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# Multi-stage Refrigeration System

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# Input Condition of Natural Gas

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<b>Contents</b>	<b>Value</b>
Pressure (bar)	53
Temperature (°C)	45
Flow Rate (Kg/hr)	625,000

<b>Component</b>	<b>Mole%</b>
Nitrogen	1.81
Methane	95.16
Ethane	2.95
Propane	8.1090E-02
I-Butane	1.4061E-03
N-Butane	6.8078E-04
I-Pentane	1.0844E-05
N-Pentane	6.0288E-06
N-Hexane	5.6613E-07
<b>Total</b>	<b>100</b>

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# Cascade Refrigeration

## C3-01

Pressure drop(Hot Side) : 0.5bar  
 Minimum of [Hot Out-Cold In]  
 and [Hot In-Cold Out] : 3 °C  
 Refrigerant Component : C3  
 Refrigerant Temp. : 11.075 °C

## C3-02

Pressure drop(Hot Side) : 0.5bar  
 Minimum of [Hot Out-Cold In]  
 and [Hot In-Cold Out] : 3 °C  
 Refrigerant Component : C3  
 Refrigerant Temp. : -17.148 °C

## C2-01

Pressure drop(Hot Side) : 0.5bar  
 Minimum of [Hot Out-Cold In]  
 and [Hot In-Cold Out] : 3 °C  
 Refrigerant Component : C2  
 Refrigerant Temp. : -69.74 °C

## C2-02

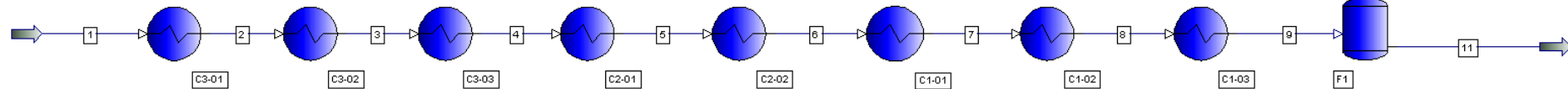
Pressure drop(Hot Side) : 0.5bar  
 Hot Product Temp. : -92 °C  
 Refrigerant Component : C2  
 Refrigerant Temp. : -95 °C

## C1-01

Pressure drop(Hot Side) : 0.5bar  
 Minimum of [Hot Out-Cold In]  
 and [Hot In-Cold Out] : 3 °C  
 Refrigerant Component : C1  
 Refrigerant Temp. : -118.78 °C

## C1-02

Pressure drop(Hot Side) : 0.5bar  
 Minimum of [Hot Out-Cold In]  
 and [Hot In-Cold Out] : 3 °C  
 Refrigerant Component : C1  
 Refrigerant Temp. : -139.29 °C



## Stream1

Pressure : 53bar  
 Temperature : 45 °C  
 Flow Rate : 625,000 kg/hr

## F1

Adiabatic : duty 0

## C3-03

Pressure drop(Hot Side) : 0.5bar  
 Hot Product Temp. : -37 °C  
 Refrigerant Component : C3  
 Refrigerant Temp. : -40 °C

## C1-03

Pressure drop(Hot Side) : 0.5bar  
 Hot Product Temp. : -152 °C  
 Refrigerant Component : C1  
 Refrigerant Temp. : -155 °C

# CN1 Condition

**PRO/II - Feedback Controller**

UDM Range Help Overview Status Notes

Unit:  Description:

Specification  
[Stream 11 Temperature in C = -162.00](#) within [an absolute tolerance of 1.0000e-006](#)

Variable  
[Flash F1 Pressure in bar](#)

