# FINAL REPORT

# WIND TUNNEL PRESSURIZATION AND RECOVERY SYSTEM

(NASA-CR-184591) WIND TUNNEL PRESSURIZATION AND RECOVERY SYSTEM Final Report (University of the Pacific) 94 p CSCL 14B
N89-18499
Unclas
G3/09 0179684

For Research Grant
NAG 2-505

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December, 1988
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Tab. 1: Design Team 1
Tab. 2: Design Team 2

Submitted to:
NASA Ames Research Center
University Affairs Office
Dr. Frank Steinle

# ABSTRACT

This project was undertaken by the students at the University of the Pacific in the course, "Applied Thermodynamics." The design project was carried out by two student design teams: One using activated charcoal in the recovery process, and one using liquid nitrogen in the recovery process. The project was directed by Professor Edwin Pejack, Chairman of the Department of Mechanical Engineering. The design teams gave a presentation of their results at NASA Ames in November, 1987.

# WIND TUNNEL PRESSURIZATION AND RECOVERY SYSTEM

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DECEMBER 15, 1987
MOFFETT FIELD, CALIFORNIA

This priliminary design of wind tunnel pressurization and recovery of Freon-12 proposed to be a part of the NASA Ames 12 X 12 feet pressurized wind tunnel at Sunnyvale, California is done by four senior Mechanical Engineering students of University of the Pacific, Stockton, CA 95211.

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# ABSTRACT

The high density, low toxicity characteristics of refrigerant-12 (dichlorodifluoromethane) make it an ideal gas for wind tunnel testing. Present limitations on R-12 emissions, set to slow the rate of ozone deterioration, pose a difficult problem in recovery and handling of large quanities of R-12. This preliminary design report is a possible solution to the problem of R-12 handling in wind tunnel testing. The design incorporates cold temperature condensation with secondary purification of the R-12/air mixture by adsorption.

# TABLE OF CONTENTS

# WIND TUNNEL PRESSURIZATION AND RECOVERY SYSTEM

## INTRODUCTION

This report is a preliminary design for a refrigerant-12 (Dichlorodifluoromethane) recovery and pressurization system. The proposed system is to be a part of the NASA AMES 12 x 12 foot pressurized wind tunnel at Sunnyvale, California. The gas handling/liquefaction system would permit the tunnel to be switched between air and R-12 up to a maximum pressure of 7 atmosphere. Items in this report include operation concepts, system flow rates, major equipment items and and process specifications such as time and power required. The major considerations in the design is to minimize the emission of R-12 to the environment in order to maintain within the limits set by the Environmental Protection Agency (EPA).

The existing 12 x 12 foot pressurized wind tunnel has been de-rated from 7 atmosphere down to 1 atmosphere. The old structure has signs of fatigue, cracks have been found in various areas on the wind tunnel shell. In order to resume high pressure wind tunnel operation, NASA AMES plan to replace the old wind tunnel with a new tunnel designed for operation at 7 atmosphere of air or R-12. The use of a denser fluid such as R-12 in the wind tunnel testing is one way to achieve higher test Reynold numbers, and therefore more nearly simulate true viscous effects in the wind tunnel. Presently, the emission of refrigerant type gases into the environment is a major concern due to the deterioration of the ozone layer. Consequently the use of the R-12 in large quantities require a well designed system for recovery of the R-12 with particular attention focused on control of emission.

## DESIGN ANALYSIS AND SELECTION

Many various concepts of the R-12 pressurization and recovery were analyzed in the early stages of the project. Liquefaction within the tunnel as well as external liquefaction were analyzed. In either case the most effective method of condensation was determined to be at cold temperature with possible increased pressure. The low temperature could be achieved with the use of cryogenics or a typical vapor compression refrigeration cycle. Total of extraction of the R-12 gas would be approached with the use of some type of filter or process which will trap R-12 but allow air to pass through. Substances such as silica gel, molecular sieves and various types of the adsorbents were examined to determine if they would meet the requirements of the design.

The system configuration chosen for further analysis consists of :

- Pumps and compressors capable of pressurizing or evacuating the tunnel from 7 atm to 0.04 atm.
- Primary liquefaction of the R-12 gas with cold temperature ( -80 degree F) supplied by a

refrigeration system.

- Secondary R-12/air separation with activated carbon which is maintained at low temperature.
- Desorbtion of R-12 gas with use of hot air.
- Long term liquid R-12 storage tank.
- Various heat exchangers, liquid pumps, driers,oil traps and other support equipment.
- A control system capable of monitoring various stages of the process to ensure optimum operating conditions at all times.

OPERATION OF SYSTEM DURING RECOVERY (see figure 1)

After running the test with 7 atmosphere of R-12 in the wind tunnel, the gas will be recovered by passing it through the recovery system. The main components of the recovery system consist of Carrier compressors, liquid ring vacuum pumps, valves and throttle valves, heat exchangers, primary separator, pumps, storage tank, and secondary separator of activated carbon. Figure 1 shows the proposed system using adsorption process.

At the beginning of the process gaseous R-12 is at 7 atmosphere, the valve V2 is opened to let the R-12 pass the throttle valve to reduce its pressure as well as to control its flowrate. By passing it through Heat Exchanger 1 (between 1 and 2), the R-12 vapor is cooled by passing liquid R-12 from pump 1 or by refrigeration system. Then it is passed through a large refrigeration unit at 3, the R-12 vapor will be liquefied while

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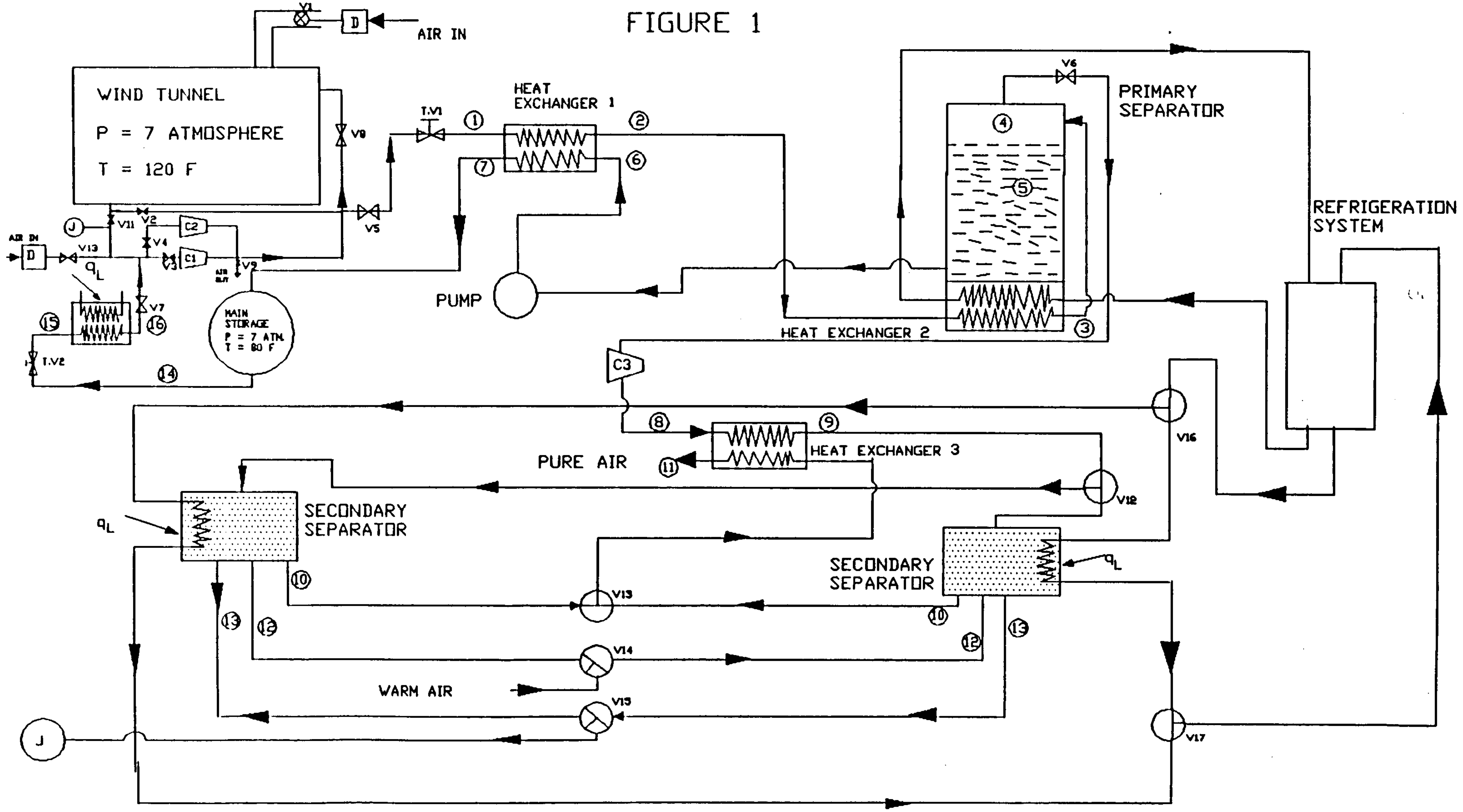
# RECOVERY SYSTEM

FIGURE 1



passing through the primary separator. Liquid R-12 Pump 1 is used to transport the refrigerant from the primary separator tank to main storage at 7 atm. The temperature of the fluid in storage will be that of ambient, assuming that it will have sufficient pressure to remain liquid.

When the Carrier compressor C1 is activated, first valve V2 is closed while V4 is opened. The C1 is capable of reducing the pressure inside the wind tunnel down to 0.25 atm. When this pressure is achieved, the liquid ring pump that is capable of reducing the pressure down to 0.04 atm. will be activated. This is the lowest pressure that can be achieved. At this point air from the atmosphere is dehumidified by dryers and then introduced into the tunnel at V1 while running the compressor C2. Pump 1 which pumps liquid R-12 to main storage will be shut down if the liquid R-12 level does not exceed the specified height since this level must be maintained to meet pump head pressure requirements which prevents cavitation.

