Multistage Cascade Refrigeration Cycle

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What is a Refrigerator>

- By letting-down the pressure of chilled and highly compressed refrigerant, we can obtain a cold temperature of refrigerant. By adjusting the pressure letting-down level, we can obtain a wanted temperature level of refrigerant.
- By cooling after compressing a vapor stream, we can obtain a liquefied refrigerant.

Input Condition of Natural Gas

Contents	Value
Pressure (bar)	53
Temperature (°C)	45
Flow Rate (kg/hr)	625,000

Component	Mole%
Nitrogen	0.22
Methane	91.33
Ethane	5.36
Propane	2.14
I-Butane	0.46
N-Butane	0.47
I-Pentane	0.01
N-Pentane	0.01
Total	**100**

Cascade Refrigeration

E01
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

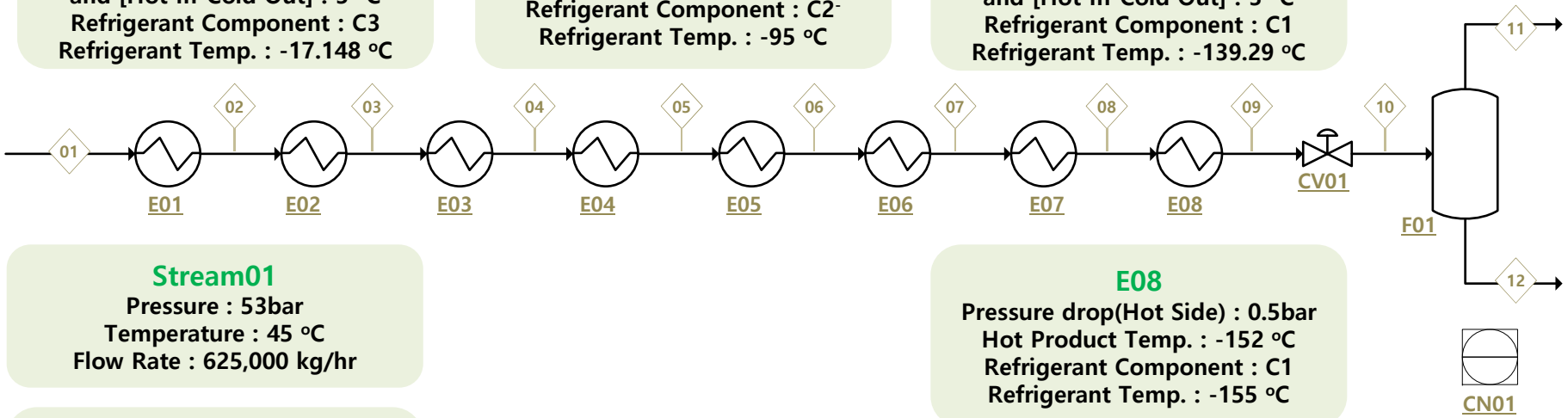
E02
Pressure drop(Hot Side) : 0.5bar
Minimum of [Hot Out-Cold In] and [Hot In-Cold Out] : 3 °C
Refrigerant Component : C3
Refrigerant Temp. : -17.148 °C

E04
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

E05
Pressure drop(Hot Side) : 0.5bar
Hot Product Temp. : -92 °C
Refrigerant Component : C2-
Refrigerant Temp. : -95 °C

E06
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

E07
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



Stream01
Pressure : 53bar
Temperature : 45 °C
Flow Rate : 625,000 kg/hr

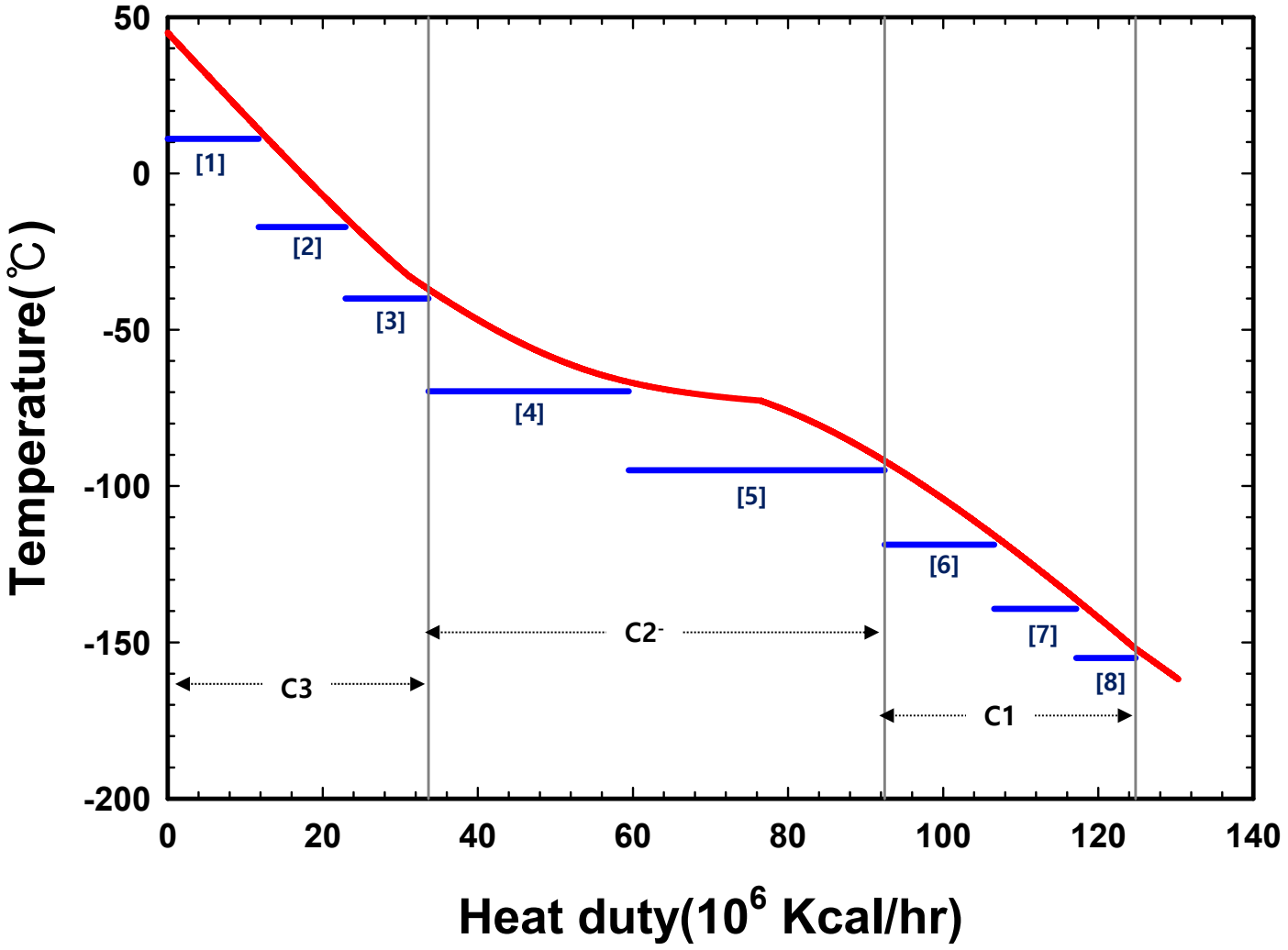
E03
Pressure drop(Hot Side) : 0.5bar
Hot Product Temp. : -37 °C
Refrigerant Component : C3
Refrigerant Temp. : -40 °C