Parameters  
Maximum Number of Iterations:   Print Results for Each Iteration

Action if Minimum/Maximum Limits are reached

Accept as Solved if Limits are Reached

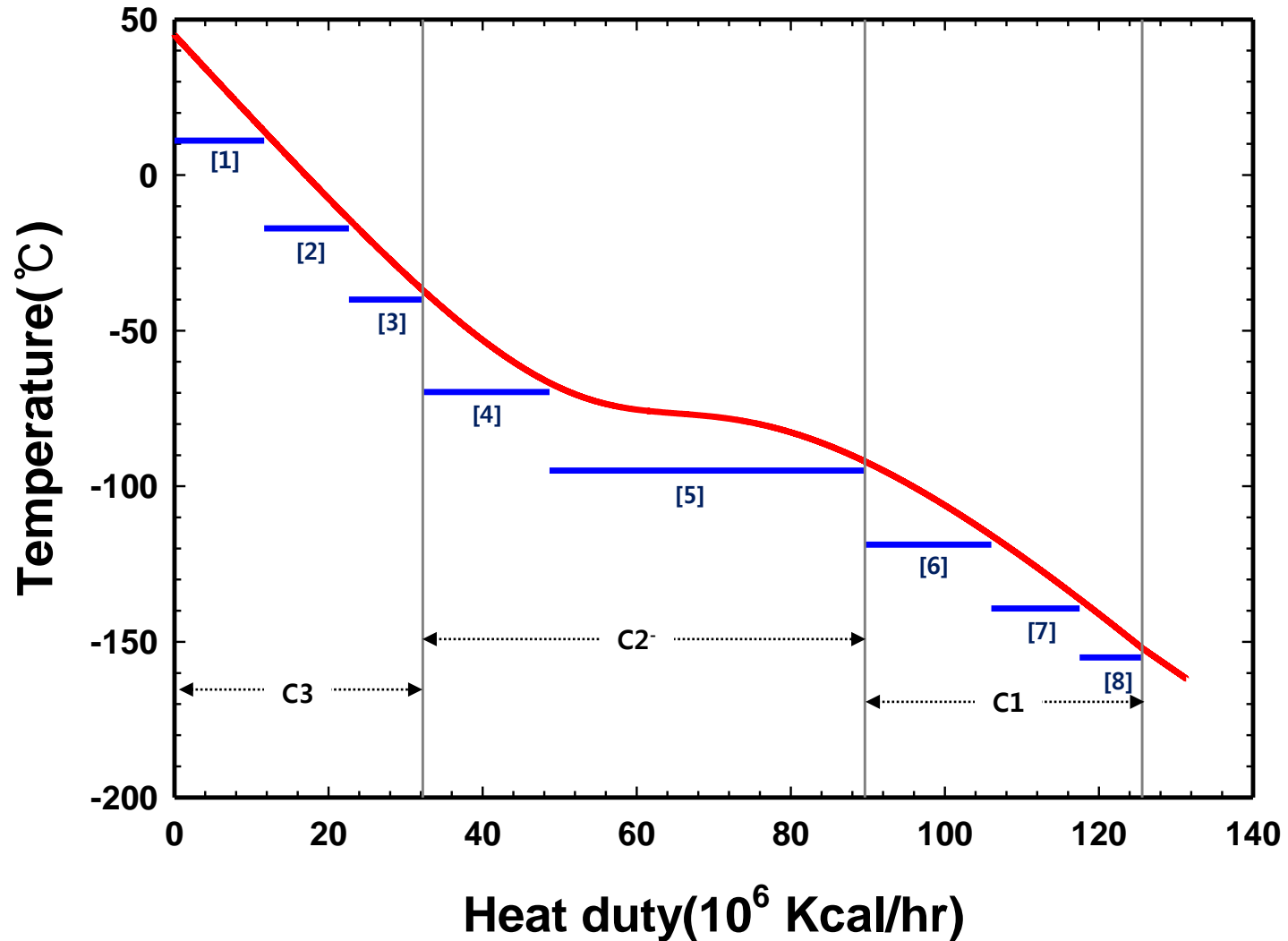
Fail Unit and Stop Calculations if Limits are Reached

Fail Unit and Continue Calculations if Limits are Reached

Next Unit Calculated after Control Variable is Changed:

Exit the window after saving all data

# Cascade Heating Curve



# Results of heating curve

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	Temperature (°C)	Heat duty (*10 <sup>6</sup> Kcal/hr)
[1]	11.08	11.6567
[2]	-17.15	10.9950
[3]	-40.00	9.6032
[4]	-69.74	16.4242
[5]	-95.00	40.9469
[6]	-118.78	16.4182
[7]	-139.29	11.4709
[8]	-155.00	8.0941
<b>Total</b>		<b>125.6092</b>

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# **Three-Stage Refrigeration : Propane**

# Three-Stage Refrigeration System

Ratio per stage

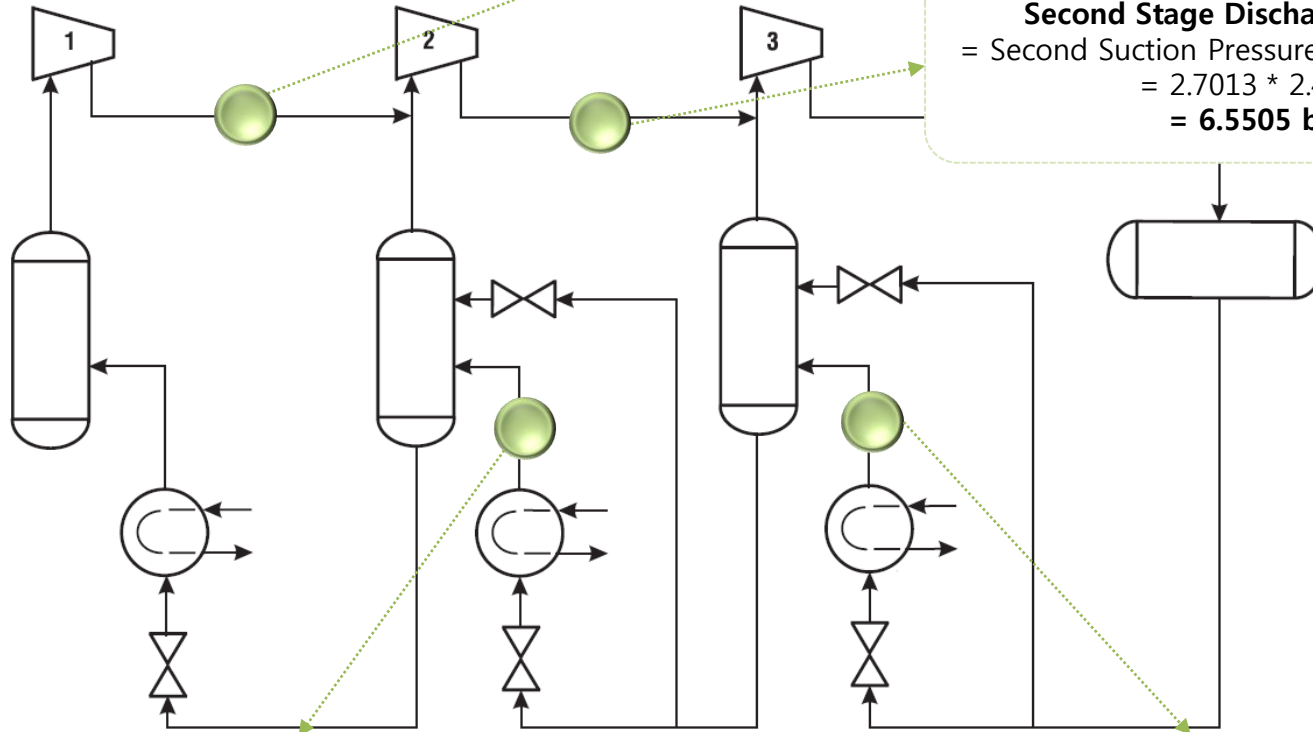
$$\left(\frac{P_d}{P_s}\right)^{1/n} = \left(\frac{15.885}{1.114}\right)^{1/3} = 2.4249$$