While air is being introduced, the secondary separator which separates R-12 from air by adsorption process is activated. This is done when air is sensed at the primary separator (4). The valve V6 is opened and the compressor C3 is started to let the mixture of air and R-12 to be cooled which aids in the adsorption process. The adsorbent beds of activated carbon are maintained at low temperature by refrigeration system. The cool pure air (at 10) that leaves the adsorbent beds will be used to cool the mixture of air and R-12 from C3 in heat exchanger 3 before being released to the atmosphere at point 11. A sensing device at 11 will detect the concentration of R-12 in the mixture of air. If the concentration of R-12 exceededs the permissible value, an alarm will be set and the system will be shut down.

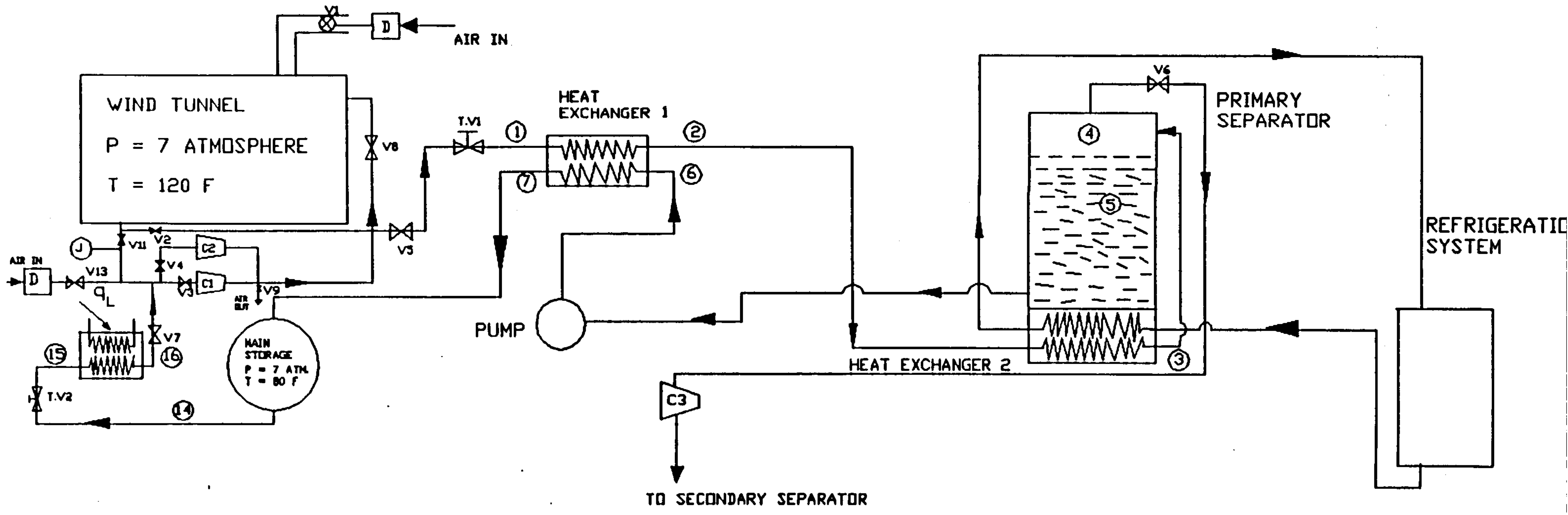
In regenerating the R-12 from the adsorbent, valve V10 will be closed and valve V11 will be opened to let warm air flow through the coils inside the secondary separator. The regenerated R-12 which leaves point 13 is passed through the vacuum pump to aid desorption process before it is taken to J. Then the mixture will pass through the primary separator where it is returned to the purifying process again. The volume of the adsorption beds will be sized to allow adsorption of the total mass of R-12 remaining in the wind tunnel at 0.04 atm. This will eliminate the need for regeneration while the secondary process is in operation. Desorption process can then proceed as a parallel task with wind tunnel work.

## PRIMARY SEPARATION (see figure 2)

The primary separation system consists of heat exchangers, a tank, a refrigeration system, a liquid pump, and the main storage tank. The tank size for the primary separator is 6 feet is in diameter and 10 feet in height, (volume of 2100 gallons). It is fully insulated and to be maintained at -80 F. The size of the liquid pump is chosen to be 180 gal/min in order to handle to condensed R-12 from the wind tunnel.

PRIMARY SEPARATION SYSTEM

FIGURE 2



Prior to the start of recovery process, the primary separator tank is initially filled with liquid refrigerant-12 at about 50% of its volume. The reasons for the additional liquid R-12 are to maintain adequate suction pressure at the liquid refrigerant-12 pump and to supply a cold mass flow of refrigerant-12 in the cold side of heat exchanger 1 is primarily used to reduce the heat of compression from the previous process. Meanwhile, the low temperature source for the primary separator is supplied directly by the refrigeration system. In order to ensure that the liquefaction process is maximum at the heat exchanger 2, a control system is installed at its outlet to sense any uncondensed refrigerant-12, so that the proper adjustment of the mass flow rate can be made at the throttle valve 1. Another controller needed in the primary separator is a liquid level controller to maintain the specified liquid level in the primary tank. This controller will automatically turn the liquid pump on and off so that the level is maintained at one half of the tank throughout the process.

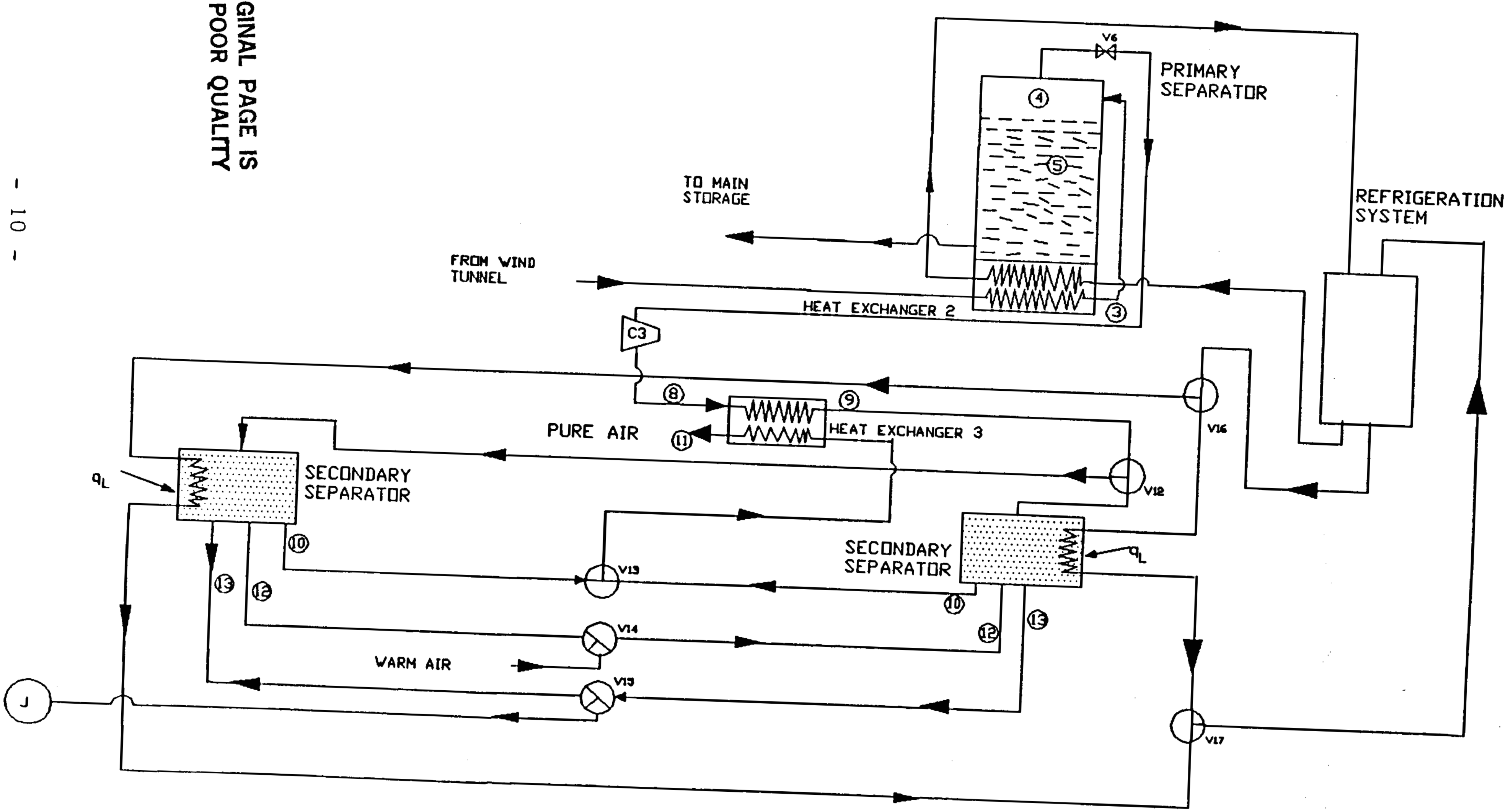
The final stage in the primary system process is to transport and store the liquid refrigerant-12 into the main storage tank. This liquid refrigerant-12, which is pumped out from the primary separator tank is transferred through the heat exchanger 1 to increase the temperature before storing it at 7 atmosphere and 80 degrees F.

## SECONDARY SEPARATION (see figure 3)

As stated in the design selection, the Secondary R-12 Seperation System will utilize activated carbon to adsorb the gaseous R-12. Activated carbon was found to be the most efficient method of separating air from refrigerants. The adsorption process reduces the partial pressure of the R-12 to a very low value, resulting in very low emission to the environment. Inspection of the adsorbent isotherm graph 2 on the next page, supplied by American Norit Company Inc., indicates that as the temperature of adsorbent decreases, its adsorption capacity increases. The amount of activated carbon required was determined from the adsorbent isotherm. Assuming that the adsorbent bed is refrigerated to 32 F, a total of 63,000 lbs of activated carbon is required to adsorb the total amount of R-12 remaining at 0.04 atm. (12,000 lb of R-12, see Appendix for calculations). A critical variable in the adsorption process is the velocity of the air/R-12 mixture. In order to maximize adsorption, an air/R-12 mixture velocity of 50 ft/min was recommended by various activated carbon manufacturers. A common large adsorption bed size is 6 ft in diameter. These parameters were used to design the adsorption bed size and to determine the maximum allowable flow rate through the beds. (See calculations in Appendix and graph 3.) The secondary separation process time may be decreased by increasing the number of adsorption beds thus allowing the flow rate to increase.

