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# ISS (Isotope Separation System)

## 초저온증류 공정시물레이션

공주대학교 화학공학부

조 정 호

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# 목 차

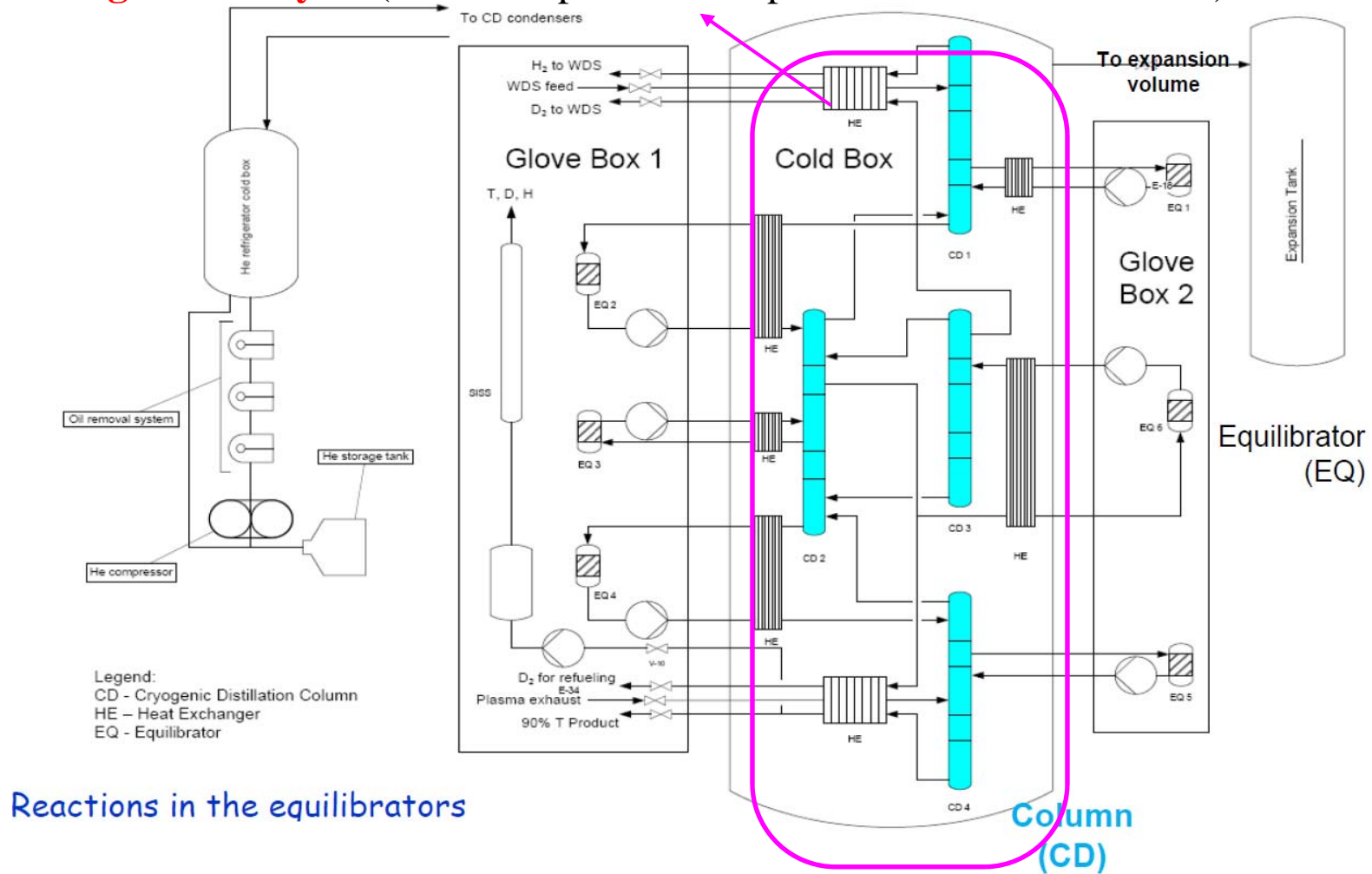
1. ISS(Isotope Separation System)소개
2. ITER ISS 평형 반응기
3. 헬륨 냉동 사이클
4. Pure Component Properties
5. ITER ISS 공정 시뮬레이션 Case 1
6. ITER ISS 공정 시뮬레이션 Case 2
7. ITER ISS 공정 시뮬레이션 Case 3

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### 3. 헬륨 냉동 사이클

# 3. 헬륨 냉동 사이클

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



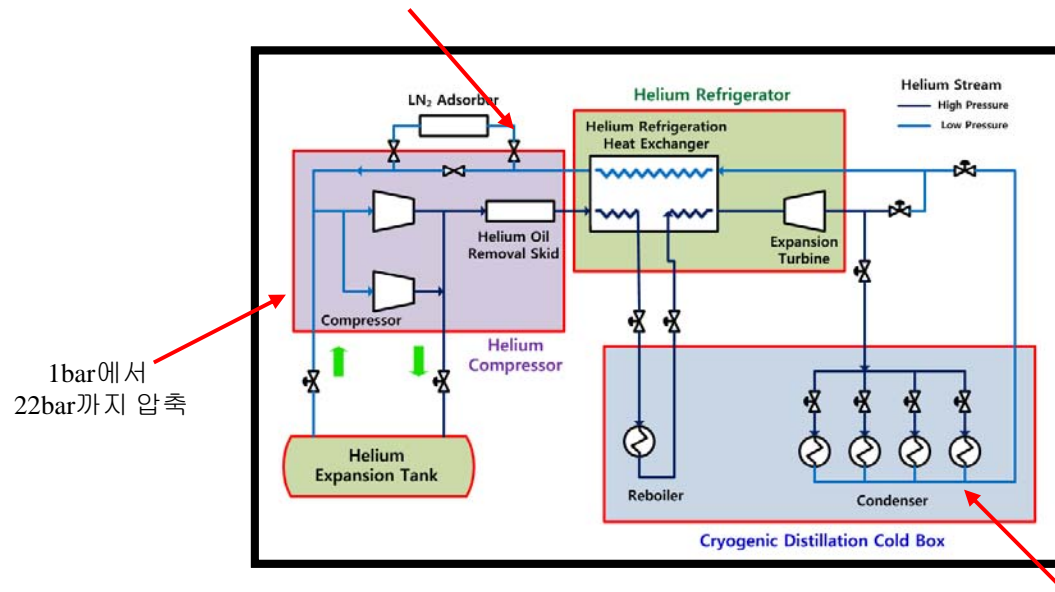
EU Contribution to ITER Fuel Cycle, Alain Teissier, IBF 2013