E08
Pressure drop(Hot Side) : 0.5bar
Hot Product Temp. : -152 °C
Refrigerant Component : C1
Refrigerant Temp. : -155 °C

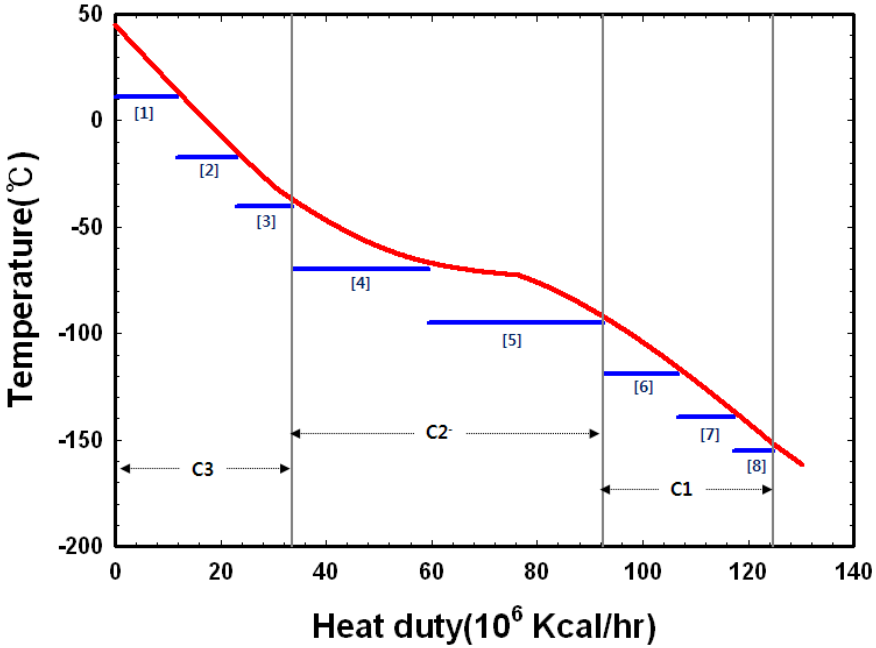
CV01
Pressure Drop : 0

F01
Adiabatic : duty 0

Cascade Heating Curve

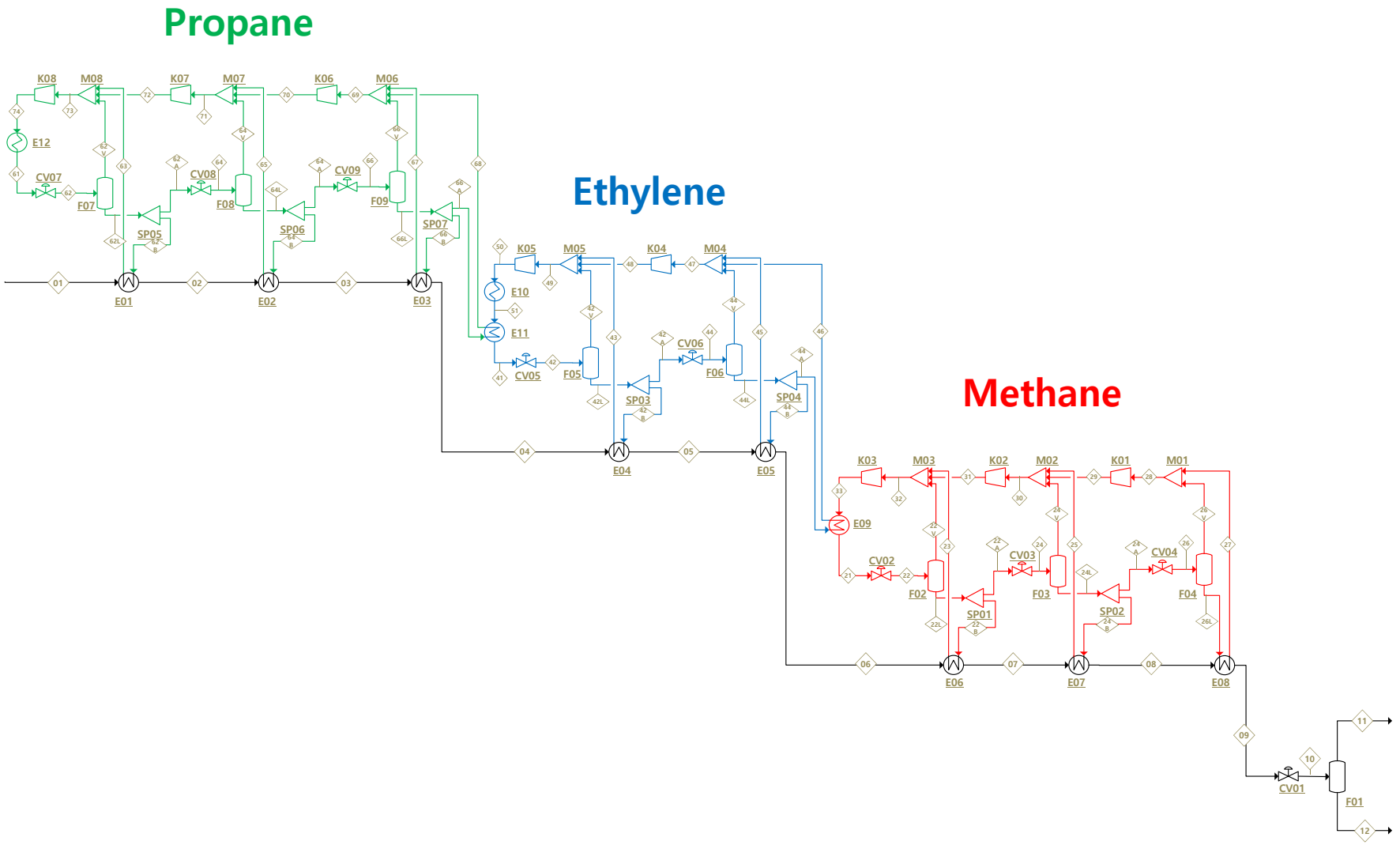


Cascade Heating Curve



	Temperature (℃)	Heat duty (*10⁶ Kcal/hr)	Flowrate of refrigerator (kg/hr)
[1]	11.08	11.7401	337452.036
[2]	-17.15	11.2082	117796.037
[3]	-40.00	10.6854	106008.027
[4]	-69.74	25.8445	253708.024
