ISS (Isotope Separation System)

초저온증류 공정시뮬레이션

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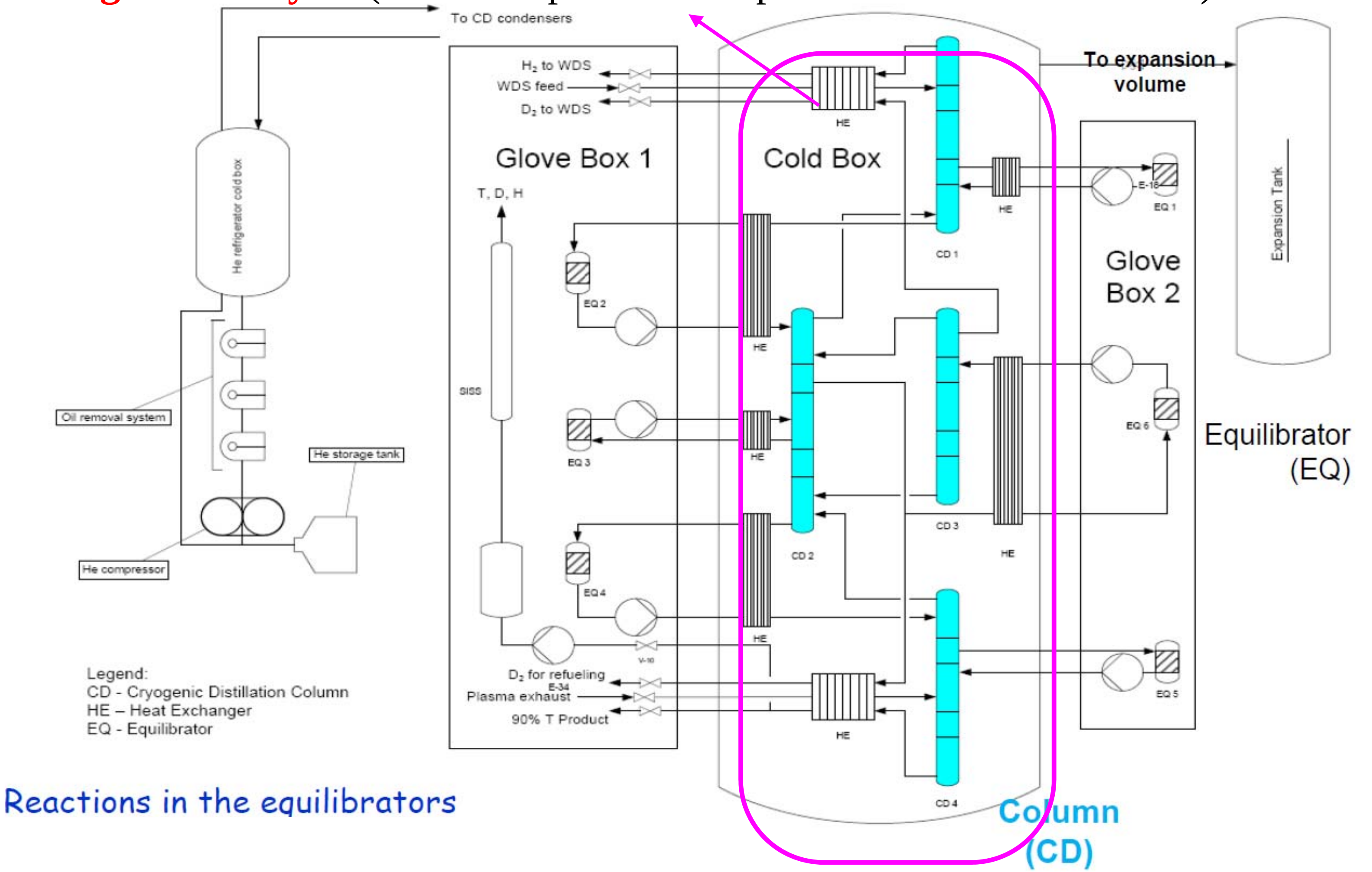
조 정 호

목 차

3. 헬륨 냉동 사이클

3. 헬륨 냉동 사이클

※ **He Refrigeration Cycle** (nominal operation temperature between **20 -24 K**)



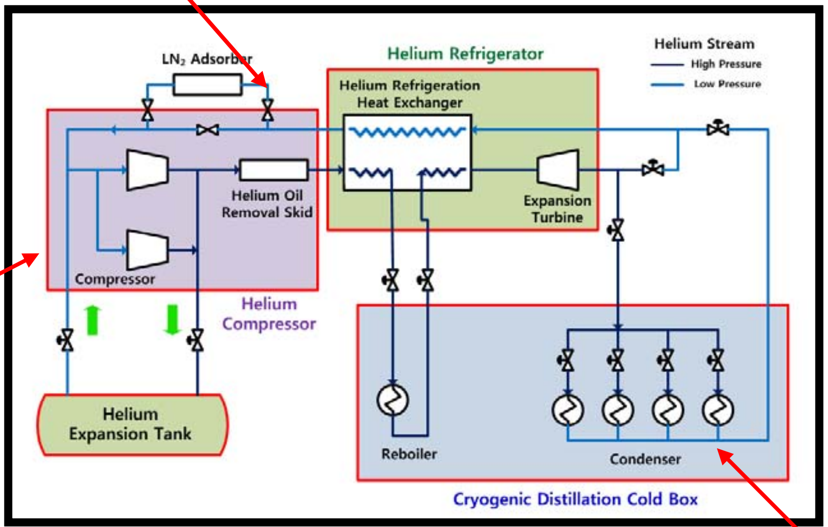
EU Contribution to ITER Fuel Cycle, Alain Teissier, IBF 2013

3. 헬륨 냉동 사이클

4.5 K Helium refrigeration unit

대기압에서 끓는점이 4.22K(-268.96℃)인 헬륨을 냉매로 이용하여 초저온 수소 동위원소 분리에 냉매로 이용함

헬륨을 320K에서 14 K까지 낮춤



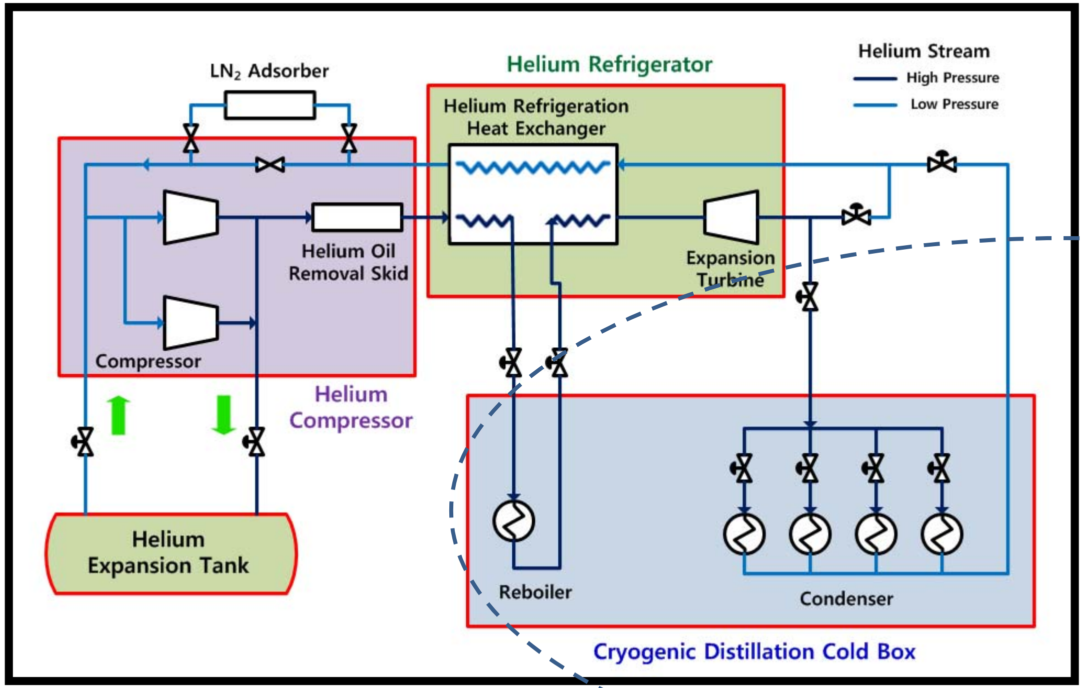
1bar에서 22bar까지 압축

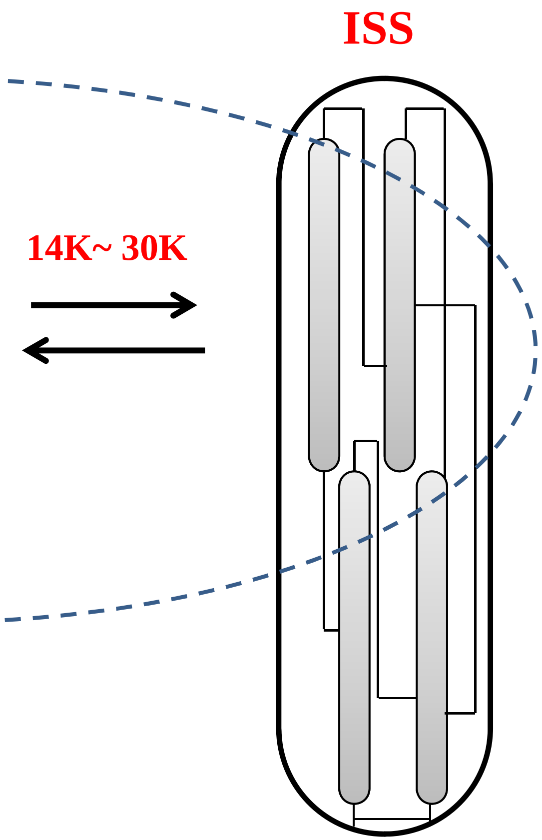
14 K까지 온도가 낮아진 헬륨을 사용해 열 교환함

Helium Refrigeration Cycle

수소 동위원소를 분리하기 위한 증류조건은 초저온(~30K)에서 운전되므로, 위해 사용되는 헬륨 냉동기는 수소동위원소 분리를 위한 헬륨냉동기의 용량은 1,800W 정도이다.