# SECONDARY SEPARATION SYSTEM

FIGURE 3



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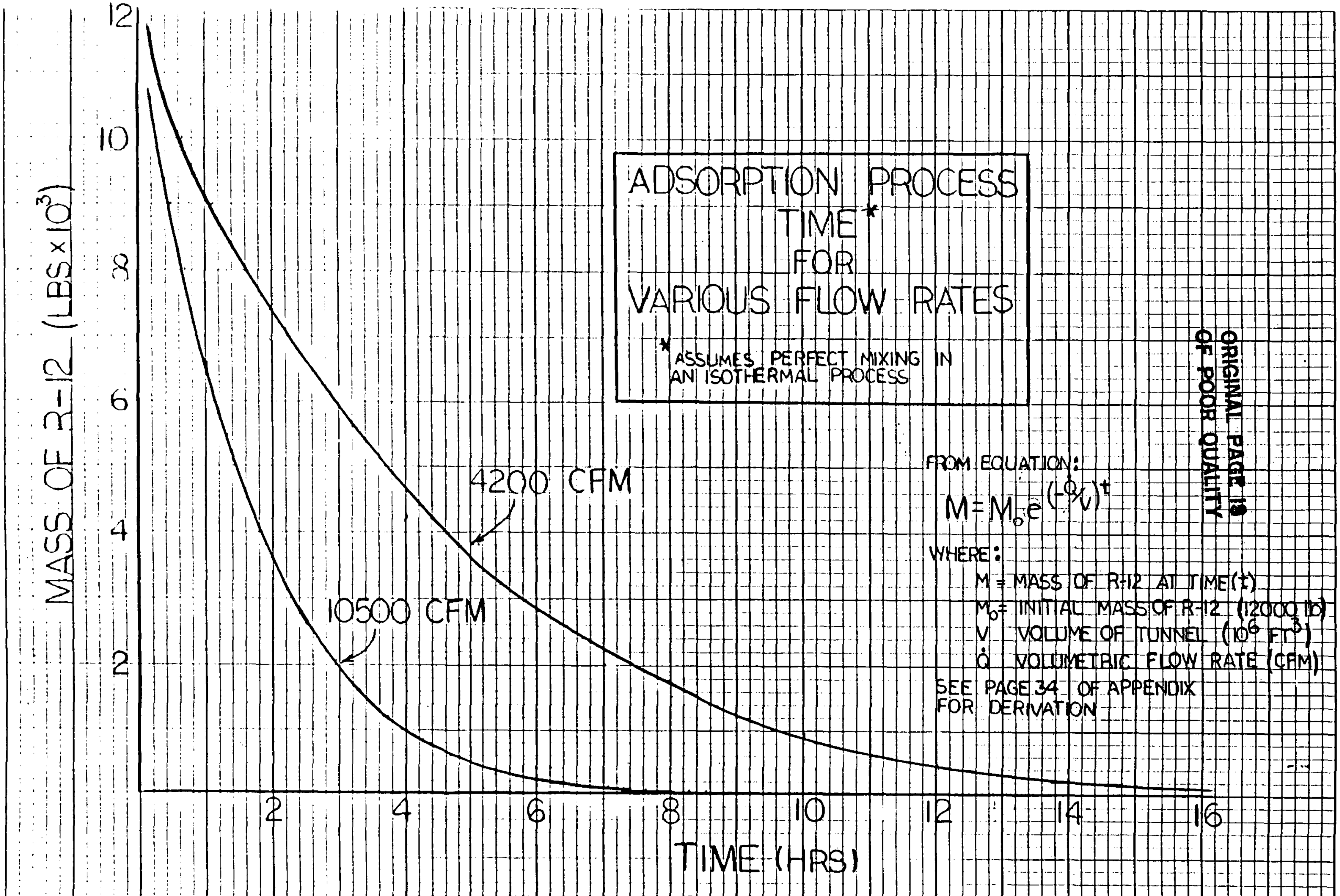

ADSORPTION PROCESS
TIME*
FOR
VARIOUS FLOW RATES

*ASSUMES PERFECT MIXING IN AN ISOTHERMAL PROCESS

FROM EQUATION:

$$M = M_o e^{(-\dot{Q}/V)t}$$

WHERE:

M = MASS OF R-12 AT TIME(t)
$M_o$ = INITIAL MASS OF R-12 (12000 lb)
V VOLUME OF TUNNEL ($10^6$ FT$^3$)
$\dot{Q}$ VOLUMETRIC FLOW RATE (CFM)

SEE PAGE 34 OF APPENDIX FOR DERIVATION

GRAPH 1

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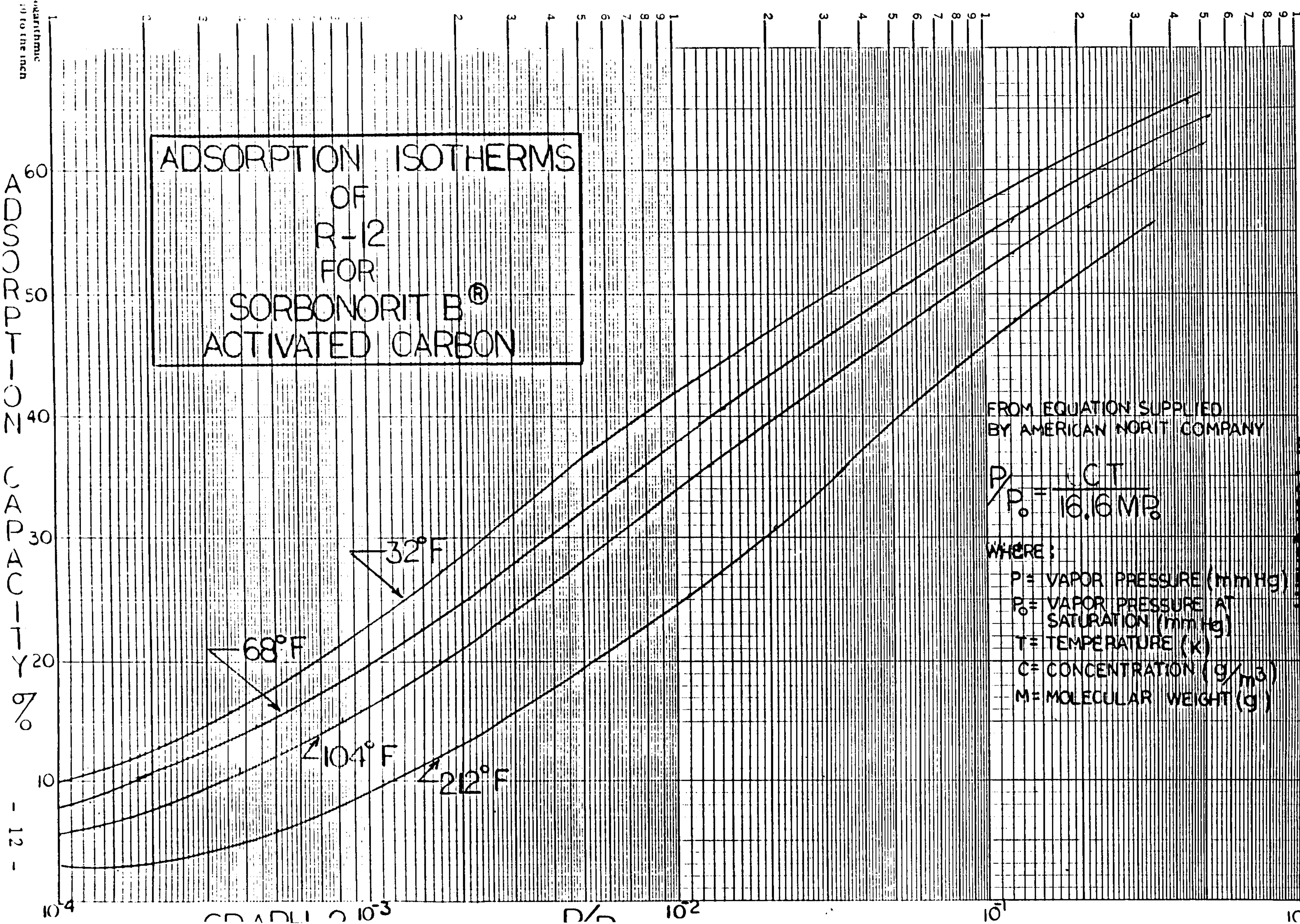


ADSORPTION ISOTHERMS OF R-12 FOR SORBONORIT B® ACTIVATED CARBON

FROM EQUATION SUPPLIED BY AMERICAN NORIT COMPANY

$$P/P_o = \frac{CT}{16.16 MP_o}$$

WHERE;