[5]	-95.00	33.0099	296820.610
[6]	-118.78	14.0877	149153.654
[7]	-139.29	10.5958	95617.043
[8]	-155.00	7.6387	64009.514
Total		**124.8103**	

Multistage Cascade Refrigeration Cycle



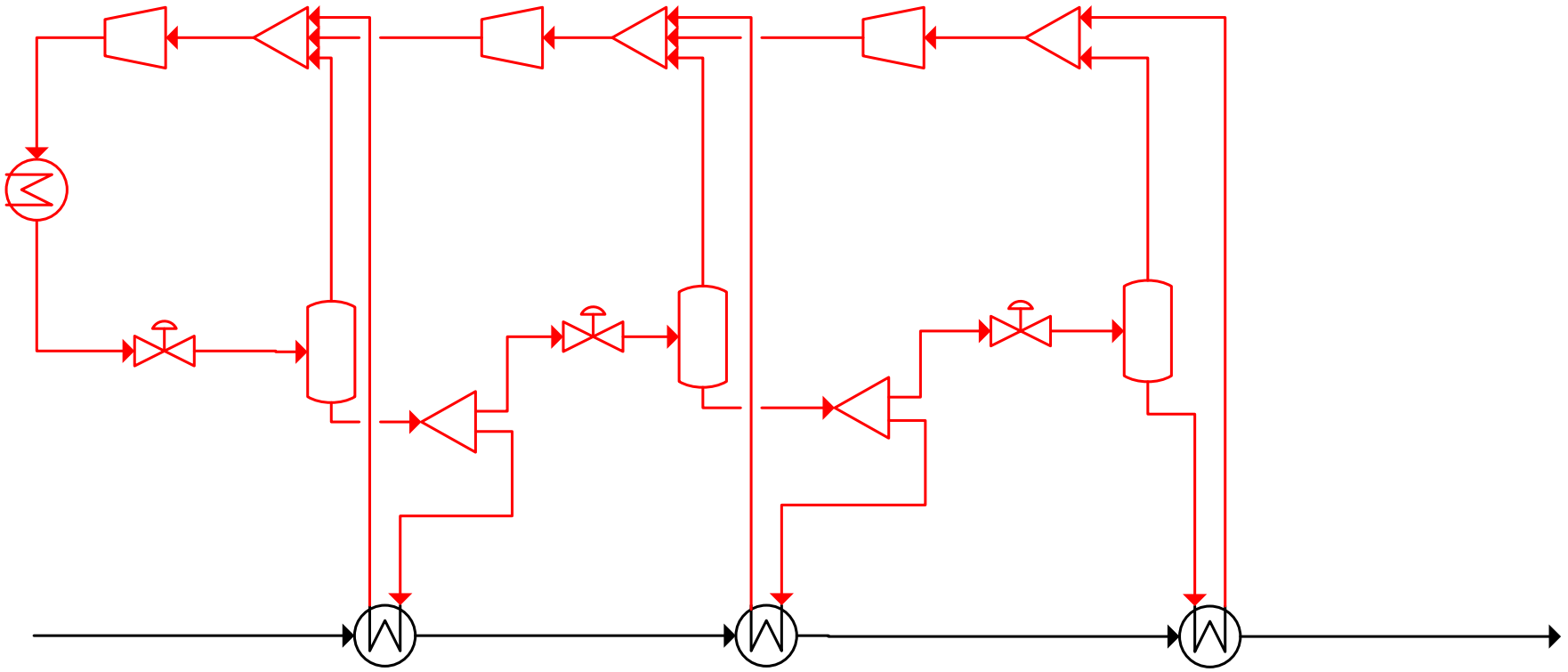
Three Stage Refrigeration Cycle

Second Stage Discharge Pressure(K02)
= Second Suction Pressure * Ratio per stage
= 4.6250 * 2.7448
= 12.6947 bar

First Stage Discharge Pressure(K01)
= First Suction Pressure * Ratio per stage
= 1.685 * 2.7448
= 4.6250 bar