3. 헬륨 냉동 사이클





Cold Box

1) **Helium Expansion Tank**

2) **Helium Screw Compressors**

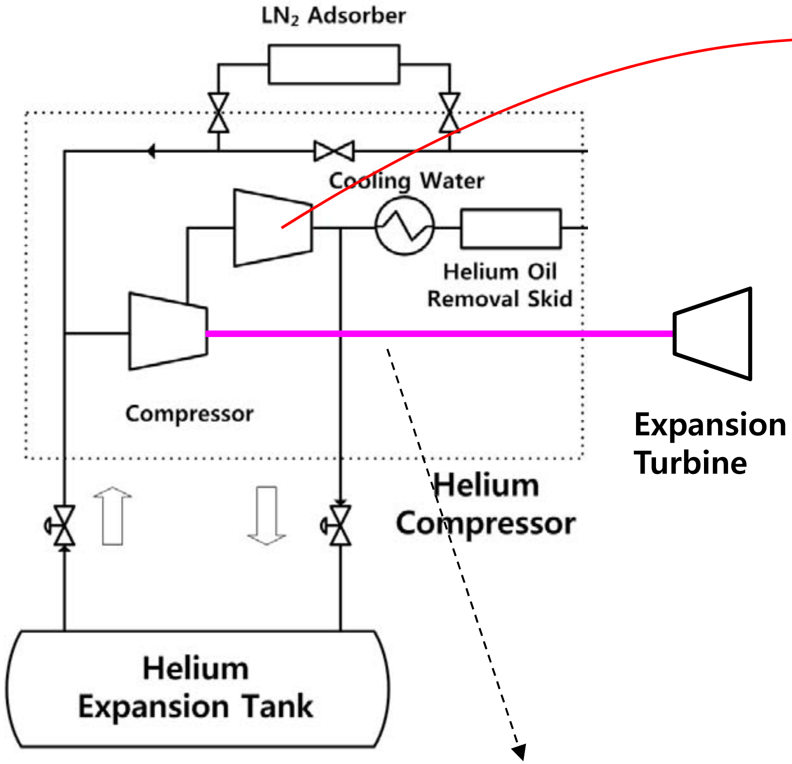
3) **Helium Refrigerator**

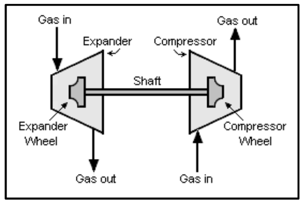
4) **Cryogenic Distillation Cold Box**

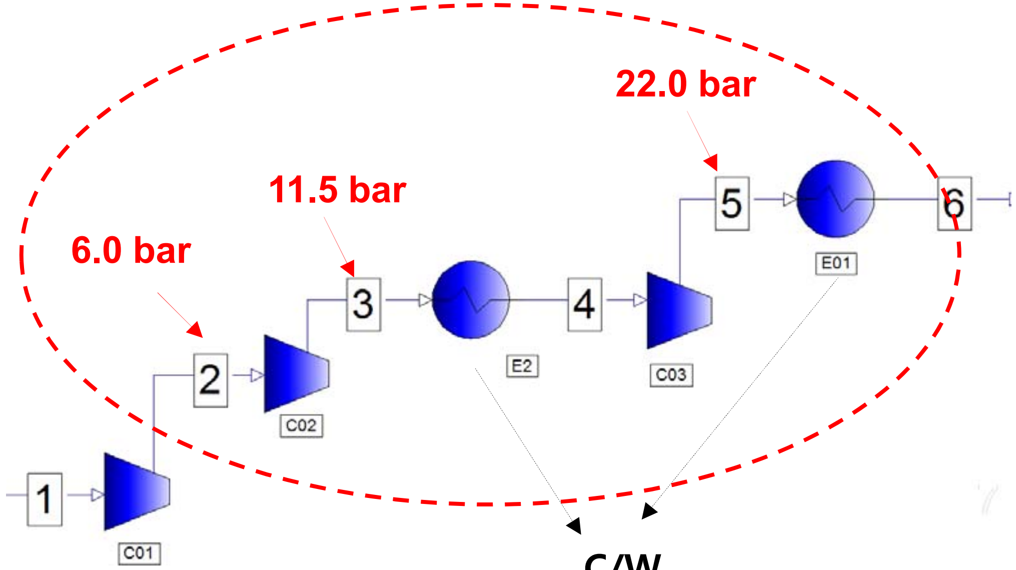
3. 헬륨 냉동 사이클

➢ Refrigeration Process Operating Pressure Determination

Considering the compression efficiency which was applied to 2-stage compression system





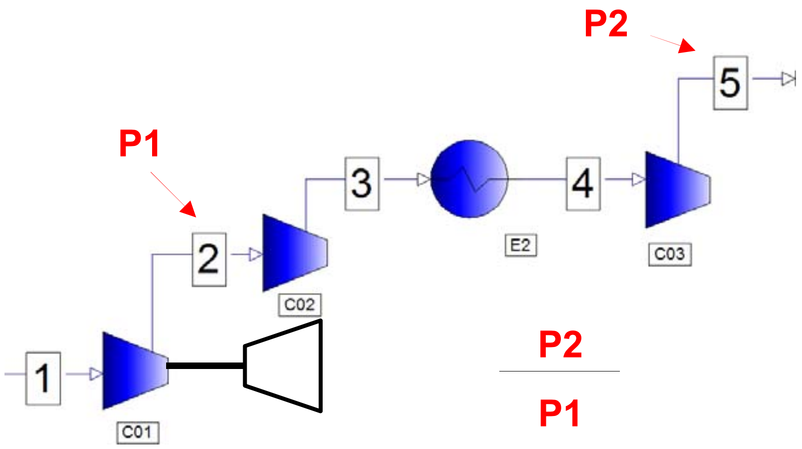


C/W
(Given the temperature in summer season in Korea, which is assumed to be cooled down to 45 ℃)

Compression Ratio $= \left(\frac{P_d}{P_s}\right)^{1/n}$

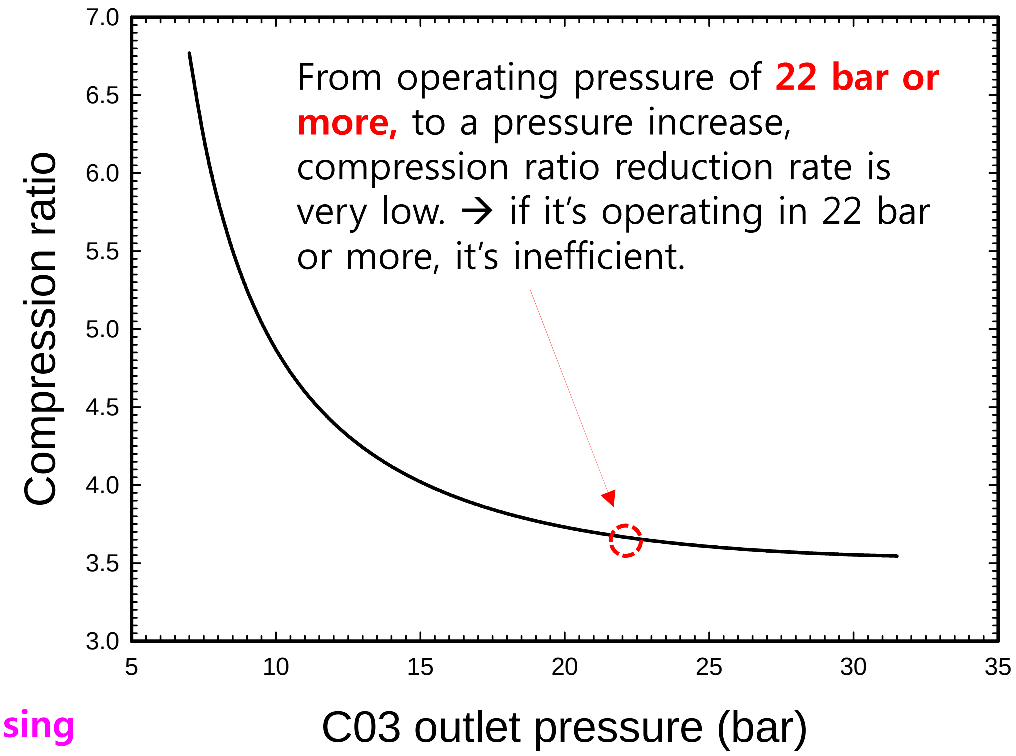
3. 헬륨 냉동 사이클

❖**Determining the optimum operating pressure from helium refrigeration process**

