Case – 14 Chlorine Condensing

Chlorine has many uses such as for making Plastics, Polyethylene, Chemicals, Water Treatments, cleaning solvents and Etc.

Chlorine gas is produced by using electrolysis process from sodium chloride solution in electrolytic cells. The gas collected in never pure and it is a mixture of rich chorine gas with a small percent of none condensable such as air, hydrogen and carbon dioxide.

Refrigeration is needed to condense or recover the chlorine from the mixture. Higher the recovery rate, lower the evaporative temperature is required. Figure 5-1 shows the typical chlorine condensing temperature curve for a typical chlorine mixture of 95% chlorine and 5% of non-condensable at the inlet pressure of 35 psig.

For most projects, the recovery rate is usually about 98%; it might not be economical to have very high chlorine recovery rate. See the partial chlorine curve shown in Figure 5-1, the partial chlorine condensing temperature is about -12^o F for 95% recovery rate. However, the chlorine partial condensing temperature might be lower to -27^o if the recovery rate increases to 97%; partial condensing temperature needs to be dropped to below -110^o F if the recovery rate is to be more than 99%. The chlorine recovery rate is never 100%.

Chlorine is a non-inflammable gas when it is presence or mix with air or carbon dioxide. However, when it is combined with some other compounds, it might become hazardous tendency. Hydrogen might be generated during the process of making the chlorine gas, it is imperative that the hydrogen is kept below 4% by Mole in the gas mixture; otherwise the gas mixture shall become exceedingly explosive. It is not suggested to use Ammonia as refrigerant for chlorine condensing system, because when chlorine mixes with ammonia, it forms nitrogen trichloride which is a very explosive substance also.

During the design of the chlorine condensing refrigeration system, it is important to check if the hydrogen gas contents in the sniff gas (tail gas) exceeds 4% mole. The sniff gas or tail gas or residue gas is the combination of chlorine gas plus other inert gases leaving the final partial condensing temperature from the refrigeration system.

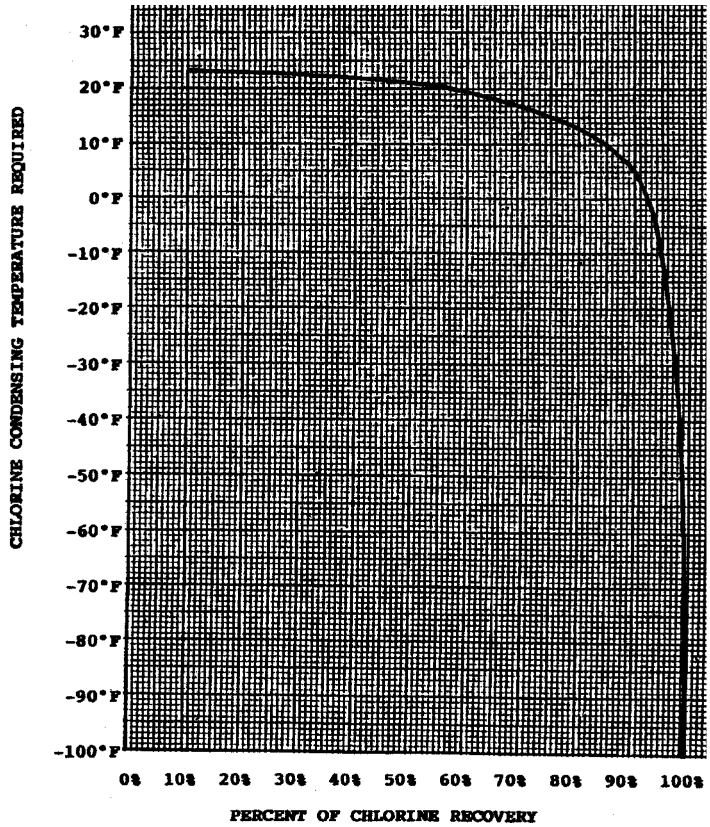

Figure 14-1 Typical Chlorine Condensing Temperature

Higher the recovery rate requires lower the partial condensing temperature. If the chlorine partial condensing is lower than -30° F, it is economical and lower power consumption to use two stages condensing consists of primary and secondary liquefaction. As rule of thumb from experiments, the primary liquefier carries about 85~90% of the recovery and the secondary shares 10~15% of the load.