# 3. 헬륨 냉동 사이클

## 4.5 K Helium refrigeration unit

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

헬륨을 320K에서 14 K까지 낮춤

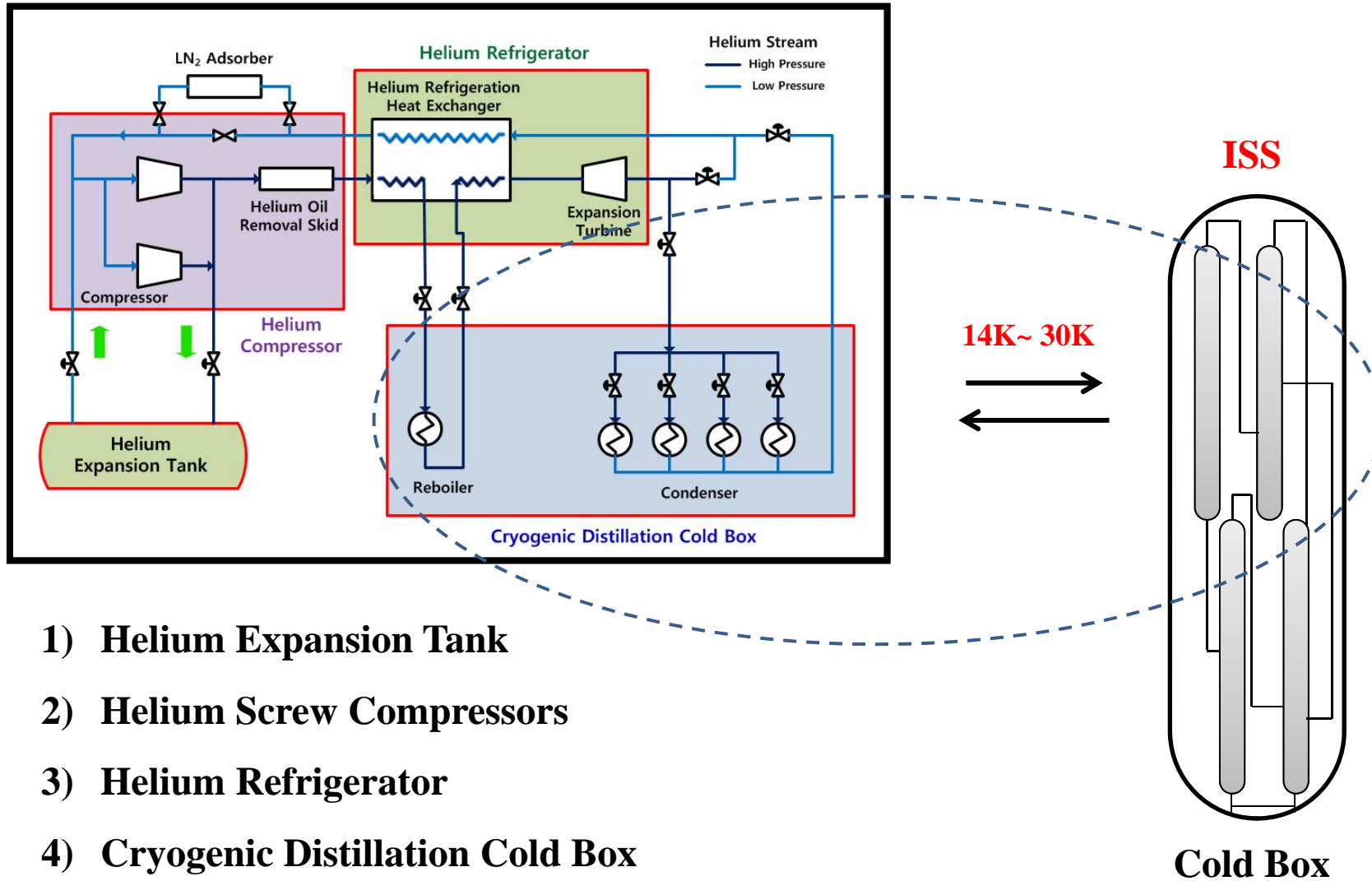


14 K까지 온도가 낮아진 헬륨을 사용해 열 교환함

### Helium Refrigeration Cycle

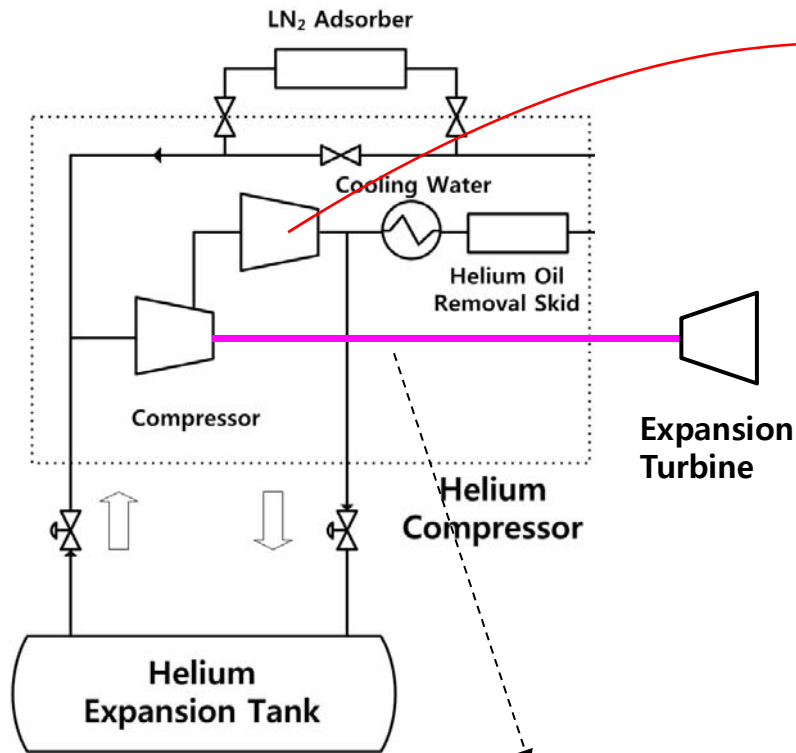
수소 동위원소를 분리하기 위한 증류조건은 초저온(~30K)에서 운전되므로, 위해 사용되는 헬륨 냉동기는 수소동위원소 분리를 위한 헬륨냉동기의 용량은 1,800W 정도이다.

# 3. 헬륨 냉동 사이클

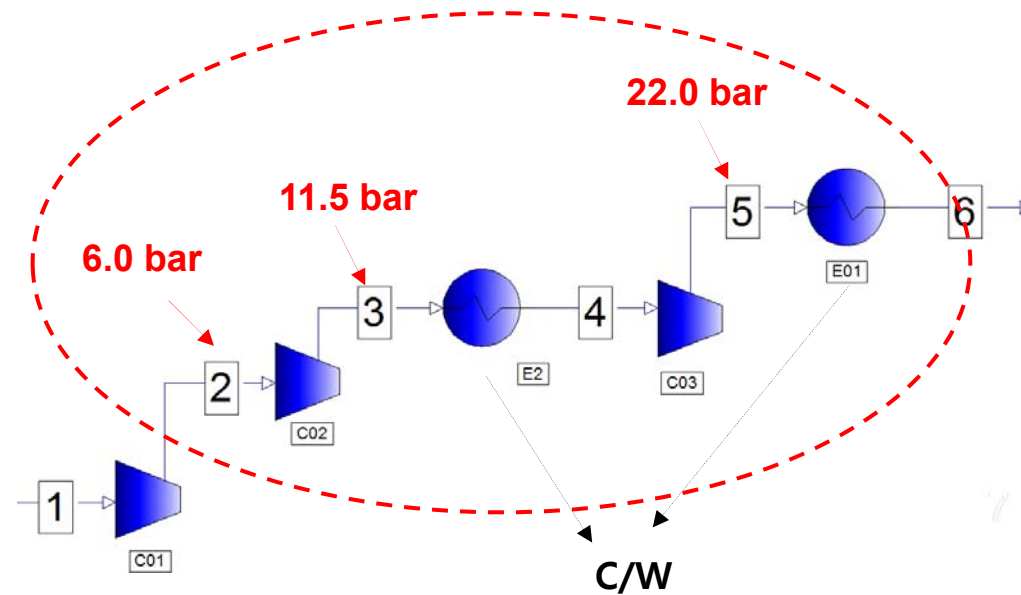


# 3. 헬륨 냉동 사이클

## ➤ Refrigeration Process Operating Pressure Determination

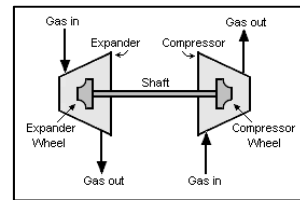


Considering the compression efficiency which was applied to 2-stage compression system



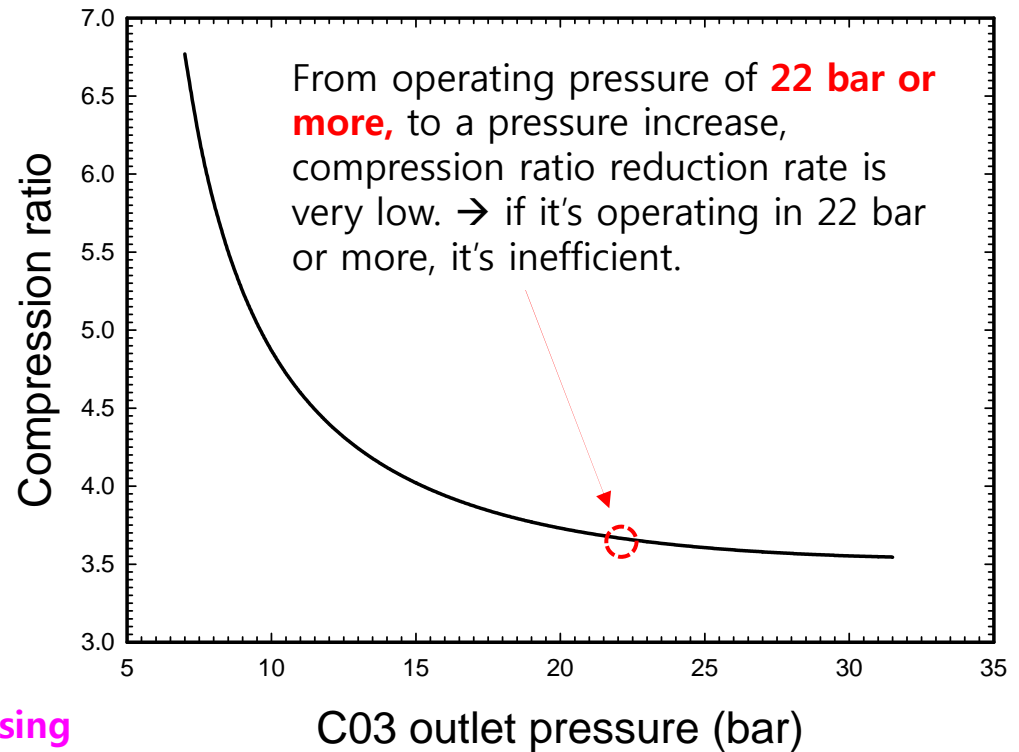
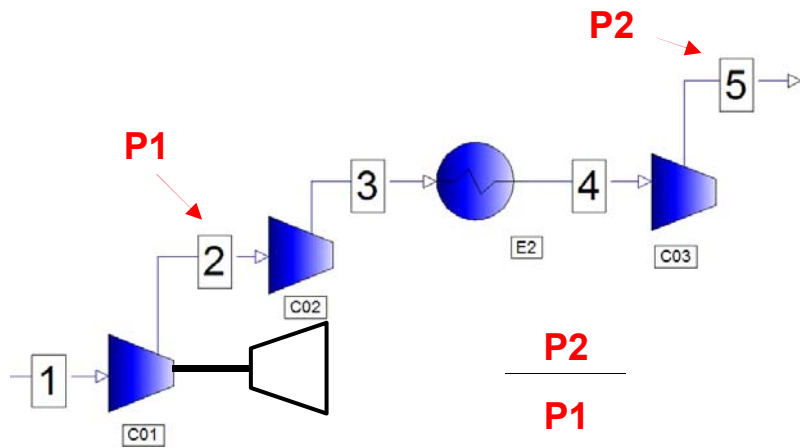
(Given the temperature in summer season in Korea, which is assumed to be cooled down to 45 °C)