**First Stage Discharge Pressure**

$$\begin{aligned} &= \text{First Suction Pressure} * \text{Ratio per stage} \\ &= 1.114 * 2.4249 \\ &= \mathbf{2.7013 \text{ bar}} \end{aligned}$$

**Second Stage Discharge Pressure**

$$\begin{aligned} &= \text{Second Suction Pressure} * \text{Ratio per stage} \\ &= 2.7013 * 2.4249 \\ &= \mathbf{6.5505 \text{ bar}} \end{aligned}$$



**Temperature of Refrigerator**

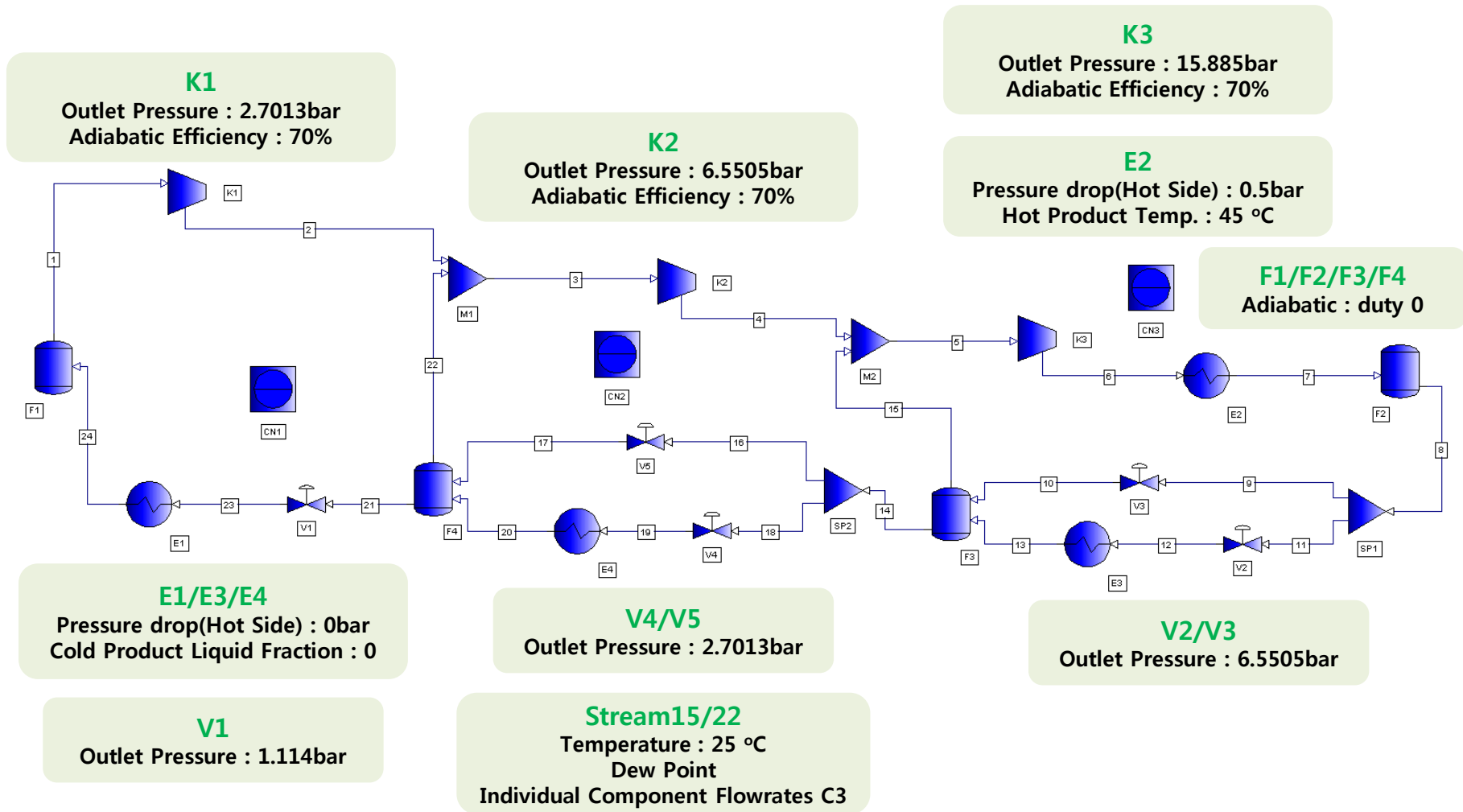
$$\begin{aligned} &= \text{Dew point temperature of propane} \\ &\quad \text{at } 2.7013 \text{ bar} \\ &= \mathbf{-17.148 \text{ }^\circ\text{C}} \end{aligned}$$