Chlorine partial condensing temperature and liquefaction are to be calculated by the gas mixture equilibrium computer program; the chlorine condenser and the evaporative temperature are also to be determined by computer equilibrium software which is usually available from the manufacturer. The equilibrium calculation program is also available from various publishing companies. Manual calculation information for estimate is available, but it is not accurate enough as compare to computer program.

This is a case of refrigeration system for chlorine condensing, the chlorine feed gas flow inlet conditions and requirements are as the following:

84.7 Psia, 100° F
98.1% recovery rate required
Chlorine feed gas flow:

Chlorine	:	14,250 Lbs/Hr
Air	:	604 Lbs/Hr
Carbon Dioxide	:	17 Lbs/Hr
Hydrogen	:	2.3 Lbs/Hr
Total Flow:		14,873.3 Lbs/Hr

From the computer program, it shows to have 98.1% recovery, the final partial condensing of the chlorine gas requires -57° F, therefore, a two stage liquefaction refrigeration system is used. First stage to have 20° F liquid leaving. The chlorine liquid condensed at this temperature level is 11,570 Lbs/Hr; the heat load is 140 TR; the gas mixture composition leaving the first stage liquefier to the second stage liquefier is as the following:

Chlorine	:	2,680 Lbs/Hr
Air	:	604 Lbs/Hr
Carbon Dioxide	:	17 Lbs/Hr
Hydrogen	:	2.3 Lbs/Hr

Check the hydrogen content at this point:

Gas Component	Flow Lbs/Hr	Molecular Weight	Mole/Hr Flow	Mole %
Chlorine	2,680	70.906	37.797	62.81
Air	604	28.964	20.853	34.65
Carbon Dioxide	17	44.01	0.386	0.64
Hydrogen	2.3	2.016	1.141	**1.90**

The hydrogen content at this point is 1.90% mole which is less than 4%. No problems.

From the computer program, the chlorine condensed from the second stage liquefier heat exchanger is 2,410 Lbs/Hr at partial condensing temperature of -57° F; heat load for the secondary liquefier is 32 TR.

After 13,980 lbs/hr (98.1%) total chlorine recovered from first and the second stage liquefiers, the remainder chlorine in the sniff gas is 270 Lbs/Hr; the remainder gas composition of the sniff gas is as the following:

Chlorine	:	270 Lbs/Hr
Air	:	604 Lbs/Hr
Carbon Dioxide	:	17 Lbs/Hr

Hydrogen : 2.3 Lbs/Hr

Check the hydrogen content in the tail gas:

Gas Component	Flow Lbs/Hr	Molecular Weight	Mole/Hr Flow	Mole %
Chlorine	270	70.906	3.808	14.54
Air	604	28.964	20.853	79.63
Carbon Dioxide	17	44.01	0.386	1.47
Hydrogen	2.3	2.016	1.141	**4.36**

The mole percent of the hydrogen content in the sniff gas is 4.36% which is greater than 4% allowed. Therefore, air must be injected into to the gas stream before the secondary chlorine condenser to make the hydrogen content to be less then 4% mole in the sniff gas.

To be on the safety side, hydrogen content is targeted for 3.2% mole, it is estimated that the air quantity required in the tails flow is about 869 Lbs/Hr instead of 604 Lbs/Hr. i.e. a new air quantity of 265 Lbs/Hr is needed for the secondary liquefier and it is shown in Figure 14-2. The gas composition of the new sniff gas is as the following:

Chlorine : 270 Lbs/Hr
Air : 869 Lbs/Hr
Carbon Dioxide : 17 Lbs/Hr
Hydrogen : 2.3 Lbs/Hr

Recheck the hydrogen content in the tail gas with air injected:

Gas Component	Flow Lbs/Hr	Molecular Weight	Mole/Hr Flow	Mole %
Chlorine	270	70.906	3.808	10.78
Air	869	28.964	30.00	84.90
Carbon Dioxide	17	44.01	0.386	1.09
Hydrogen	2.3	2.016	1.141	**3.23**

The hydrogen concentration in the tail gas is now reduced to 3.23% mole which is less than 4% mole.

