

## Case-16 Cascade Refrigeration System for LPG Subcooling

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### Case Background:

This is a case of using a cascade refrigeration system to subcool the LPG (Liquefied Petroleum Gas) liquid for the purpose of avoiding flash gas during loading and unloading of the LPG liquid.

It is the preference of the user to use R-134a refrigerant for the high stage and R-23 refrigerant for the low stage instead of using R-1270 (Propylene) for the high side and R-1150 (Ethylene) for the low stage as the logical refrigerant selection for cascade systems for most hydrocarbon industries.

The system is required to provide fast pull-down during start-up after shut-down, therefore, liquid subcooling and suction gas heat exchanger is not used for the low stage compressor suction. The superheat gas might flash all the liquid in the heat exchanger and might sometimes delaying the pull down process during start-up.

Nickel steel is to be used for the low stage evaporator. Cast steel casing is required for the screw compressor for the low stage circuit.

### Related Technical Data and Information for the Case:

The refrigeration system is to cool 237,510 Lbs/Hr of LPG from -50°F to -62°F, 15 Psia. The average specific gravity and the specific heat at the average temperatures for the LPG liquid are:

Estimate specific gravity = 0.6  
Specific heat = 0.4334

Cooling water is available, 85°F in and 95°F out.

Maximum ambient design temperature: 110°F  
Fouling factor for all heat exchangers: 0.001

Electrical classification for the area is Class I, Group D, Division II.

Power supply: 4,160-3-60  
 460-3-60  
 120-1-60

Actually, the evaporative temperature for this case is within the range of one refrigerant using compound system. However, because the user prefers to have positive pressure in the refrigeration system, therefore cascade system with R-23 refrigerant is used for the low stage. R-134a is selected over the R-717 and R-22 for the high stage as suggested by the user.

## System Design Logic and Approach:

The working principal of a cascade system is to use two separate working refrigerants linked together through a cascade condenser as shown in Figure 16-1. Each of the two refrigerants is contained in a separate complete independent refrigerant circuit. The cascade condenser performs as the condenser for the low stage and as the evaporator for the high stage.