**Temperature of Refrigerator**

$$\begin{aligned} &= \text{Dew point temperature of propane} \\ &\quad \text{at } 6.5505 \text{ bar} \\ &= \mathbf{11.075 \text{ }^\circ\text{C}} \end{aligned}$$



# Three-Stage Refrigeration Cycle



# SP1 Condition

**PRO/II - Splitter**

Range Help Overview Status Notes

Unit:  Description:

Thermodynamic System:  ▾

Product Rate Specifications

	Stream	Specification
1	9	Parameter = value
2	11	<a href="#">Stream 11 Flowrate of All Components on a Wet basis in kg-mol/hr = 50,000</a>

Options When Feed is Inadequate to Satisfy Product Rate Specifications

Satisfy Each Specification in Order Until Feed is Exhausted

Satisfy Each Specification and Normalize Flowrates if Needed

Exit the window after saving all data

# SP2 Condition

**PRO/II - Splitter**

Range Help Overview Status Notes

Unit:  Description:

Thermodynamic System:

Product Rate Specifications

	Stream	Specification
1	18	Parameter = value
2	18	<a href="#">Stream 18 Flowrate of All Components on a Wet basis in kg-mol/hr = 50,000</a>

Options When Feed is Inadequate to Satisfy Product Rate Specifications

Satisfy Each Specification in Order Until Feed is Exhausted

Satisfy Each Specification and Normalize Flowrates if Needed

Exit the window after saving all data

# CN1 Condition

**PRO/II - Feedback Controller**

UOM Range Help Overview Status Notes

Unit:  Description:

Specification  
[Heat Exchanger E1 Duty in  \$\times 10^6\$  Kcal/hr = 9.6032](#) within [the default tolerance](#)

Variable  
[Stream 23 Flowrate in kg-mol/hr](#)

Parameters  
Maximum Number of Iterations:   Print Results for Each Iteration

Action if Minimum/Maximum Limits are reached

Accept as Solved if Limits are Reached

Fail Unit and Stop Calculations if Limits are Reached

Fail Unit and Continue Calculations if Limits are Reached

Next Unit Calculated after Control Variable is Changed:

Exit the window after saving all data

# CN2 Condition

**PRO/II - Feedback Controller**

UOM Range Help Overview Status Notes

Unit:  Description:

Specification  
[Heat Exchanger E4 Duty in x 10<sup>6</sup> Kcal/hr = 10.995](#) within [the default tolerance](#)

Variable  
[Splitter SP2 Specification on Stream 18](#)

Parameters  
Maximum Number of Iterations:   Print Results for Each Iteration

Action if Minimum/Maximum Limits are reached

Accept as Solved if Limits are Reached

Fail Unit and Stop Calculations if Limits are Reached

Fail Unit and Continue Calculations if Limits are Reached

Next Unit Calculated after Control Variable is Changed:

Exit the window after saving all data

# CN3 Condition

**PRO/II - Feedback Controller**

UOM Range Help Overview Status Notes

Unit:  Description:

Specification  
[Heat Exchanger E3 Duty in  \$\times 10^6\$  Kcal/hr = 11.657](#) within [the default tolerance](#)

Variable  
[Stream 11 Flowrate in kg-mol/hr](#)

Parameters  
Maximum Number of Iterations:   Print Results for Each Iteration

Action if Minimum/Maximum Limits are reached

Accept as Solved if Limits are Reached

Fail Unit and Stop Calculations if Limits are Reached

Fail Unit and Continue Calculations if Limits are Reached

Next Unit Calculated after Control Variable is Changed:

Exit the window after saving all data

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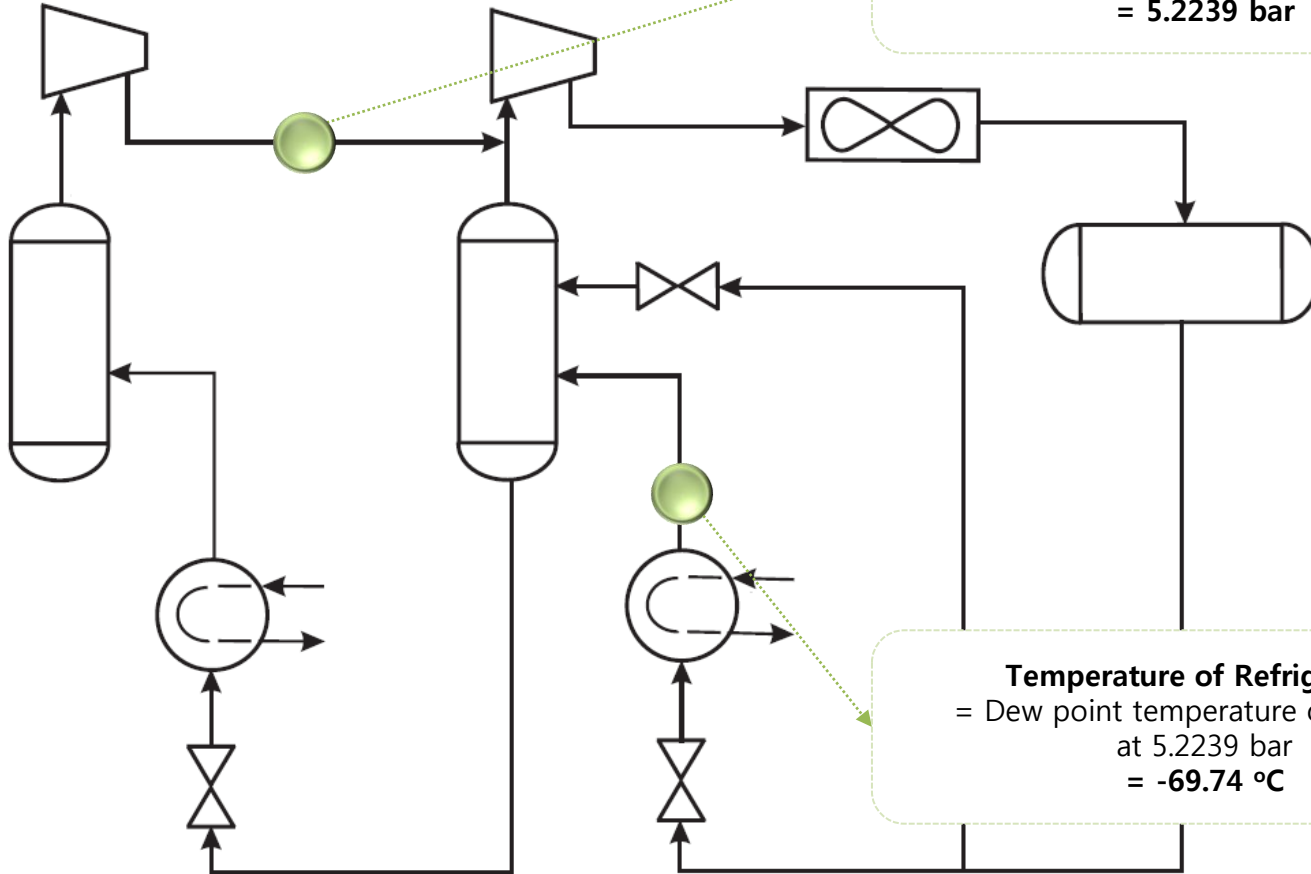
# **Two-Stage Refrigeration : Ethylene**

# Two-Stage Refrigeration System

Ratio per stage

$$\left(\frac{P_d}{P_s}\right)^{1/n} = \left(\frac{16.390}{1.665}\right)^{1/2} = 3.1375$$

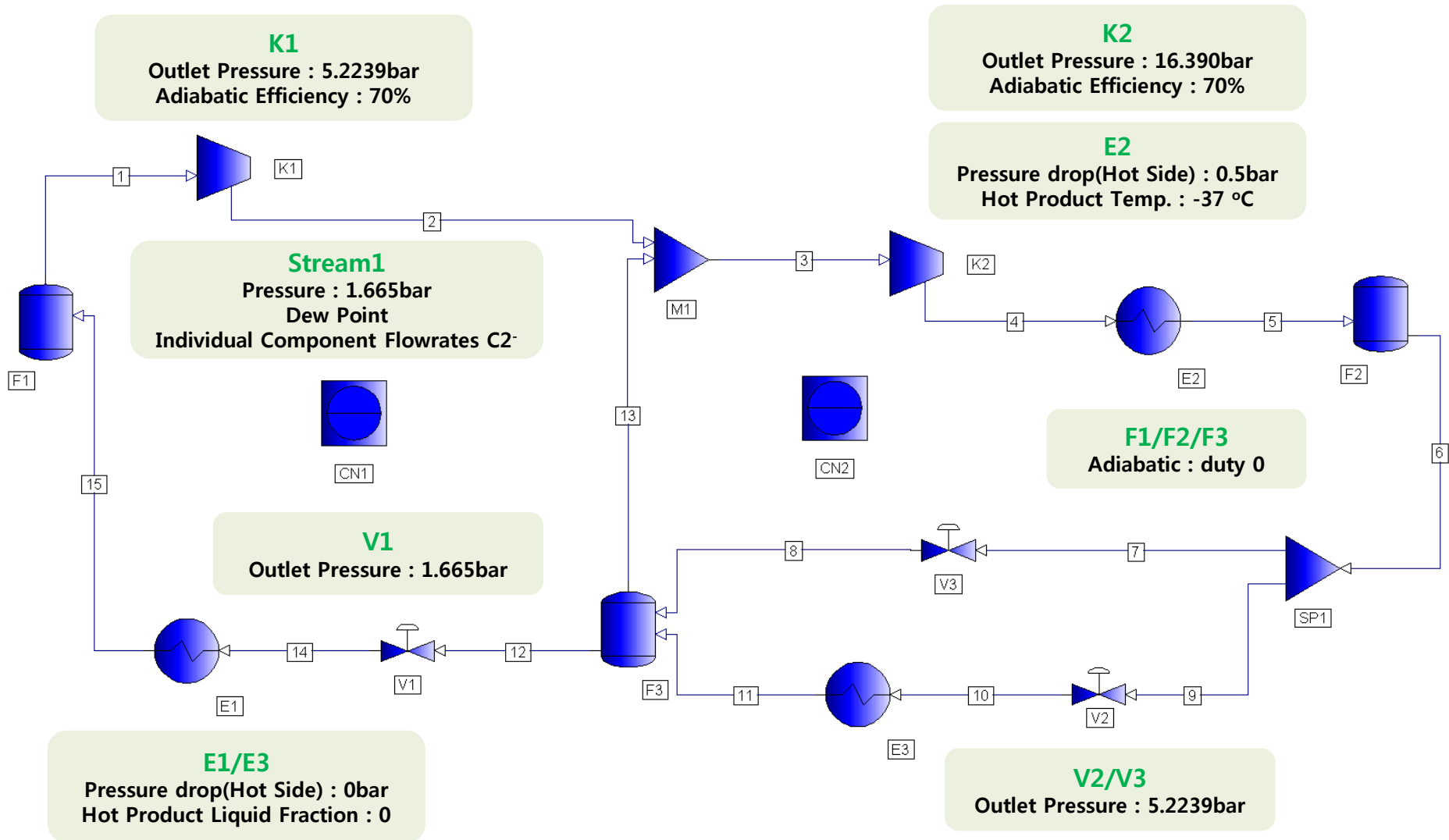
**First Stage Discharge Pressure**  
= Suction Pressure \* Ratio per stage  
= 1.665 \* 3.1375  
= 5.2239 bar