Ratio per stage

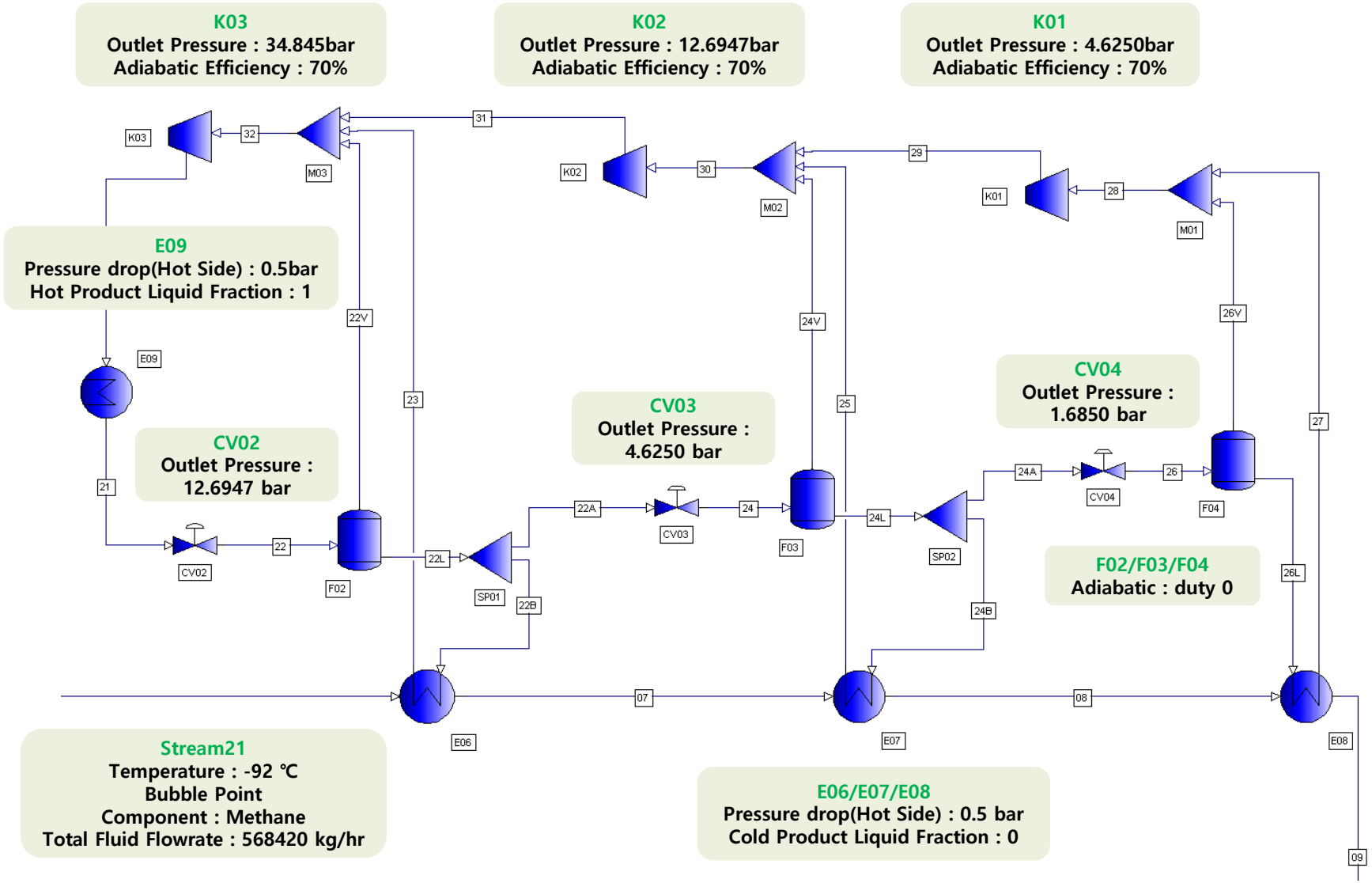
$$\left(\frac{P_d}{P_s}\right)^{1/n} = \left(\frac{34.845}{1.685}\right)^{1/3} = 2.7448$$



Temperature of Refrigerator(E06)
= Dew point temperature of propane
at 4.6250 bar
= -118.78 ºC

Temperature of Refrigerator(E07)
= Dew point temperature of propane
at 12.6947 bar
= -139.29 ºC

