text{ g/sec}$$

Pump flow rate = 13.14 + 148.7 = 161.84 g/sec

Pump Work: 161.84 x 2.73 = 441.8 W

Pump Displacement:

161.84 x 8.28 = 1,340 cc/sec

= 81.7 cu in./sec

At 180 rpm, displacement = 27.2 cu in.

Stroke: 3"

Bore: 3.386" = 3-3/8"

CCI expansion engine will do!!

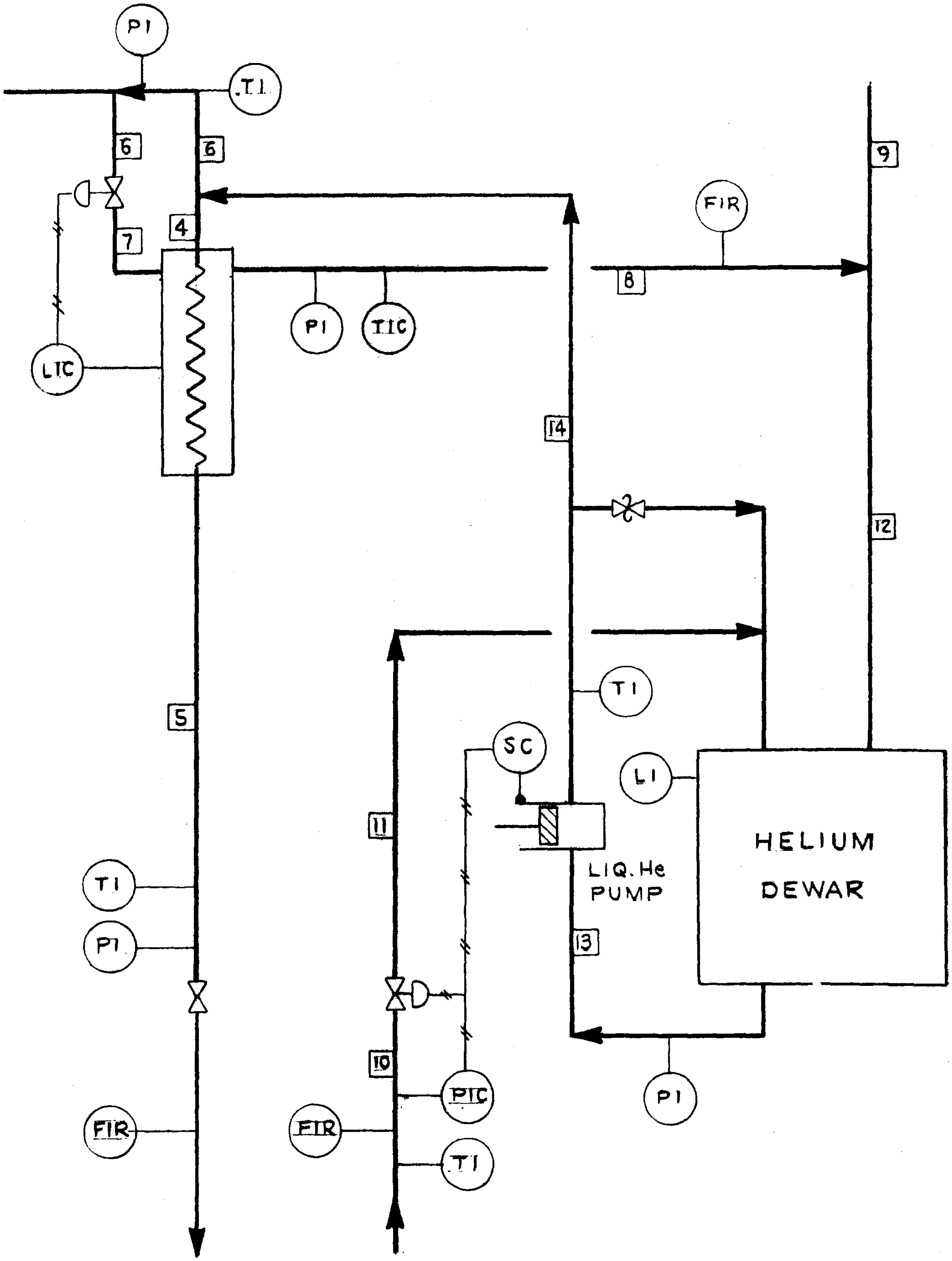


FIGURE 3, MODE 2 FLOWSHEET

Subcooler Duty:

148.7 (13.53 - 12.08) = 215.6 W
= 739.5 Btu/hr

This means that the subcooler is very large for this duty. Compare with the table of p. 6. This shows that we only need part of the last section of the subcooler.

Control of Pump:

It would be useful to have a speed control on the pump to provide the right kind of flow. A pressure signal in the pump discharge will be a reasonable device, because the large inventory in the line will only require sluggish control.

Check this:

Lines (ring) = 1-1/2" IPS, Sch. 5 pipe with a nominal length of 20,000 ft.

$$\text{Volume:} \quad 20000 \times \frac{2.46}{144} = 341.57 \text{ cft}$$
$$= 9{,}700 \text{ liters}$$

Contained Mass at Various Conditions

P	3.5	4.0	3.0
T	4.6	4.65	4.55
V_s cc/gr	7.70	7.634	7.774
M (g)	1,259,740	1,270,631	1,247,749
M (lb)	2774.7	2798.7	
S	3.533	3.533	3,533
M		+10891	-11991

$$\frac{\Delta M}{\Delta P} = \frac{10891}{.5 \times 14.7} = 1{,}482 \text{ g/psi}$$

$$\frac{\Delta M}{\Delta P} = \frac{-11991}{.5 \times 14.7} = -1631 \text{ g/psi}$$

This indicates that 10 sec of full flow rate without use of liquid will raise the pressure in the line by 1 psig. If the unbalance is 10% of this, some 100 sec are required to raise the pressure 1 psig.