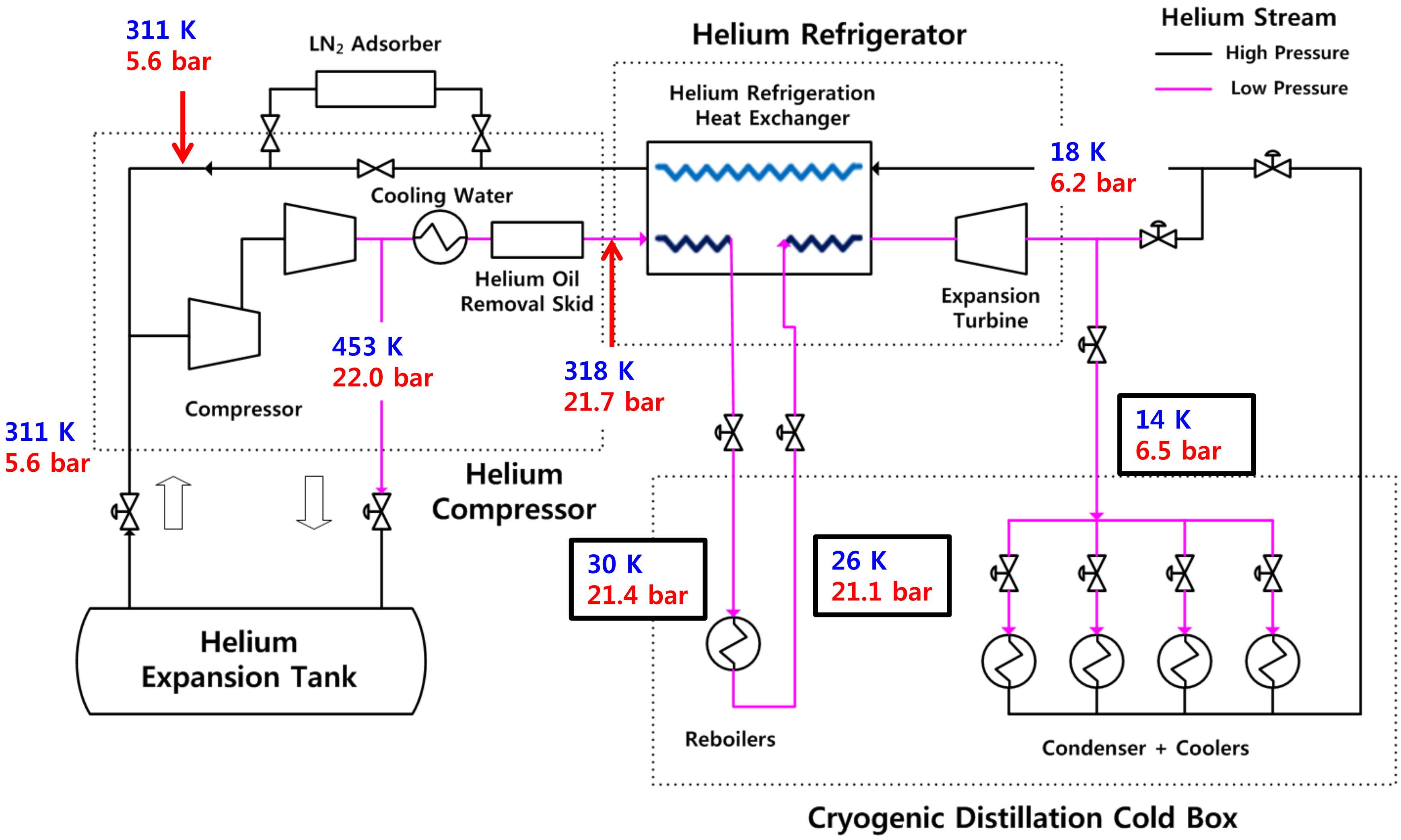


$$\frac{P2}{P1}$$

Decreasing Compressor power required

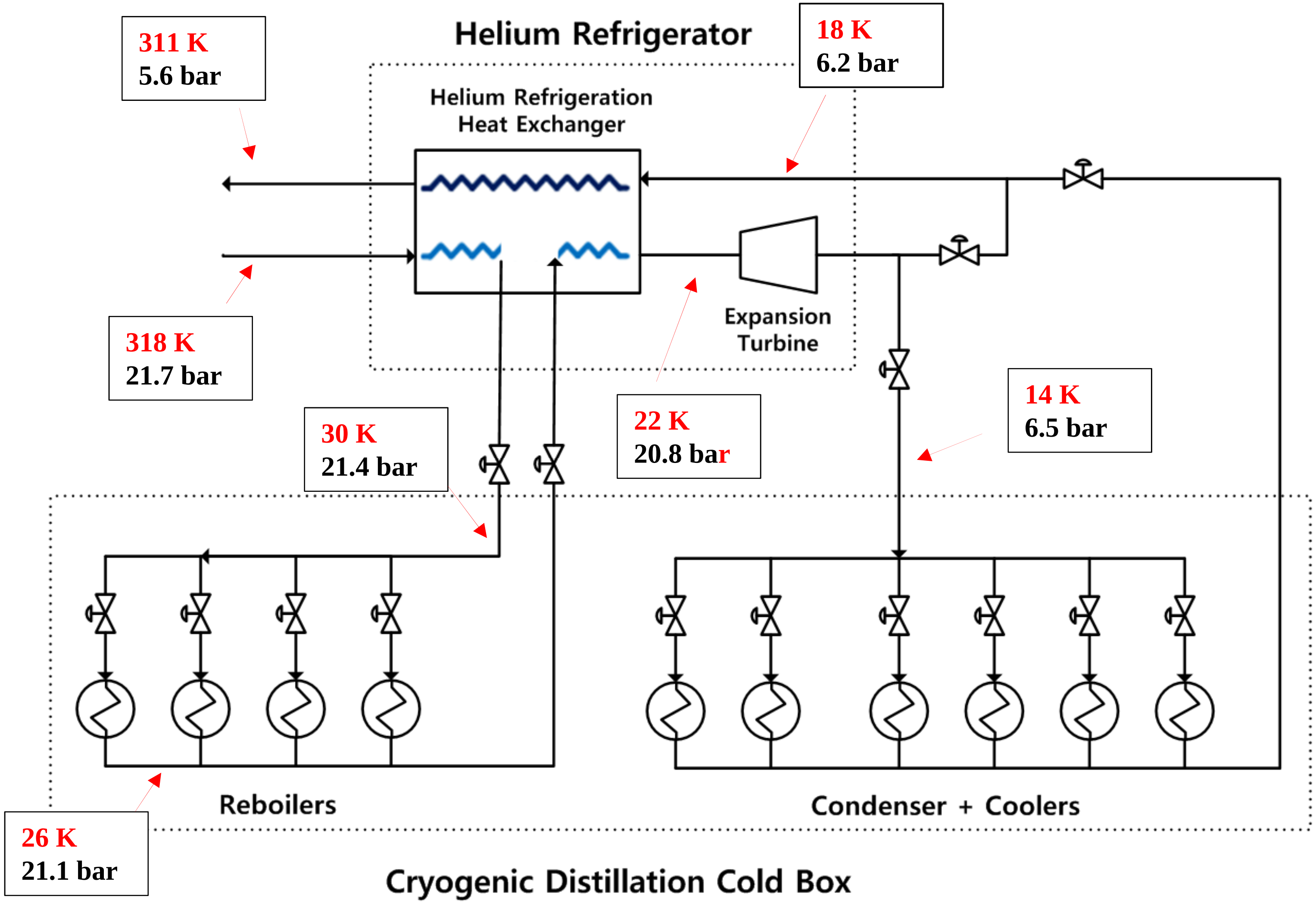


3. 헬륨 냉동 사이클



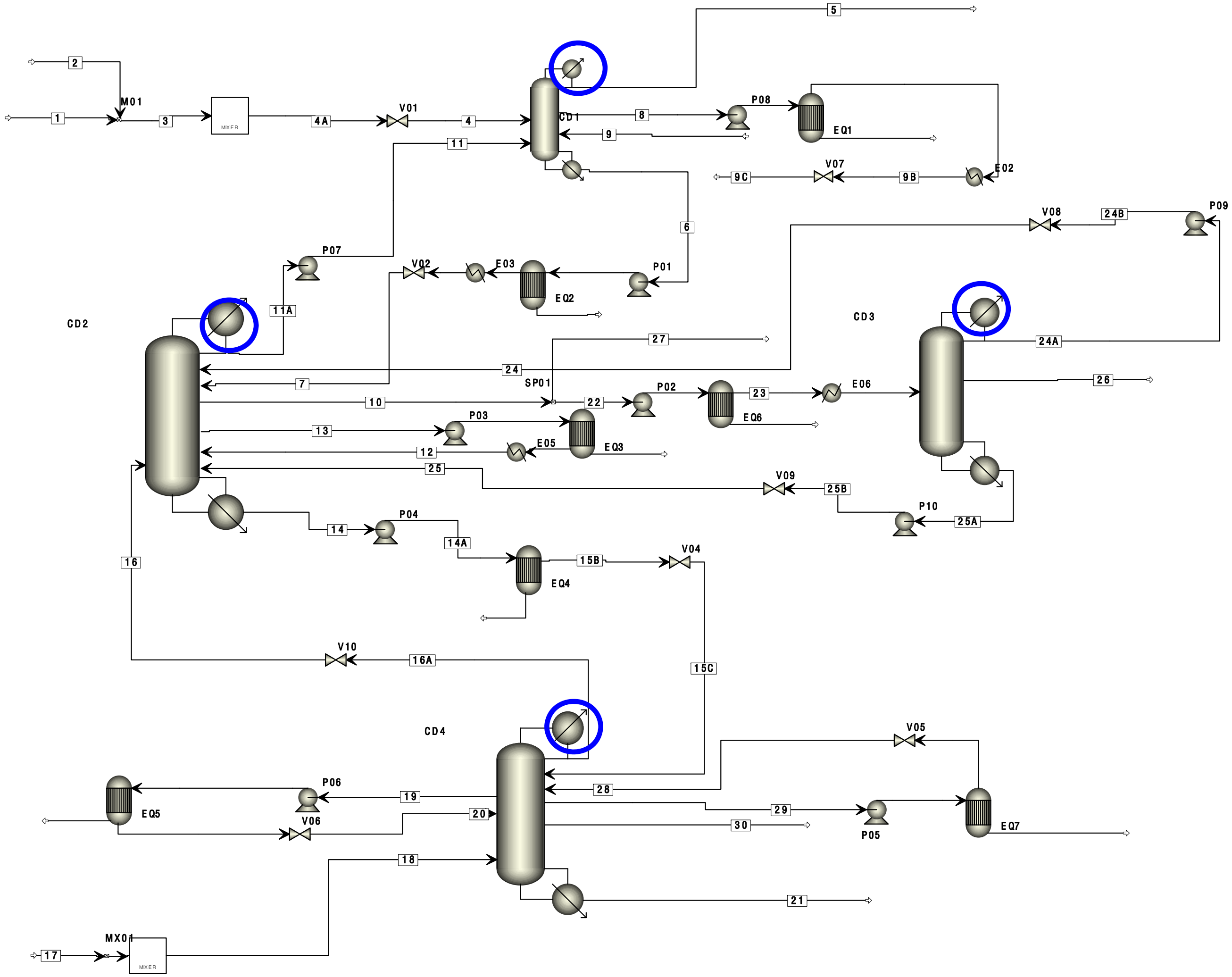
311 K
5.6 bar
LN2 Adsorber
Helium Refrigerator
Helium Stream
High Pressure
Low Pressure
Helium Refrigeration
Heat Exchanger
18 K
6.2 bar
Cooling Water
Helium Oil
Removal Skid
Expansion
Turbine
453 K
22.0 bar
318 K
21.7 bar
Compressor
14 K
6.5 bar
311 K
5.6 bar
Helium
Compressor
30 K
21.4 bar
26 K
21.1 bar
Helium
Expansion Tank
Reboilers
Condenser + Coolers
Cryogenic Distillation Cold Box

3. 헬륨 냉동 사이클



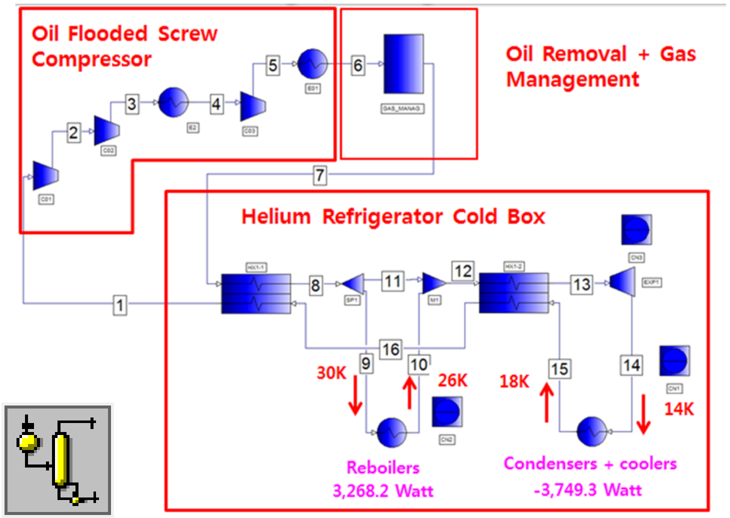
Helium Refrigerator
311 K
5.6 bar
18 K
6.2 bar
Helium Refrigeration
Heat Exchanger
Expansion
Turbine
318 K
21.7 bar
30 K
21.4 bar
22 K
20.8 bar
14 K
6.5 bar
Reboilers
Condenser + Coolers
26 K
21.1 bar
Cryogenic Distillation Cold Box

3. 헬륨 냉동 사이클

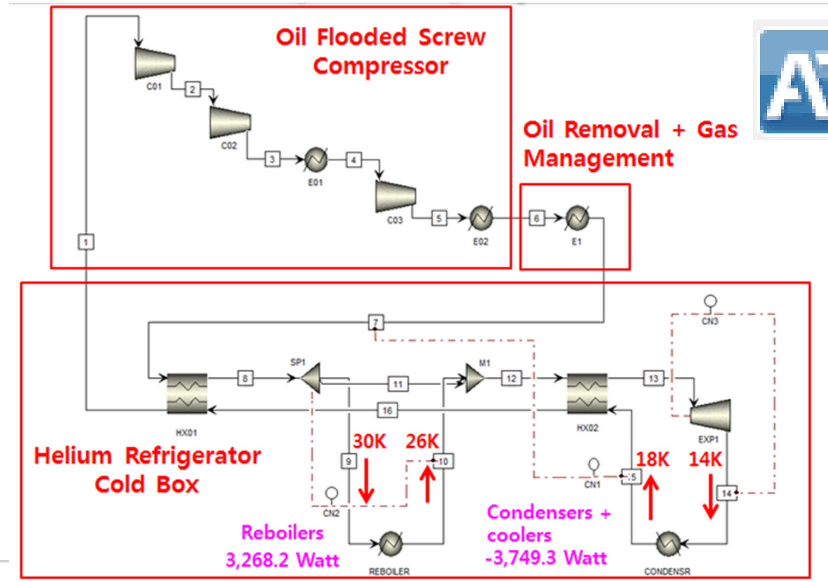


1
2
M01
3
MIXER
4A
V01
4
CD1
5
8
9
11
P08
EQ1
9C
V07
9B
E02
6
V08
24B
P09
P07
V02
E03
P01
EQ2
11A
CD2
CD3
27
24A
24
7
SP01
26
10
22
P02
23
E06
EQ6
13
P03
EQ3
12
E05
25
V09
25B
P10
25A
14
P04
14A
15B
V04
EQ4
16
V10
16A
15C
CD4
V05
28
19
P06
EQ5
V06
20
29
30
P05
EQ7
18
21
MX01
17
MIXER

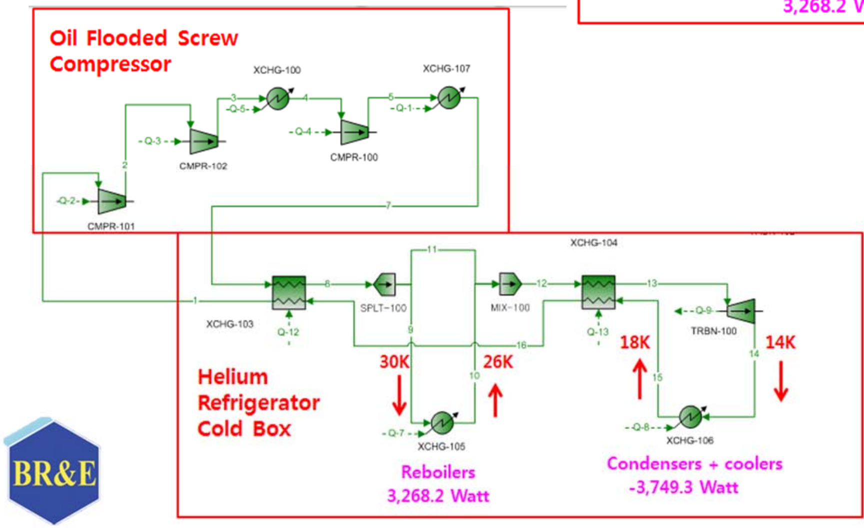
3. 헬륨 냉동 사이클



Oil Flooded Screw Compressor
Oil Removal + Gas Management
Helium Refrigerator Cold Box
30K
26K
18K
14K
Reboilers
3,268.2 Watt
Condensers + coolers
-3,749.3 Watt