From computer program, the chlorine condensers are selected for the evaporative temperature and pressure drop as allocated for the chlorine condensing temperature as calculated for the liquefiers:

First Stage Chlorine Condenser: ET = -5^{o} F
Chlorine gas pressure drop = 1.5 Psi
Liquid and gas leaving temperature = 20^{o} F

Second Stage Chlorine Condenser: ET = -67° F
Chlorine gas pressure drop = 1.5 Psi
Liquid and gas leaving temperature = -57° F

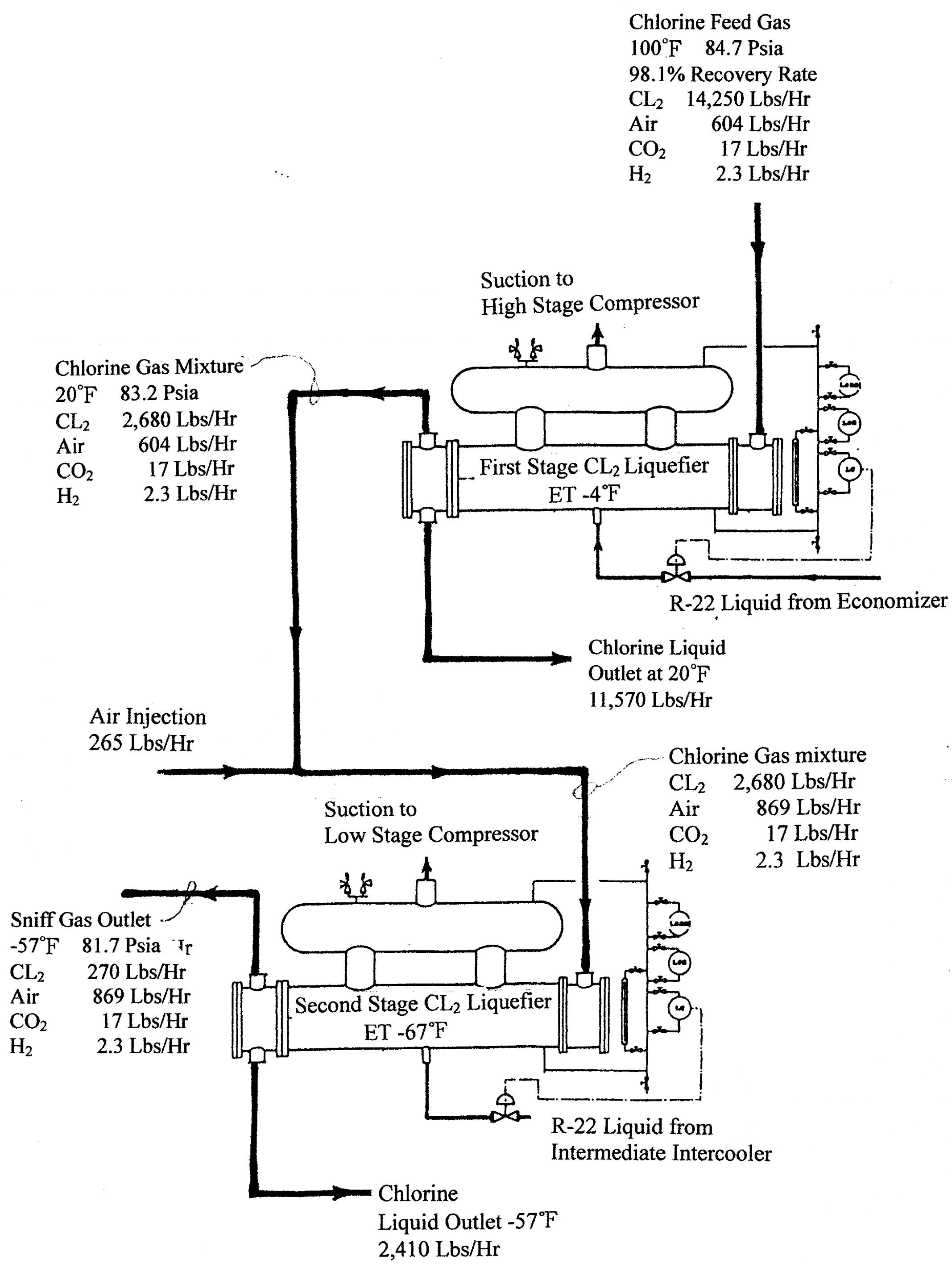

Figure 14-2 First and Secondary Chlorine Liquefiers

Refrigeration System Design and Design Approach:

The P-H diagram can be structured by following the design concepts and the logics step by step as the following:

Water cooled condenser is used, the condensing temperature for the condenser is selected for 108° F for water supply at 90° F, leaving at 100° F,

Two chlorine liquefiers are used; the evaporative temperature assigned to the First Stage Chlorine Condenser is -4° F for leaving gas of 20° F; the evaporative temperature assigned to the Second Stage Chlorine Condenser is -67° F for tail gas of -57 ° F.

It is logically to use a compound system for this two evaporative temperature levels refrigeration system. The TR is not big, it might too small for the use of centrifugal compressors. Therefore, screw compressors are proposed for the booster and high stage compression application.

Refrigerant use: R-22. Condensing pressure is 234.7 Psia. The evaporative pressure for the first stage liquefier is 35.5 Psia and the evaporative pressure for the secondary chlorine condenser is 7.2 Psia.

High stage compressor is to take care of the 140 TR load with ET of 20° F and the booster compressor is for the 32 TR load with ET of -67° F.

For the simplification of the refrigeration system design and cost saving, -4° F is designed to be the intermediate intercooling temperature for the compound system, so the suction gas can be combined together with the primary chlorine condenser and return to high stage compressor suction; For better power consumption, economizer is used for the high stage screw compressor. But, this system is a close coupled system within a central engine room. Therefore flash type economizing is used instead of shell-and-tube liquid subcooling economizer; the flash type economizer is combined with the receiver for cost saving. A high pressure float valve is used to drain the liquid refrigerant from condenser to the economizer-receiver; the flash gas is returned to the economizer connection of the high stage screw compressor.

The P-H diagram for this refrigeration cycle is now completed and it is shown in Figure 14-3.