PROCESS POINTS

Point	Pres. atm	Temp. °K	Enthalpy J/gr	Flow Rate g/sec
1	-	-	-	-
2	-	-	-	-
3	-	-	-	-
4	3.5	4.883	13.53	148.7
5	3.5	4.6	12.08	148.7
6	3.5	4.883	13.53	13.14
7	1.2	4.42	21.40	13.14
8	1.2	4.42	29.94	13.14
9	1.2	-	-	-
10	3.5	-	-	-
11	1.2	4.42	-	-
12	1.2	4.42	29.94	-
13	1.2	4.42	10.80	161.84
14	3.5	4.883	13.53	161.84

Mode 3 (See Figure 4):

a. CHL operational.

b. Two satellite refrigerators partially down.

c. Liquid helium pump operational.

This mode is a combination of Modes 1 and 2. The CHL does not make enough liquid helium to maintain the ring at pressure. The pump will be used at low capacity to make up the rest.

Assume that the flow to the ring is 20% larger compared to Modes 1 and 2. Process points are shown on p. 16.

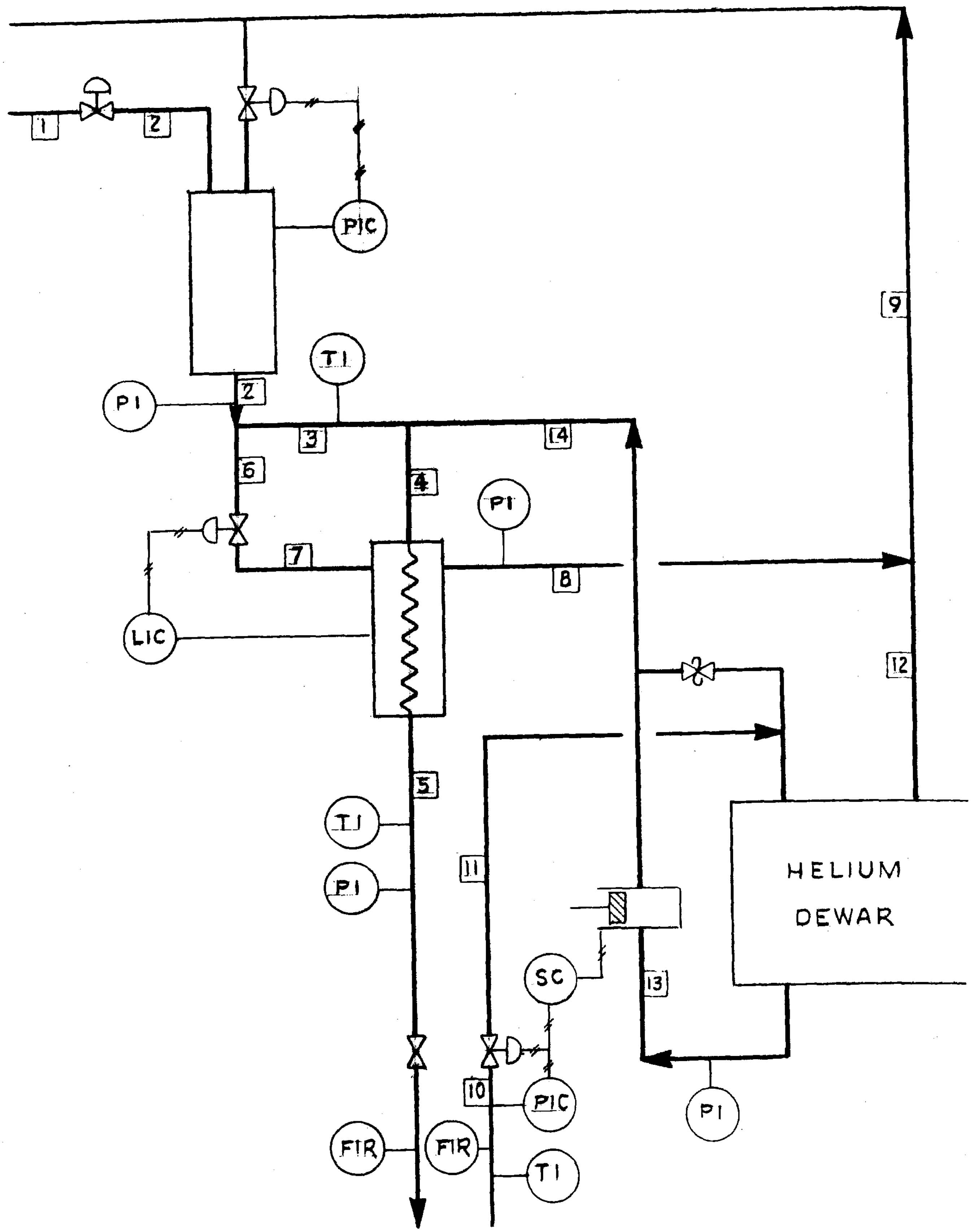


FIGURE 4, MODE 3 FLOWSHEET

PROCESS POINTS

Point	Pres. atm	Temp. °K	Enthalpy J/gr	Flow Rate g/sec
1	11.0	6.14	21.40	311.0
2	3.5	5.725	21.40	311.0
3	3.5	5.725	21.40	
4	3.5	-	-	178.44
5	3.5	4.6	12.08	178.44
6	3.5	5.725	21.40	
7	1.2	4.42	21.40	
8	1.2	4.42	29.94	
9	1.2	4.42	29.94	
10	3.5	-	-	
11	1.2	4.42	-	
12	1.2	4.42	29.94	
13	1.2	4.42	10.80	
14	3.5	4.883	13.53	

Balance Subcooler:

In

[3] (311 - X) (21.40) =
[14] (Y) (13.53 =
[7] (X) (21.40) =

6655.4 + (Y) (13.53)

Out

[8] (X) (29.94) =
[5] (178.44) (12.08) =

2155.56 + (X) (29.94)

4499.84 + (Y) (13.53) = (X) (29.94)