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



### 3. 헬륨 냉동 사이클

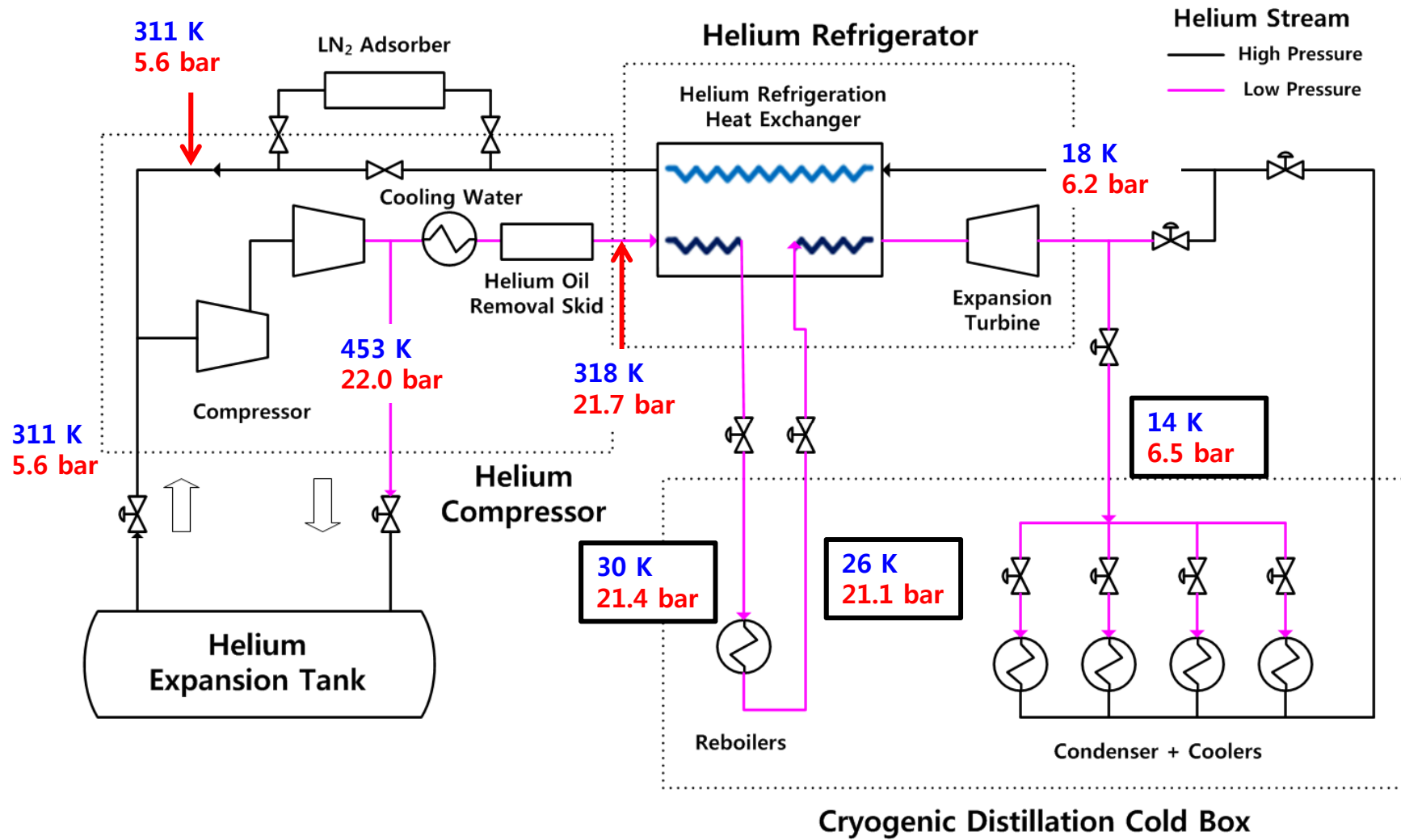
❖ Determining the optimum operating pressure from helium refrigeration process



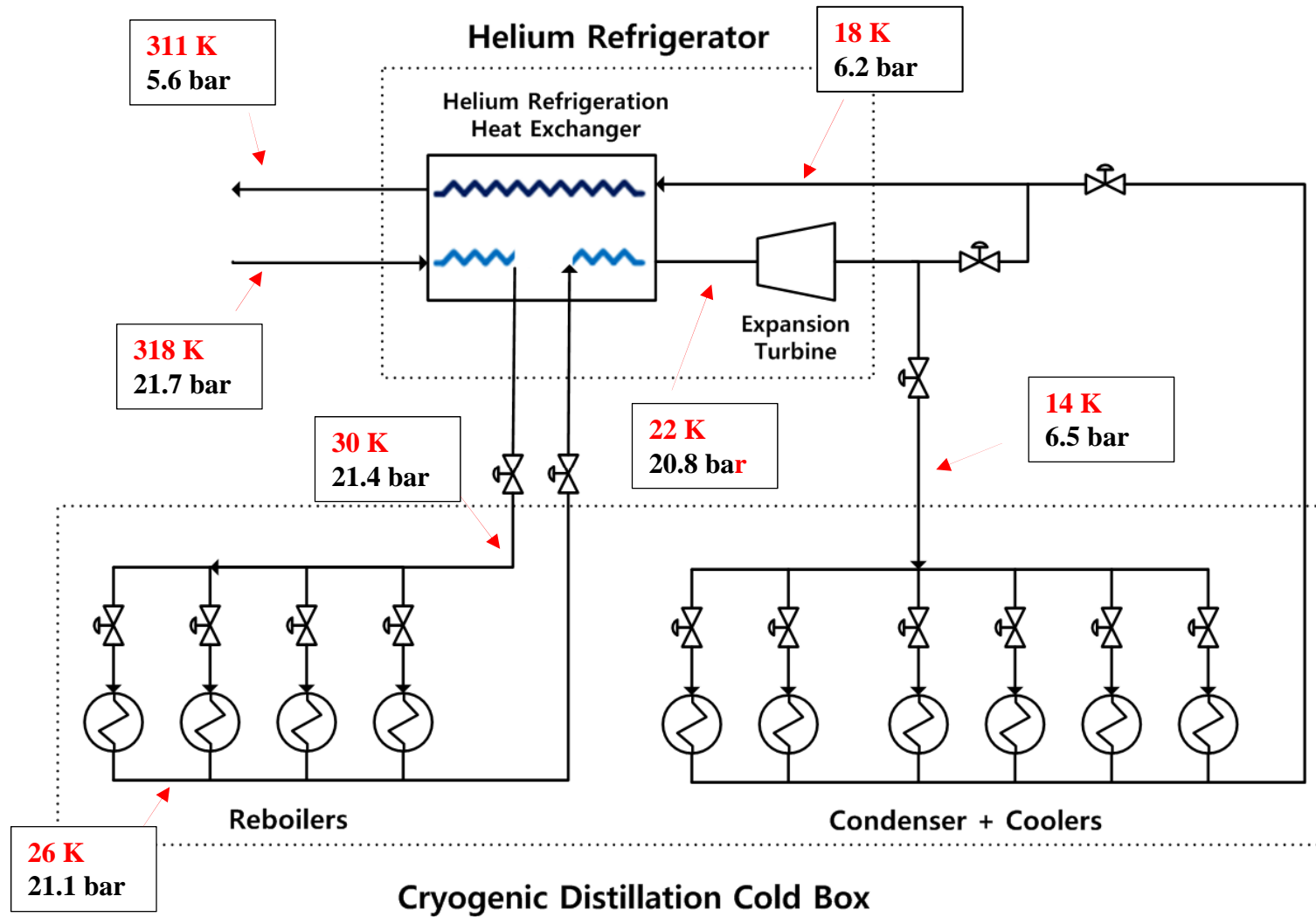
Decreasing  
Compressor  
power required