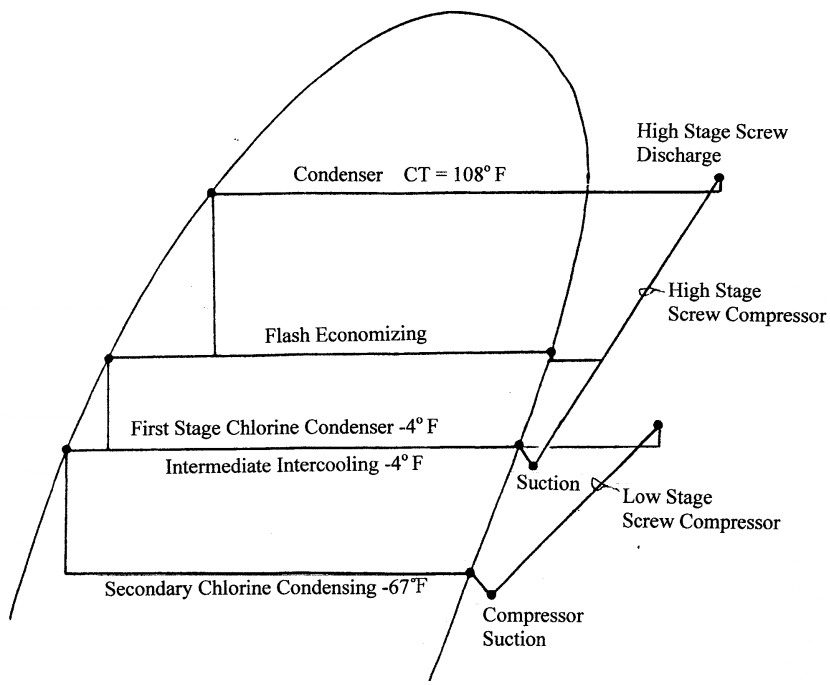

Figure 14-3 P-H Diagram of the Compound System for Chlorine Condensing

The functions shown in the P-H diagram are transformed to a refrigerant flow diagram as shown in Figure 14-4. The details of the chlorine gas flow for the two stage chlorine condensing with relative temperatures and pressure data are shown in Figure 14-2.

Screw compressor partial load capability is 5~100%, therefore, hot gas bypass is not required unless if the system is to be operation down to 0% for stand-by purpose.

A flash type intermediate intercooler and desuperheater for the compound operation are used for the booster and high stage compressor as shown in Figure 14-4; a double drums automatic purge unit (not shown) is suggested for the system; suction traps are not used because the gas/liquid separation is designed for the economizer-receiver and intermediate intercooler; full bundle heat exchanger with surge drum design are used for the chlorine condensers; a suction gas and liquid heat exchanger is provided for the suction of the booster compressor to produce a 25℉ superheat for the booster compressor.

The design suction temperature for the booster compressor is -42℉ instead of -67℉ saturated. However, the liquid subcooled by this heat exchanger is not counted for the NRE for the secondary chlorine condenser.