Y = (2.219) (X) - 332.58) (1)

Material Balance

$311 + Y = (X) + 178.44$

$Y = X - 132.56$ (2)

$(1.219)(X) - 200.02 = 0$

$X = 164.09$ g/sec

$Y = 31.53$ g/sec

Stream [4]

$(146.91)(21.40) + (13.53)(31.53) = (178.44)(H_4)$

H_4 = [illegible].62 + 2.39 = 20.01 J/gr

T_4 = [illegible].64°K

The subcooler as designed for Mode 1 will be capable of providing the same discharge temperature (stream 5). Pressure drop will be higher by about 40%. Then:

$\Delta P = 1.4 \times 1.18 = 1.65$ psig

Mode 4 (See Figure 5):

System down, ring being kept full of liquid. There is no demand for liquid helium by the doubler. The transfer line is kept full of liquid, in order to be ready to start quickly. The line has heat leak. This is assumed to be 200 W. In order to maintain the line at full condition, we can do one of the following:

a. Let the line sit with a pressure controller bleeding of excess fluid to the vapor space of the liquid helium storage tank.

b. Pump liquid around with the liquid helium pump at a low flow rate and transport heat out of the ring at a low rate.

c. Lower pressure in the line, and pump liquid helium around at a high flow rate to transport heat out at a high rate.

d. Pump liquid around and keep line pressure constant. Bleed excess off vapor space of storage tank.

e. Pump liquid around, and keep pressure constant by providing refrigeration to the subcooler. Liquid helium temperature in line rises with distance traveled.

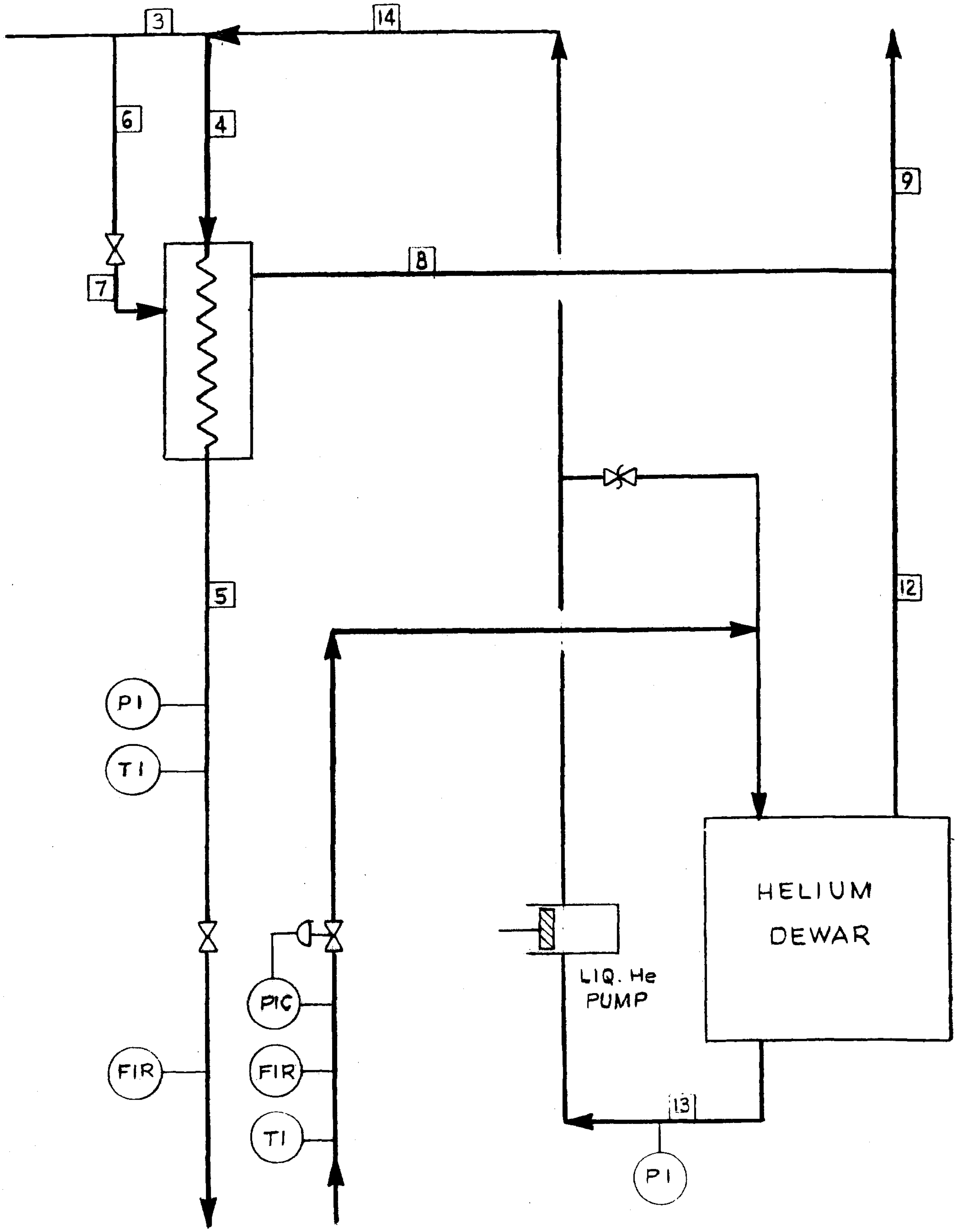


FIGURE-5, MODE 4 FLOWSHEET

Pressure Drop in Liquid Pumping

Flow Rate = 150 g/sec = 1189.4 lb/hr

Length of Line = 20,000 ft

Area for Flow = 2.46 sq in. (1-1/2 Sch. 5)

Diameter = 1.77 in. = .1475 ft

Viscosity at 1 = .0082 lb/ft hr

P = 3.5 atm - 4.7°K

$$Re = \frac{69623 \times .1475}{.0082} = 1.25 \times 10^6$$

$$f = \frac{.046}{Re^{.2}} = .00277$$

$$\rho = 8.5 \text{ lb/cft}$$

$$Pr = Pr^{2/3}$$

$$\frac{\Delta P}{L} = \frac{.00277 \times (19.34)^2}{193 \times 8.5 \times 1.77} = .000357 \text{ psig/ft}$$

$$\Delta P = 20000 \times .00357 = 7.14 \text{ psig}$$

Assume actual pressure drop with ells, tees, valves, etc. is 14.7 psig.