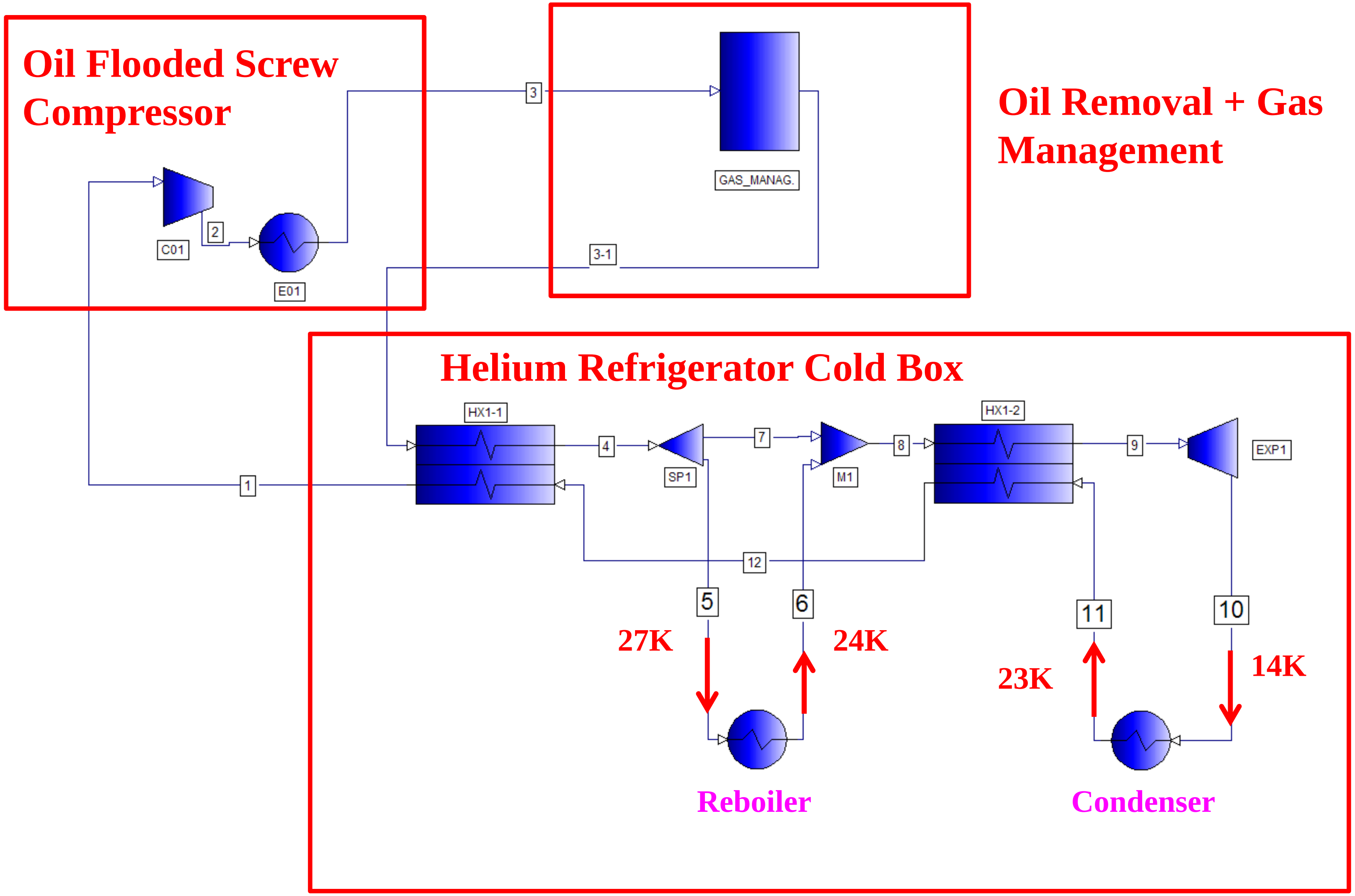


Oil Flooded Screw Compressor
Oil Removal + Gas Management
Helium Refrigerator Cold Box
30K
26K
18K
14K
Reboilers
3,268.2 Watt
Condensers + coolers
-3,749.3 Watt
REBOILER
CONDENSR



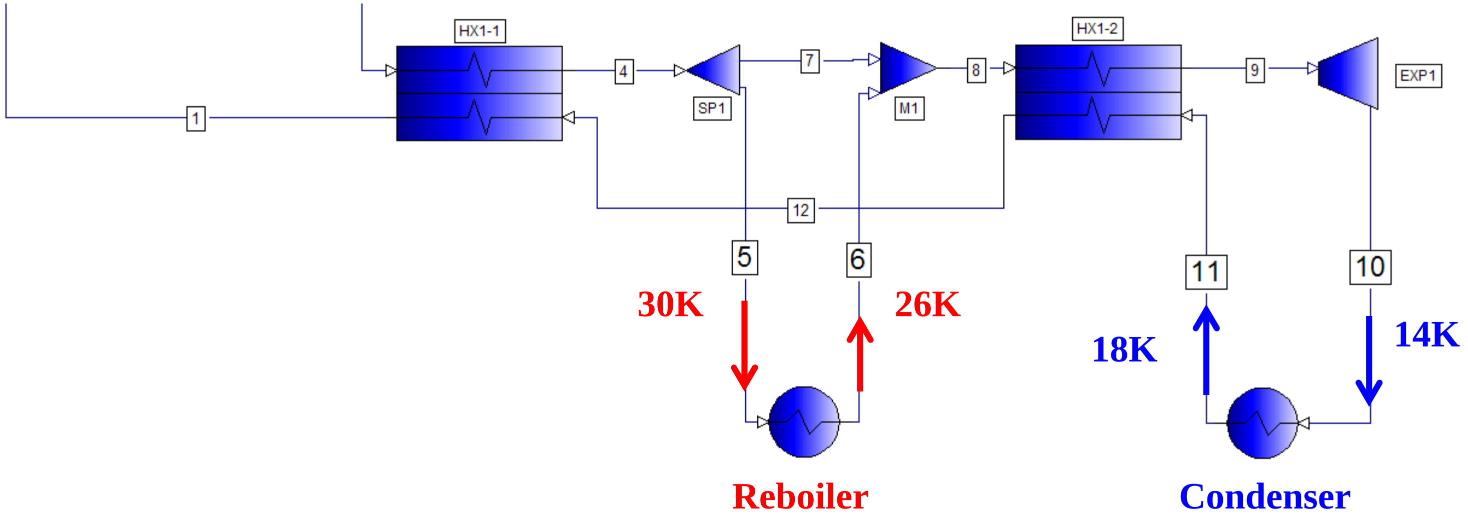
Oil Flooded Screw Compressor
XCHG-100
XCHG-107
CMPR-102
CMPR-100
CMPR-101
XCHG-103
SPLT-100
MIX-100
XCHG-104
TRBN-100
Helium Refrigerator Cold Box
30K
26K
18K
14K
XCHG-105
XCHG-106
Reboilers
3,268.2 Watt
Condensers + coolers
-3,749.3 Watt

3. 헬륨 냉동 사이클



Oil Flooded Screw Compressor
Oil Removal + Gas Management
Helium Refrigerator Cold Box
GAS_MANAG.
3
3-1
2
C01
E01
1
HX1-1
4
SP1
7
M1
8
HX1-2
9
EXP1
12
5
6
27K
24K
Reboiler
11
10
23K
14K
Condenser

3. 헬륨 냉동 사이클



Stream Number	5		6		10		11	
Stream Name	**Reboiler Inlet**		**Reboiler Outlet**		**Condenser Inlet**		**Condenser Outlet**	
Temperature (K)	**30.00**		**26.00**		**14.05**		**18.08**	
Pressure (ATM)	20.00		20.00		6.25		6.25	
Phase	Vapor		Vapor		Vapor		Vapor	
Total Molar Rate (KG-MOL/HR)	113.18		113.18		128.58		128.58	
Total Mass Rate (KG/HR)	**453.00**		**453.00**		**514.66**		**514.66**	
	Flow rate (kmol/hr)	Percent (mol%)	Flow rate (kmol/hr)	Percent (mol%)	Flow rate (kmol/hr)	Percent (mol%)	Flow rate (kmol/hr)	Percent (mol%)
Helium	**113.18**	100.00	113.18	100.00	**128.58**	100.00	128.58	100.00

PRO/II를 활용한 냉동사이클 공정모사 방법

Refrigeration cycle Example

Problem.

프로판을 냉매로 사용하여 증기 재압축 냉동사이클에 대한 전산모사를 수행하고자 한다. 액화 하고자 하는 원료는 다음의 표와 같다. 원료 스트림의 액화 후 온도는 -30℃ 이다.

➢ **액화하고자 하는 원료 조건**

Component	Mole%
Propane	7.80
Iso-Butane	49.08
N-Butane	43.12
Temperature (℃)	25.0
Pressures (bar)	1.2
Flow rate (kg/hr)	15,078

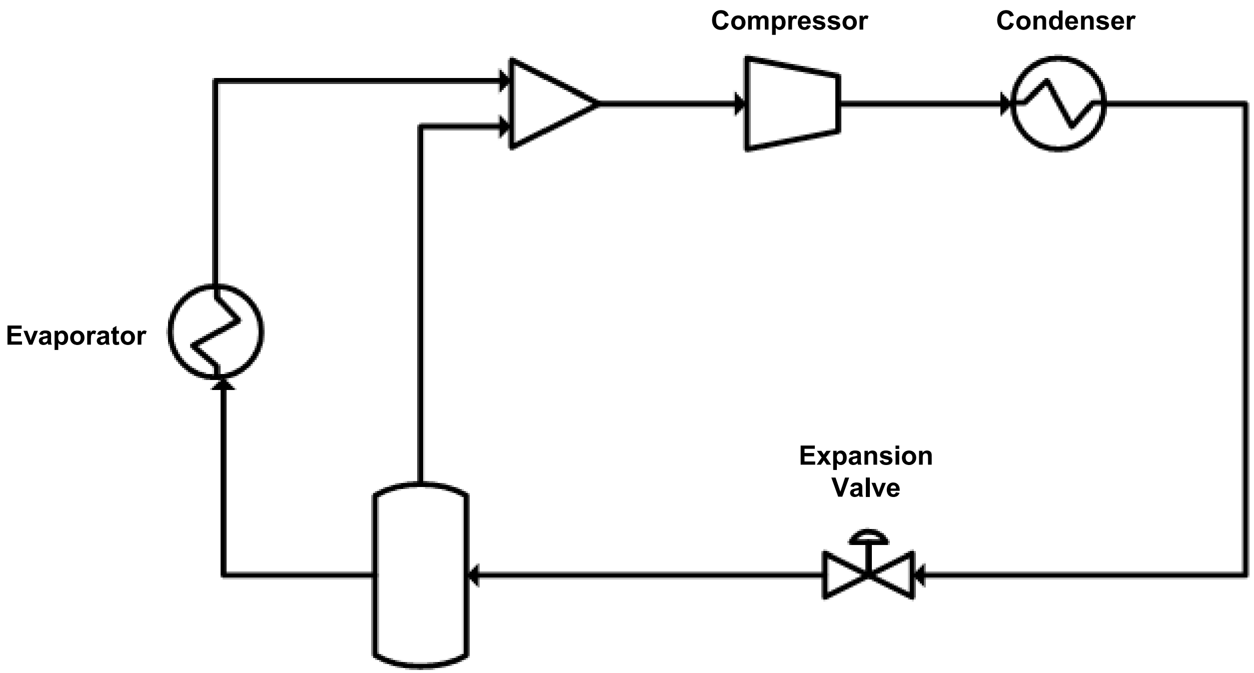
냉매로는 순수한 프로판을 사용한다. 냉매 응축기에서 2차 냉매로써 냉각수를 사용하며, 공급온도는 32℃이고 회수온도는 37℃이다. 2차 냉매에 의해 프로판은 45℃까지 응축되고 응축기 압력강하는 0.5 bar 가정. 냉매가 증발기로 주입되는 온도는 -40℃이다. 열역학 모델식 Peng-Robinson 상태방정식 적용

Problem: 1

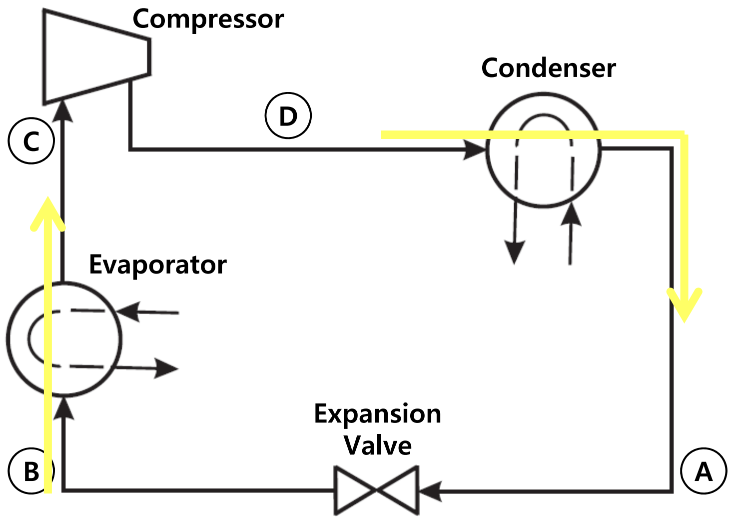
증기 재압축 냉동 사이클의 개요도를 그리고, 개략적으로 설명하라. 단, 팽창밸브 후단의 Two-phase flow는 기액 분리를 위해서 Flash drum을 설치한다.