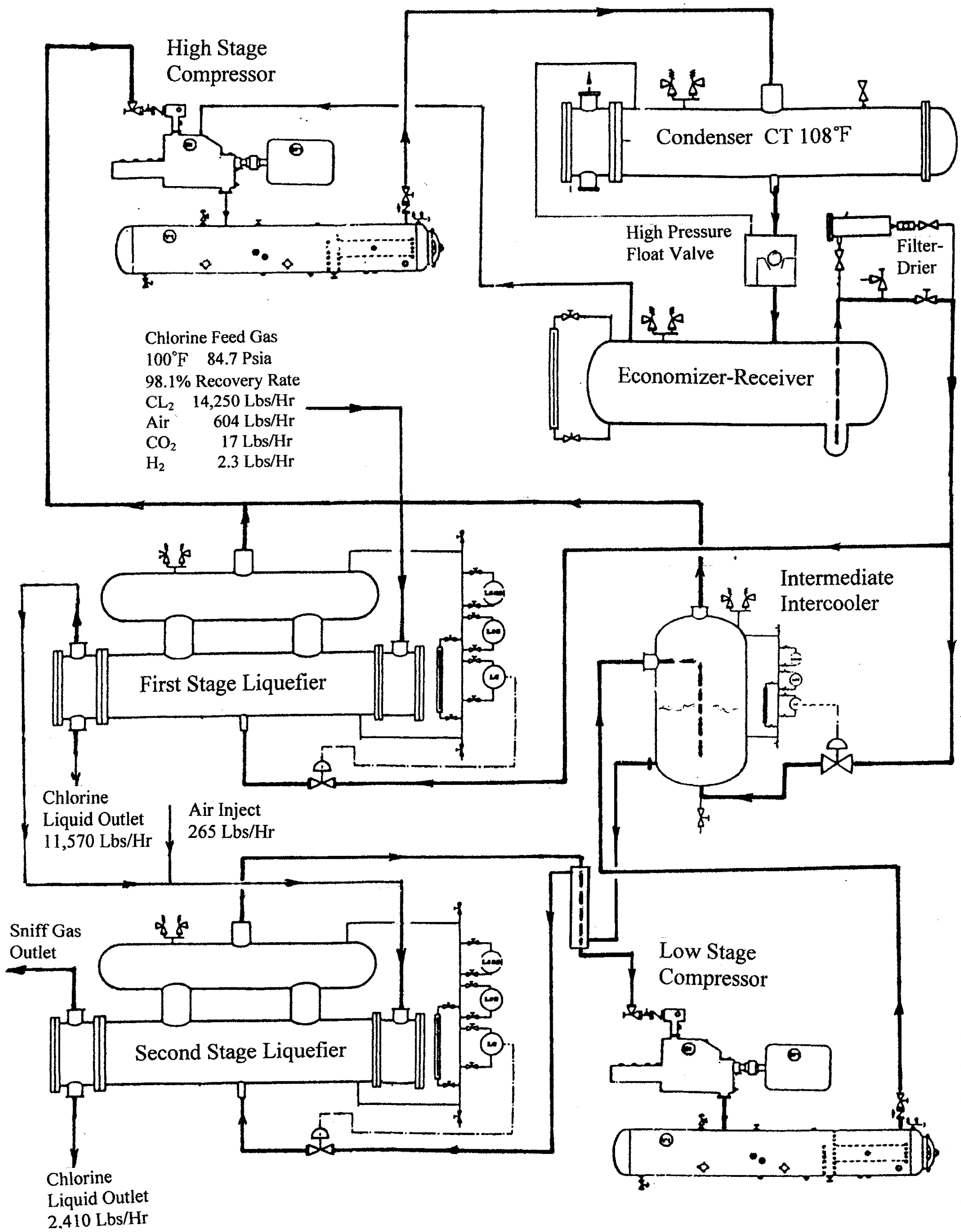

Figure 14-4 Refrigeration System for the Chlorine Condensing Compound Refrigeration System

Compressor Selection:

Booster Screw Compressor Selection:

Operating conditions for the low stage compressor:

Capacity:	32 TR
Refrigerant:	R-22
Intermediate temperature:	-4℉
Evaporative temperature:	-67℉
Suction superheat:	25℉
Suction pressure drop:	0.3 Psi
Discharge pressure drop:	1.0 Psi
Economizer:	None
Oil cooling:	Water Cooled
Oil pump:	Full-lube
Discharge valves:	Maker's standard
Suction valves:	Maker's standard
Power supply:	460-3-60, 120-1-60
Compressor speed:	3,540 rpm

Compressor selected by manufacturer for the above operating conditions:

Model:	RW-134
Power consumption:	79 BHP
Oil cooling heat removal:	78,500 Btu/Hr

Heat Load for High Stage Compressor:

= Heat load from first stage chlorine condenser + Heat rejection from low stage compressor

$$= 140 + 32 + \frac{79 \times 2545 - 78{,}500}{12{,}000}$$

= 140 + 32 + 10.2

= 182.2 TR

High Stage Screw Compressor Selection:

Operating conditions for the high stage compressor:

Capacity:	182.2 TR
Refrigerant:	R-22

Condensing temperature:	108℉
Evaporative temperature:	-4℉
Suction superheat:	5℉
Suction pressure drop:	0.5 Psi
Discharge pressure drop:	1.0 Psi
Economizer:	Flash type
Economizer line PD:	5.0 psi
Oil cooling:	Water Cooled
Oil pump:	Pre-lube
Discharge valves:	Maker's standard
Suction valves:	Maker's standard
Power supply:	460-3-60, 120-1-60
Compressor speed:	3,540 rpm

Compressor selected by manufacturer for the above operating conditions:

Model:	RW-177 (W/Flash Economizing)
Power consumption:	403.1 BHP
Oil cooling heat removal:	408,300 Btu/Hr
Liquid to first stage Chlorine condenser:	41.3℉
Liquid to intermediate Intercooler:	41.3℉

Cooling water for water cooled condenser:

Heat rejection to condenser = 182.2 x 12,000 + 403.1 x 2,545 – 408,300

= 2,186,400 + 1,025,890 – 408,200

= 2,804,090 Btu/Hr

Cooling water 90℉ entering and 100℉ leaving

$$GPM = \frac{Btu/Hr}{499.8 \times (T2 - T1)}$$

$$= \frac{2,804,090}{499.8 \times (100 - 90)}$$

$$= 561$$

Cooling water 561 GPM required, 90℉ to 100℉.