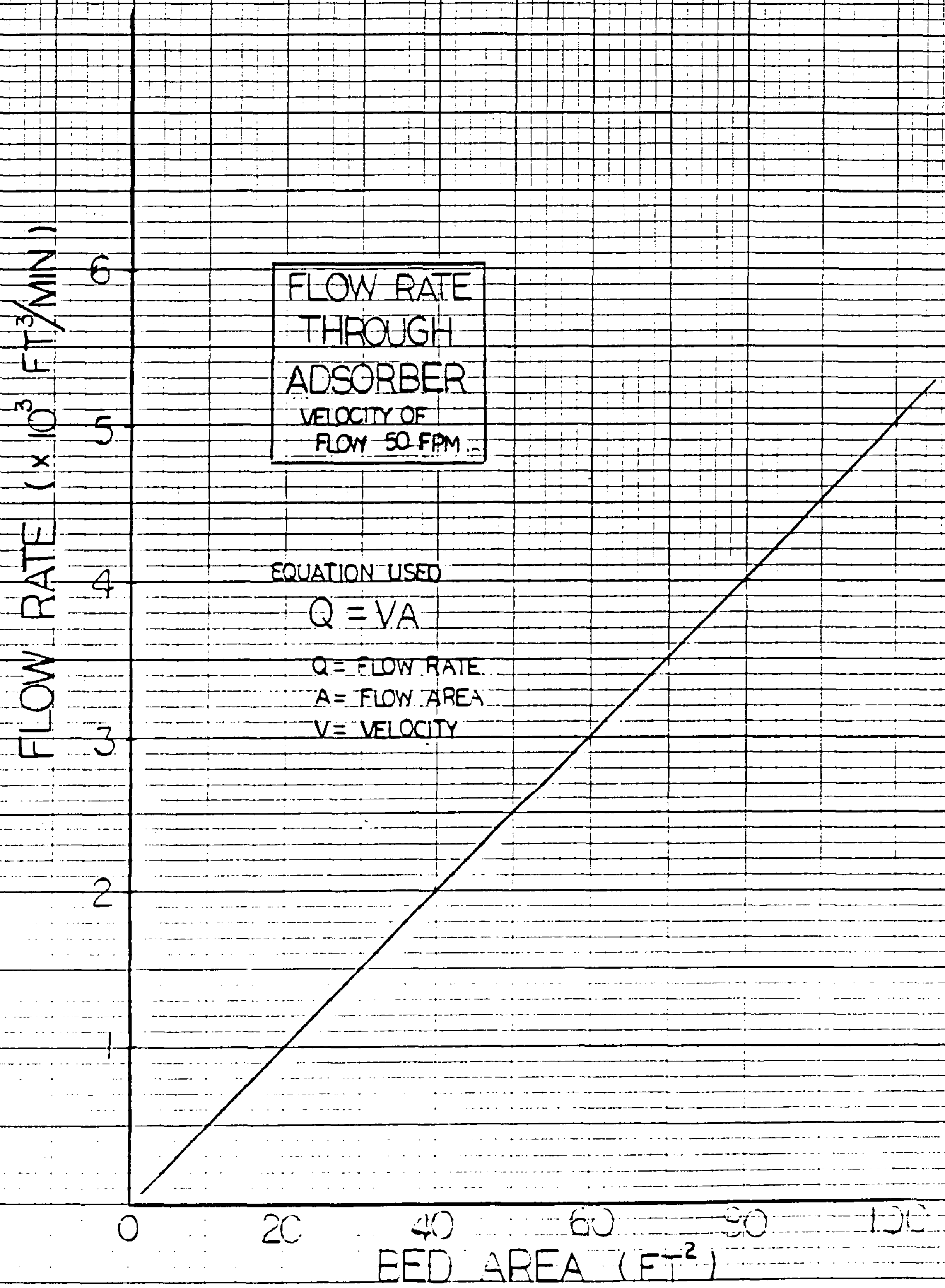
P = VAPOR PRESSURE (mm Hg)

$P_o$ = VAPOR PRESSURE AT SATURATION (mm Hg)

T = TEMPERATURE (K)

C = CONCENTRATION (g/m³)

M = MOLECULAR WEIGHT (g)


FLOW RATE (x 10³ FT³/MIN)
6
5
4
3
2
1
FLOW RATE THROUGH ADSORBER
VELOCITY OF FLOW 50 FPM
EQUATION USED
Q = VA
Q = FLOW RATE
A = FLOW AREA
V = VELOCITY
0
20
40
60
80
100
BED AREA (FT²)

GRAPH 3

Once the wind tunnel pressure is at 0.04 atm., air will be introduced into the wind tunnel. A variable conductance valve will be automatically controlled in order to maintain the pressure of the air in the tunnel at 0.1 atmosphere. The air will also be dehumidified with silica-gel to prevent water vapor condensation in the cold condenser coils of the primary separator. The air/R-12 mixture will be cooled down to a very low temperature as it passes through the primary separator. Once air is detected in the primary separator, the adsorption process compressor (C3) is activated. Compressor C3 is needed in order to overcome the pressure drop across the adsorbent beds and exhaust the purified air to the atmosphere. The compressed air/R-12 is then cooled by the cold purified air from the adsorbent bed before reaching the adsorbent beds. The process will continue until the mass of refrigerant in the tank is as low as reasonably achievable. (See graph 1 of adsorption process time.)

Desorption of the activated carbon is achieved with the use of hot air which is passed through coils with-in the beds. The desorbed R-12 gas will be introduced back into the primary system where it will be compressed and liquified. The ring pumps will be utilized to speed up the desorption process. The desorption time is directly related to the temperature of the hot air. Most activated carbon manufacturers recommened the use of high temperature steam in the regeneration process. This method was not used, the added equipment required to remove the moisture from the R-12 would complicate the system.

## PRESSURIZATION WITH R-12

When the test is desired to be run with high density fluid in the tunnel, the liquid R-12 from the main storage will be vaporized before filling process can be done. When pressurizing the tunnel with R-12, there are two major steps : 1) Evacuation of air with-in the tunnel, and 2) Evaporation and pressurization of the R-12 gas.( Figure 4 shows the pressurization system components.)

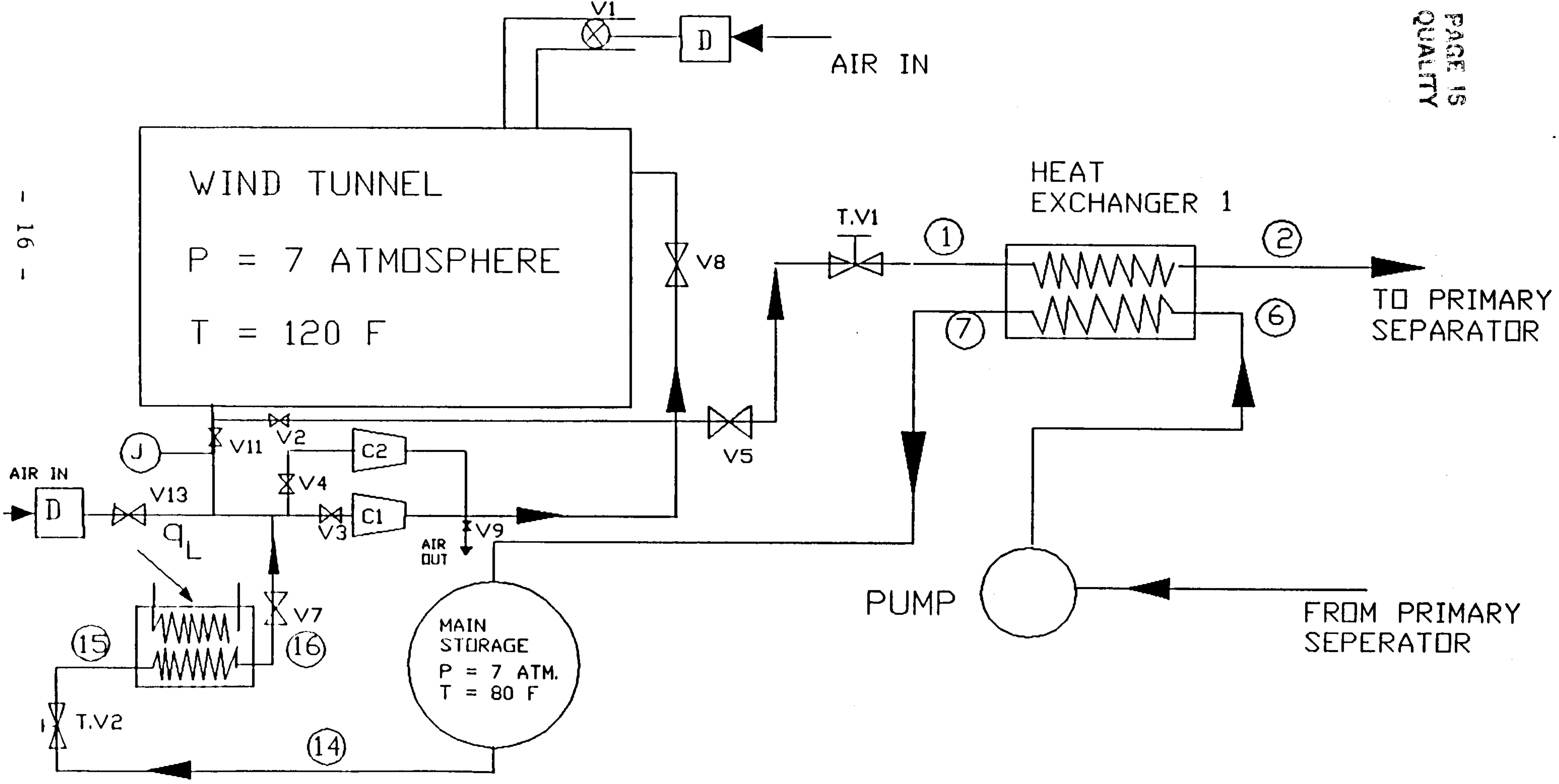
### 1) Evacuating Air

Initially the pressure inside the tunnel is at 1 atm. The tunnel is proposed to have all R-12 gaseous at 7 atm, therefore all air must be taken out. It is very difficult to get rid of air since perfect vacuum conditions inside the tunnel cannot be achieved. By selecting the right pump the amount of air inside the tunnel can be minimized. In this design the lowest possible pressure that can be achieved is 0.04 atm. This is done by using two Carrier compressors with capability of 25,000 CFM for each compressor and five liquid ring vacuum pumps with capability of 2,100 CFM for each pump.