Three Stage Refrigeration Cycle

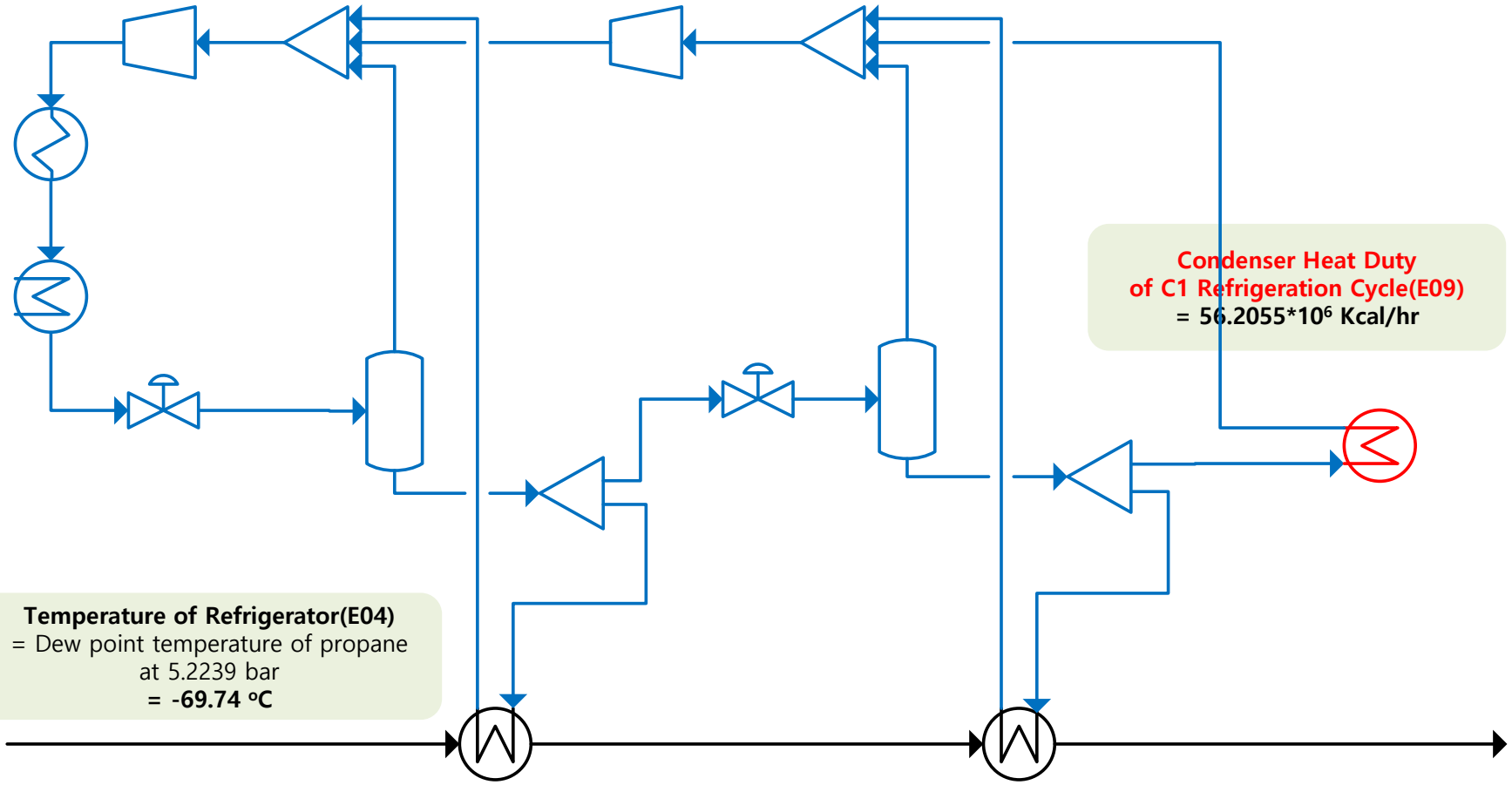


Two Stage Refrigeration Cycle

First Stage Discharge Pressure(K04)
= Suction Pressure * Ratio per stage
= 1.665 * 3.1375
= 5.2239 bar

Ratio per stage

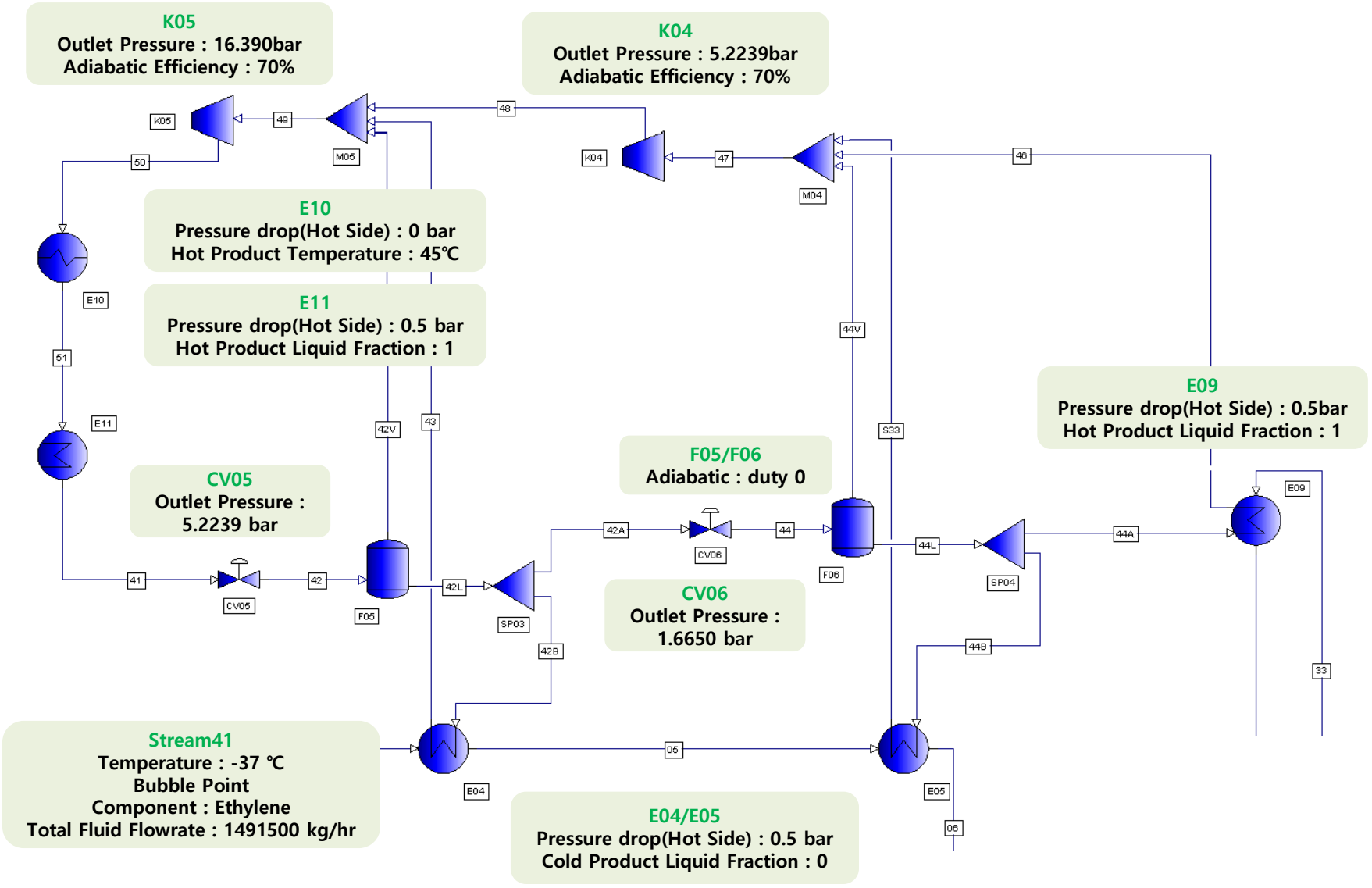
$$\left(\frac{P_d}{P_s}\right)^{1/n} = \left(\frac{16.390}{1.665}\right)^{1/2} = 3.1375$$