Problem 1: 냉동사이클 개요도

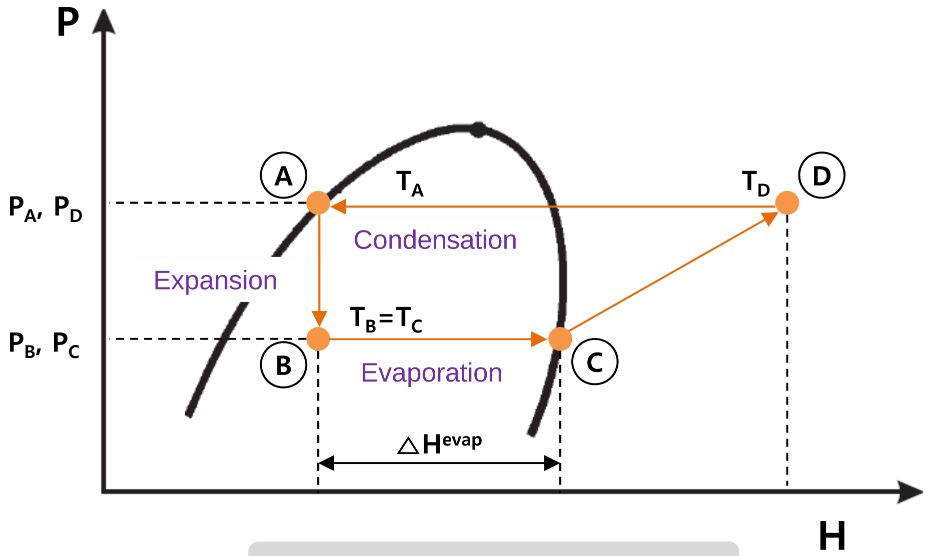
Refrigeration Cycle Diagram



증기 재압축을 이용한 냉동 사이클의 기본원리



Refrigeration Cycle Diagram



Pressure Enthalpy Diagram

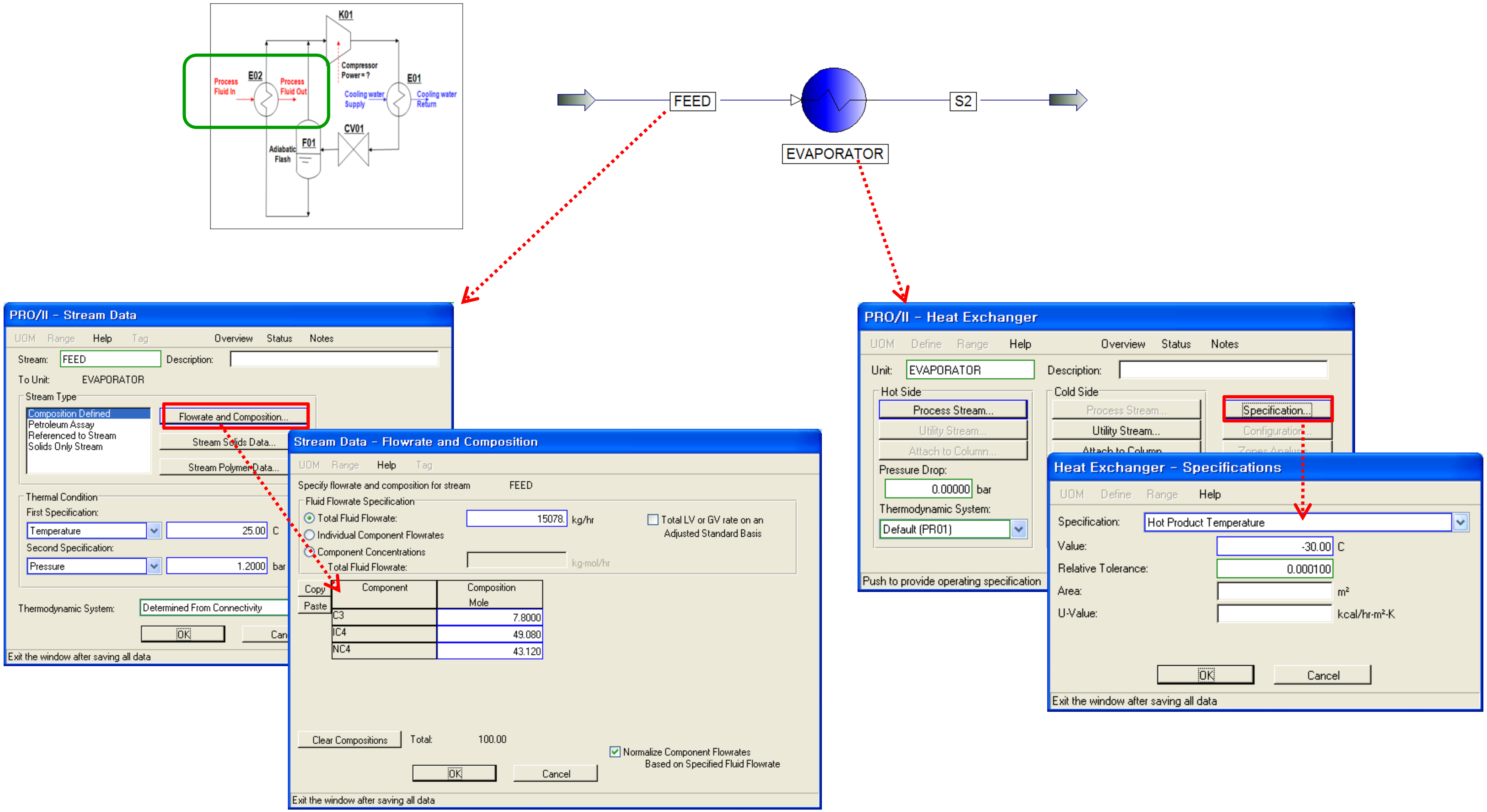
Refrigeration Cycle Step :

Ⓐ Expansion
Ⓑ Evaporation
Ⓒ Compression
Ⓓ Condensation

Problem 2

증발기의 heat duty를 결정하라.

Problem 2: 증발기의 heat duty 결정



Problem 2: 증발기의 heat duty 결정

- **증발기의 heat duty**

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UNIT 1, 'EVAPORATOR'

 OPERATING CONDITIONS

      DUTY, M*KCAL/HR                1.712
      LMTD, C                        29.383
      F FACTOR (FT)                  1.000
      MTD, C                         29.383
      U*A, KCAL/HR-C                 58247.946
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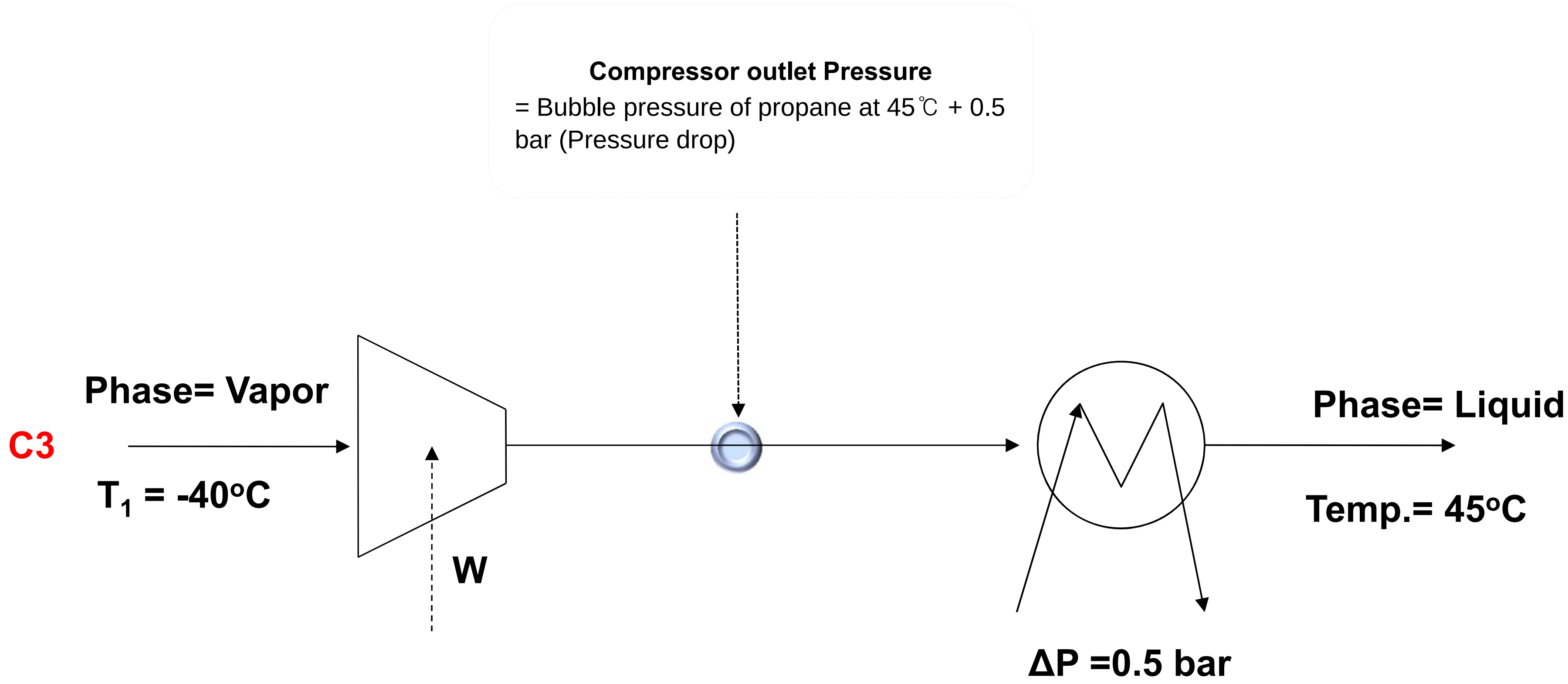
Problem 3

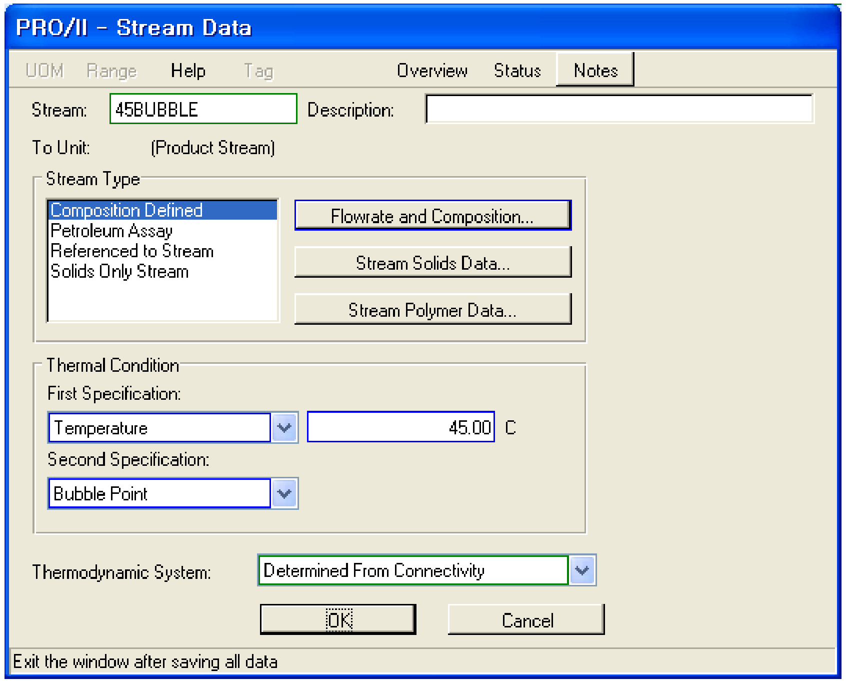
압축기 후단의 압력을 결정하라.