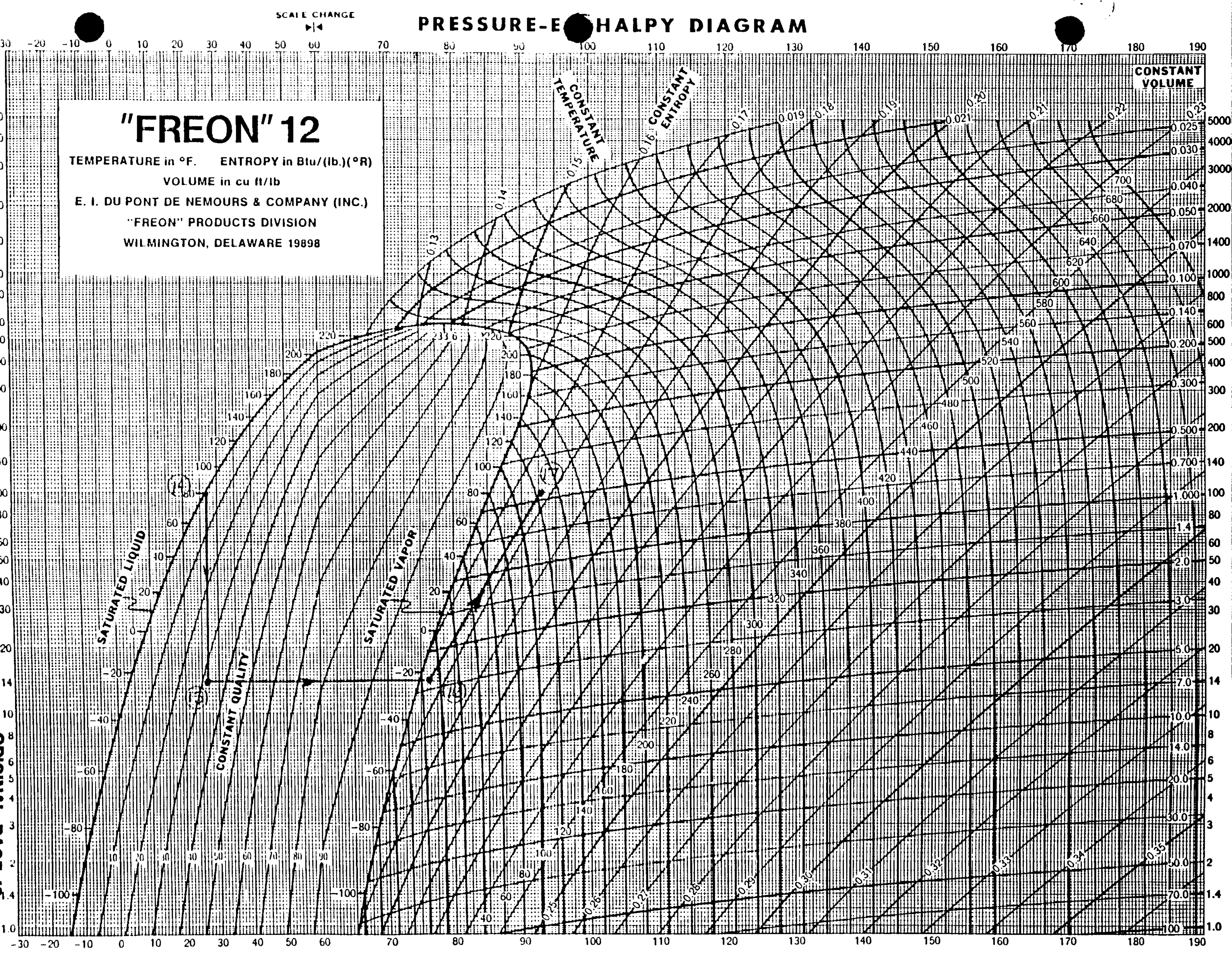
First of all, two Carrier compressors will be used to reduce the wind tunnel pressure from 1 atm to 0.25 atm. The compressors will discharge the air from the tunnel through V11 and release it into the atmosphere. Time required is 28 minutes.

# PRESSURIZATION SYSTEM

FIGURE 4



# PRESSURE-ENTHALPY DIAGRAM



## "FREON" 12

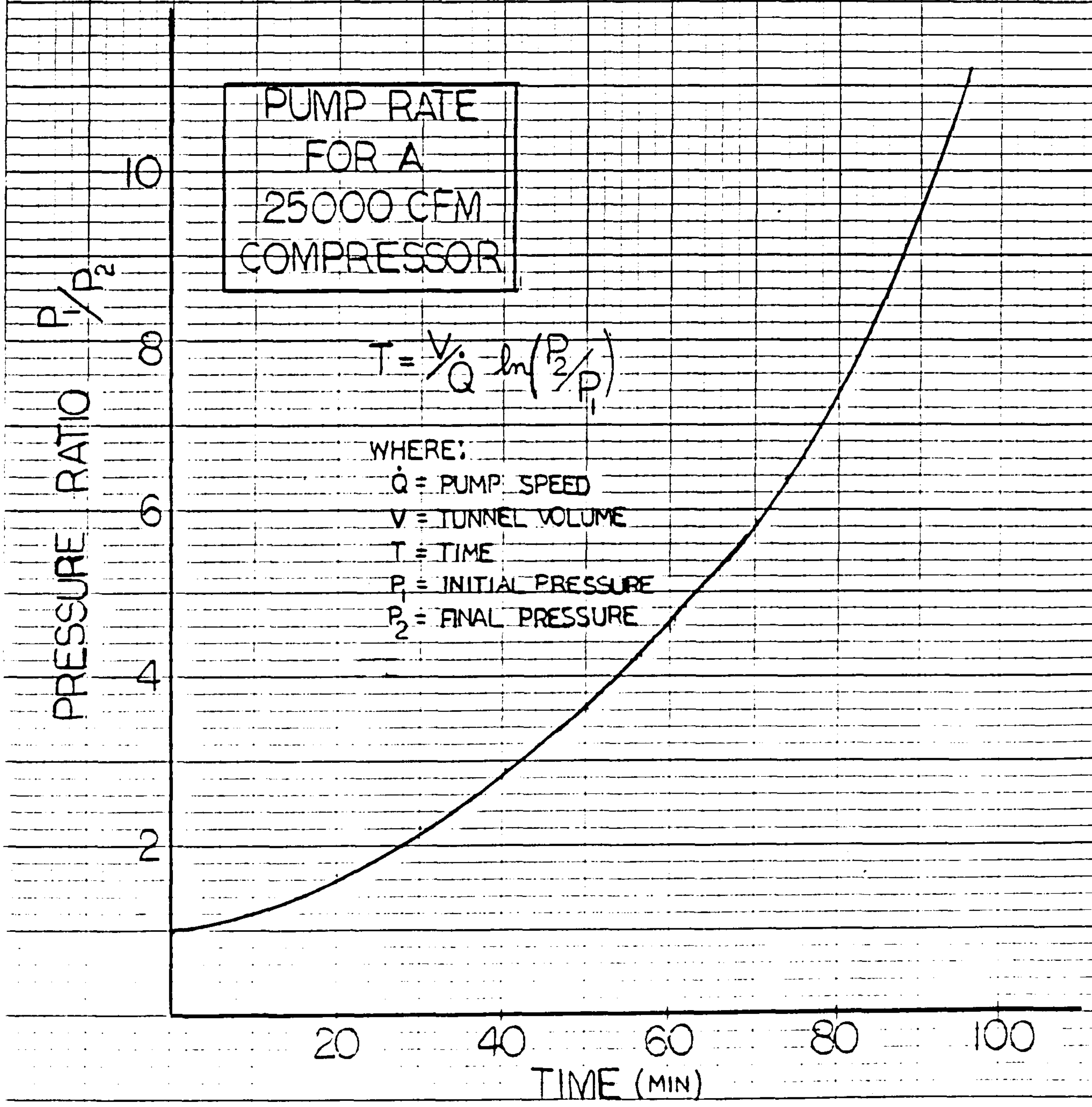
TEMPERATURE in °F. ENTROPY in Btu/(lb.)(°R)
VOLUME in cu ft/lb
E. I. DU PONT DE NEMOURS & COMPANY (INC.)
"FREON" PRODUCTS DIVISION
WILMINGTON, DELAWARE 19898

After the pressure of 0.25 atm is achieved, all liquid ring vacuum pumps will be used while the large compressors are idle. The ring pumps will reduce the pressure down to 0.04 atm in approximately 174 minutes. This is the lowest pressure inside the tunnel that can be achieved with the proposed configuration of pumps. After this pressure is attained, the filling process can be started.

## II) Filling

During the filling process the gaseous R-12 will be injected into the tunnel with the use of the compressors. The stages of vaporization and pressurization are shown on the P-H located on the next page. In order to fill the tunnel with gaseous R-12 at 7 atm pressure it is required that 1,075,032 kg ( 2,370,000 lbs ) of liquid R-12 must be vaporized.

During the pressurization process, the stored liquid R-12, initially at 7 atm, will be throttled by passing it through throttle valve V2. The throttling process will reduce the pressure as well as control the flow rate such that the heat exchanger is capable of vaporizing all liquid R-12. A sensor, located near the outlet of the vaporizer, will control the flow rate to ensure complete vaporization of R-12. If liquid refrigerant is detected, the valve area will automatically be varied to decrease the flow rate ensuring all liquid is vaporized. In order to vaporize the R-12, a total of 126,000,000 KJ of energy is required. The heat from the cooling water of the