The pump will operate between 3.0 and 4.0 atm. Pump conditions are as follows:

In		Out		Out	
P =	3.0	P =	4.0	P =	4.0
T =	4.86	T =	5.01	T =	5.07
H =	13.4	H =	14.21	H =	14.56
S =	3.896	S =	3.896		
V_s =	8.29			V_s =	8.16
ΔH =	.81 J/gr	η =	.7	ΔH =	1.16

Work by pump is 1.16 x 1.50 = 174 W

Subcooler needs to remove 374 W.

If we use a refrigerator, one satellite refrigerator operating with both warm and cold expander will do. With wet expander only, some liquid helium will be consumed. For every gram of circulation, we obtain approximately 18 W of refrigeration. Unbalanced flow will be 8.5%.

Total then: $\frac{374}{18} \times .085 = 1.766$ g/sec

$= 50.9$ l/hr

Operationally, it will be simple if we pump liquid from the 5,000 gal dewar, but at a lower flow rate. From p. 16 pump work per gram is 2.73 J.

We can pump $\frac{174}{2.73} = 64$ g/sec

Say pump at 50 g/sec. Then total heat load is:

200 + 136 = 336 W

Temperature rise of liquid in line is:

$\frac{200}{50} = 4$ J/gr

$H_5 = 12.08$ J/gr

$H_{10} = 16.08$ J/gr

$T_{10} = 5.26°K$

Applicable flow sheet is the one for Mode 3 (Figure 4).

P R O C E S S   P O I N T S

Point	Pres. atm	Temp. °K	Enthalpy J/gr	Flow Rate g/sec
1	-	-	-	-
2	-	-	-	-
3	3.5	4.883	13.53	4.42
4	3.5	4.883	13.53	50.0
5	3.5	4.6	12.08	50.0
6	3.5	4.883	13.53	4.42
7	1.2	4.42	13.53	4.42
8	1.2	4.42	29.94	4.42
9	1.2	4.42	29.94	18.21

-continued-

PROCESS POINTS (Continued)

Point	Pres. atm	Temp. °K	Enthalpy J/gr	Flow Rate g/sec
10	3.5	5.26	16.08	50.0
11	1.2	4.42	16.08	50.0
12	1.2	4.42	29.94	13.79
13	1.2	4.42	10.80	54.42
14	3.5	4.883	13.53	54.42

Balance Subcooler

$$(50 + X)\ (13.53) = (50)\ (12.08) + (X)\ (29.04)$$

$$X = \frac{50 \times 1.45}{16.41} = 4.42 \text{ g/sec}$$

Flashing of liquid returning to 5,000 gal dewar:

$$(50)\ (16.08) = (X)\ (10.80) + (50 - X)\ (29.94)$$

$$X = \frac{50 \times 13.86}{19.14} = 36.21$$

Vapor Fraction = 13.79 g/sec

Bleed excess fluid from line, without pumping liquid around.
Heat flux = 200 W.
At time zero line conditions are:

T	=	0	2	4	6	8 hrs
P	=	3.5	3.5	3.5	3.5	3.5 atm
H	=	12.08	13.22	14.41	15.65	16.95
V_s	=	7.704	8.011	8.343	8.750	9.246
M	=	1259086	1210835	1162651	1108571	1049102
ΔM	=	0	48251	96435	150514	209984
T	=	4.6	4.82	5.04	5.21	5.37°K

T	=	10	12	14	16	18	20
P	=	3.5	3.5	3.5	3.5	3.5	3.5
H	=	18.32	19.78	21.35	23.05	24.92	
V_s	=	9.844	10.58	11.47	12.58		
T	=	5.51	5.625	5.72	5.805	5.887	
M	=	985371	916824	845684	771065		
ΔM	=	273714	342262	413401	488021		

Most of the excess fluid flashed into the 5,000 gal storage tank will become vapor.

Total vaporization is:

<u>0-2 hrs</u>

$$(48251)\ (12.65) = (48251 - X)\ (10.8) + (X)\ (29.94)$$

$$X = \frac{89264}{19.14} = 4,664 \text{ gr}$$

<u>2-4 hrs</u>

$$(48184)\ (13.82) = (48184 - X)\ (10.8) + (X)\ (29.94)$$

$$X = \frac{145515}{19.14} = 7,603 \text{ gr}$$

<u>4-6 hrs</u>

$$(54079)\ (15.03) = (54079 - X)\ (10.8) + (X)\ (29.94)$$

$$X = \frac{228754}{19.14} = 11,952 \text{ gr}$$

<u>6-8 hrs</u>

$$(59470)\ (16.3) = (59470 - X)\ (10.8) + (X)\ (29.94)$$

$$X = \frac{327085}{19.14} = 17,089 \text{ gr}$$

Total vapor generated in 8 hrs is 41,308 gr = 330 liters (liquid).

Total liquid returned to 5,000 gal dewar = 209984 -

- 41308 = 168,676 gr

= 1,349 liters

After the line has been bleeding for a period of 16 hrs, the helium pump could be started, and the line filled with fluid at a lower enthalpy. It would not be necessary to operate the subcooler. In that case, fluid enters the line at H = 13.53 J/gr (p. 11) and leaves at H = 23-24 J/gr. For each gram that leaves, 1.55 to 1.65 grams of liquid is added. If we pump at 150 g/sec, volume added to the line is:

$$\frac{150 \times 8.097 \times 3600}{1000} = 4{,}372 \text{ liters/hr}$$

Approximately 2.2 hrs are required to replace the warm liquid from the line.