**Temperature of Refrigerator**  
= Dew point temperature of propane  
at 5.2239 bar  
= -69.74 °C



# Two-Stage Refrigeration Cycle



# SP1 Condition

**PRO/II - Splitter**

Range Help Overview Status Notes

Unit:  Description:

Thermodynamic System:

Product Rate Specifications

	Stream	Specification
1	7	Parameter = value
2	9	<a href="#">Stream 9 Flowrate of All Components on a Wet basis in kg-mol/hr = 1000.0</a>

Options When Feed is Inadequate to Satisfy Product Rate Specifications

Satisfy Each Specification in Order Until Feed is Exhausted

Satisfy Each Specification and Normalize Flowrates if Needed

Exit the window after saving all data

# CN1 Condition

**PRO/II - Feedback Controller**

UOM Range Help Overview Status Notes

Unit:  Description:

Specification  
[Heat Exchanger E1 Duty in  \$\times 10^6\$  Kcal/hr = 40.947](#) within [the default tolerance](#)

Variable  
[Stream 12 Flowrate in kg-mol/hr](#)

Parameters  
Maximum Number of Iterations:   Print Results for Each Iteration

Action if Minimum/Maximum Limits are reached

Accept as Solved if Limits are Reached

Fail Unit and Stop Calculations if Limits are Reached

Fail Unit and Continue Calculations if Limits are Reached

Next Unit Calculated after Control Variable is Changed:

Exit the window after saving all data

# CN2 Condition

**PRO/II - Feedback Controller**

UOM Range Help Overview Status Notes

Unit:  Description:

Specification  
[Heat Exchanger E3 Duty in  \$\times 10^6\$  Kcal/hr = 16.424](#) within [the default tolerance](#)

Variable  
[Stream 9 Flowrate in kg-mol/hr](#)

Parameters  
Maximum Number of Iterations:   Print Results for Each Iteration

Action if Minimum/Maximum Limits are reached

Accept as Solved if Limits are Reached

Fail Unit and Stop Calculations if Limits are Reached

Fail Unit and Continue Calculations if Limits are Reached

Next Unit Calculated after Control Variable is Changed:

Exit the window after saving all data

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# **Three-Stage Refrigeration : Methane**