Condenser Heat Duty of C1 Refrigeration Cycle(E09)
= 56.2055*10⁶ Kcal/hr

Temperature of Refrigerator(E04)
= Dew point temperature of propane at 5.2239 bar
= -69.74 ºC

Two Stage Refrigeration Cycle



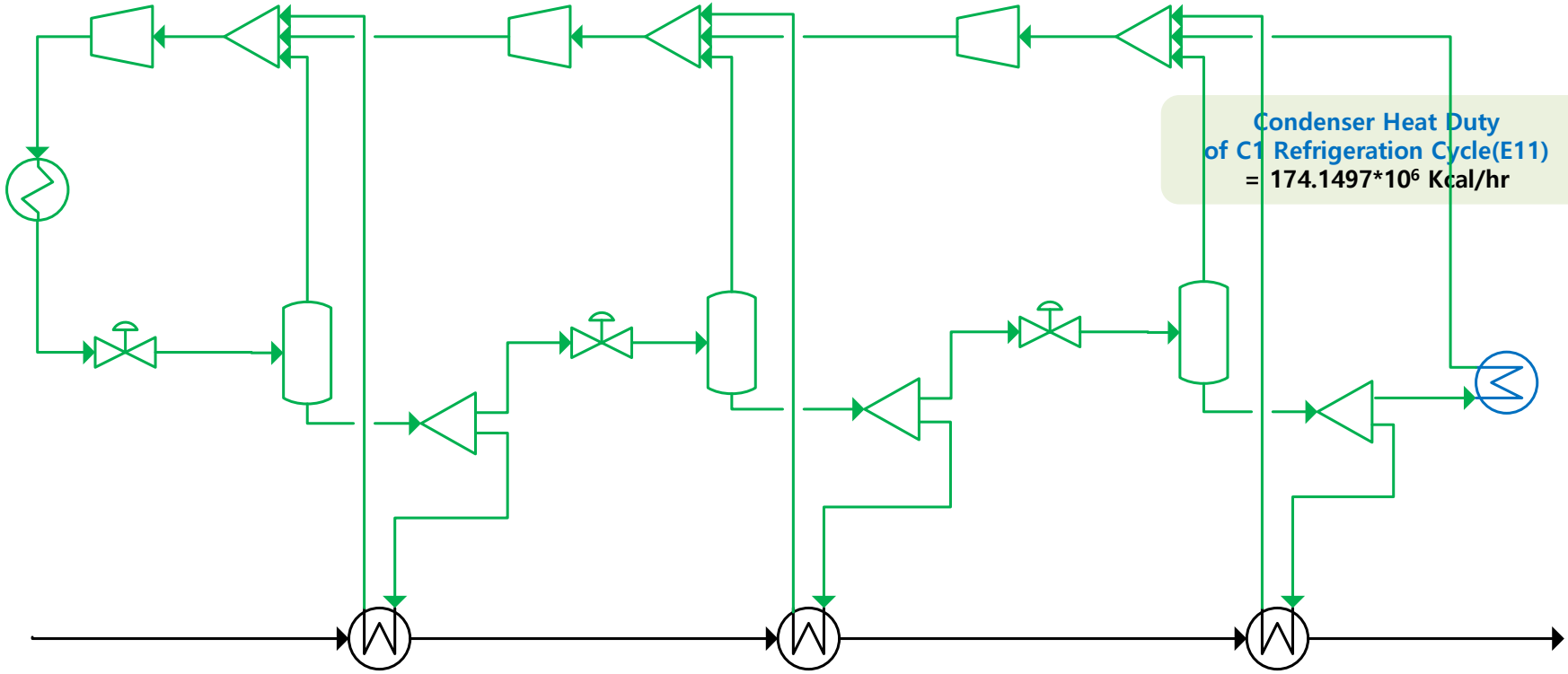
Three Stage Refrigeration Cycle

Second Stage Discharge Pressure(K07)
= Second Suction Pressure * Ratio per stage
= 2.7013 * 2.4249
= 6.5505 bar

First Stage Discharge Pressure(K06)
= First Suction Pressure * Ratio per stage
= 1.114 * 2.4249
= 2.7013 bar

Ratio per stage

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



Condenser Heat Duty of C1 Refrigeration Cycle(E11)
= 174.1497*10⁶ Kcal/hr

Temperature of Refrigerator(E01)
= Dew point temperature of propane at 2.7013 bar
= -17.148 ºC

Temperature of Refrigerator(E02)
= Dew point temperature of propane at 6.5505 bar
= 11.075 ºC