A scenario for downtime of the system, while maintaining a full transfer line is then:

16 hrs of venting to the liquid storage tank

2.2 hrs of pumping

16 hrs venting, etc.

Mode 5:

System down; no flow to the ring. This mode is the same as Mode 4, but without ever pumping fresh liquid into the ring. The table on p. 22 indicates that the line can be held in the cold condition for periods in excess of 24 hrs.

Mode 6 (See Figure 5):

One section of the ring is out. Liquid helium flows from the CHL in two directions. Pressure in the line is maintained, and excess liquid is returned to the storage tank.

In case additional liquid is required for the ring, the liquid pump will be started and operated at low speed, as shown on pp. 14 & 16.

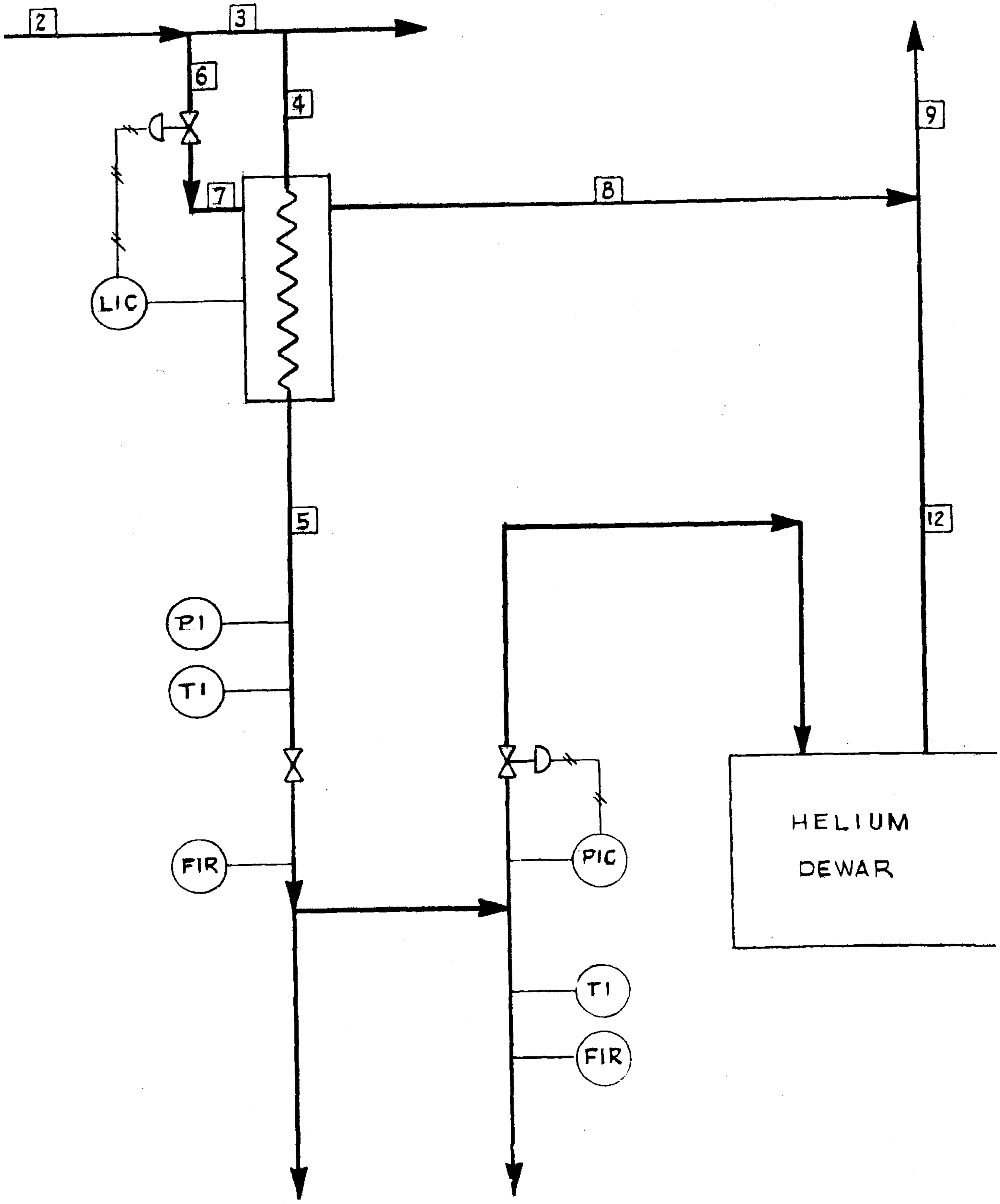


FIGURE-6, MODE 6 FLOWSHEET

PROCESS POINTS

Point	Pres. atm	Temp. °K	Enthalpy J/gr	Flow Rate g/sec
1				
2	3.5	5.725	21.40	311
3	3.5	5.725	21.40	311
4	3.5	5.725	21.40	148.7
5	3.5	4.6	12.08	148.7
6	3.5	5.725	21.40	162.3
7	1.2	4.42	21.40	162.3
8	1.2	4.42	29.94	162.3
9	1.2	4.42	29.94	162.3
10				
11				
12				
13				
14				

Mode 7 (See Figure 7):

1. One section of the ring warmed and later cooled for removal and replacement of a magnet.

2. Ring is kept full.

3. CHL down.

4. Satellite refrigerators operate as self-sustained refrigerators.

It is assumed that the satellite refrigerators have enough capacity to keep the energy doubler in the ready mode, except for the section to be warmed. The CHL probably can be shut down, because refrigeration demand of the line is small and can be supplied by the satellite refrigerators.