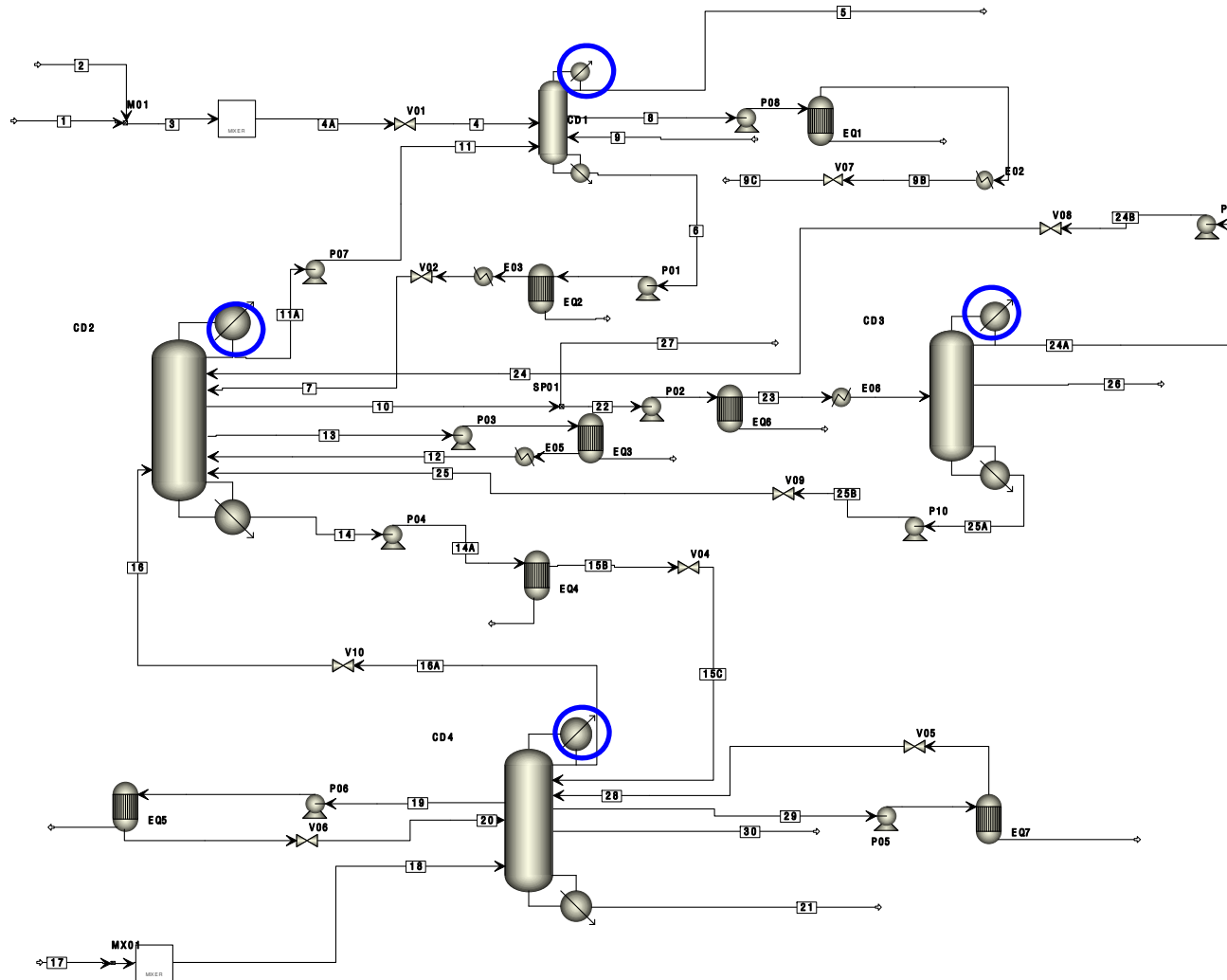
# 3. 헬륨 냉동 사이클



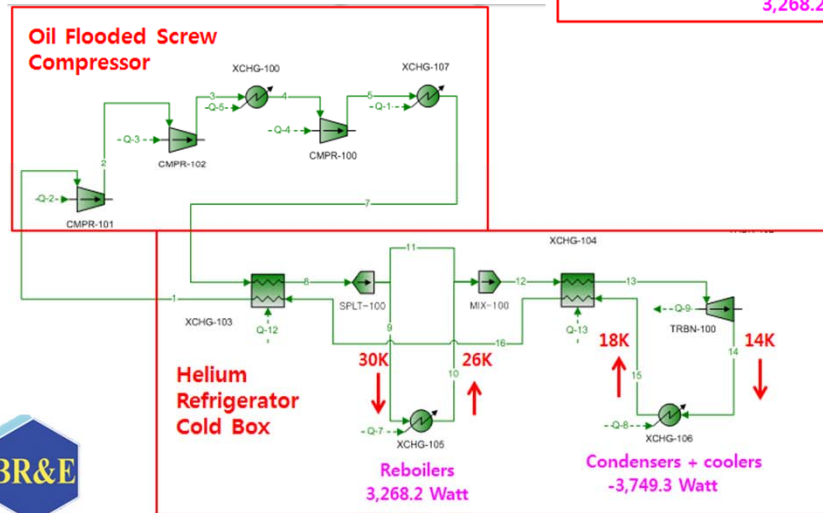
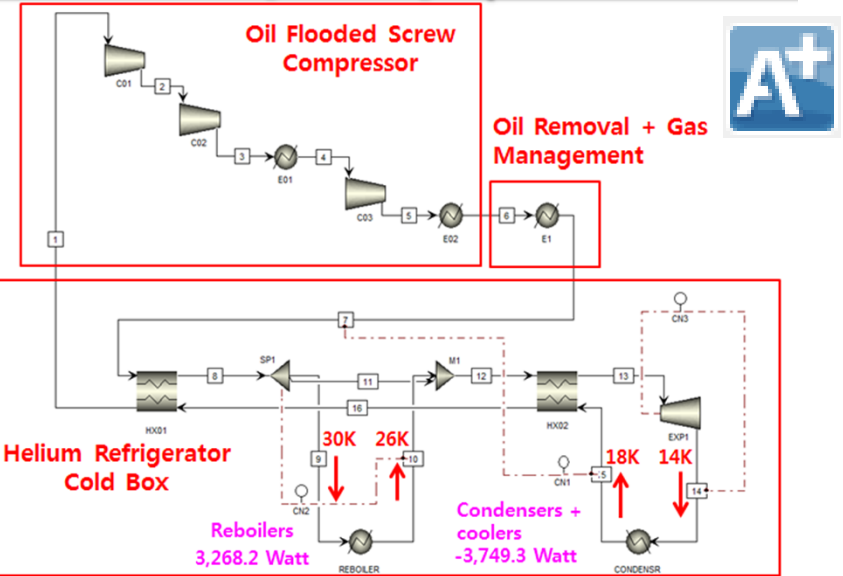
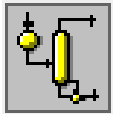
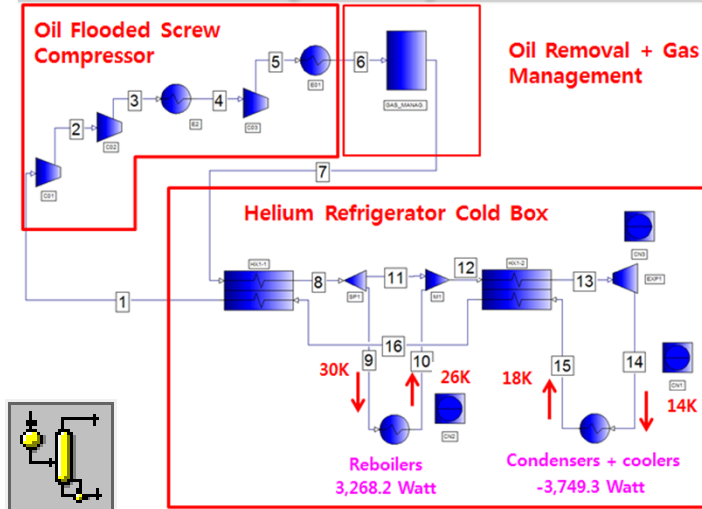
# 3. 헬륨 냉동 사이클



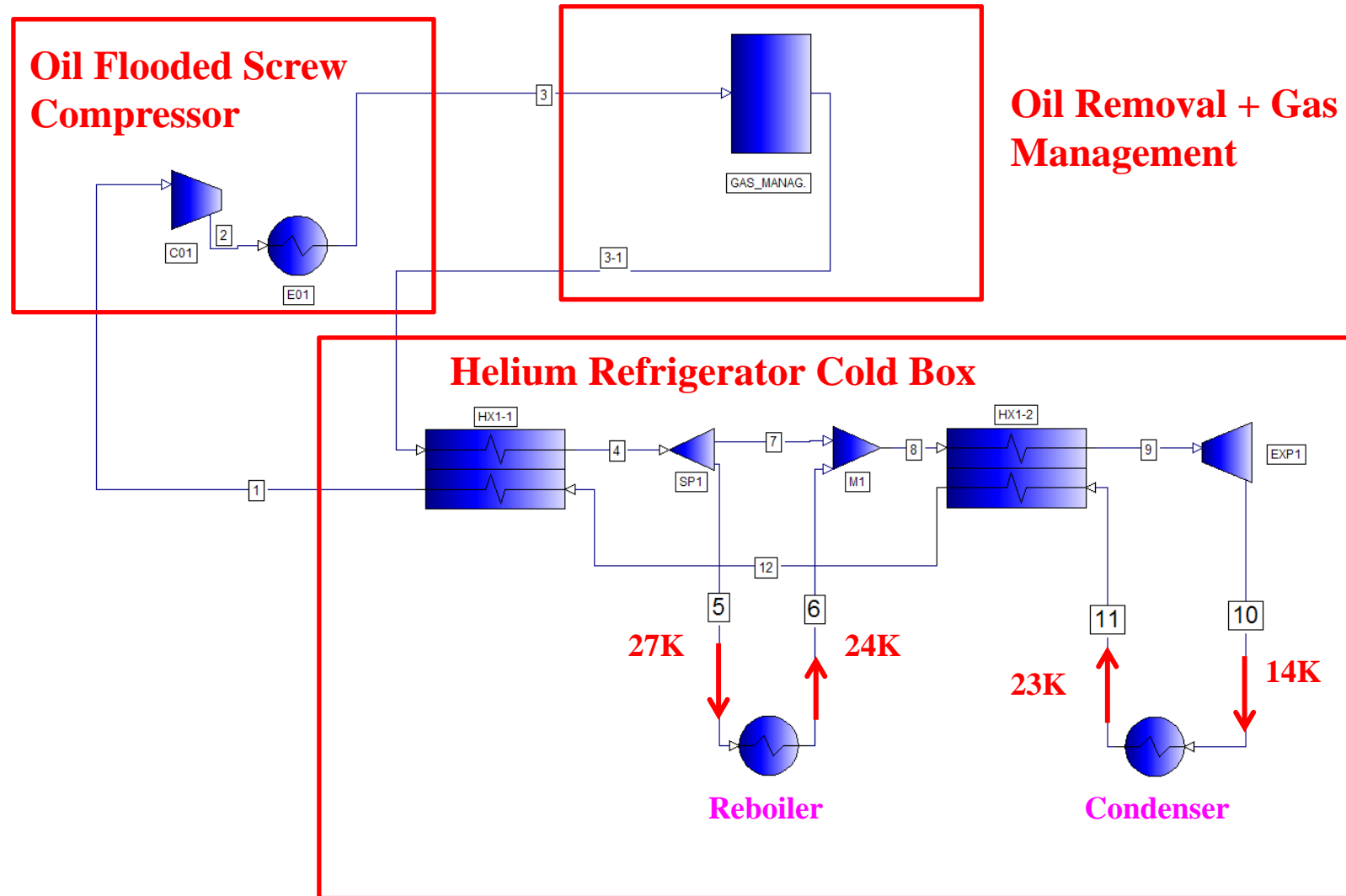
# 3. 헬륨 냉동 사이클



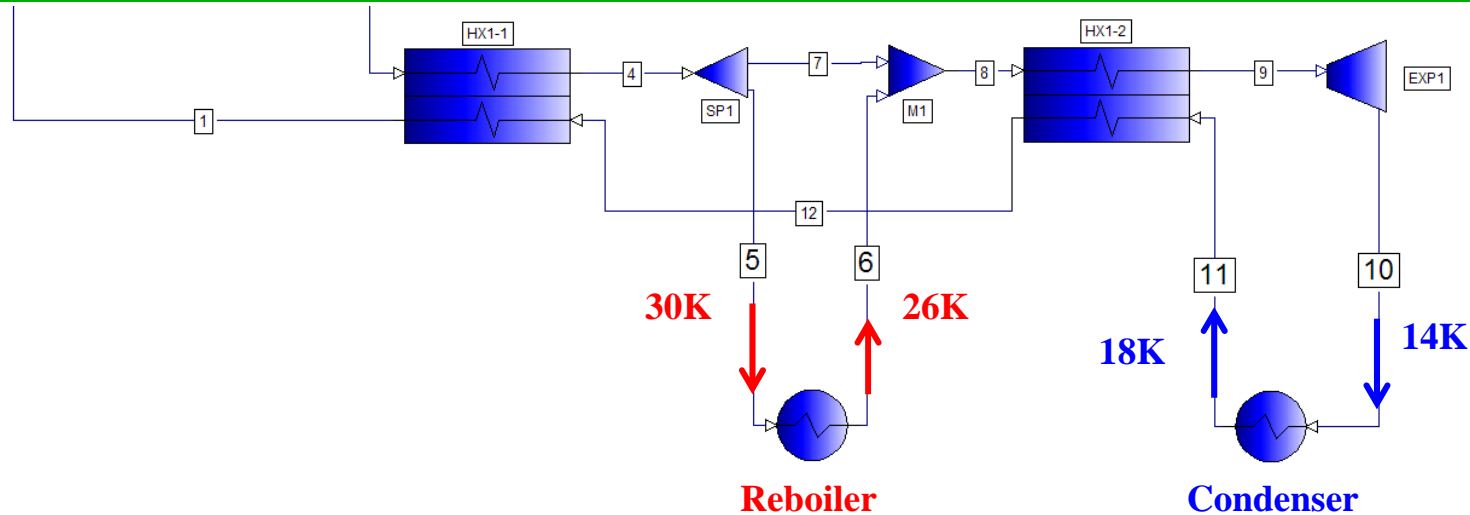
# 3. 헬륨 냉동 사이클



# 3. 헬륨 냉동 사이클



# 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	
<b>Total Mass Rate (KG/HR)</b>	<b>453.00</b>		<b>453.00</b>		<b>514.66</b>		<b>514.66</b>	
	Flow rate (kmol/hr)	Percent (mol%)	Flow rate (kmol/hr)	Percent (mol%)	Flow rate (kmol/hr)	Percent (mol%)	Flow rate (kmol/hr)	Percent (mol%)
<b>Helium</b>	<b>113.18</b>	100.00	113.18	100.00	<b>128.58</b>	100.00	128.58	100.00

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# PRO/II를 활용한 냉동사이클 공정모사 방법

# Refrigeration cycle Example

## Problem.

프로판을 냉매로 사용하여 증기 재압축 냉동사이클에 대한 전산모사를 수행하고자 한다. 액화하고자 하는 원료는 다음의 표와 같다. 원료 스트림의 액화 후 온도는  $-30^{\circ}\text{C}$  이다.