Three Stage Refrigeration Cycle

K08
Outlet Pressure : 15.885bar
Adiabatic Efficiency : 70%

K07
Outlet Pressure : 6.5505bar
Adiabatic Efficiency : 70%

K06
Outlet Pressure : 2.7013bar
Adiabatic Efficiency : 70%

E12
Pressure drop(Hot Side) : 0.5bar
Hot Product Liquid Fraction : 1

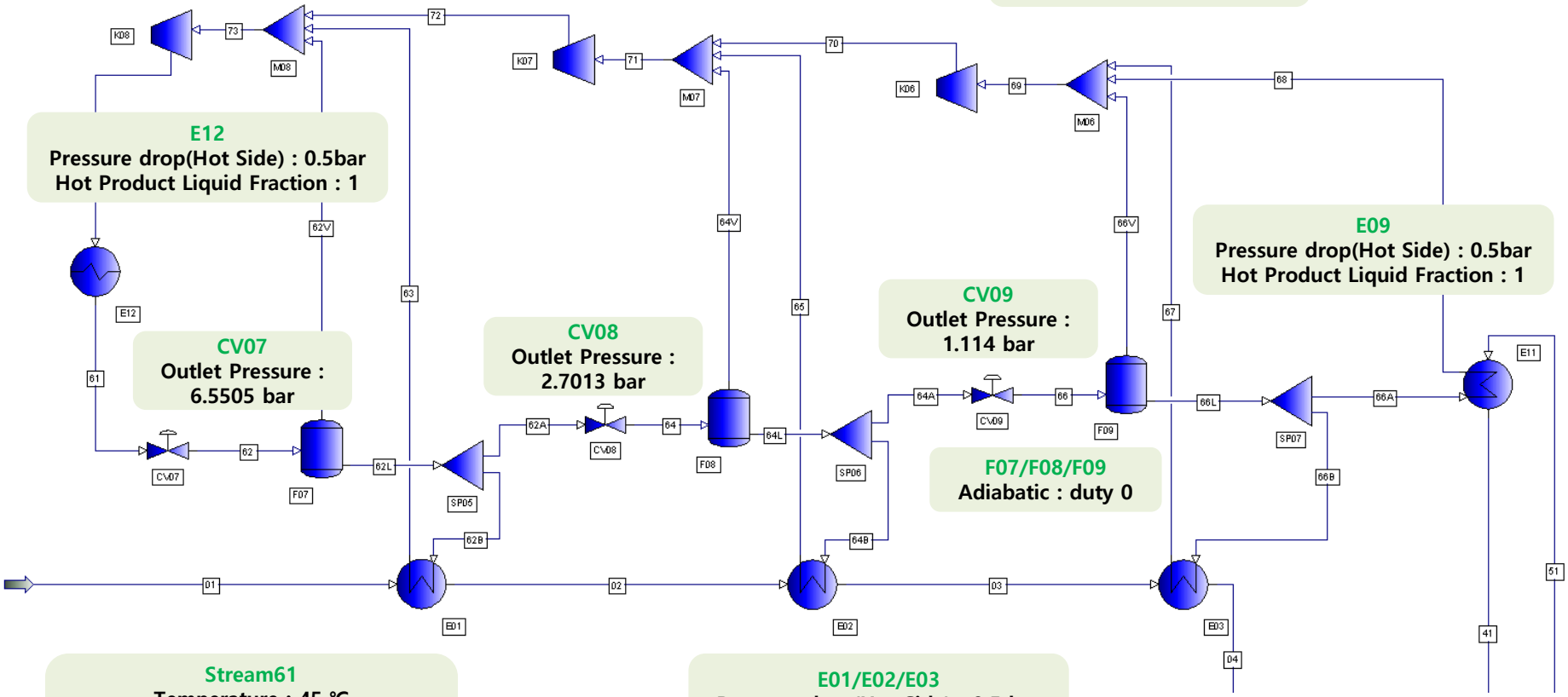
CV07
Outlet Pressure :
6.5505 bar

CV08
Outlet Pressure :
2.7013 bar

CV09
Outlet Pressure :
1.114 bar

E09
Pressure drop(Hot Side) : 0.5bar
Hot Product Liquid Fraction : 1

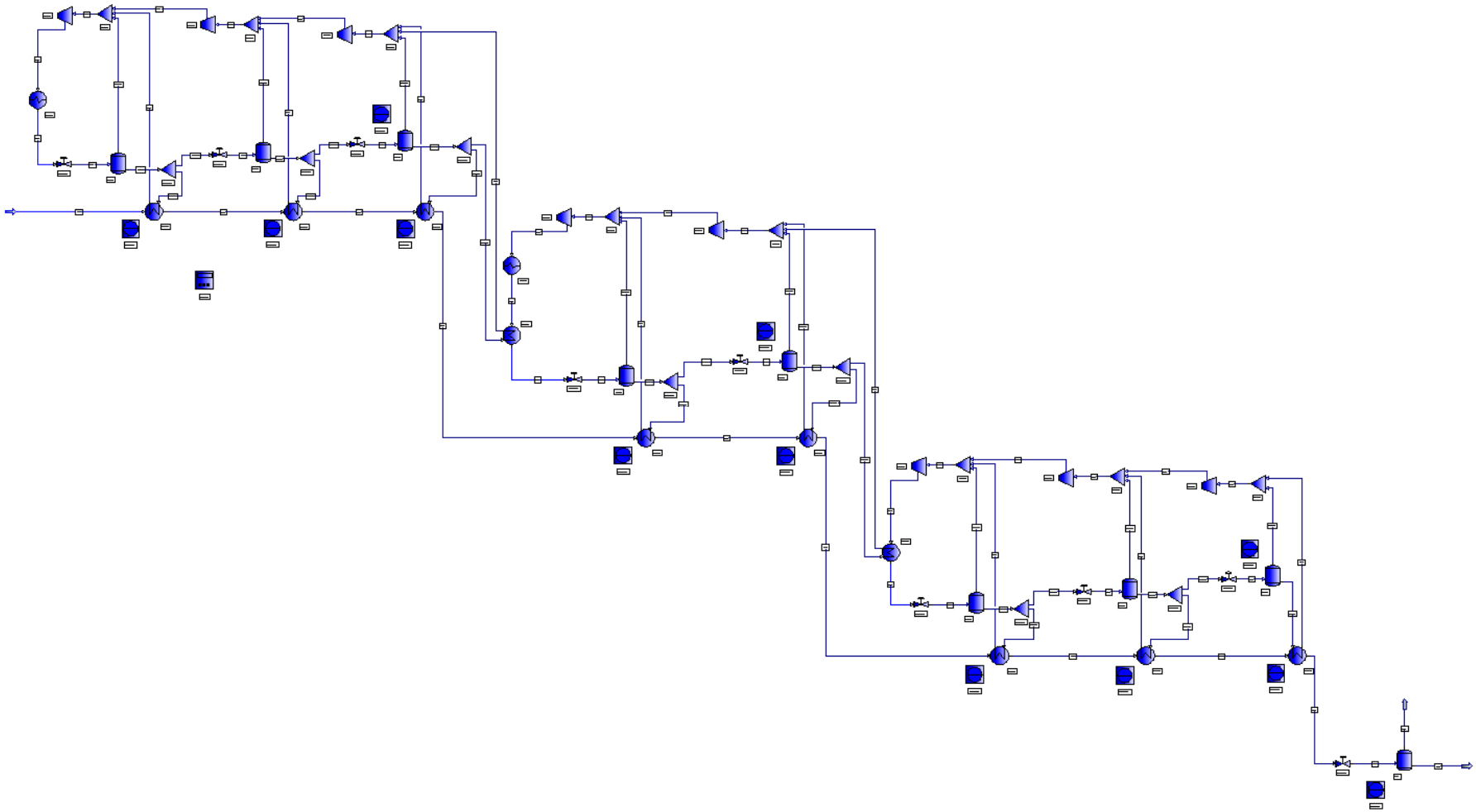
F07/F08/F09
Adiabatic : duty 0



Stream61
Temperature : 45 ℃
Bubble Point
Component : Propane
Total Fluid Flowrate : 3841400 kg/hr