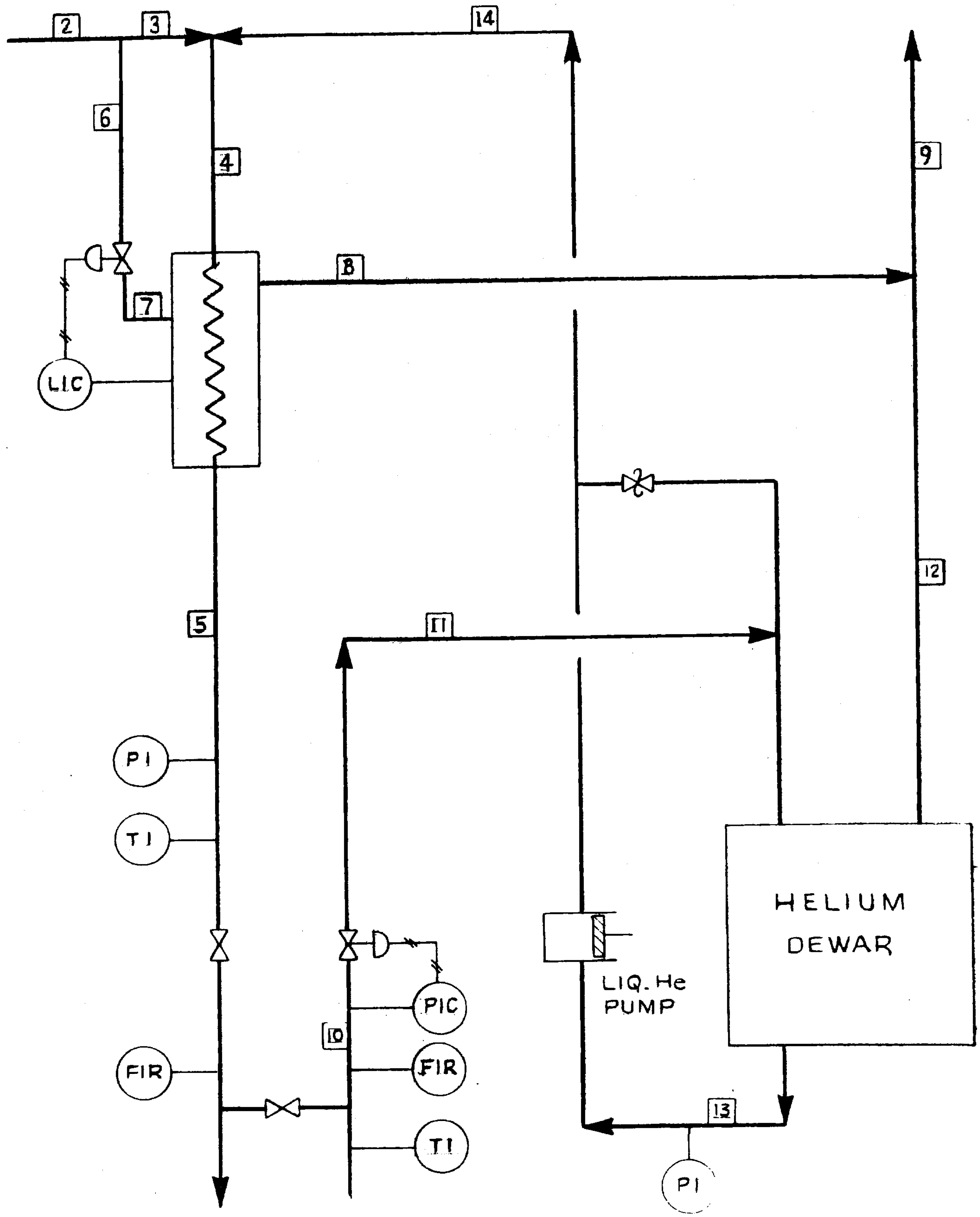


FIGURE-7 : MODE 7 FLOWSHEET

PROCESS POINTS

(For Period of 2.2 Hours When Pump Operates)

Point	Pres. atm	Temp. °K	Enthalpy J/gr	Flow Rate g/sec
1				-0-
2				-0-
3				-0-
4	3.5	4.883	13.53	150.0
5	3.5	4.883	13.53	150.0
6				-0-
7				-0-
8				-0-
9	1.2	4.42	29.94	61.66
10	3.5	5.805	23.05	96.34
11	1.2	4.42	23.05	96.34
12	1.2	4.42	29.94	61.66
13	1.2	4.42	10.8	150.0
14	3.5	4.883	13.53	150.0

Stream 12

$$(23.05)\ (96.34) = (X)\ (10.80) + (96.34 - X)\ (29.94)$$

$$X = \frac{(96.34)\ (23.05 - 29.94)}{29.94 - 10.8} = 34.68$$

Stream 12 is 96.34 - 34.68 = 61.66 g/sec.

Alternate Mode 7:

An alternate operating scheme for Mode 7 is to not use the pump for a period of 2.2 hours. Instead, the CHL could be used, basically in a mixture of liquefaction and refrigeration mode. The CHL operation needs to be analyzed in terms of providing refrigeration. Most likely, the flow rate to the ring will be somewhat greater than 148.7 g/sec, and time of operation will be less than 2.2 hours.