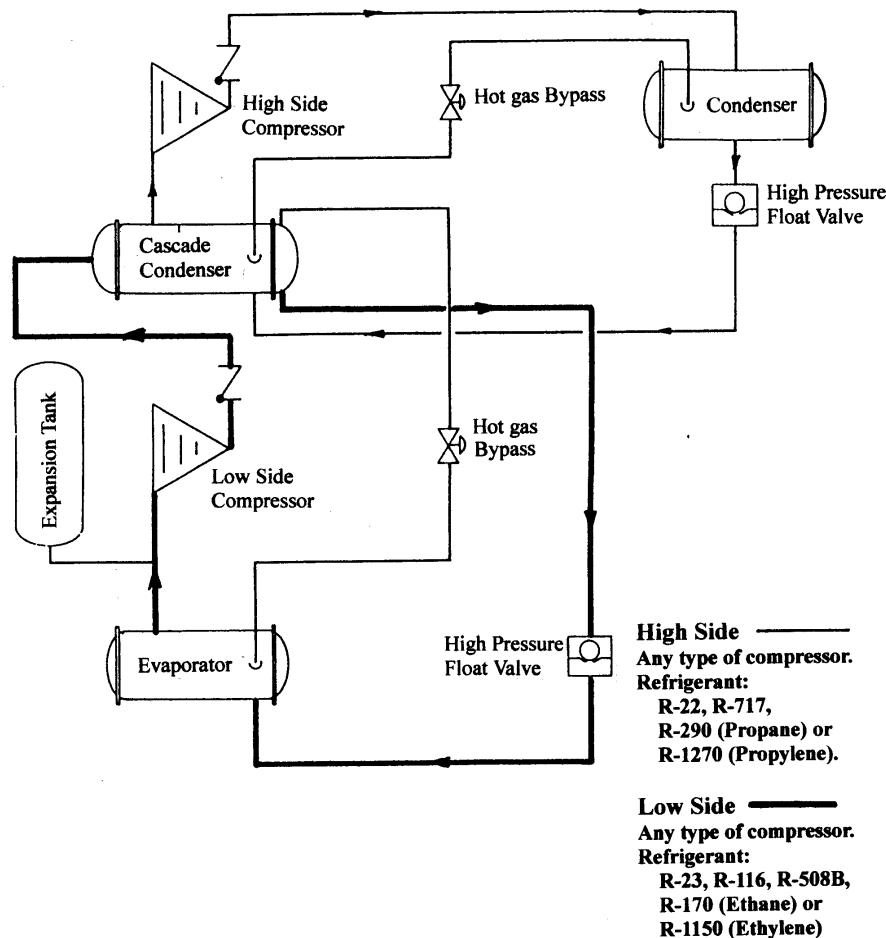


Figure 16-1 Principal of Cascade Refrigeration system

The refrigerant selected for the low stage is a low temperature refrigerant which is having higher pressure and smaller specific volume at the low temperature.

In this case, the refrigerant for the low stage circuit is R-23, the liquid refrigerant absorbs the heat from the evaporator, evaporated and the vapor is compressed by the low stage compressor, the refrigerant vapor is condensed in the tube side of the cascade condenser. The refrigerant for the high stage is R-134a, the R-134a liquid in the evaporator, the shell side of the cascade condenser, absorbs the heat, the evaporated gas is compressed by the high stage compressor and is condensed in the water cooled condenser at the high stage.

In accordance with the guide line given by the user, the construction of the shell-and-tube evaporator heat exchanger for the LPG liquid subcooling shall be TEMA-B U-tube design. The leaving LPG shall be -62°F, the fouling factor is 0.001, the evaporative temperature of -76°F is assumed for the evaporator. This shall provide a temperature difference of 14°F between the leaving LPG liquid and the ET for the heat transfer.

Therefore: ET = -76°F for the low stage LPG cooler.

LPG liquid subcooling heat load:

Specific Gravity = 0.6  
Specific heat = 0.4334

Cooling 237,510 Lbs/Hr. of LPG from -50°F to -62°F

$$\text{GPM flow} = \frac{\text{Lbs/Min flow}}{8.33 \times \text{Sp.Gr.}} = \frac{237,510/60}{8.33 \times 0.6} = 792 \text{ GPM}$$

$$\text{TR} = \frac{\text{GPM}}{24} \times \text{S.G.} \times C_p \times \Delta T$$

$$= \frac{792}{24} \times 0.6 \times 0.4336 \times 12 \\ = 103 \text{ TR}$$

The cooling water is available is 85°F in and the design leaving cooling water temperature is 95°F. The condensing temperature for the high stage is designed at 108°F.

The next step is to fix the CT and ET for the Cascade Condenser. As a general guide for cascade system, it is to design the low stage system for a maximum design working pressure of not more than 300 Psig and the expansion tank is sized to have extra volume for 250 Psig storage pressure at design ambient temperature of 110° F.

If the design condensing temperature for R-23 is to be designed for 15° F, use 10° F temperature difference between CT and ET, the evaporative temperature for R-134a high stage system is to be 5° F.

### Low Stage Refrigeration Circuit:

The P-H diagram for the low stage refrigeration system is shown in Figure 16-2:

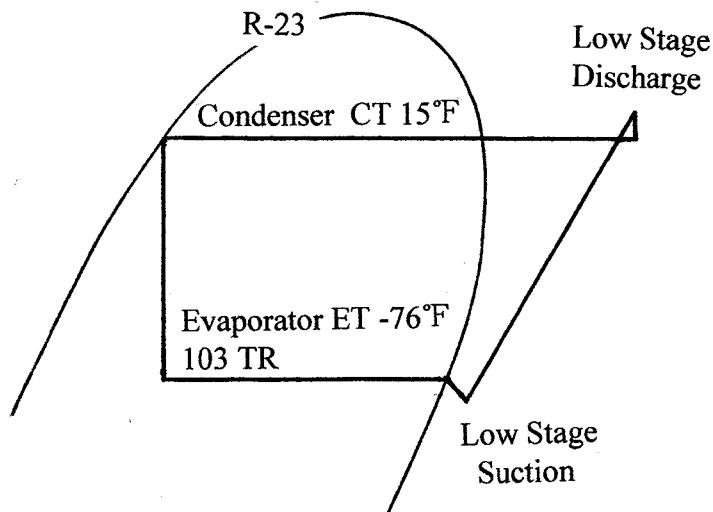


Figure 16-2 P-H Diagram for the Low Stage Refrigeration System

Operating conditions and specifications for the evaporator for LPG subcooling:

Heat load:	103 TR
Heat Exchanger design:	Flooded, Full Bundle with surge drum
Material:	3-1/2% nickel steel
Construction:	TEMA-B
Tube Side:	
Tubes:	16 BWG
LPG flow:	237,510 Lbs/Hr
LPG inlet & outlet:	-50°F to -62°F

Inlet pressure:	15 Psia
Average specific gravity:	0.6
Average specific heat:	0.4334
Estimate specific gravity:	0.6
Specific heat:	0.4334
Fouling factor:	0.001
Design working pressure:	150 Psig
Shell Side:	
Refrigerant:	R-23
Refrigerant feed:	Flooded
Evaporative temperature:	-76° F
Liquid temperature to shell:	15° F
Design working pressure:	300 Psig

The operating conditions for low stage screw compressor unit and computer selection input data:

Capacity:	103 TR
Refrigerant:	R-23
Evaporative Temperature:	-76° F
Condensing Temperature:	15° F
Suction pressure drop:	0.5 Psi
Suction superheat:	15° F
Discharge pressure drop:	1.0 Psi
Compressor speed:	3,550 rpm
Oil pump:	Recycling
Oil cooling:	Water cooled

Compressor unit selected:

Model Number:	RW-100
Power consumption:	354 BHP
Oil cooling heat removal:	20,800 Btu/Hr.

Compressor construction:

Casing:	cast steel
Design working pressure:	300 Psig

The refrigerant flow diagram for this low stage R-23 system is shown in Figure 16-3.

An expansion tank is used for the R-23 low stage system. The expansion tank is connected to the suction side of the low stage compressor; it is to provide additional volume for the low stage refrigerant to expand during shutdown when the system is warmed up to room temperature.