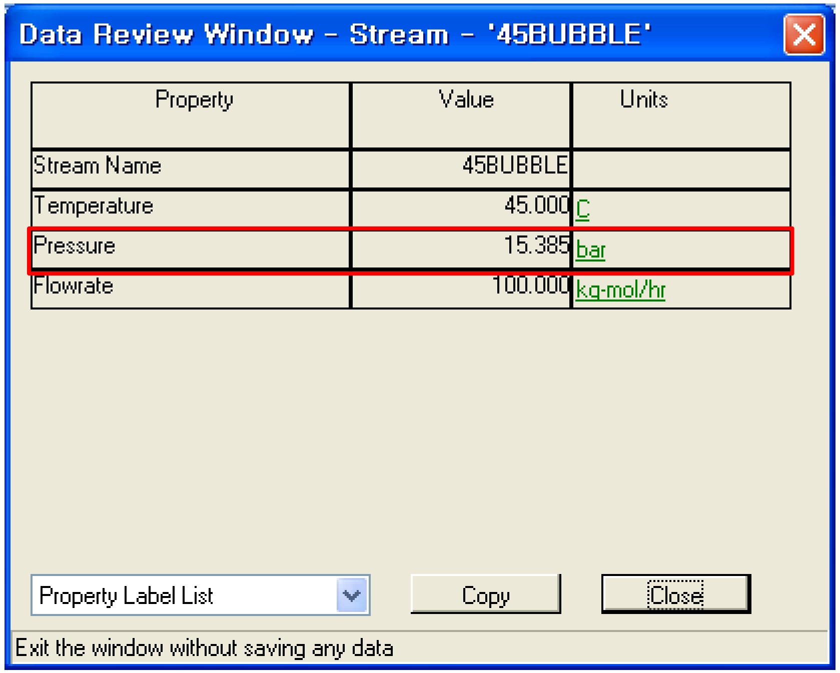
Problem 3: 압축기 후단 압력 결정



Problem 3: 압축기 후단 압력 결정

Result

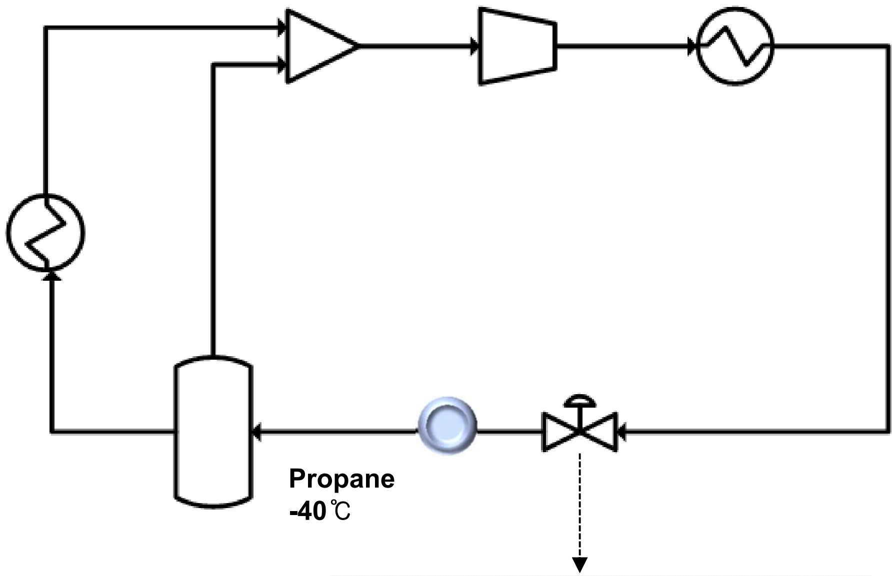




Problem 4

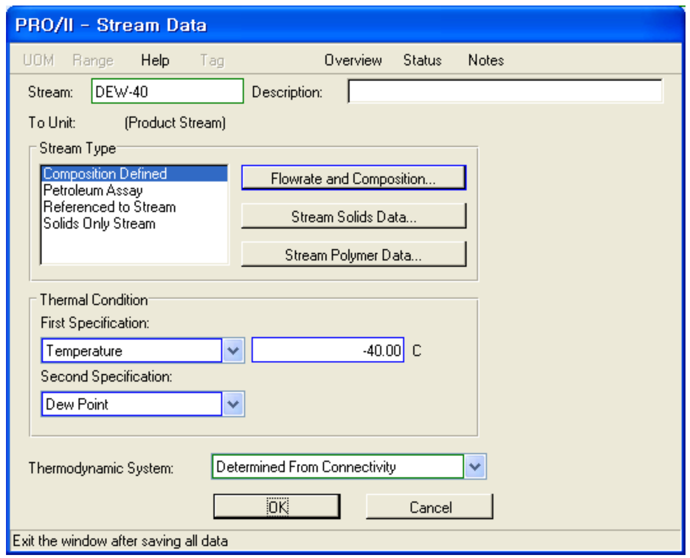
팽창 밸브 후단의 압력을 결정하라.

Problem 4: 팽창 밸브 후단압력 결정

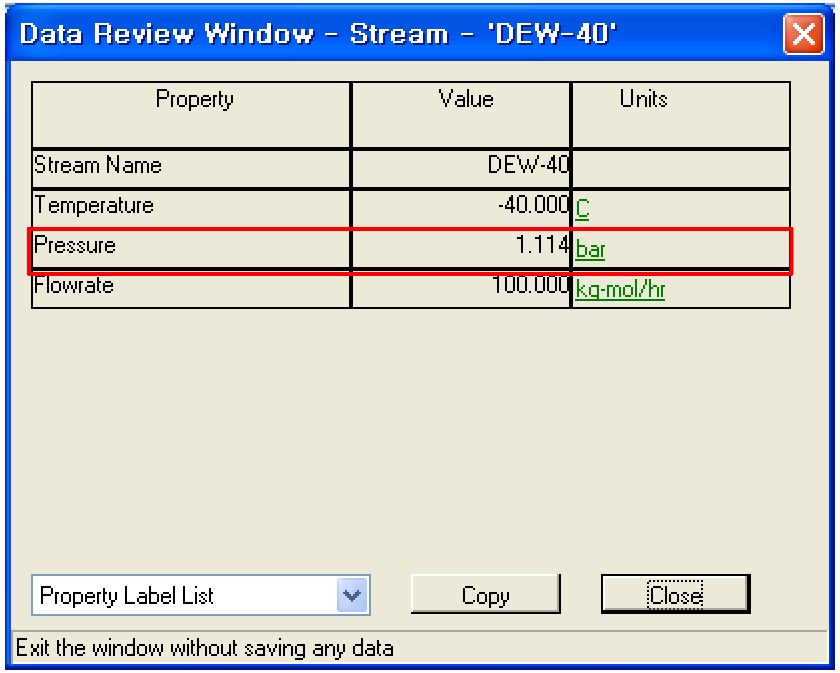


Valve outlet Pressure

= Dew Pressure of Propane at -40℃



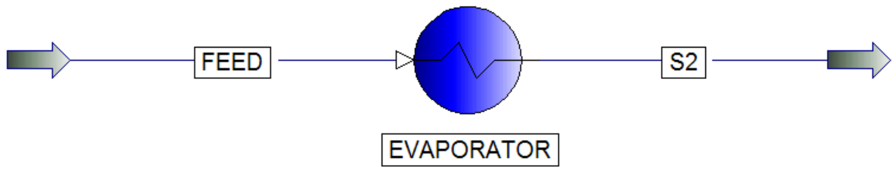
Problem 4: 팽창 밸브 후단압력 결정

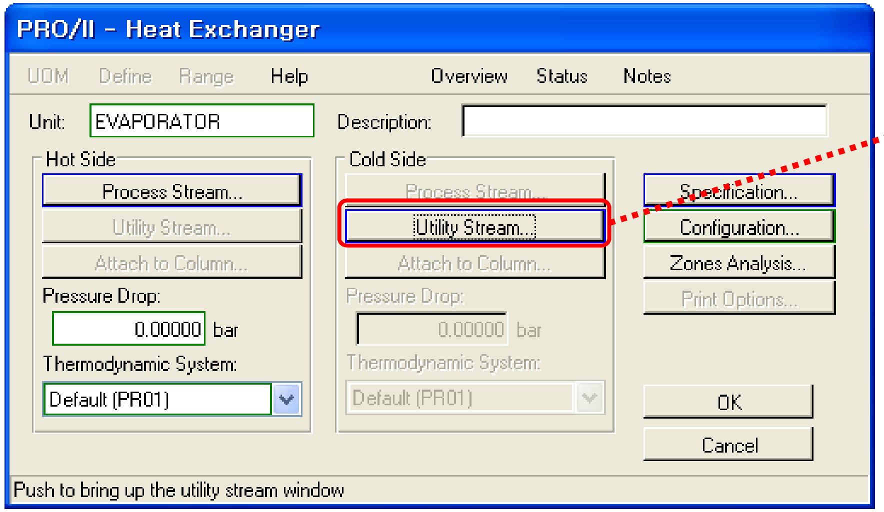


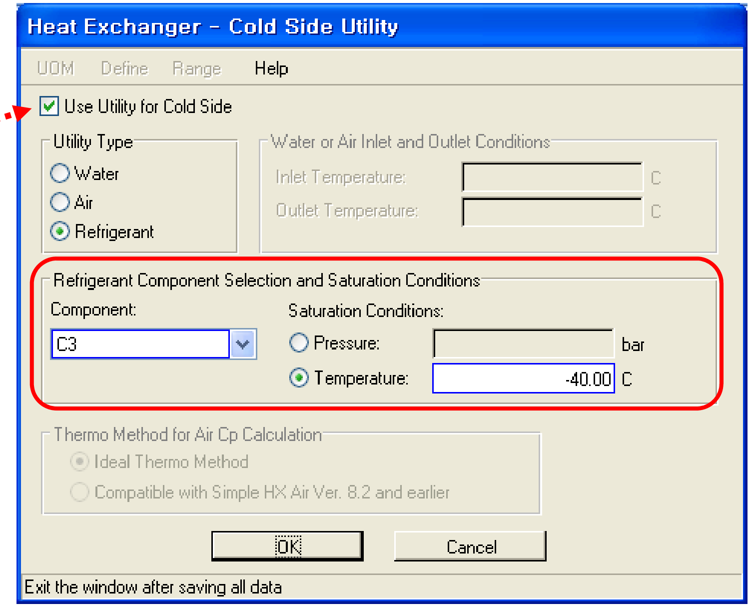
Problem 5

증발기로 주입되는 냉매의 유량을 결정하라.

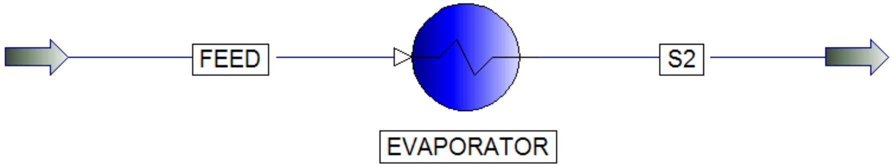
Problem 5: 증발기로 주입되는 냉매의 유량 결정







Problem 5: 증발기로 주입되는 냉매의 유량 결정

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UNIT 1, 'EVAPORATOR'

 OPERATING CONDITIONS

      DUTY, M*KCAL/HR                                   1.712

      CONDENSATION, KG-MOL/HR                                       264.390
       TEMPERATURE, C                                  25.000       -30.000
       PRESSURE, BAR                                    1.200         1.200

 COLD SIDE CONDITIONS                                   INLET        OUTLET
                                                  -----------   -----------
      REFRIGERANT, KG/HR                            16946.501     16946.501
      SATURATION PRESSURE, BAR                          1.109
      SATURATION TEMPERATURE, C                       -40.000
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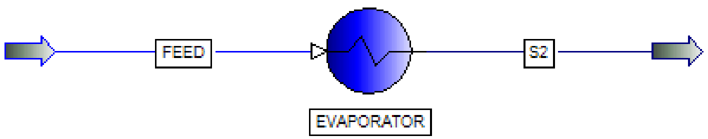
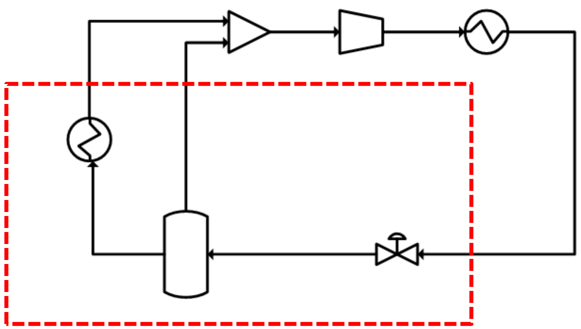
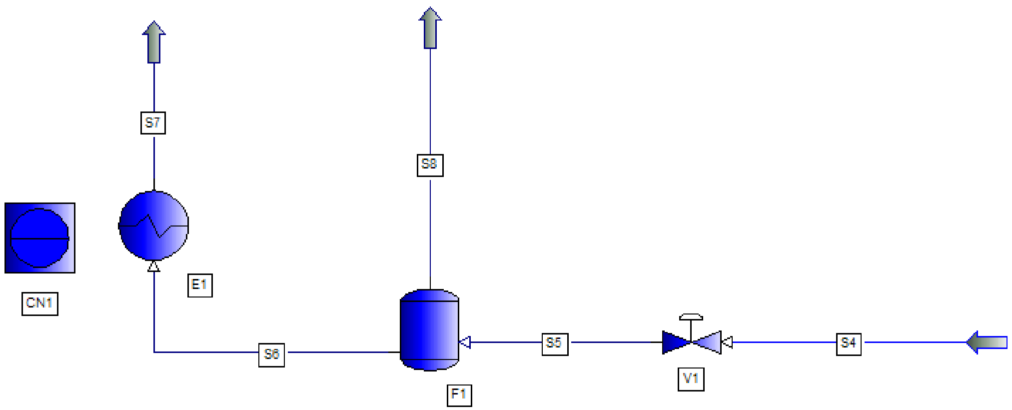
Problem 6

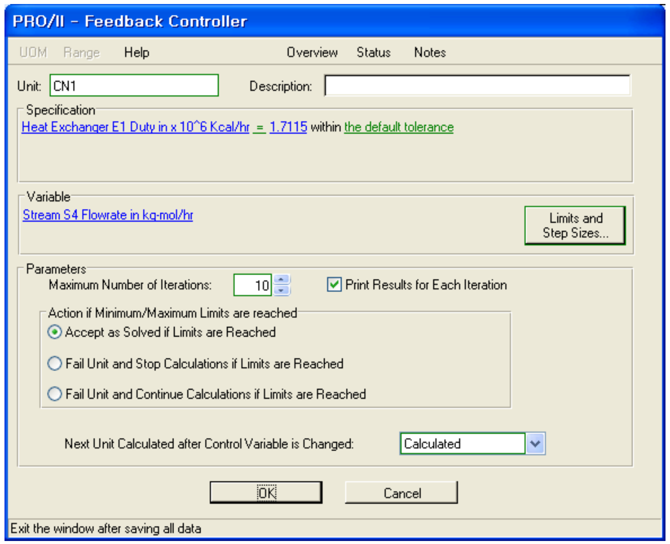
냉매의 총 순환유량을 결정하라.