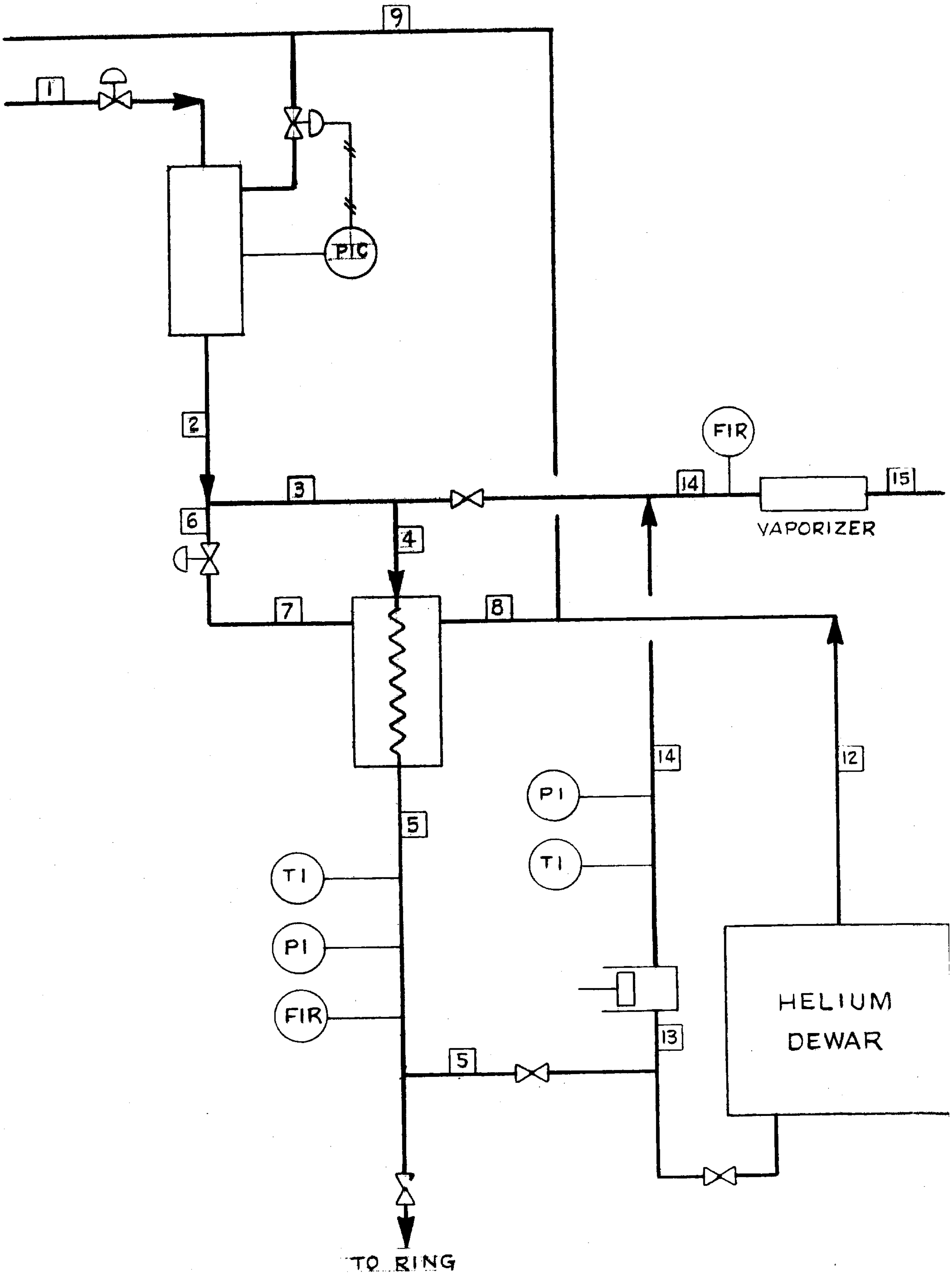


FIGURE-8, MODE 7 FLOWSHEET (ALTERNATE)

PROCESS POINTS

Alternate Mode 7

Point	Pres. atm	Temp. °K	Enthalpy J/gr	Flow Rate g/sec
1	11.0	6.14	21.40	311
2	3.5	5.725	21.40	311
3	3.5	5.725	21.40	148.7
4	3.5	5.725	21.40	148.7
5	3.5	4.6	12.08	148.7
6	3.5	5.725	21.40	162.3
7	1.2	4.42	21.40	162.3
8	1.2	4.42	29.94	162.3
9	1.2	4.42	29.94	162.3
10				
11				
12				
13	3.5	4.6	12.08	148.7
14	11.0	5.85	20.05	148.7
15	11.0	300.0	1576.0	148.7

Mode 8:

Verification of CHL performance.

1. Make liquid into helium dewar.
2. Maintain constant liquid level.
3. Vaporize liquid and return at pressure to the CHL.

Flow rate to be verified is 4,000 l/hr or 138.9 g/sec.

Pump Performance:

In		Out		Out	
P	= 3.5	P	= 11.0	P	= 11.0
T	= 4.6	T	= 5.26	T	= 5.85
H	= 12.08	H	= 17.66	H	= 20.05
V_s	= 7.704	V_s	= 7.00	V_s	= 7.357
S	= 3.533	S	= 3.533	S	=
ΔH	= 5.58	η	= .7	ΔH	= 7.97

Pump Work = 7.97 x 148.7 = 1,185 W

We need a 2 bhp motor to drive the pump.

Vaporizer:

Supply 148.7 x (1576 - 20.05) = 231,377 W.

Suppose we reliquefy the N_2 used in the liquefaction process.

N_2 flow rate = .6 liters of liquid N_2 per liter of liquid.

$$.6 \times \frac{148.7 \times 3600}{125} = 2{,}569.5 \text{ l/hr}$$

$$= 571 \text{ g/sec (2.26 tons/hr)}$$

To liquefy 571 g/sec of N_2, supply:

571 x (200 + 230) = 245,530 W

We do not have enough refrigeration. So look at condensation at 80°K.

Helium can supply:

148.7 (406.4 - 20.05) = 57,450 W

$$\text{Condense: } \frac{57450}{200} = 287 \text{ g/sec}$$

Approximately half of nitrogen quantity required.

LINE SIZING OF LIQUID HELIUM DISTRIBUTION BOX

Line No.	Pres. (Max) atm	Temp. Max. °K	Temp. Min. °K	Flow Rate Max. g/sec	$1/2\rho v^2$ psig	Size IPS
1						
2	3.5	300	4.5	320		1-1/2"
3	3.5	300	4.5	320		1-1/2"
4	3.5	300	4.5	180		1"
5	3.5	300	4.5	180		1"
6	3.5	300	4.5	180		1"
7	2.0	300	4.4	180		1"
8						
9	2.0	300	4.4	320		2"
10	3.5	300	4.5	180		1"
11	2.0	300	4.4	320		1"
12	2.0	300	4.4	320	.068	2"
13	1.4	5.0	4.4	150		1-1/2"
14	3.5	5.0	5.0	150		1"
15	1.2	4.2	4.2	10		1/2" OD
16	2.0		4.2	150		1"
17	3.5	300	4.5	180		1"
18						
19	2.0	300	80	747		1-1/2"
20						1"
21						3/4"

Line 12:

Cold vapor return from dewar.