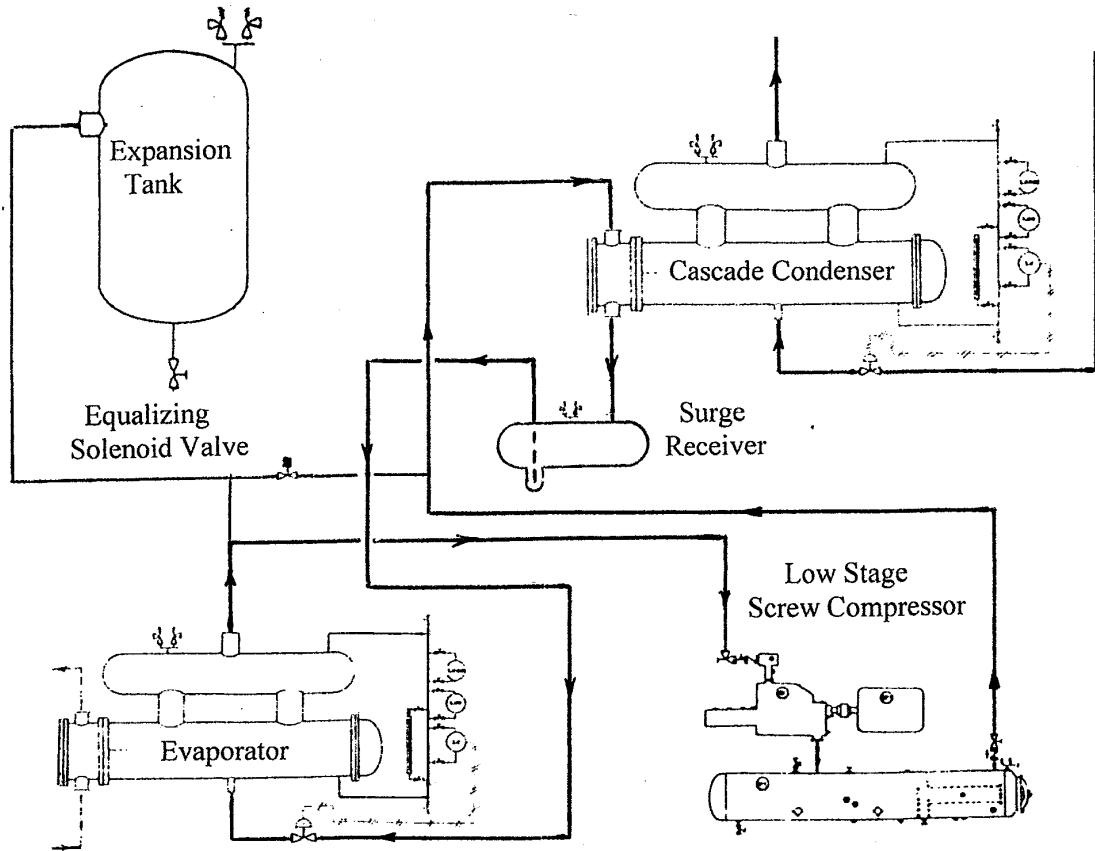


Figure 16-3 Refrigerant Flow Diagram for the R-23 Low Stage System

A surge receiver is for the purpose of providing liquid seal; a solenoid valve connecting between the high side and the low side of the R-23 circuit is to equalizing the pressure between the high side and the low side of the system.

The design working pressure for the low stage system is 300 Psig.

The expansion tank is sized to have enough volume for R-23 stand-by pressure of 250 Psig at 110° F maximum ambient temperature.

#### High Stage R-134a Refrigeration Circuit:

Heat load for the high stage refrigeration Circuit is the total heat rejection from the low stage refrigeration Circuit.

Heat rejection from low stage R-23 system = 103 TR + Heat input from low stage

$$\begin{aligned}
 &= 103 + \frac{354 \times 2545 - 20,800}{12,000} \\
 &= 103 + 176.3 = 176.3 \text{ TR}
 \end{aligned}$$

Heat load for the high stage circuit = 176.3 TR

The ET is 5° F and the CT is 108° F. The high stage R-134a system is to be equipped with economizer for the lowering of power consumption. The economizer is to be shell-and-tube liquid subcooling design.

The operating conditions for high stage screw compressor unit and computer selection input data:

Capacity:	176.3 TR
Refrigerant:	R-134a
Evaporative Temperature:	5° F
Condensing Temperature:	108° F
Suction pressure drop:	0.5 Psi
Suction superheat:	10° F
Discharge pressure drop:	1.0 Psi
Compressor speed:	3,550 rpm
Oil pump:	Recycling
Oil cooling:	Water cooled
Economizer:	Shell-and-tube
P.D. for economizer:	5 Psi
Approach for economizer:	10° F

Compressor unit selected:

Model Number:	RW-222 Economizing
Power consumption:	351 BHP
Oil cooling heat removal:	175,000 Btu/Hr.
Economizer ET:	53.5° F
Liquid to evaporator:	63.5° F

High stage compressor construction:

Casting:	Maker standard
Design working pressure:	200 Psig

The P-H diagram for the high stage R-134a refrigeration circuit is shown in Figure 16-4:

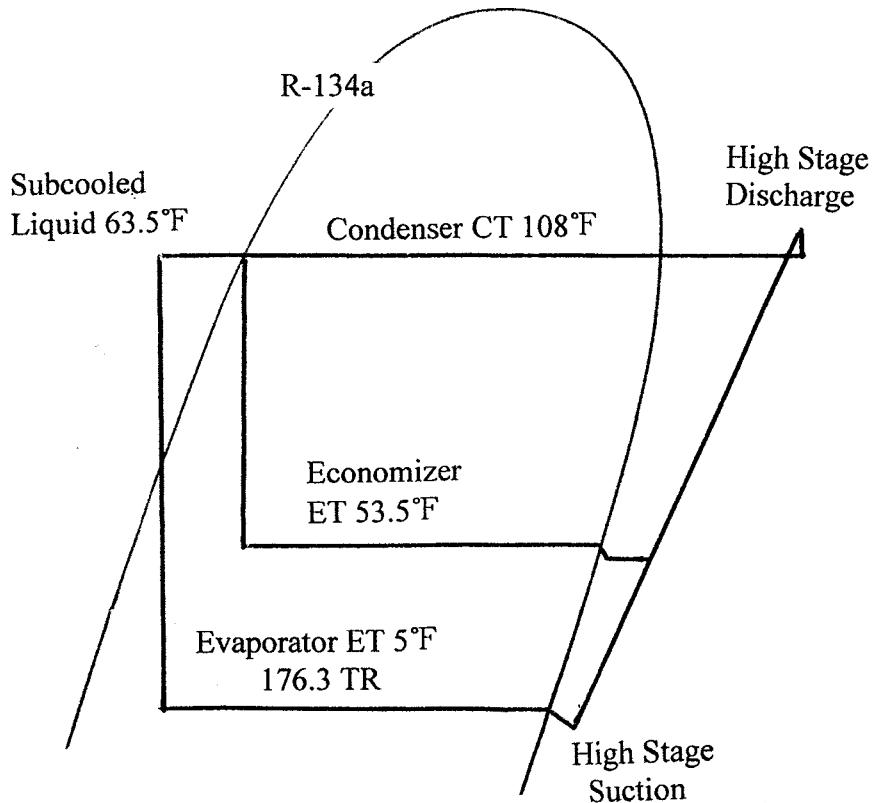


Figure 16-4 P-H Diagram for R-134a High Stage Refrigeration Circuit

The design working pressure for the high stage refrigeration system is 200 Psig.

The heat rejection to the water cooled condenser:

$$= 176.3 \times 12,000 + 351 \times 2545 - 175,000$$

$$= 2,833,895 \text{ Btu/Hr}$$

Cooling water flow for condenser:

$$\text{GPM} = \frac{\text{Btu/Hr}}{499.8 \times \Delta T}$$

$$= \frac{2,833,895}{499.8 \times (95 - 85)}$$

$$= 567 \text{ GPM}$$

The refrigerant flow diagram for the high stage refrigeration system is shown as in the Figure 16-5:

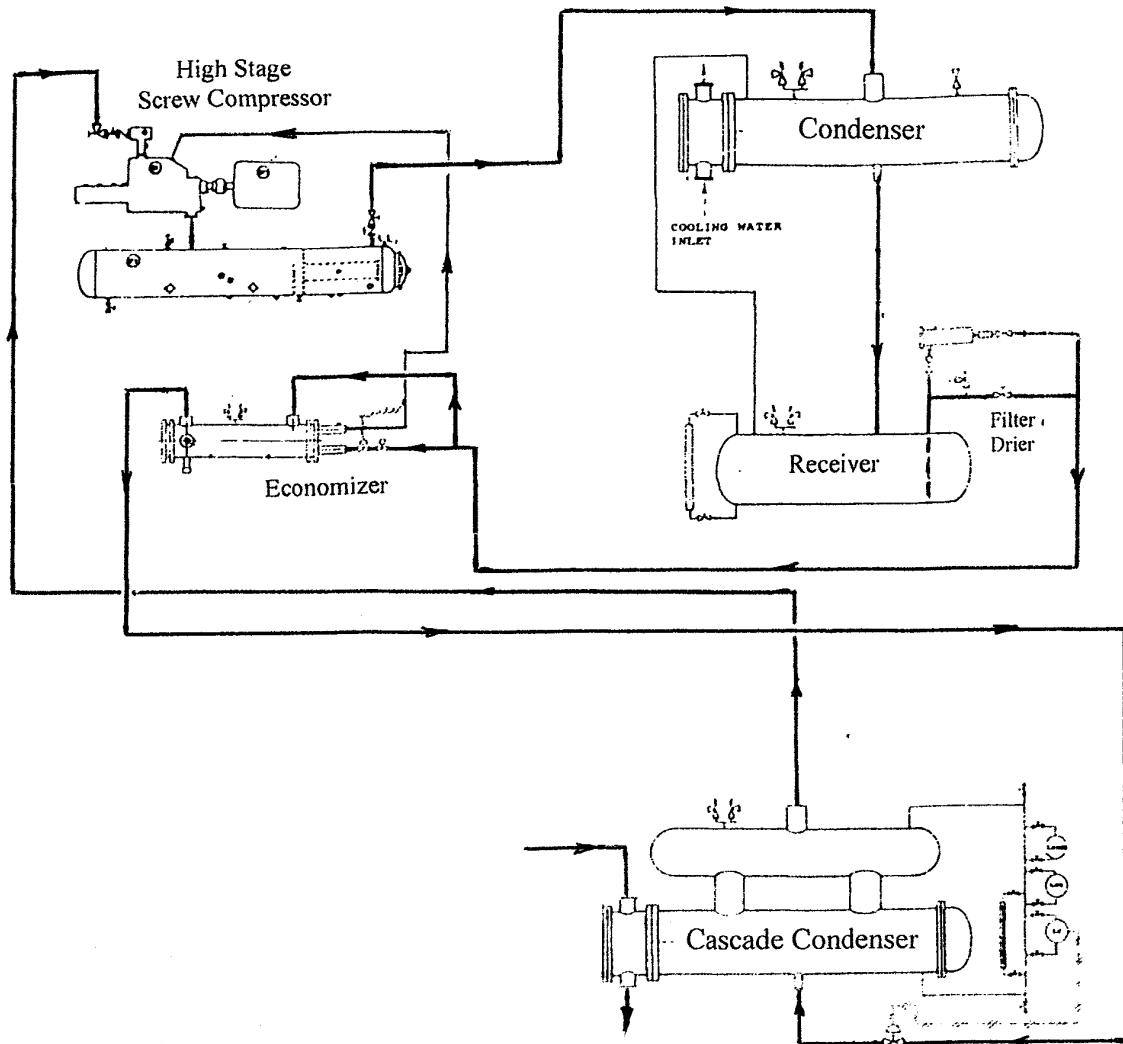


Figure 16-5 Refrigerant Flow Diagram for the R-134a Refrigeration System

Operating conditions and specifications for the water cooled condenser for the high stage refrigeration circuit:

Heat load:	2,833,895 Btu/Hr
Construction:	TEMA-B
Tube Side:	
Tubes:	16 BWG
Material:	Carbon steel

Water flow:	567 GPM
Water inlet & outlet temperature:	85°F to 95°F
Design working pressure:	150 Psig
Shell Side:	
Refrigerant:	R-134a
condensing temperature:	108°F
Design working pressure:	200 Psig

The P-H diagram for the cascade system is shown in Figure 16-6 which is combining the Figure 16-2 and Figure 16-4:

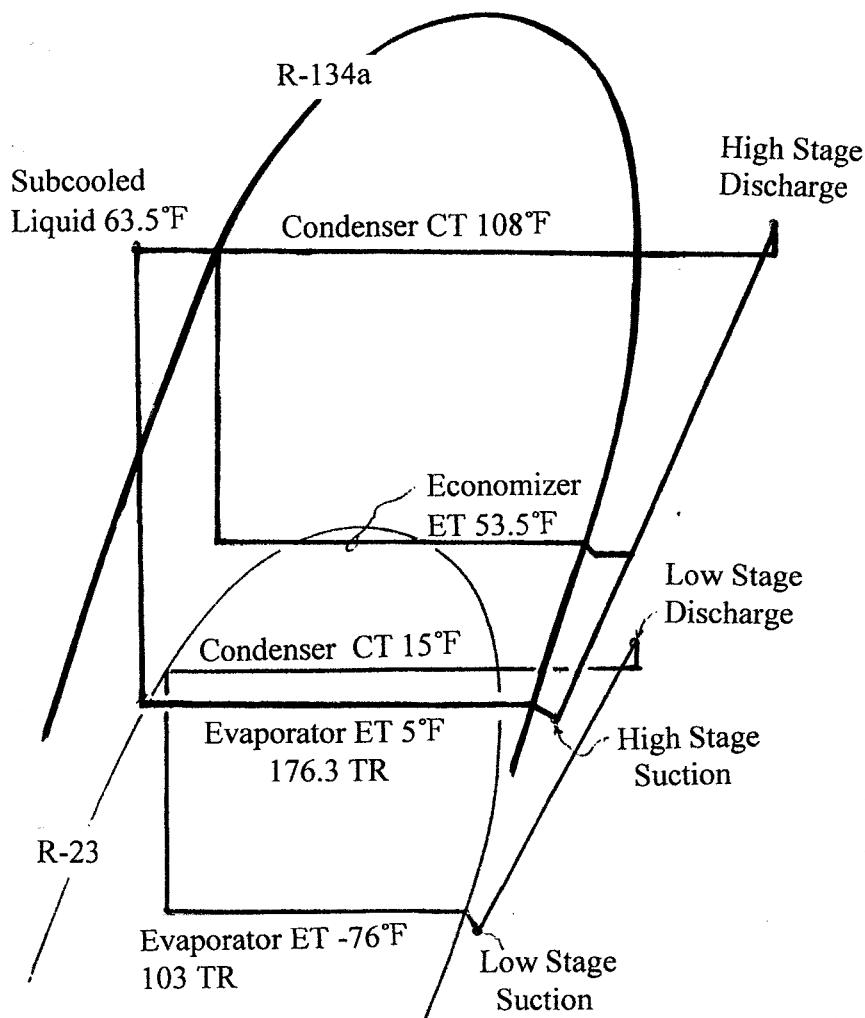


Figure 16-6 P-H Diagram for the Cascade System

The refrigerant flow diagram for the cascade system is shown in Figure 16-7 which is the combination of the Figure 16-3 and Figure 16-5.