# Three-Stage Refrigeration System

Ratio per stage

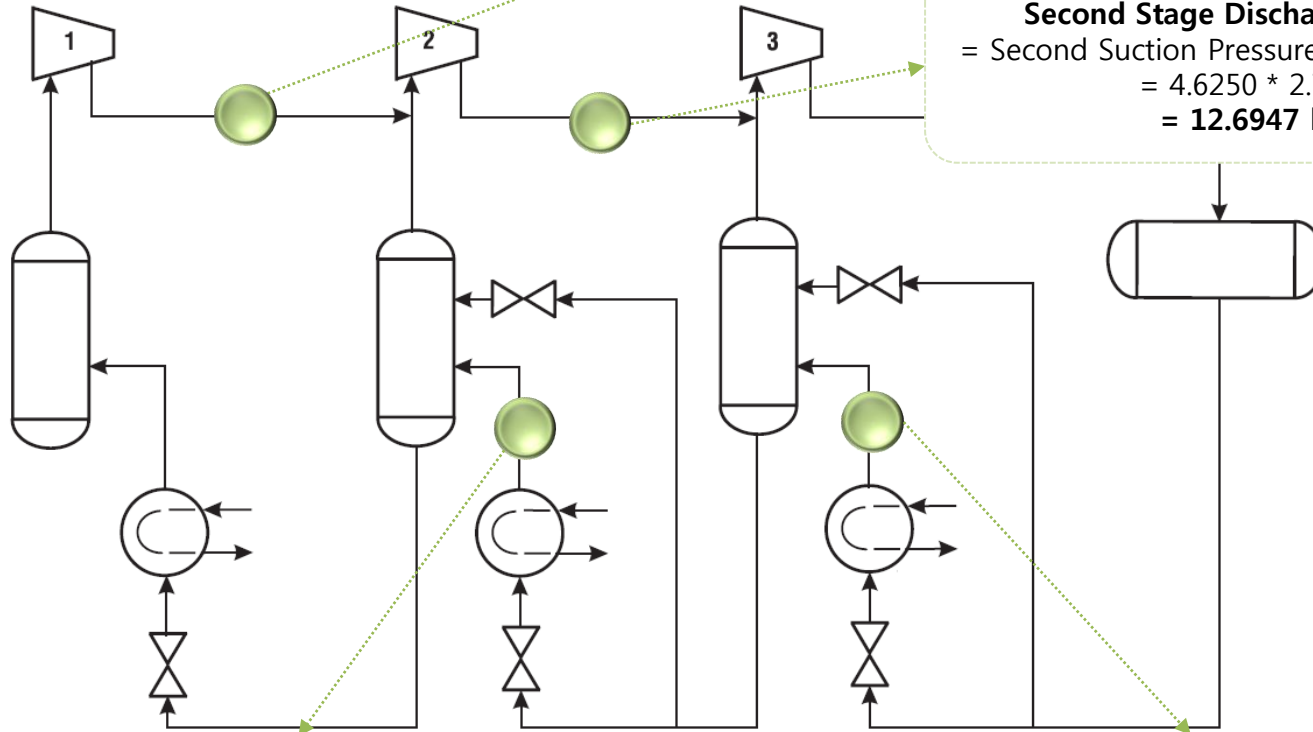
$$\left(\frac{P_d}{P_s}\right)^{1/n} = \left(\frac{34.845}{1.685}\right)^{1/3} = 2.7448$$

**First Stage Discharge Pressure**

$$\begin{aligned} &= \text{First Suction Pressure} * \text{Ratio per stage} \\ &= 1.685 * 2.7448 \\ &= \mathbf{4.6250 \text{ bar}} \end{aligned}$$

**Second Stage Discharge Pressure**

$$\begin{aligned} &= \text{Second Suction Pressure} * \text{Ratio per stage} \\ &= 4.6250 * 2.7448 \\ &= \mathbf{12.6947 \text{ bar}} \end{aligned}$$