- 액화하고자 하는 원료 조건

Component	Mole%
Propane	7.80
Iso-Butane	49.08
N-Butane	43.12
Temperature ( $^{\circ}\text{C}$ )	25.0
Pressures (bar)	1.2
Flow rate (kg/hr)	15,078

냉매로는 순수한 프로판을 사용한다. 냉매 응축기에서 2차 냉매로써 냉각수를 사용하며, 공급온도는  $32^{\circ}\text{C}$  이고 회수온도는  $37^{\circ}\text{C}$  이다. 2차 냉매에 의해 프로판은  $45^{\circ}\text{C}$  까지 응축되고 응축기 압력강하는 0.5 bar 가정. 냉매가 증발기로 주입되는 온도는  $-40^{\circ}\text{C}$  이다. 열역학 모델식 Peng-Robinson 상 태방정식 적용

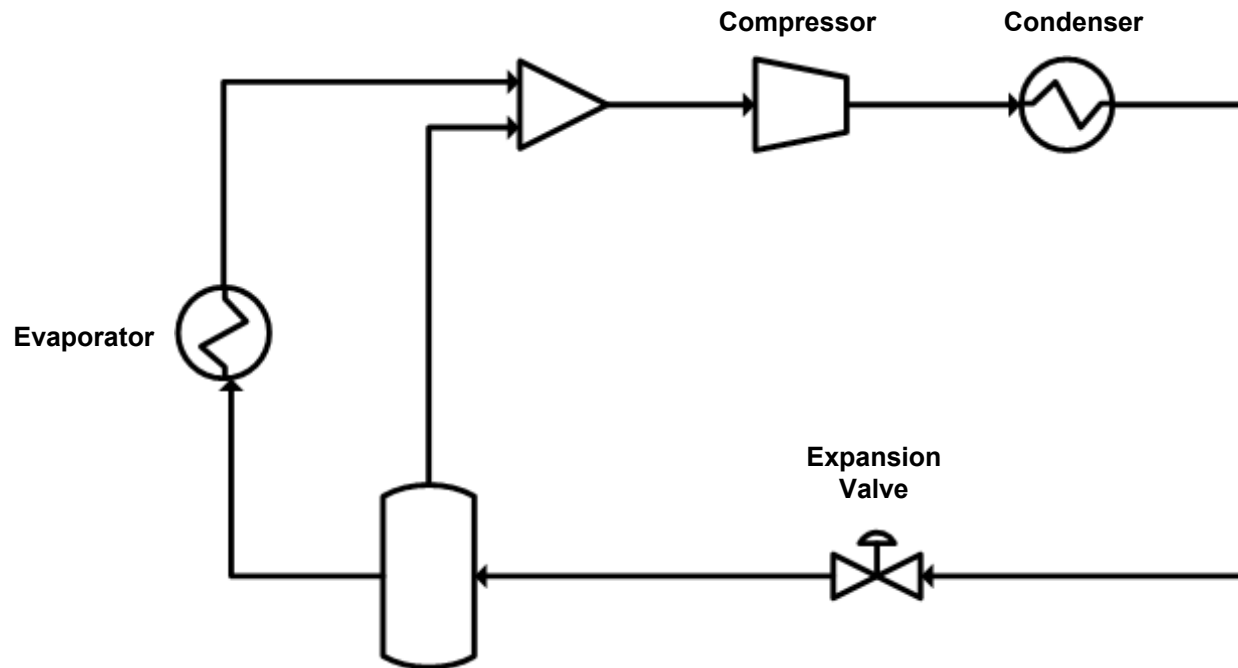


# Problem: 1

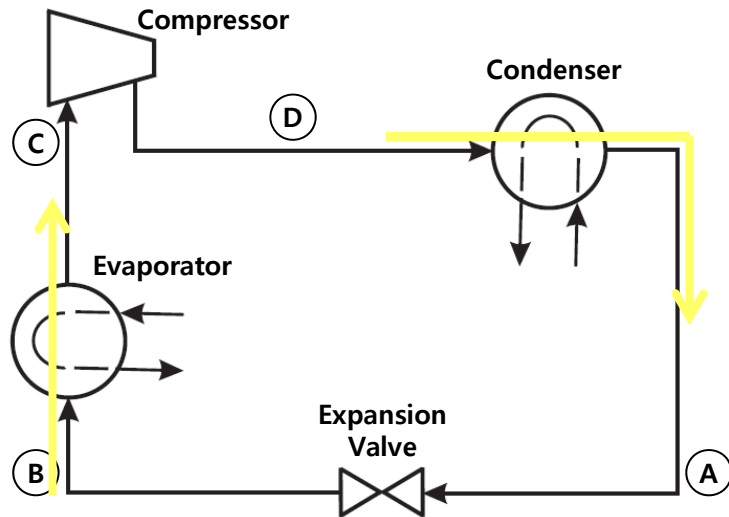
증기 재압축 냉동 사이클의 개요도를 그리고, 개략적으로 설명하라. 단, 팽창밸브 후단의 Two-phase flow는 기액 분리를 위해서 Flash drum 을 설치한다.

# Problem 1: 냉동사이클 개요도

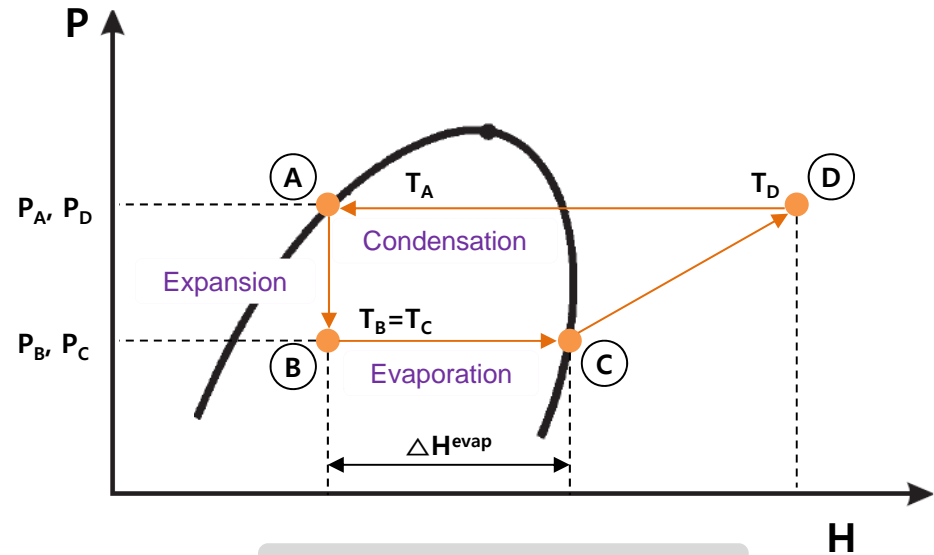
## Refrigeration Cycle Diagram



# 증기 재압축을 이용한 냉동 사이클의 기본원리



Refrigeration Cycle Diagram



Pressure Enthalpy Diagram

Refrigeration Cycle Step :

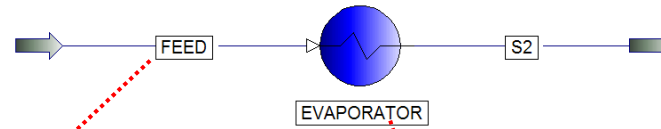
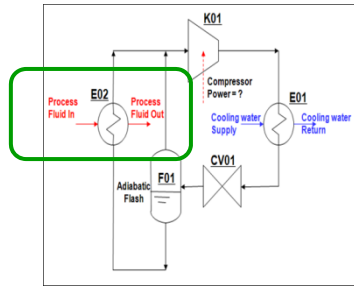
- Ⓐ Expansion
- Ⓑ Evaporation
- Ⓒ Compression
- Ⓓ Condensation

## Problem 2

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**증발기의 heat duty를 결정하라.**

# Problem 2: 증발기의 heat duty 결정



PRO/II - Stream Data

Stream: FEED Description:

To Unit: EVAPORATOR

Stream Type: **Flowrate and Composition...**

Thermal Condition:  
 First Specification: Temperature 25.00 C  
 Second Specification: Pressure 1.2000 bar

Thermodynamic System: Determined From Connectivity

Stream Data - Flowrate and Composition

Specify flowrate and composition for stream FEED

Fluid Flowrate Specification:  
 Total Fluid Flowrate: 15078 kg/hr  
 Individual Component Flowrates

Component Concentrations:  
 Total Fluid Flowrate: kg-mol/hr

Copy	Component	Composition Mole
Paste	C3	7.8000
	IC4	49.080
	NC4	43.120

Total: 100.00

Normalize Component Flowrates Based on Specified Fluid Flowrate

PRO/II - Heat Exchanger

Unit: EVAPORATOR Description:

Hot Side: Process Stream...  
 Cold Side: **Specification...**

Pressure Drop: 0.00000 bar  
 Thermodynamic System: Default (PRO1)

Push to provide operating specification

Heat Exchanger - Specifications

Specification: Hot Product Temperature

Value: -30.00 C  
 Relative Tolerance: 0.000100  
 Area: m<sup>2</sup>  
 U-Value: kcal/hr-m<sup>2</sup>-K

## Problem 2: 증발기의 heat duty 결정

➤ 증발기의 heat duty

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UNIT 1, 'EVAPORATOR'

OPERATING CONDITIONS

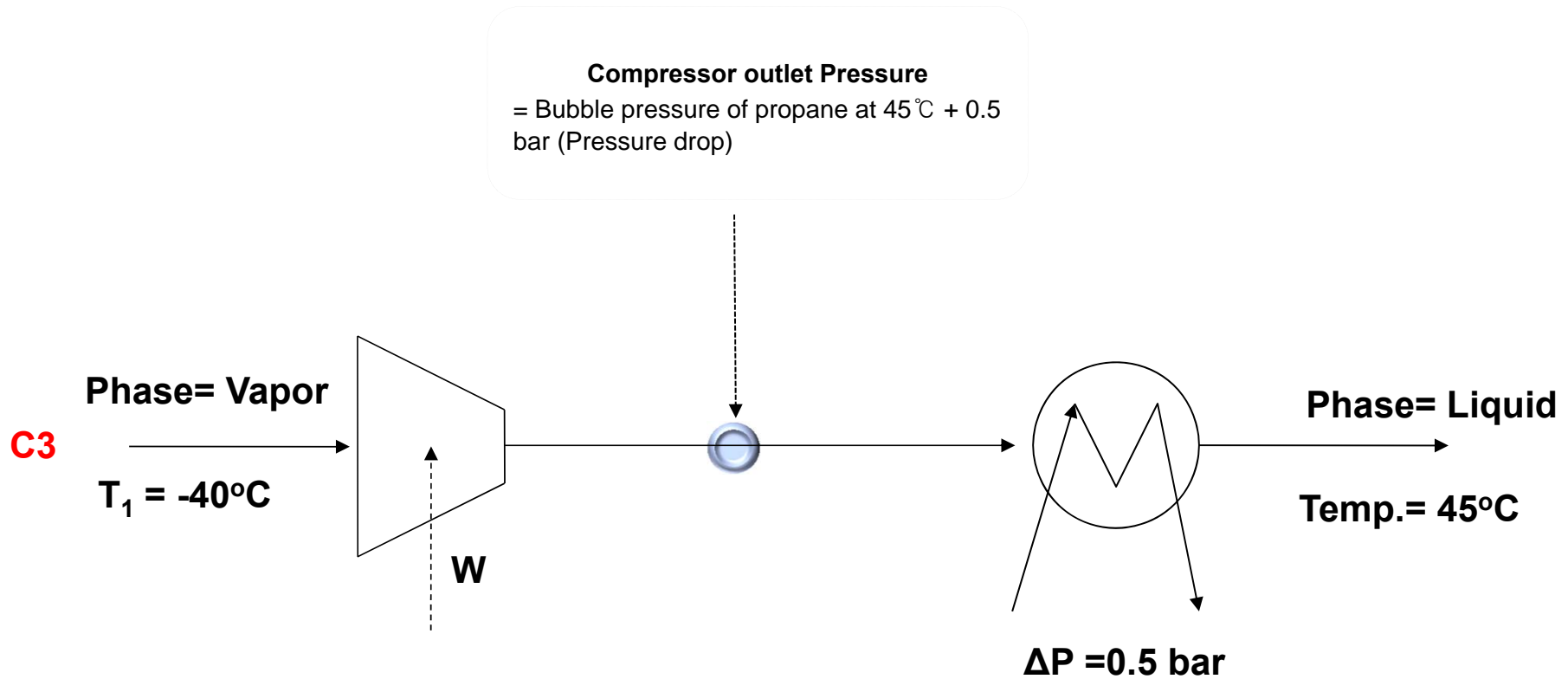
<b>DUTY, M*KCAL/HR</b>	<b>1.712</b>
LMTD, C	29.383
F FACTOR (FT)	1.000
MTD, C	29.383
U*A, KCAL/HR-C	58247.946

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## Problem 3

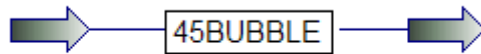
**압축기 후단의 압력을 결정하라.**

# Problem 3: 압축기 후단 압력 결정





# Problem 3: 압축기 후단 압력 결정



Result

PRO/II - Stream Data

UDM Range Help Tag Overview Status Notes

Stream: 45BUBBLE Description:

To Unit: (Product Stream)

Stream Type

- Composition Defined
- Petroleum Assay
- Referenced to Stream
- Solids Only Stream

Thermal Condition

First Specification:

Temperature  C

Second Specification:

Bubble Point

Thermodynamic System:

Exit the window after saving all data

Data Review Window - Stream - '45BUBBLE'

Property	Value	Units
Stream Name	45BUBBLE	
Temperature	45.000	C
Pressure	15.385	bar
Flowrate	100.000	kg-mol/hr

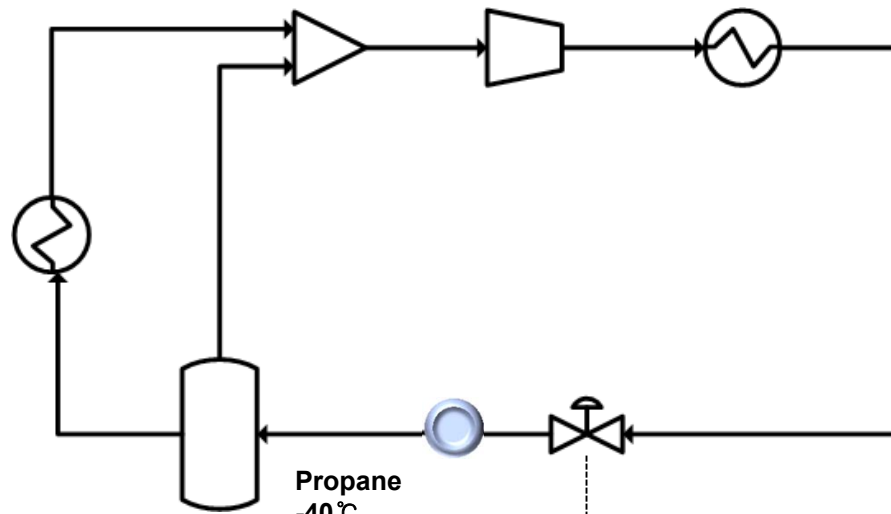
Property Label List

Exit the window without saving any data

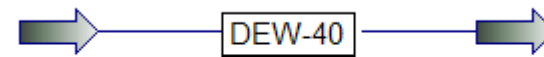
## Problem 4

팽창 밸브 후단의 압력을 결정하라.

# Problem 4: 팽창 밸브 후단압력 결정



**Valve outlet Pressure**  
= Dew Pressure of Propane at  $-40^{\circ}\text{C}$



PRO/II - Stream Data

UDM Range Help Tag Overview Status Notes

Stream: DEW-40 Description:

To Unit: (Product Stream)

Stream Type

- Composition Defined
- Petroleum Assay
- Referenced to Stream
- Solids Only Stream

Flowrate and Composition...

Stream Solids Data...

Stream Polymer Data...

Thermal Condition

First Specification:

Temperature  $-40.00$  C

Second Specification:

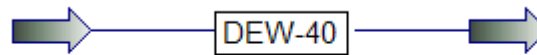
Dew Point

Thermodynamic System: Determined From Connectivity

OK Cancel

Exit the window after saving all data

# Problem 4: 팽창 밸브 후단압력 결정



Data Review Window - Stream - 'DEW-40'

Property	Value	Units
Stream Name	DEW-40	
Temperature	-40.000	C
Pressure	1.114	bar
Flowrate	100.000	kg-mol/hr

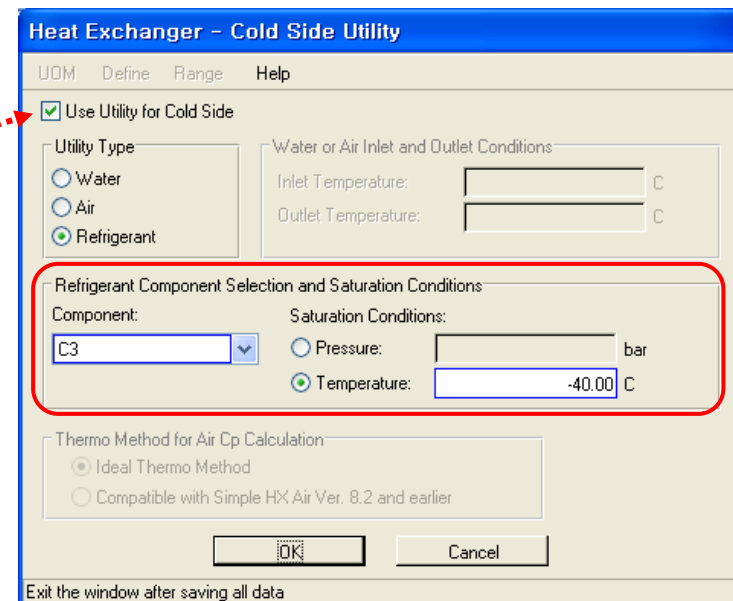
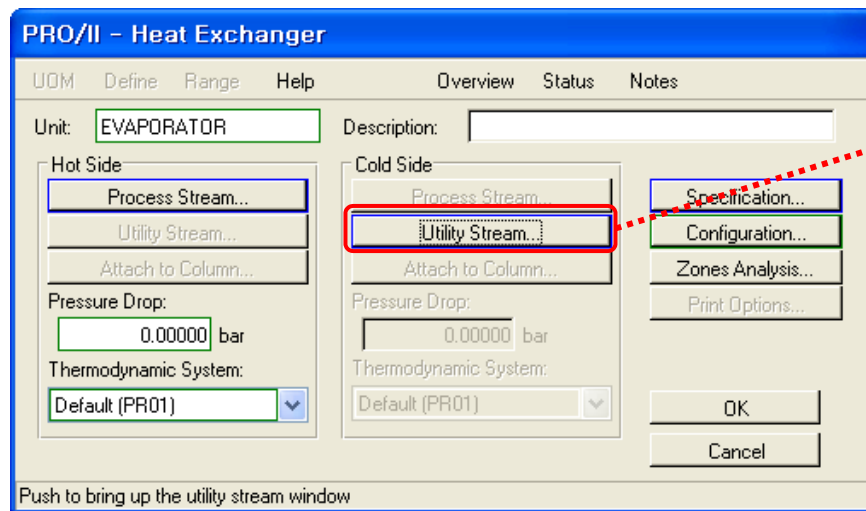
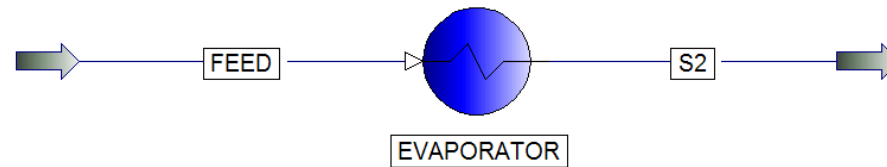
Property Label List