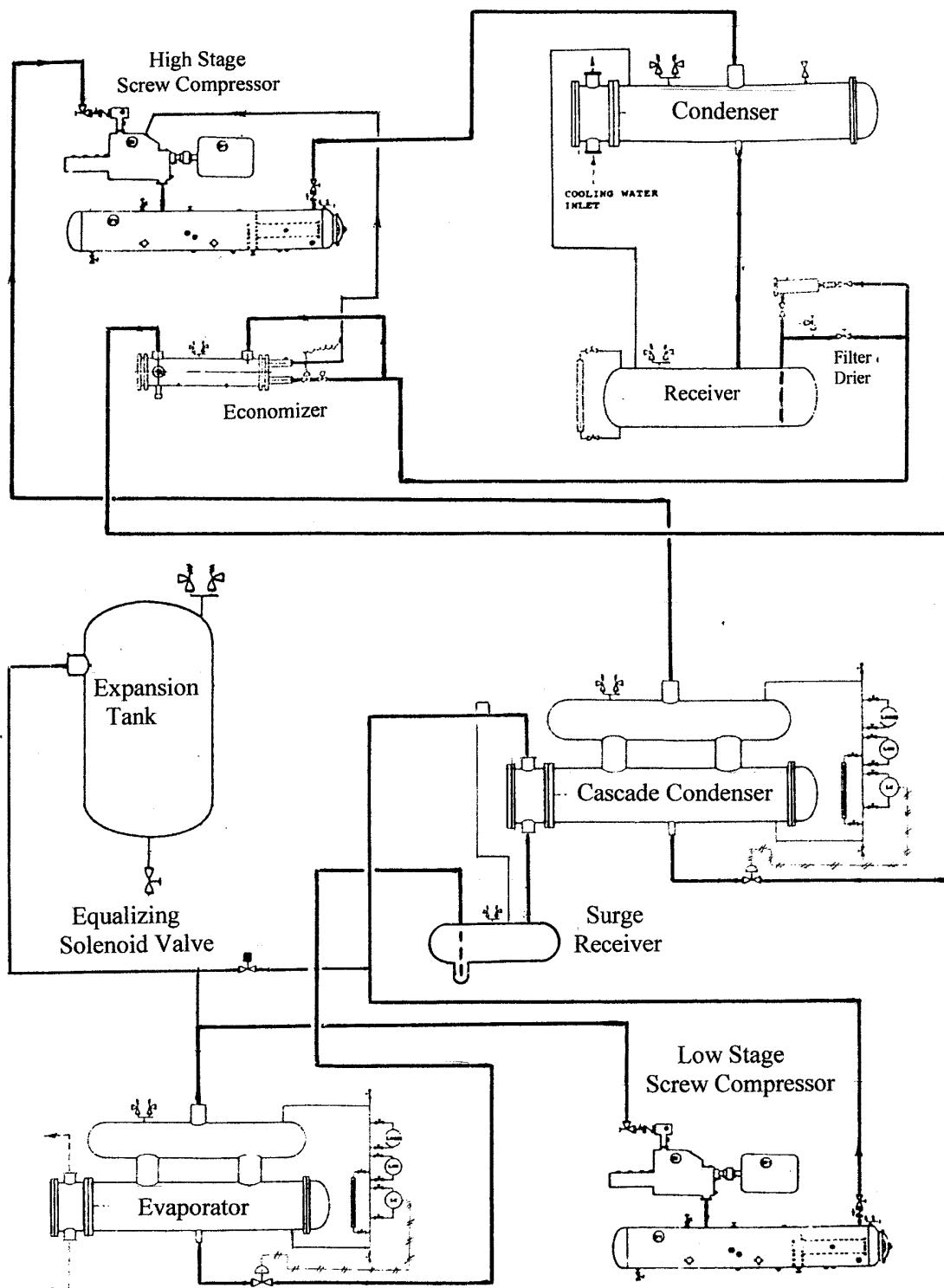


Figure 16-7 Refrigerant Flow Diagram for the Cascade System

Operating conditions and specifications for the cascade condenser:

Heat load:	176.3 TR
Heat Exchanger design:	Flooded, Full Bundle with surge drum
Construction:	TEMA-B
Tube Side:	
Tubes:	14 BWG
Material:	Carbon steel
Gas:	R-23
R-23 flow:	320 Lbs/Min
Condensing temperature:	15°F
Leaving R-23 temperature:	15°F
Inlet pressure:	279 Psia
Fouling factor:	0.001
Design working pressure:	300 Psig
Shell Side:	
Refrigerant:	R-134a
Refrigerant feed:	Flooded
Liquid to evaporator temperature:	63.5°F
Liquid pressure to evaporator:	156.5 Psia
Evaporative temperature:	5°F
Design working pressure:	200 Psig