Problem 6: 냉매의 총 순환유량 결정

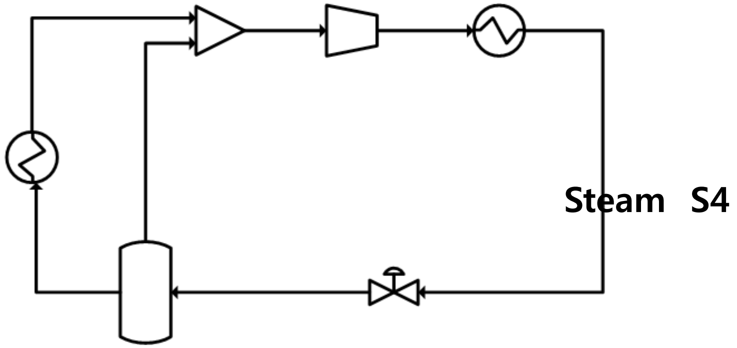








Problem 6: 냉매의 총 순환유량 결정



STREAM 'S4'

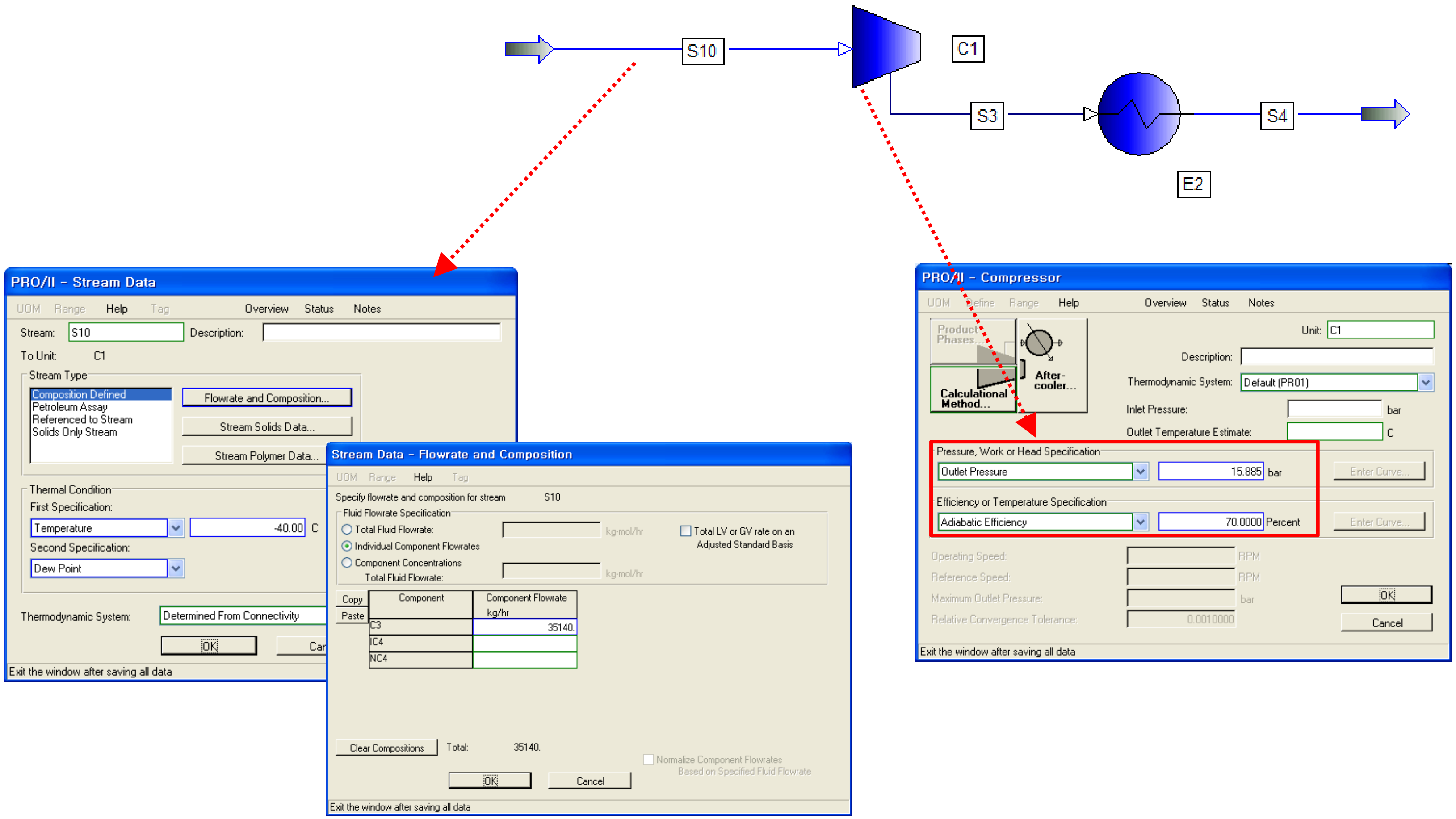
	TOTAL	LIQUID
RATE, KG/HR	**35139.6939**	**35139.6939**
TEMPERATURE, C	45.00	45.00
PRESSURE, BAR	15.38	15.38
MOLECULAR WEIGHT	44.0965	44.0965
WEIGHT FRACTION		1.0000
ENTHALPY, KCAL/KG	30.9152	30.9152
CP, KCAL/KG-C	0.7693	0.7693
MASS FLOWRATES, KG/HR		
1 - C3	35139.6939	35139.6939
2 - IC4	0.0000	0.0000
3 - NC4	0.0000	0.0000

Problem 7

압축기의 소요동력을 추산하라. 단, 압축기의 효율은 70%라고 가정하라.

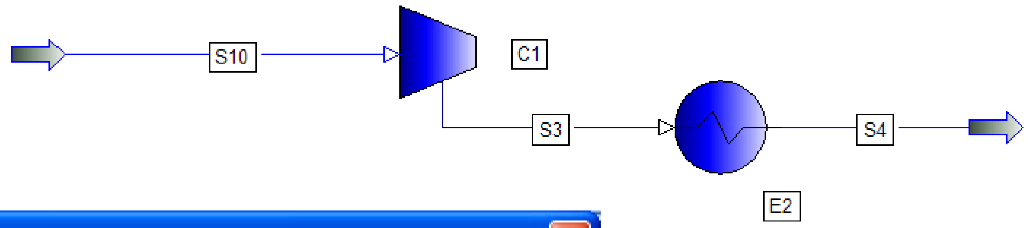
Problem 7: 압축기 소요동력 추산하라

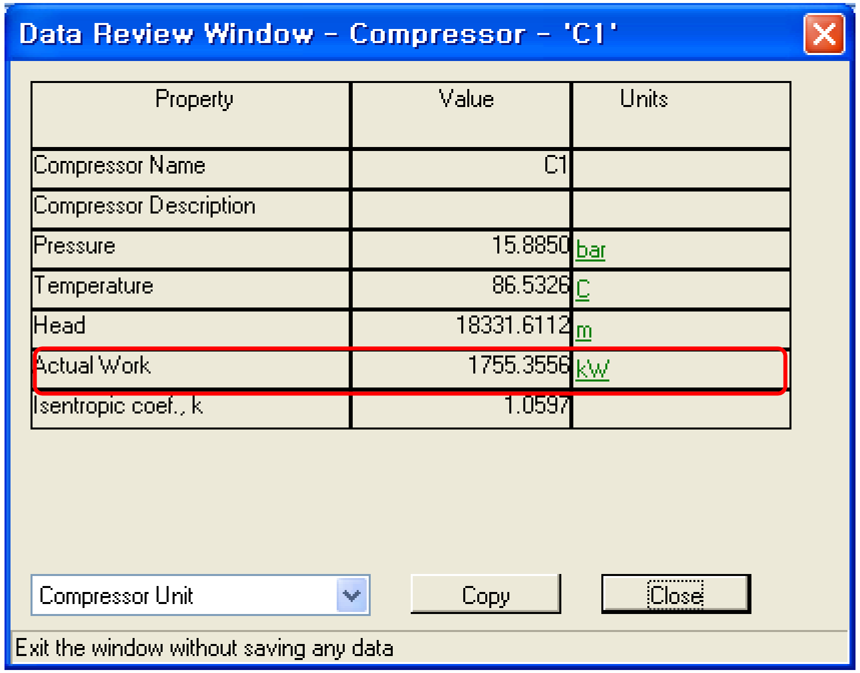
➢ **압축기 효율 70%**



Problem 7: 압축기 소요동력 추산하라

- 압축기 효율 70%





Data Review Window - Compressor - 'C1'

Property	Value	Units
Compressor Name	C1	
Compressor Description		
Pressure	15.8850	bar
Temperature	86.5326	C
Head	18331.6112	m
Actual Work	1755.3556	kW
Isentropic coef., k	1.0597	

Compressor Unit | Copy | Close

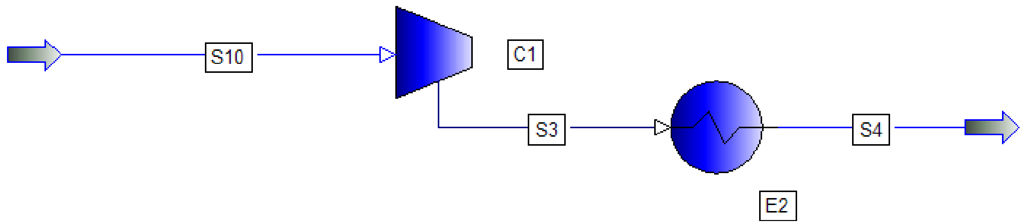
Exit the window without saving any data

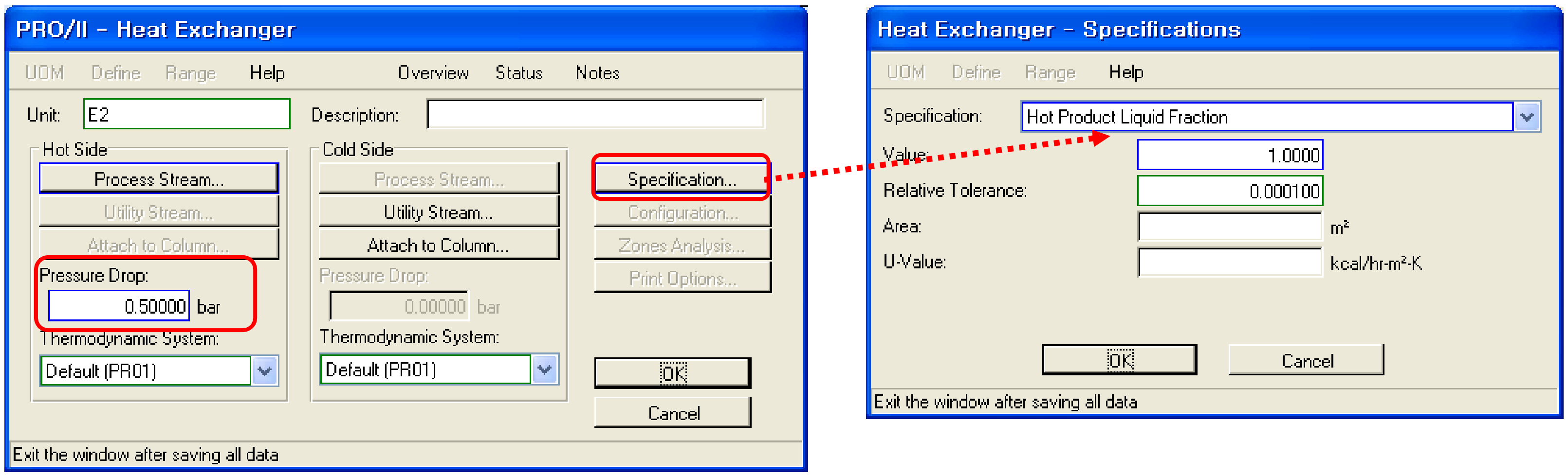
Problem 8

응축기의 heat duty를 결정하라.