E01/E02/E03
Pressure drop(Hot Side) : 0.5 bar
Cold Product Liquid Fraction : 0

Multi Stage Cascade Refrigeration Cycle



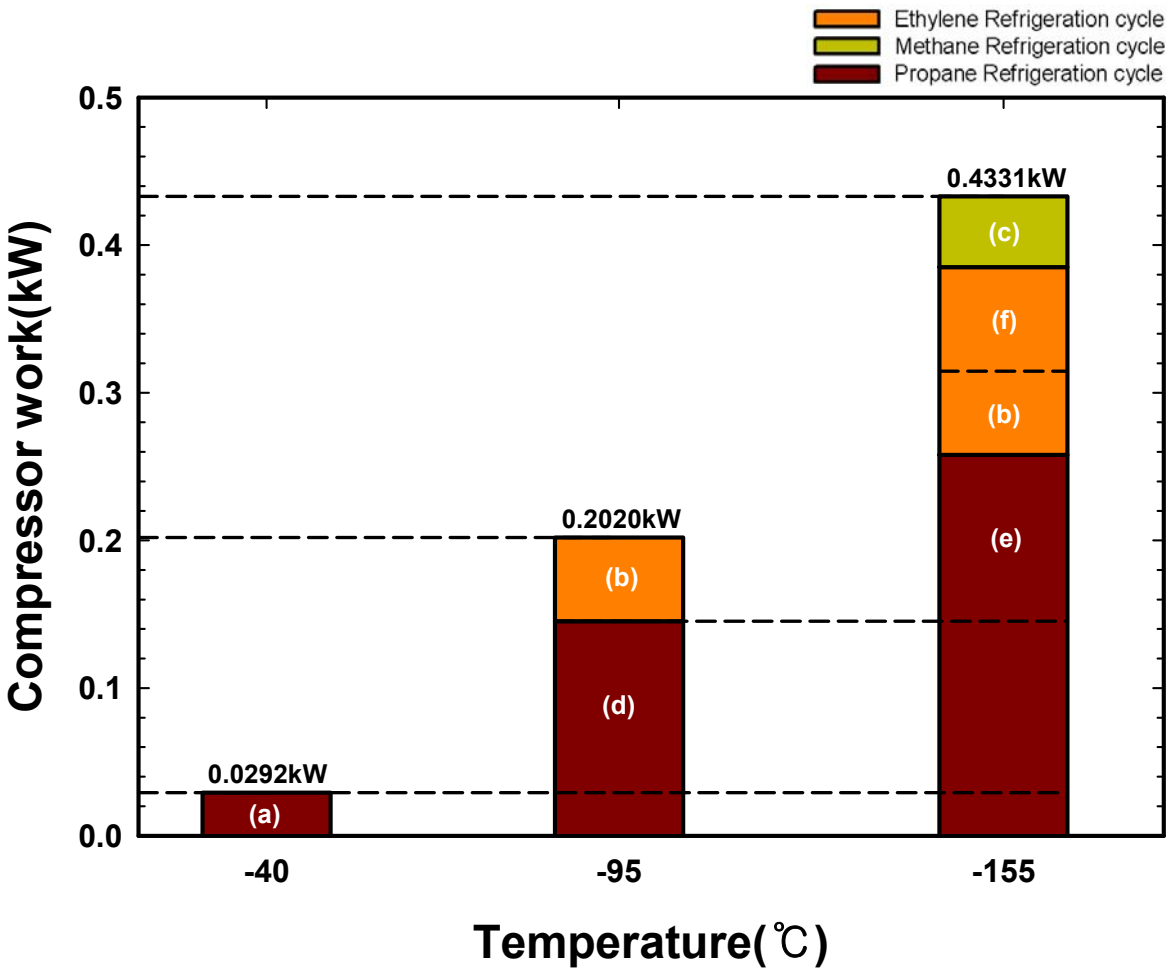
Results

Refrigerator	Contents	Actual Work (kW)
Propane	K08	6.97935E+04
Propane	K07	4.65535E+04
Propane	K06	3.26463E+04
Ethylene	K05	4.93771E+04
Ethylene	K04	2.40789E+04
Methane	K03	1.94100E+04
Methane	K02	6.41777E+03
Methane	K01	1.91124E+03
Total		**2.50188E+05**

LNG Flowrate (kg/hr)	**577679.6567**

Actual Work
0.4331 kW / kg/hr LNG

Compression Work Summary



	Compressor Work (kW)
(a)	0.0292
(b)	0.0568
(c)	0.0480
(d)	0.1160
(e)	0.1127
(f)	0.0704
(a)+(d)	0.1452
(a)+(d)+(e)	0.2579
(b)+(f)	0.1272

THANK YOU