Steady state flow rate may be 163 g/sec (1292.5 lb/hr)
Try 2" IPS, Sch. 10 (Wall = .109")

Area	=	3.65 sq in = .0254 ft^2
d_h	=	2.157" = .18 ft
μ	=	.0032 at 4.4°K
G	=	50,886 lb/hr ft^2
Re	=	2.86×10^6
f	=	.00235
ρ	=	1.28 lb/cft
Velocity	=	11.0 ft/sec = 336 cm/sec
$1/2\rho v^2$	=	$dynes/cm^2$ = .017 psig

At 1.2 atm

$$\frac{\Delta P}{L} = \frac{.00235 \times (14.14)^2}{193 \times 1.28 \times 2.157} = .00088 \text{ psig/ft}$$

At double the flow rate (320 g/sec):

Re	=	5.72×10^6
f	=	.00204
$\frac{\Delta P}{L}$	=	.00307 psig/ft
$1/2\rho v^2$	=	.068 psig

Line 11:

Under steady state conditions we may pump liquid helium around the ring with the pump at a flow rate of 150 g/sec (4,320 l/hr). Also, we may take the full flow rate from the CHL and put it into the dewar. Flow rate = 320 g/sec at P = 2.0 atm and H = 21.40 gr (two-phase flow).

Size for 150 g/sec of subcooled liquid at 3 atm.

ρ = 7.33 lb/cft
T = 5.0°K
H = 14.21

Volume Flow Rate = 1,280 cc/sec

Try 1-1/2" IPS, Sch. 10 pipe or 1" IPS, Sch. 10

ID = 1.682"

Area = 2.22 sq in. = .945 sq in.

Velocity = 89 cm/sec = 209 cm/sec

Line 10:

Return liquid helium from ring to dewar. Normally, flow rate is low. Try 1" IPS, Sch. 10 line for a flow rate of 180 g/sec.

Area for Flow = .945 sq in. = 6.09 cm^2

Volume Flow Rate = 180 x 8.28 = 1,490 cc/sec

d_h = 1.097"

Velocity = 244.7 cm/sec

$$1/2\rho v^2 = \frac{1}{2 \times 8.28} \times (244.7)^2 \times 14.7 \times 10^{-6} =$$

$$= .053 \text{ psig} \quad \text{Okay!}$$

Line 13:

Pump suction. Maximum flow rate is 150 g/sec. In order to preserve NPSH of the pump, operate the liquid helium tank under a slight amount of pressure.

At 1.2 psig and 4.4°K:

V_s = 8.28 cc/gr V = 1,242 cc/sec

Try 1-1/2" IPS pipe, Sch. 10

Area = 2.22 sq in. = 14.32 cm^2

$$\text{Velocity} = \frac{1242}{14.32} = 86.7 \text{ cm/sec}$$

$$1/2\rho v^2 = \frac{1}{2 \times 8.28} \times 86.7^2 = 453.9 \text{ dynes/cm}^2$$

$$= .45 \text{ cm } H_2O$$

$$= 3.6 \text{ cm He}$$

The liquid helium is pulled into the sump of the pump by bleeding a small amount of vapor from the pump dewar. Driving force is generated by back pressure controller on vapor return line from the storage tank.

Assume tank is held at 1.4 atm and liquid boils in pump cavity at 1.2 atm. Then we flash:

$$(150 + X)\ 11.91 = (X)\ (150)\ (10.80) + (X)\ (29.94)$$

$$X = \frac{1.11}{18.03} = 9.23 \text{ g/sec}$$

Line 14:

Pump discharge.

Flow Rate = 150 g/sec at 3.5 atm.

Try 1" IPS, Sch. 10 line.

Area for Flow = .945 sq in. = 6.07 cm^2

Volume Flow Rate = 1,239 cc/sec at

P = 3.5 atm and T = 5.0°K.

$$\text{Velocity} = \frac{1239}{6.09} = 203.4 \text{ cm/sec}$$

$$1/2\rho v^2 = \frac{1}{2 \times 8.26} \times (203.4)^2 = 2{,}505 \text{ dynes/cm}^2$$

$$= 2.5 \text{ cm } H_2O \qquad \text{Okay!}$$

Line 15:

Vapor flow from pump sump.

Try 1/2" OD, .035" wall.

Flow Rate = 10 g/sec

Volume Flow Rate = 487 cc/sec

Area = .936 cm^2

Velocity = 520 cm/sec

$$1/2\rho v^2 = \frac{1}{97.4} \times (520)^2 \doteq 2{,}778 \text{ dynes/cm}^2$$

$$= 2.8 \text{ cm } H_2O \qquad \text{Okay!}$$

Line 16:

Liquid flows from tank directly to the ring. Possibly during cooldown or for a period of time, when CHL and pump do not work.

Same as pump discharge.

Line 17:

Same as lines 5, 15, etc.

Line 18:

Relief line from liquid helium dewar.
Size for massive air failure and condensation of air on helium shell. Evaluate after looking at tank drawings.

Line 19:

Liquid nitrogen flow for CHL and ring.

$$\text{Total flow is} \quad 2600 + \frac{34000}{200} \; \frac{1}{800} \times 3600 =$$

$$= 3{,}365 \text{ l/hr} = 5{,}929 \text{ lb/hr}$$

$$= 71 \text{ tons/day}$$

Volume flow rate = 934 cc/sec.

Try 1-1/2" Sch. 10 pipe.

Area = 2.22 sq in. = 14.13 cm^2

Velocity = 65 cm/sec

Line 20:

Flow rate = 2,600 l/hr