Problem 8: 응축기의 heat duty를 결정

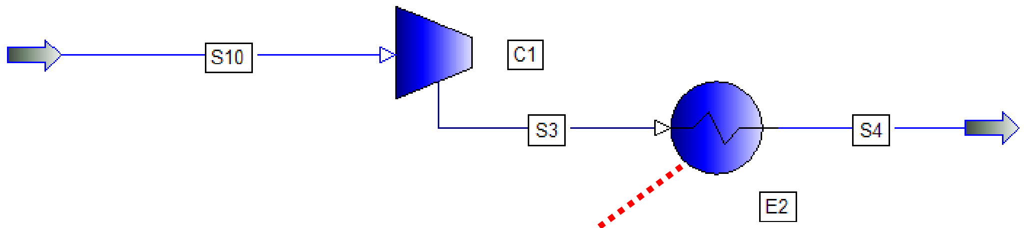
➢ **응축기 압력강하 0.5 bar , 45℃까지 프로판 응축**

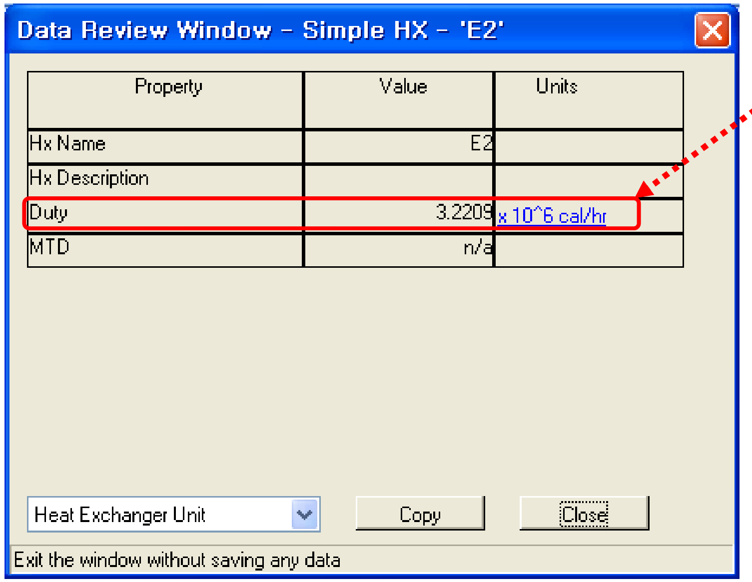




Problem 8: 응축기의 heat duty를 결정

➢ **응축기 압력강하 0.5 bar , 45℃까지 프로판 응축**





Data Review Window - Simple HX - 'E2'

Property	Value	Units
Hx Name	E2	
Hx Description		
Duty	3.2209	x 10^6 cal/hr
MTD	n/a	

Heat Exchanger Unit | Copy | Close

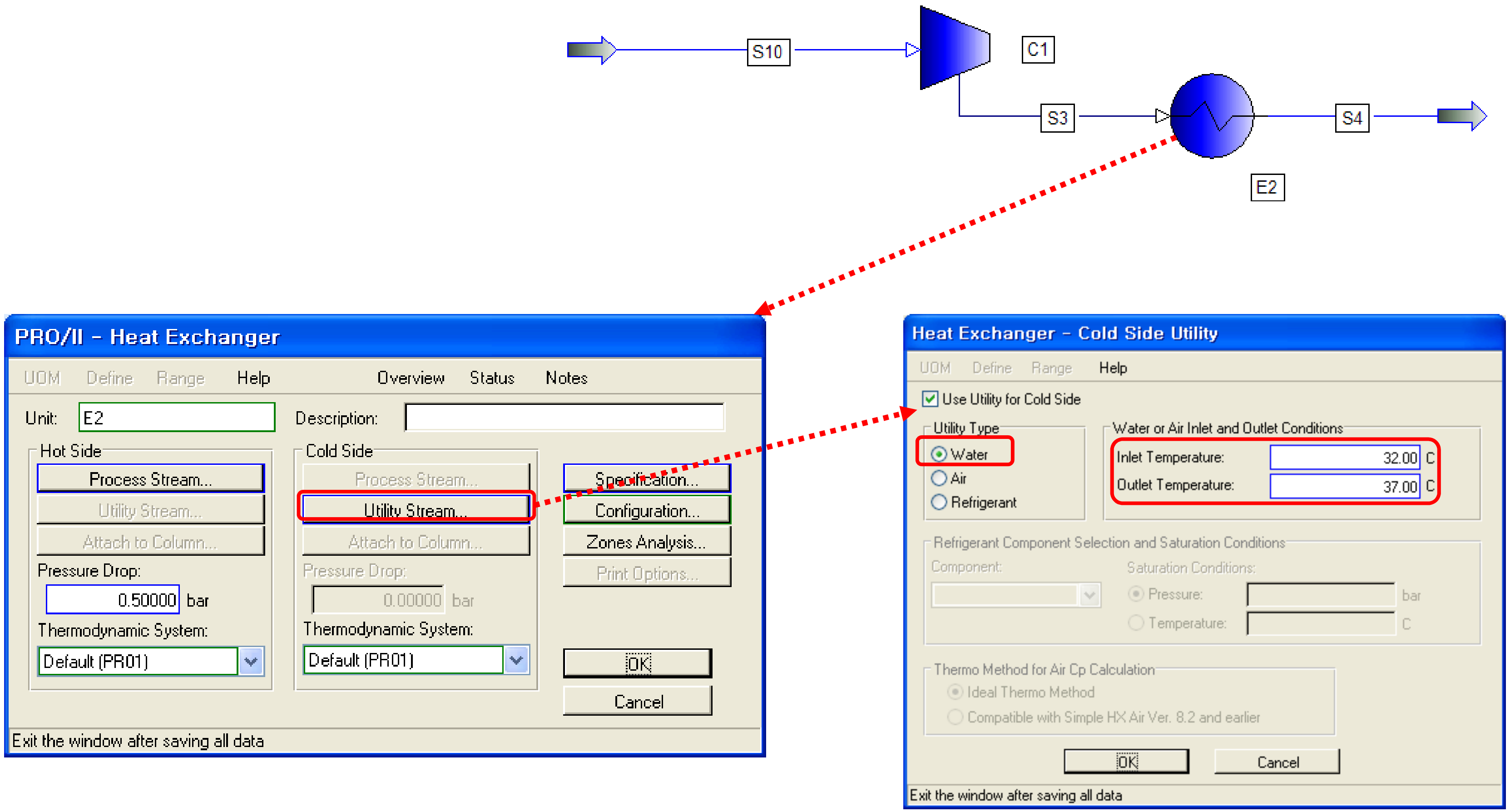
Exit the window without saving any data

Problem 9

냉각수 소모량을 추산하라.

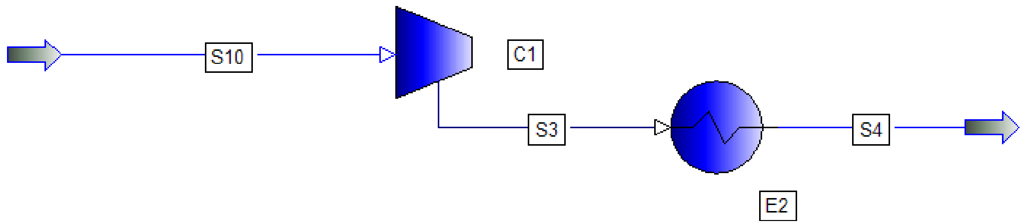
Problem 9: 냉각수 소모량 추산

➢ 냉각수 in/out 32℃/37℃, 프로판 45℃까지 응축



Problem 9: 냉각수 소모량 추산

➢ 냉각수 in/out 32℃/37℃, 프로판 45℃까지 응축

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 UNIT 5, 'E2'

 OPERATING CONDITIONS

      DUTY, M*KCAL/HR                          3.221
      LMTD, C                                 27.312
      F FACTOR (FT)                            0.947
      MTD, C                                  25.860
      U*A, KCAL/HR-C                      124551.633

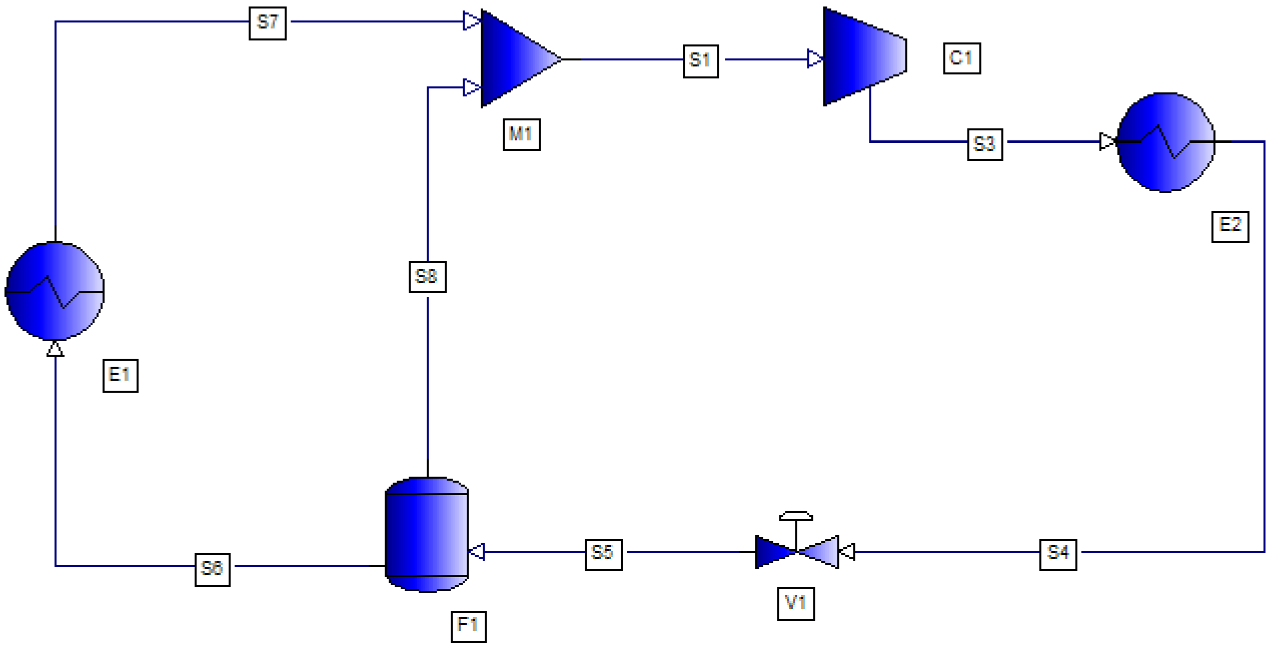
CONDENSATION, KG-MOL/HR                              796.881
       TEMPERATURE, C                         86.533        45.001
       PRESSURE, BAR                          15.885        15.385

 COLD SIDE CONDITIONS                          INLET        OUTLET
                                          -----------  -----------
      COOLING WATER, KG/HR                644179.101    644179.101
      TEMPERATURE, C                          32.000        37.000
-------------------------------------------------------------------------------------------------
```

Problem 10

전체 냉동사이클을 하나의 PRO/II File로 완성하고, 각각의 결과와 전체 결과를 서로 비교하라.

Problem 10



Problem 10

Contents	단계별 계산	전체시스템 계산
증발기 heat duty (M*kcal/hr)	1.7115	1.7115
압축기 후단압력 (bar)	15.385	15.385
팽창 밸브 후단의 압력 (bar)	1.114	1.114
증발기로 주입되는 냉매 유량 (kg/hr)	16,946	16,978
냉매의 총 순환유량 (kg/hr)	35,139	35,139
압축기 소요동력 (kW)	1,755	1,755
응축기 heat duty (M*kcal/hr)	3.2209	3.2209
냉각수 소모량 (kg/hr)	644,179	644,196

감사합니다