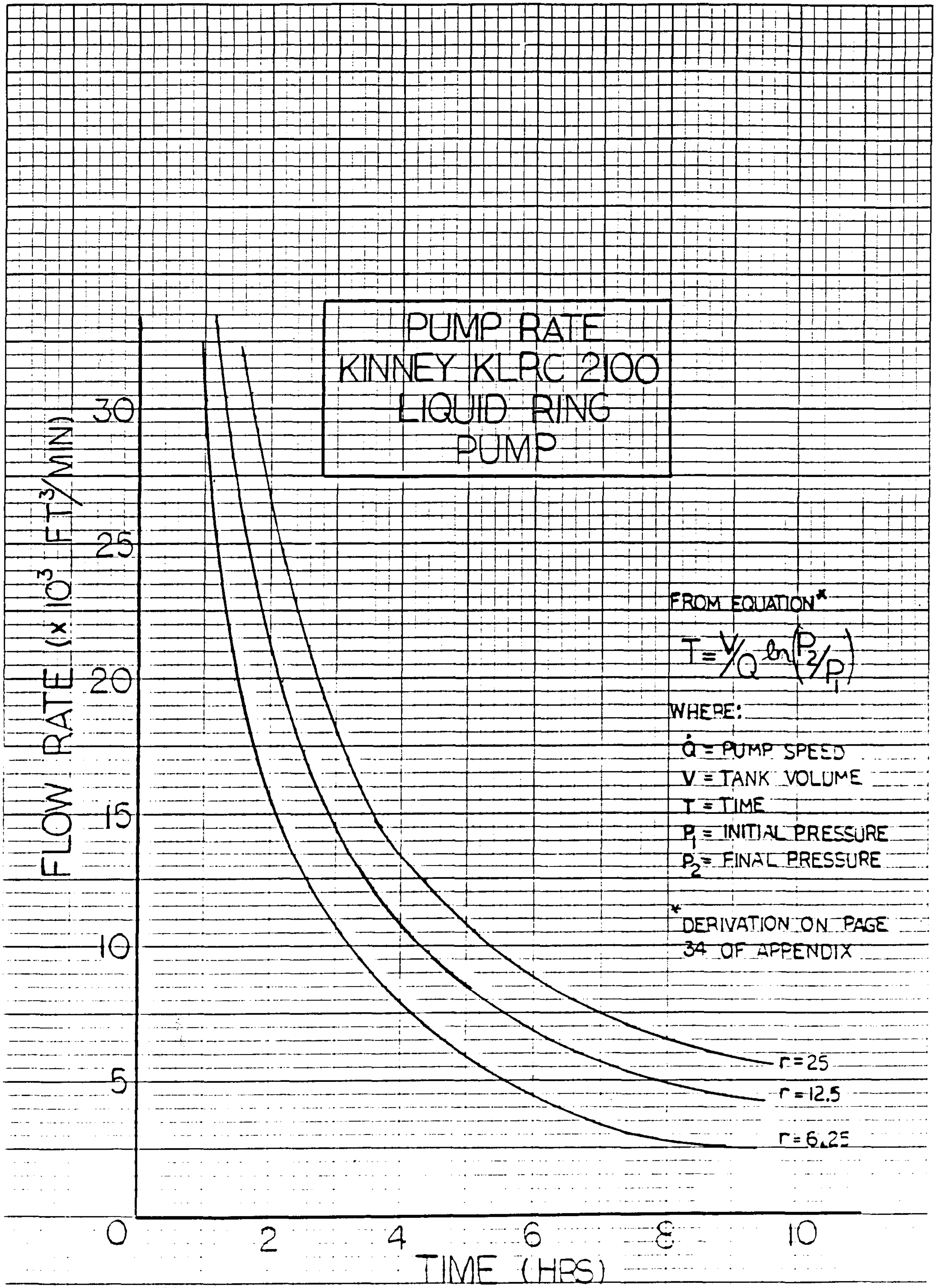


PUMP RATE
FOR A
25000 CFM
COMPRESSOR

$$T = \frac{V}{\dot{Q}} \ln\left(\frac{P_2}{P_1}\right)$$

WHERE:
$\dot{Q}$ = PUMP SPEED
V = TUNNEL VOLUME
T = TIME
$P_1$ = INITIAL PRESSURE
$P_2$ = FINAL PRESSURE

GRAPH 4



PUMP RATE
KINNEY KLRC 2100
LIQUID RING
PUMP

FROM EQUATION*

$$T = V/Q \, \ln(P_2/P_1)$$

WHERE:

$\dot{Q}$ = PUMP SPEED
V = TANK VOLUME
T = TIME
$P_1$ = INITIAL PRESSURE
$P_2$ = FINAL PRESSURE

*DERIVATION ON PAGE 34 OF APPENDIX

GRAPH 5

compressors at NASA AMES, which is usually cooled by a cooling tower, can be used to supply part of this heat. This will help to reduce the temperature of the cooling water very effectively as well as reduce the operating costs of the pressurization process. After being vaporized, the R-12 gas will be pressurized by using two Carrier compressors. The estimated time for this process is approximately 103 minutes.

## SAFETY AND HAZARDS

As in any situation, safety is of the utmost importance in order to prevent injury, loss of life or damage to equipment. To prevent any unsafe situations, strict operating procedures and guidelines should be understood by all. Plans of evacuation and methods of response should be developed to ensure proper actions are taken if a hazardous situation occurs.

Handling and storage of large amounts of R-12 can create a hazard in low lying areas such as pits, trenches and other areas in which the gas could accumulate resulting in an oxygen deficient atmosphere. Installation of permanent oxygen monitors as well as available portable oxygen monitors will eliminate the possibility of suffocation.

Areas called "safe haven" should be incorporated in the facility to provide safety if a large leak of R-12 should ever occur. A "safe haven" is a room which would be deemed as having a safe atmosphere (purified make up air). Self-contained breathing apparatus should be on hand in order to allow personel to evacuate from the oxygen deficient area if the need arises.

As in any typical work environment, strict guidlines on lock and tag procedures should be followed when working on any power equipment.

Other hazards inherent in the recovery process include:

- noise level
- high and low temperatures
- rotating machinery

The occurance of injuries caused by the hazards associated with the recovery process can be reduced by appropriate signs which warn people of the nearby danger.

## SYSTEM SPECIFICATION

The following is a list of system specifications for the various parts of the R-12 pressurization and recovery process as well as various assumptions made in order to perform the necessary calculations.

### WINDTUNNEL

Volume : 1 E06 cubic feet

Mass of R-12 in tunnel : 2.37 E06 lbs

Tunnel operating pressure : 7 atmospheres

### PRIMARY SEPARATION SYSTEM

Refrigeration system : 9,600 tons at -80 F

Primary separation tank : 6' dia. by 10' (2100 gal)

Carrier Compressors (2) : 25000 CFM each

Liquid Ring Pumps (5) : 2100 CFM each

Liquid pump : 180 GPM

SECONDARY SEPARATION SYSTEM

Adsorption beds (3) : 6 ft diameter by 27 ft long

Adsorbent process compressor (C3) : 6/1 compression ratio

Adsorbent : Activated Carbon Sorbonorit B

Density - 28 lbs/cu ft

Pellet size - 3.8mm dia.

Pressure drop - 3" of water/ft of bed

Assumed bed temperature - 32 F

Regeneration method - hot air

Required amount - 63,000 lbs

Total cost - $87,000 @ $1.38/lb

In order to reduce the total amount of time required for adsorption, the flow rate through the adsorbent beds needs to be increased. The increased flow rate would require additional adsorbent beds to ensure complete purification of the air (see graph 3).

The assumed bed temperature of 32 F was used as an example. Lower temperatures at the same adsorption capacity would result in lower vapor pressure of R-12, thus reducing the amount of refrigerant emitted to the atmosphere.

## STORAGE OF R-12

Storage tank volume : 35,000 cu ft

Storage temperature : ambient

Storage pressure : 7 atmospheres

## REQUIRED TIME FOR EACH PROCESS

Recovery process

| | |
|---|---|
| - from 7 atm to 0.25 atm @ 25,000 CFM<br>(see graph 4 page 19) | 133 min |
| - from 0.25 to 0.04 @ 10,500 CFM<br>(see graph 5 page 20) | 174 min |

Adsorption process time

(leaving less than 150 lbs of R-12 in tunnel)

| | |
|---|---|
| Flow rate of 4200 CFM | 1500 min |
| Flow rate of 10,500 CFM | 420 min |

(see graph 1 page 11)

The increase of flow rate during the adsorption process reduces the required time by a large amount. See graph 1 page 11.

Total recovery time

| | |
|---|---|
| - Using 5 liquid ring pumps in adsorption process | 12.1 hrs |
| - Using 2 liquid ring pumps in adsorption process | 30.0 hrs |

Pressurization time

| | |
|---|---|
| - Pump down of tunnel 1 atm to 0.25 atm @ 50,000 CFM (see graph 4 page 19) | 27 min |
| - 0.25 atm to 0.04 atm @ 10,500 CFM (see graph 5 page 20) | 174 min |
| - Pressurization of tunnel with R-12 to 7 atm (see graph 4 page 19) | 103 min |
| Total pressurization time | 304 min |

## CONCLUSION

The proposed refrigerant-12 recovery and pressurization system is a very effective method in R-12 reclaimation. Many improvements can be made to the system which will decrease the recovery time. There must be a great deal of process time/cost analysis done in order to design the optimum system. Many assumptions, based on technical knowledge, were made in order to complete this preliminary design.

The design group, consisting of senior level mechanical engineeering students, found this design project to be a very challenging experience. The completion of the project gave us a close look at the real world of engineering and design. Valuable experience gained while working on the project will be a benefit to us in our future years as engineers.

# APPENDIX

## A) PRESSURIZATION PROCESS

### I) CALCULATING THE REQUIRED MASS OF R-12

In order to have a pressurized wind tunnel with R-12 at 7 atm and at a temperature of 120 degree F the required mass is:

At 120 degree F, pressure of 7 atm = 103 psi
Volume = 1.0 E06 cubic feet
Specific volume = 0.4412 cu ft/lb
Mass = volume/specific volume
= 2,266,546 lbm ( 1,028,105 kg )

Therefore the required mass is 2,370,000 lbm ( 1,075,032 kg ), which is 5% excess.

### II) CALCULATING THE VOLUME OF THE LIQUID R-12

The liquid R-12 is stored at 7 atm and a temperature of 80 degrees F (ambient temperature). The amount of liquid R-12 needed to be vaporized is:

Specific volume is 0.012277 cu ft/lb

Therefore the volume will be

Volume = (2,370,000 lb)(0.012277 cu ft/lb)
= 29,097 cu. ft (824 cu meter)

In this design the proposed container will be a spherical shape container. This is because the spherical shape is capable of holding higher stress at any section compared to other shapes. The diameter will be 38 ft ( 11.5 meter ).

In this design it is impossible to vaporize all liquid R-12 from the container otherwise vacuum conditions would exist in the main storage and the condenser is nct cabaple of producing vacuum. It is suggested that about 20% of extra mass of R-12 should be stored in the main storage. Thus, the volume will be 35,000 cu. ft ( 991 cu. m ) with diameter 40 ft ( 12.5 m ).

## III) CALCULATING HEATING REQUIREMENT FOR VAPORIZATION

To maintain R-12 in form of gases in wind tunnel, the temperature inside must be maintained at about 100 F. Due to heat loss when injecting the R-12 gases into the tunnel, since the filling process takes a long time before the tunnel can be completely vaporized, higher temperature should be selected. In this design the temperature is to be maintained at 120F.

Calculating heating requirement to vaporize liquid R-12:

$$Q = m ( h1 - h2 )$$

where Q is the total heat to vaporize 2,370,000 lb ( 1,075,032 kg ) of liquid R-12

m = mass of liquid R-12

h2 = enthalpy of liquid R-12
= 26.365 Btu/lb

h1 = enthalpy of R-12 gases before entering the compressor

= 76.85 Btu/lb

P2 = The pressure of liquid R-12

= 7 atm

P1 = the pressure of R-12 gases before entering the compressor

P1 = 1 atm

Therefore the total heating requirement is:

Q = 2,370,000 lb ( 76.85 - 26.365 Btu/lb)

= 120 E06 Btu or ( 126 E06 KJ )

## B) RECOVERY PROCESS

Calculating the total power required to condense 1 E06 cubic feet of gas R-12.