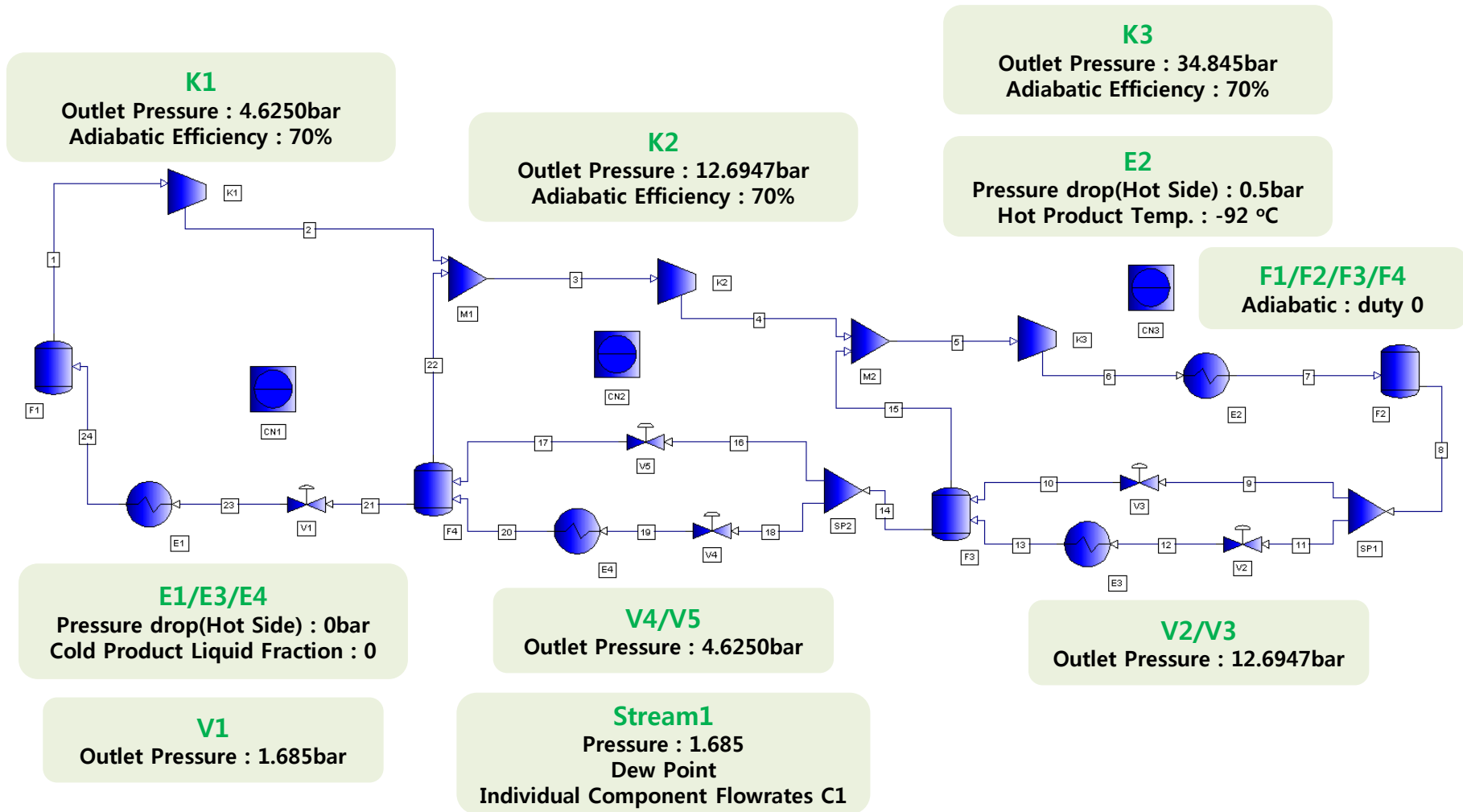
**Temperature of Refrigerator**

$$\begin{aligned} &= \text{Dew point temperature of propane} \\ &\quad \text{at } 4.6250 \text{ bar} \\ &= \mathbf{-118.78 \text{ }^\circ\text{C}} \end{aligned}$$

**Temperature of Refrigerator**

$$\begin{aligned} &= \text{Dew point temperature of propane} \\ &\quad \text{at } 12.6947 \text{ bar} \\ &= \mathbf{-139.29 \text{ }^\circ\text{C}} \end{aligned}$$

# Three-Stage Refrigeration Cycle



# SP1 Condition

**PRO/II - Splitter**

Range Help Overview Status Notes

Unit:  Description:

Thermodynamic System:

Product Rate Specifications

	Stream	Specification
1	9	Parameter = value
2	11	<a href="#">Stream 11 Flowrate of All Components on a Wet basis in kg-mol/hr = 500.00</a>

Options When Feed is Inadequate to Satisfy Product Rate Specifications

Satisfy Each Specification in Order Until Feed is Exhausted

Satisfy Each Specification and Normalize Flowrates if Needed

Exit the window after saving all data



# SP2 Condition

**PRO/II - Splitter**

Range Help Overview Status Notes

Unit:  Description:

Thermodynamic System:  ▾

Product Rate Specifications

	Stream	Specification
1	18	Parameter = value
2	18	<a href="#">Stream 18 Flowrate of All Components on a Wet basis in kg-mol/hr = 500.00</a>

Options When Feed is Inadequate to Satisfy Product Rate Specifications

Satisfy Each Specification in Order Until Feed is Exhausted

Satisfy Each Specification and Normalize Flowrates if Needed

Exit the window after saving all data

# CN1 Condition

**PRO/II - Feedback Controller**

UOM Range Help Overview Status Notes

Unit:  Description:

Specification  
[Heat Exchanger E1 Duty in  \$\times 10^6\$  Kcal/hr = 8.0941](#) within [the default tolerance](#)

Variable  
[Stream 21 Flowrate in kg-mol/hr](#)

Parameters  
Maximum Number of Iterations:   Print Results for Each Iteration

Action if Minimum/Maximum Limits are reached

Accept as Solved if Limits are Reached

Fail Unit and Stop Calculations if Limits are Reached

Fail Unit and Continue Calculations if Limits are Reached

Next Unit Calculated after Control Variable is Changed:

Exit the window after saving all data

# CN2 Condition

**PRO/II - Feedback Controller**

UOM Range Help Overview Status Notes

Unit:  Description:

Specification  
[Heat Exchanger E4 Duty in x 10<sup>6</sup> Kcal/hr = 11.471](#) within [the default tolerance](#)

Variable  
[Splitter SP2 Specification on Stream 18](#)

Parameters  
Maximum Number of Iterations:   Print Results for Each Iteration

Action if Minimum/Maximum Limits are reached

Accept as Solved if Limits are Reached

Fail Unit and Stop Calculations if Limits are Reached

Fail Unit and Continue Calculations if Limits are Reached

Next Unit Calculated after Control Variable is Changed:

Exit the window after saving all data

# CN3 Condition

**PRO/II - Feedback Controller**

UOM Range Help Overview Status Notes

Unit:  Description:

Specification  
[Heat Exchanger E3 Duty in x 10<sup>6</sup> Kcal/hr = 16.418](#) within [the default tolerance](#)

Variable  
[Splitter SP1 Specification on Stream 11](#)

Parameters  
Maximum Number of Iterations:   Print Results for Each Iteration

Action if Minimum/Maximum Limits are reached

Accept as Solved if Limits are Reached

Fail Unit and Stop Calculations if Limits are Reached

Fail Unit and Continue Calculations if Limits are Reached

Next Unit Calculated after Control Variable is Changed:

Exit the window after saving all data