Exit the window without saving any data

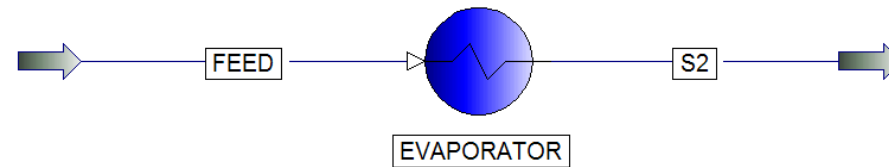
## Problem 5

**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
<b>REFRIGERANT, KG/HR</b>	<b>16946.501</b>	<b>16946.501</b>
SATURATION PRESSURE, BAR	1.109	
SATURATION TEMPERATURE, C	-40.000	

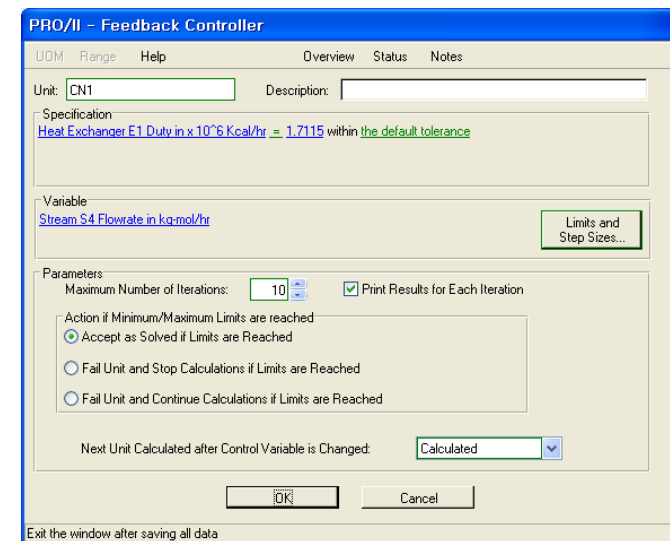
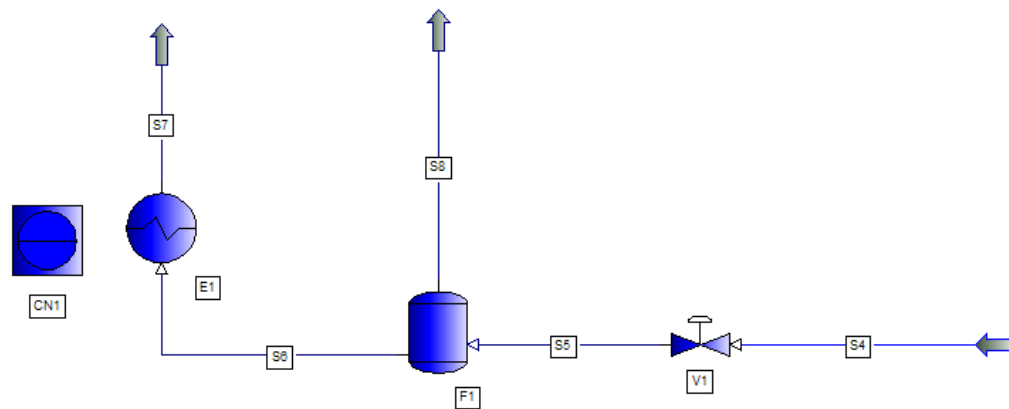
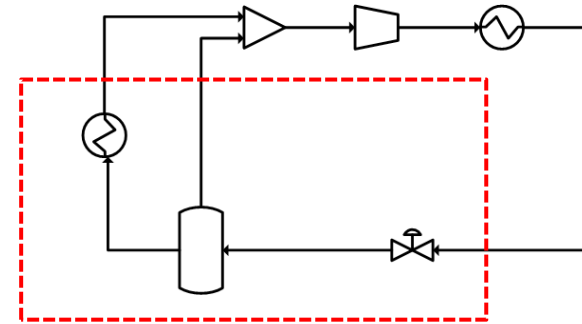
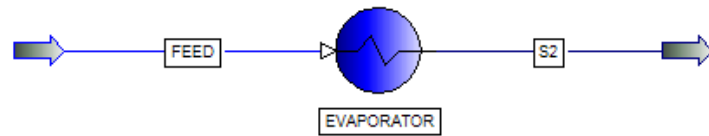
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## Problem 6

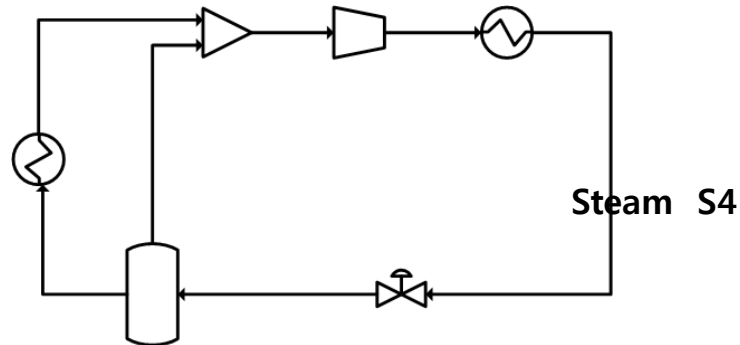
**냉매의 총 순환유량을 결정하라.**



# Problem 6: 냉매의 총 순환유량 결정



# Problem 6: 냉매의 총 순환유량 결정



STREAM 'S4'

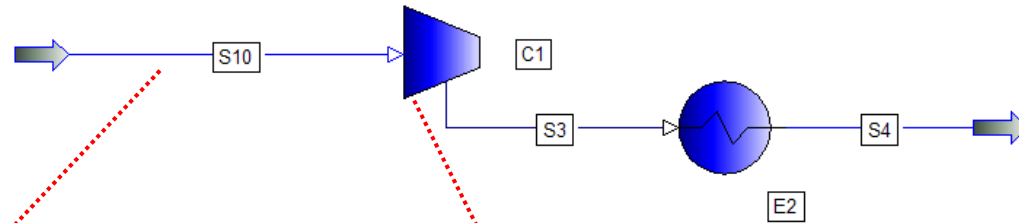
	TOTAL	LIQUID
<b>RATE, KG/HR</b>	<b>35139.6939</b>	<b>35139.6939</b>
TEMPERATURE, C	45.00	45.00
PRESSURE, BAR	15.38	15.38
MOLECULAR WEIGHT	44.0965	44.0965
WEIGHT FRACTION		1.0000
ENTHALPY, KCAL/KG	30.9152	30.9152
CP, KCAL/KG-C	0.7693	0.7693
MASS FLOWRATES, KG/HR		
1 - C3	35139.6939	35139.6939
2 - IC4	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%



PRO/II - Stream Data

Stream: S10 Description:

To Unit: C1

Stream Type

- Composition Defined
- Petroleum Assay
- Referenced to Stream
- Solids Only Stream

Thermal Condition

First Specification: Temperature -40.00 C

Second Specification: Dew Point

Thermodynamic System: Determined From Connectivity

Exit the window after saving all data

Stream Data - Flowrate and Composition

Specify flowrate and composition for stream S10

Fluid Flowrate Specification

- Total Fluid Flowrate: 35140 kg-mol/hr
- Individual Component Flowrates
- Component Concentrations

Component	Component Flowrate kg/hr
C3	35140
IC4	
NC4	

Total Fluid Flowrate: 35140

Exit the window after saving all data

PRO/II - Compressor

Unit: C1

Description:

Thermodynamic System: Default (PR01)