From heat exchanger 2, assuming that the efficiency is 100% :

$$Q = m ( h1 - h2 )$$

where

m = The total mass of gass R-12

T1 = The inlet temperature at hot side

T2 = The outlet temperature at hot side

h1 = The enthalpy at the inlet temperature

h2 = The enthalpy at the outlet temperature

knowing that

T1 = 120 F ( 321.9 K )

T2 = -80 F ( 210.8 K )

P = 103 Psi ( 710 kPa )

using ( P-H ) diagram for R-12

h1 = 95 Btu/lb ( 221 KJ/kg )

h2 = -9 Btu/lb ( -21 KJ/kg )

since

$$Q = m ( h1 - h2 )$$

$$Q = ( 1,075,032 \text{ kg} ) ( 221 + 21 \text{ KJ/kg} )$$

$$Q = 2.60157 \text{ E08 KJ} \quad \text{or} \quad ( 2.46654 \text{ E08 Btu} )$$

Power required

$$P = Q/t$$

where

t = Is the time during maximum flow rates (worst case)

= 133 min ( 7980 sec )

thus

$$P = 2.60157 \text{ E08 KJ} / 7980 \text{ sec}$$

$$= 32 \text{ KW} \quad \text{or} \quad ( 9600 \text{ Tons} )$$

## C) CALCULATING FOR SECONDARY SEPERATOR

Recommendations on the type of activated carbon which would efficiently adsorb R-12 was obtained by contacting various carbon manufacturers. The general information obtained includes:

- Pressure drop is 0.11 psi/ft of bed depth
- The usual diameter for the bed is 6 ft
- For each 20 lb of R-12, 100 lb of activated carbon charcoal is needed

- For best results of the adsorption process the flow through the beds should be 50 ft/min

At pressure of 0.04 atm and temperature of 120 degree F the amount of R-12 left inside the tunnel is;

Mass = volume / specific volume

Volume = 1.0 E06 cu.ft

Specific volume = 87.16 cu. ft/lb

Mass = ( 1.0 E06 cu. ft )/ ( 87.16 cu. ft/lb )

= 11,480 lb

For best result, the mass left is assumed to 12,000 lb . Therefore 60,000 lb of activated carbon charcoal is needed to adsorb 12,000 lb of R-12

The density of charcoal is 28 lb/cu. ft

The volume of the adsorption beds is:

Volume = mass/density

= ( 60,000 lb )/( 28 lb/cu. ft )

= 2,143 cu.ft of charcoal

In this design the amount of the R-12 to be adsorbed is maximized by having larger volume of the adsorbent beds.
the chosen value in the analysis is 2,250 cu. ft ( 5% more than needed ). The shape of the beds will be cylindrical.

Volume = ( 3.142/4 ) ( L )( D**2)

where

L is the total height of the cylinder

D is the diameter of the cylinder which is 6 ft

Knowing

Volume = 2,250 cu. ft

Therefore the total length is:

L = 80 ft

This total length will be used to find how many beds are needed. The number of beds is to be minimized to reduce the cost while the flow which passes through the beds is appropriate with the flow rate of the liquid ring pump.

Calculate number of beds needed:

The cross sectional area of 6 ft diameter of cylinder is 28 ft square.

Q = (N) (V) (A)

Where

Q is the flow rate of R-12 mixture

N is the number of the liquid ring pumps to be used

V is the velocity of the mixture which is 50 ft/min

A is the area of the adsorbent bed which is 28 sq.ft

The flow rate will be

Q = ( 1,400 ) ( N cu. ft/min )

By using three beds

Q = 4,200 cu. ft/min

The mixture will be pumped using liquid ring pump with a capacity of 2,100 cu. ft/min; Therefore, two pumps will be used.

By using three beds, the height of each adsorbent bed is:

$$L = (80\ \text{ft})/(3) = 27\ \text{ft}$$

## D) CALCULATING THE PRESSURE RATIO OF COMPRESSOR C3

The pressure drop for the flow of the mixture through the adsorbent bed is 0.11 psi/ft of the bed depth. Therefore for 27 ft depth the pressure drop is 3 psi.

The compressor C3 is used to compress the mixture that flows from the primary seprator to the secondary separator. In order to have the air pressure at 10 coming at 1 atm (14.7 psi), the compressor C3 has to have a pressure ratio of 1:6. The average pressure at 4 is 3 psi using pump 1.

## E) CALCULATING TIME OF BLOW DOWN THE TUNNEL

The initial pressure inside the tunnel is 7 atm ( 103 psi or 710 KPa ), the temperature is 120 degree F ( 49 degree C or 322 Kelvin ). The volume of the tunnel is 1.0 E06 cu. ft ( 28,312 cu. m ).

Defining variables:

mo is the mass flow rate of the R-12 leaving the tunnel.

M is the mass of the R-12 inside the tunnel

$V$ is the volume of the tunnel

$R$ is the R-12 gas constant

$T$ is the temperature of the R-12. The temperature is assumed to be constant

$N$ is the number of compressors or pumps being used

$Q$ is the capacity of compressor or pump. For Carrier compressor, the capacity is 25,000 CFM and 2,100 CFM for liquid ring pump.

$Pf$ is the final pressure

$Pi$ is the initial pressure which is 7 atm

$tf$ is the final time

$to$ is the initial time which is zero min

Since

$$mo = -(dM/dt)$$

Assuming ideal case

$$M = (P)(V)/(R)(T)$$

Thus

$$(V)(dP)/(dT) = (N)(Q)(P)$$

Seperating variables and integrating gives

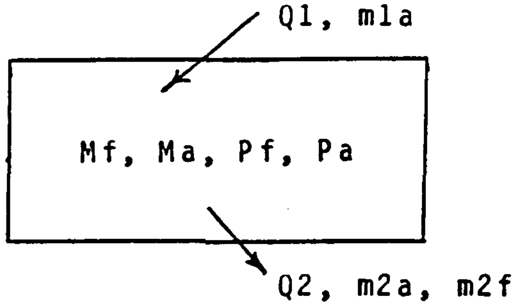
$$\ln (Pf)/(Pi) + [(Q)(N)/(V)]\,[tf - to] = 0$$

Therefore; the time to blow down the tunnel is:

$$t = \ln (Pf)/(Pi)\,[\,-(V)/(Q)(N)\,]$$

## F) CALCULATING MASS OF R-12 IN THE TUNNEL WITH RESPECT TO TIME

In order to find the rate of change in mass of R-12 in the tunnel a control volume was placed at the tank walls. During process, the pressure is assumed to be constant at 0.1 atm. The following diagram shows the variables which were used to derive the equation.



Variable definition:

Q1 - volumetric flow rate into the tunnel

m1a - mass of air entering the tunnel

Mf - mass of R-12 in tunnel

Ma - mass of air in tunnel

Mfo - initial mass of R-12 in tunnel

Pfo - initial presure in tunnel

Pf - partial pressure of R-12 in tunnel

Pa - partial pressure air in tunnel

P - total pressure in tunnel (Pf + Pa)

Q2 - volumetric flow rate out of tunnel (same as Q1)

m2a - mass flow of air leaving the tunnel

m2f - mass flow of R-12 leaving the tunnel

V - volume of tunnel

Rf - gas constant for R-12
Ra - gas constant for air
T - temperature of air in tunnel
dens1 - density of R-12
dens2 - density of air

Applying mass balance of R-12 at control volume:

$$dMf/dt = (m1f - m2f)$$

Since there is no R-12 entering the tunnel, m1f = 0

Therefore,

$$dMf/dt = -m2f$$

Since,

$$m2f = (Q2)(dens1)$$

Assuming R-12 is an ideal gas, from the ideal gas law,

$$dens1 = (Pf)/(Rf)(T)$$

Substituting,

$$dMf/dt = (-Q)(Pf)/(Rf)(T)$$

Applying mass balance of air at control volume:

$$dMa/dt = m1a - m2a$$

Or in terms of volumetric flow rate and density,

$$dMa/dt = (Q1)(P)/(Ra)(T) - (Q2)(Pa)/(Ra)(T)$$

Since,

$$Q1 = Q2$$

Then,

$$dMa/dt = (P - Pa)(Q)/(Ra)(T)$$

Substituting,

$$Ma = (Pa)(V)/(Ra)(T) \quad \text{and} \quad (P - Pa) = Pf$$

The equation becomes,

$$(d/dt)(Pa)(V)/(Ra)(T) = (Pf)(Q)/(Ra)(T)$$

differentiating,

$$(V)(dPa)/(dt) = (Pf)(Q)$$

Or,

$$(dPa)/(dt) - (Pf)(Q)/(V) = 0$$

Substituting,

$$(P - Pf) \text{ in for } (Pa)$$

Then,

$$d(P - Pf)/(dt) - (Pf)(Q)/(V) = 0$$

Since $dP/dt = 0$,

Then,

$$d(Pf)/(dt) + (Pf)(Q)/(V) = 0$$

Separating varibles and intergrating,

$$\ln(Pf/Pfo) = t(-Q/V)$$

From ideal gas law, $PV = mRT$ and since the volume, gas constant and the temperature are assumed to be constant, then;

$$Pf/Pfo = Mf/Mfo$$

Therefore,

$$Mf = (Mfc)EXP(-tQ/V)$$

The value of $Q/V$ is known as the reciprocal of the system's time constant. This value clearly reveals the importance of a high flow rate which depends on the configuration of the pumping system.

$$\text{TIME CONSTANT} = V/Q = (10E06 \text{ cu ft})/4200 \text{ CFM} = 240 \text{ min}$$

or

$$= (10E06 \text{ cu ft})/10500 \text{ CFM} = 95 \text{ min}$$

**NORIT**

**Activated Carbon**

American Norit Company, Inc.
420 AGMAC AVENUE
Jacksonville, Fl. 32205

PRODUCT INFORMATION
Bulletin No. 206
Revised 11-87

## SORBONORIT B
## GRANULAR ACTIVATED CARBON

The SORBONORIT grades of NORIT Activated Carbon are designed especially for recovery of solvent vapors from air. They are characterized by a highly developed pore structure, good resistance to abrasion, uniform particle structure, and low resistance to air flow.