Inlet Pressure: bar

Outlet Temperature Estimate: C

Pressure, Work or Head Specification

Outlet Pressure: 15.885 bar

Efficiency or Temperature Specification

Adiabatic Efficiency: 70.0000 Percent

Operating Speed: RPM

Reference Speed: RPM

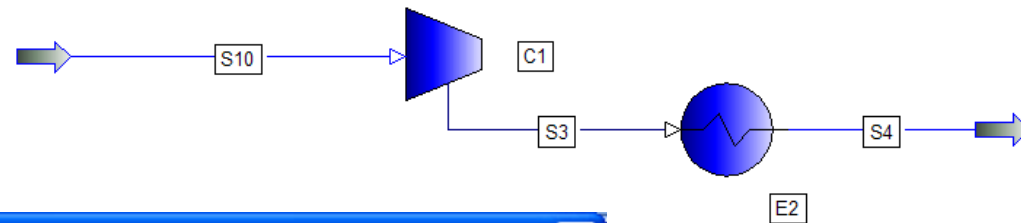
Maximum Outlet Pressure: bar

Relative Convergence Tolerance: 0.0010000

Exit the window after saving all data

# 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

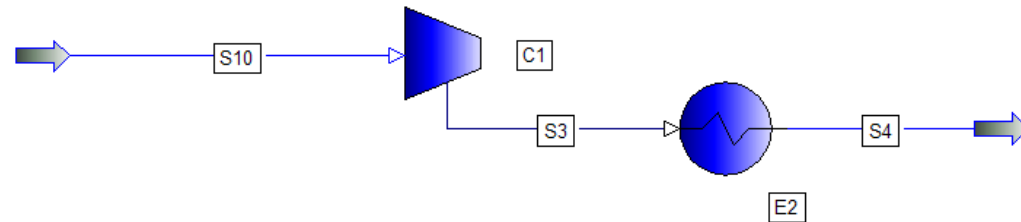
Exit the window without saving any data

## Problem 8

**용축기의 heat duty를 결정하라.**

# Problem 8: 응축기의 heat duty를 결정

- 응축기 압력강하 0.5 bar , 45°C 까지 프로판 응축

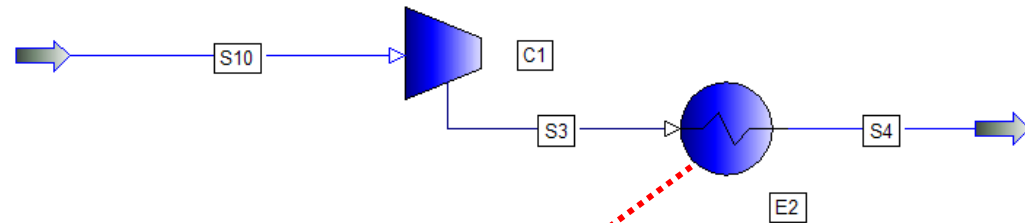


The screenshot shows the 'PRO/II - Heat Exchanger' dialog box. It has a menu bar with 'UOM', 'Define', 'Range', and 'Help'. Below the menu bar, there are tabs for 'Overview', 'Status', and 'Notes'. The 'Unit' is set to 'E2'. The 'Description' field is empty. There are two columns for 'Hot Side' and 'Cold Side', each with buttons for 'Process Stream...', 'Utility Stream...', and 'Attach to Column...'. The 'Pressure Drop' field is set to '0.50000 bar'. The 'Thermodynamic System' is set to 'Default (PR01)'. A 'Specification...' button is highlighted with a red box. At the bottom, there are 'OK' and 'Cancel' buttons and the text 'Exit the window after saving all data'.

The screenshot shows the 'Heat Exchanger - Specifications' dialog box. It has a menu bar with 'UOM', 'Define', 'Range', and 'Help'. The 'Specification' dropdown is set to 'Hot Product Liquid Fraction'. The 'Value' field is set to '1.0000'. The 'Relative Tolerance' field is set to '0.000100'. The 'Area' field is empty with a unit of 'm²'. The 'U-Value' field is empty with a unit of 'kcal/hr-m²-K'. At the bottom, there are 'OK' and 'Cancel' buttons and the text 'Exit the window after saving all data'.

# Problem 8: 응축기의 heat duty를 결정

- 응축기 압력강하 0.5 bar , 45°C 까지 프로판 응축



Data Review Window - Simple HX - 'E2'

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

Heat Exchanger Unit

Exit the window without saving any data



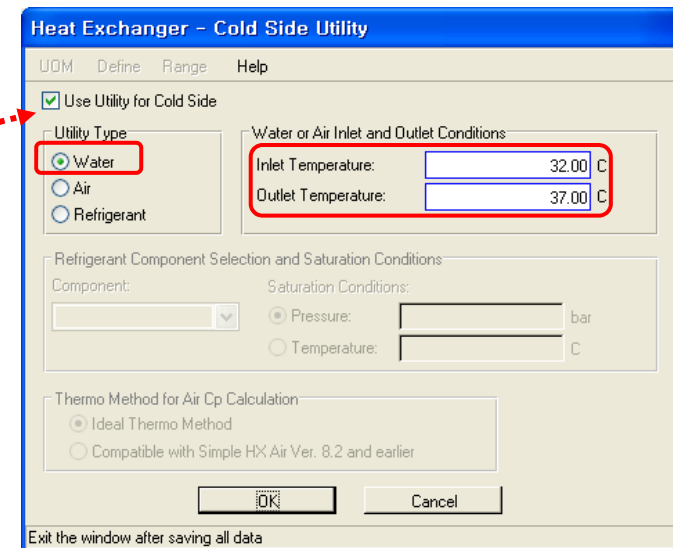
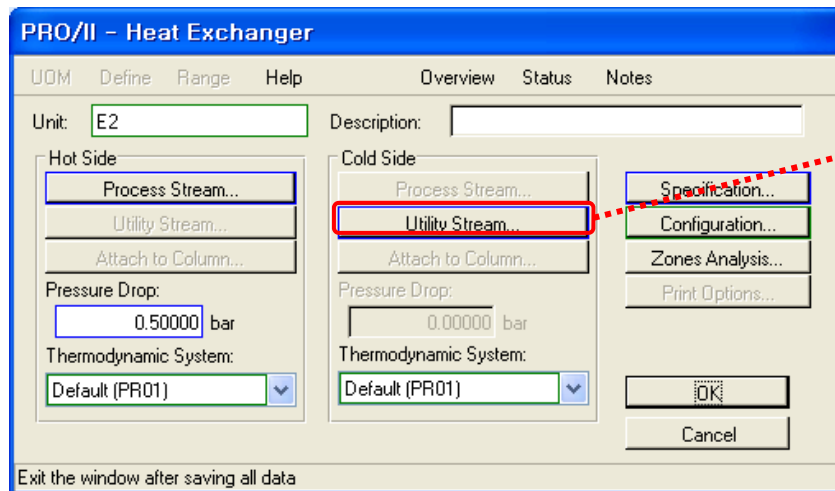
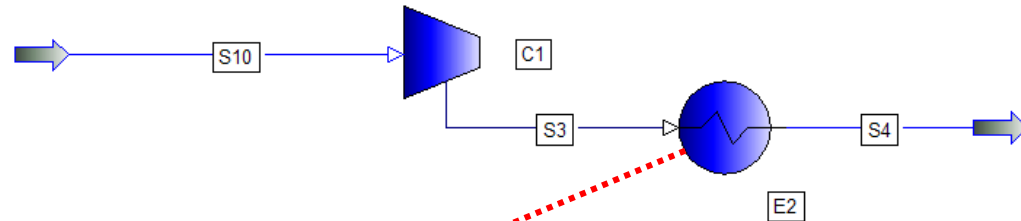
## Problem 9

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**냉각수 소모량을 추산하라.**

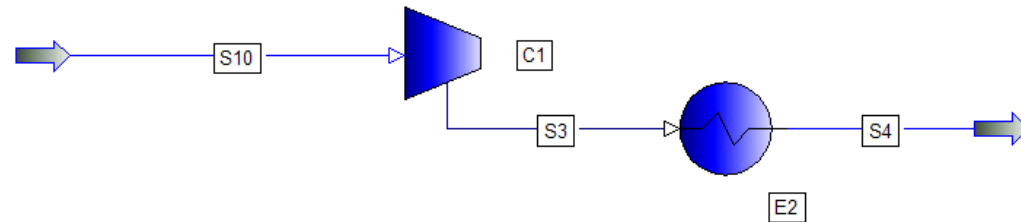
# Problem 9: 냉각수 소모량 추산

- 냉각수 in/out 32°C/37°C, 프로판 45°C 까지 응축



# Problem 9: 냉각수 소모량 추산

➤ 냉각수 in/out 32°C/37°C, 프로판 45°C 까지 응축



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

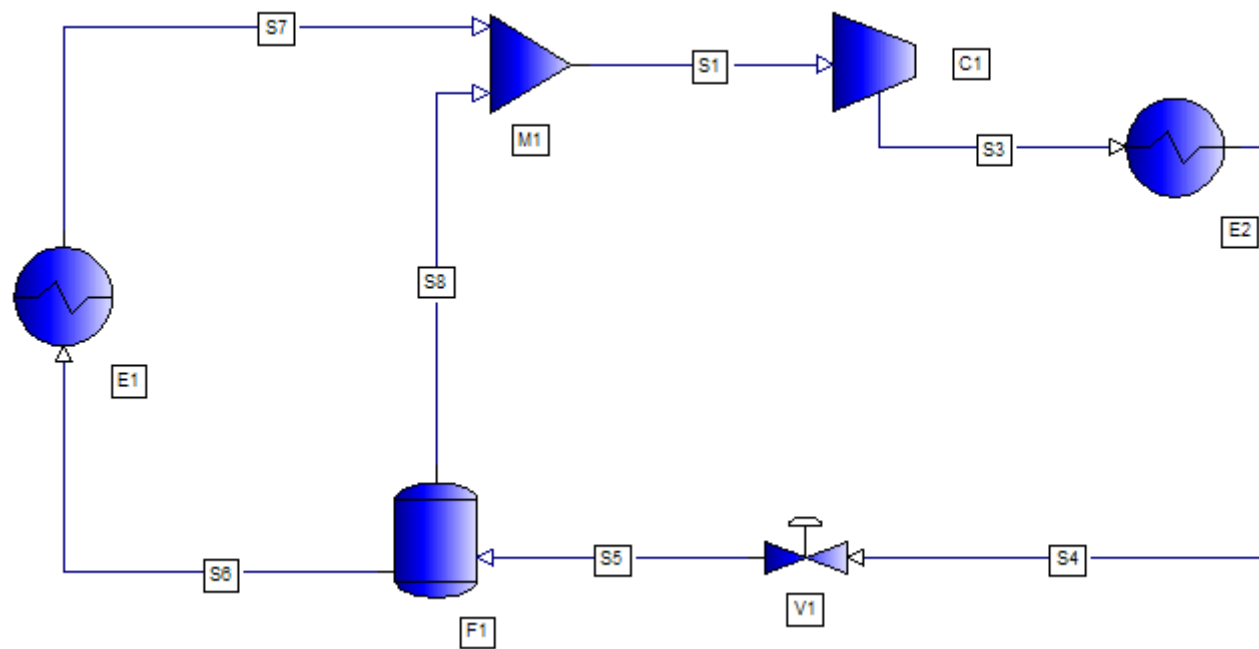
CONDENSATION, KG-MOL/HR	796.881
TEMPERATURE, C	86.533      45.001
PRESSURE, BAR	15.885      15.385

COLD SIDE CONDITIONS	INLET	OUTLET
<b>COOLING WATER, KG/HR</b>	<b>644179.101</b>	<b>644179.101</b>
TEMPERATURE, C	32.000	37.000

## Problem 10

**전체 냉동사이클을 하나의 PRO// File로 완성  
하고, 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

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**감사합니다**