This carbon is available in various pellet sizes to meet specific requirements. Listed below are typical property data:

| | SORBONORIT | | |
|---|---|---|---|
| | B2 | B3 | B4 |
| Bulk density, - g/ml | .460 | .430 | .430 |
| - lbs./cu.ft. | 28.7 | 26.8 | 26.8 |
| Moisture, % as packed | 2 | 2 | 2 |
| Ash, % | 6 | 6 | 6 |
| Hardness (ASTM) | 99 | 99 | 99 |
| Ignition temp. (ASTM), °C | 450 | 450 | 450 |
| Pore size distribution, ml/g: | | | |
| - micropores (less than 1 nm) | 0.42 | 0.42 | 0.42 |
| - transitional (1-100 nm) | 0.09 | 0.09 | 0.09 |
| - macropores (greater than 100 nm) | 0.42 | 0.42 | 0.42 |
| Surface area ($N_2$-BET), $m^2/g$ | 1100-1200 | 1100-1200 | 1100-1200 |
| Pellet diameter, mm | 2.0 | 2.9 | 3.8 |

### Packaging

44.1 lb. net multiwall paper bags, - bags palletized in unitloads containing 40 bags each. Net pallet weight is 1764 lbs. Orders less than unitload are supplied in bags plus shipping cartons without palletizing.

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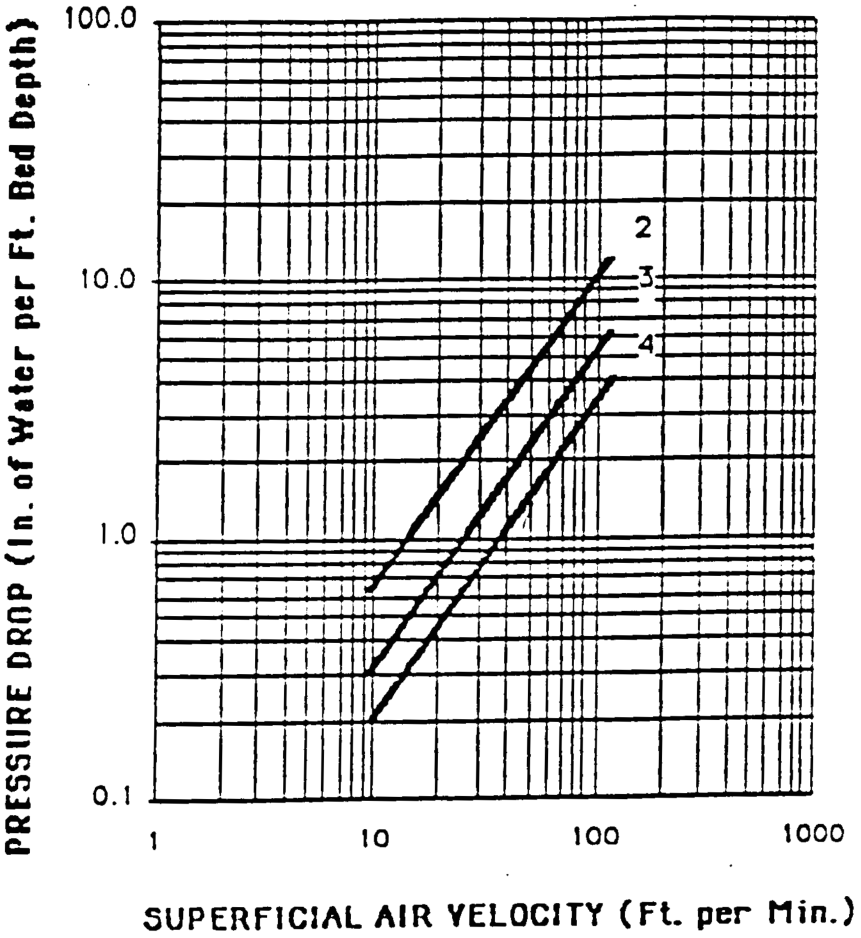
# TYPICAL PRESSURE DROP FOR SORBONORIT B IN AIR



# TECHNICAL NOTE

# Refrigerant Freon-12 equations

By H. Al-Sadafi*

*The basic equations for the thermodynamic behaviour of commonly used refrigerant Freon-12, expressed in SI units, are presented in this note for the use of engineers in the designing of refrigeration equipment. These fundamental formulae are intended for computer based modelling and system simulation of refrigeration machinery.*

## Introduction

Pressure-volume-temperature, density, heat capacity, enthalpy and entropy properties of R12 are reported below.

The derived relations, which generate data in SI units, are based on the equations with Imperial unit constants established by Downing.[1]

This additional information may be of assistance in heat transfer calculation and computer-aid determination of refrigeration processes.

## Saturation properties equations

The thermophysical properties of R12 formulated by R. C. Downing[1] are shown in simplified form. These relationships are suitable for the temperature range −100°C to 100°C; the constants for the equations are given in Table 1.

Downing is the reference source for all the equations in this section ($d_{liq}, P, C_v, h_{vap}, s_{vap}$).

### Note — Additional equations

To increase the speed of computation, additional equatios for the refrigerant properties have been developed by the author[3] using regression methods and have been validated by comparison with ASHRAE published data.[2]

*Vapour specific volume:* A power curve for specific volume of the vapour in terms of absolute saturation temperature has been fitted and plotted in Figure 1.

**Liquid density**

$$d_{liq} = A + BT' + C(T')^{1/2} + D(T')^{1/3} + E(T')^{2}$$

where $T' = 385.166 - T$

for $d_{liq}$ in kg/m³ and $T$, saturation temperature, in kelvin (273.166 + °C).

**Vapour pressure**

$$\log P = A + \frac{B}{T} + C\log T + DT$$

for $P$ in kPa and $T$ in K.

**Equation of state**

$$P = \frac{AT}{V'} + \frac{B + CT + D(\text{Exp.})}{(V')^{2}} + \frac{E + FT + G(\text{Exp.})}{(V')^{3}} + \frac{H}{(V')^{4}} + \frac{IT + J(\text{Exp.})}{(V')^{5}}$$

where $V' = V - 4.063\,681\,115\,21\,E \times 10^{4}$ and Exp. $= e^{(\text{[illegible]} \times 10^{2} T)}$ for $P$ in kPa, $V$ in m³/kg and $T$ in K.

**Heat capacity of vapour at constant volume**

$$C_v = A + BT + CT^{2} + DT^{3} + ET(\text{Exp.})\left(\frac{F}{(V')} + \frac{G}{(V')^{2}} + \frac{H}{(V')^{4}}\right)$$

where $V'$ and Exp. are as defined above for $C_v$ in kJ/kgK, $V$ in m³/kg and $T$ in K.

**Latent heat of vaporisation**

$$h_{v} = AT(v_{vap} - v_{liq})P\left(\frac{B}{T^{2}} + \frac{C}{T} + D\right)$$

for $h_v$ in kJ/kg, $P$ in kPa, $v_{vap}$ and $v_{liq}$ in m³/kg and $T$ in $K$.

**Enthalpy of vapour**

$$h_{vap} = AT + BT^{2} + CT^{3} + DT^{4} + E(PV) + \left(\frac{F}{V'} + \frac{G}{(V')^{2}} + \frac{H}{(V')^{3}}\right) +$$

$$(1 + IT)(\text{Exp.})\left(\frac{J}{V'} + \frac{K}{(V')^{2}} + \frac{L}{(V')^{4}} + M\right)$$

for $h_{vap}$ in kJ/kg, $V$ in m³/kg, $P$ in kPa and $T$ in K.

**Entropy of vapour**

$$s_{vap} = A(B + \log T) + CT - DT^{2} + ET^{3} + F(\log V' + G) +$$

$$\left(\frac{H}{V'} + \frac{I}{(V')^{2}} + \frac{J}{(V')^{3}}\right) - (\text{Exp.})\left(\frac{K}{V'} + \frac{L}{(V')^{2}} + \frac{M}{(V')^{4}}\right) + N$$

where $V'$ and Exp. are as defined above for $s_{vap}$ in kJ/kgK, $V$ in m³/kg and $T$ in K

---

*The author of this note is with the Department of

## Table 1: Constants for R12 equations

| Equation / Constants | Liquid density | Vapour pressure | Equation of state | Vapour heat capacity | Latent heat | Enthalpy of vapour | Entropy of vapour |
|---|---|---|---|---|---|---|---|
| *A* | 558.083 146 4 | 37.538 653 545 9 | 6.874 059 155 74 E × $10^{-4}$ | 0.033 891 671 5 | 4.145 179 421 95 | 0.033 890 052 6 | 4.335 262 773 21 E × $10^{-4}$ |
| *B* | 0.777 343 826 88 | -1909.240 126 | -9.161 448 000 1 E × $10^{-2}$ | 2.507 140 429 2 E × $10^{-3}$ | 1060.688 959 26 | 1.253 510 335 44 E × $10^{-3}$ | 0.255 272 505 103 |
| *C* | 17.943 303 302 4 | -12.471 522 28 | 7.710 559 265 93 E × $10^{-5}$ | 3.274 662 346 85 E × $10^{-6}$ | -3.009 062 948 4 | -1.091 501 975 46 E × $10^{-6}$ | 1.392 789 261 6 E × $10^{-3}$ |
| *D* | 117.435 807 269 | 8.514 796 395 6 E × $10^{-3}$ | -1.525 083 705 61 | 1.641 815 239 4 E × $10^{-9}$ | 4.730 442 44 E × $10^{-3}$ | 4.104 342 037 45 E × $10^{-10}$ | -9.095 849 795 52 E × $10^{-7}$ |
| *E* | -3.402 286 880 79 E × $10^{-4}$ | – | 1.010 393 437 81 E × $10^{-4}$ | 8.697 560 186 28 E × $10^{-5}$ | – | 1.000 126 971 92 | 3.040 253 361 07 E × $10^{-10}$ |
| *F* | – | – | -5.674 815 470 06 E × $10^{-8}$ | -3.543 586 024 52 | – | -9.162 308 008 15 E × $10^{-7}$ | 8.794 508 814 11 E × $10^{-2}$ |
| *G* | – | – | 2.199 603 584 97 E × $10^{-3}$ | 2.555 428 431 41 E × $10^{-3}$ | – | 5.052 608 647 02 E × $10^{-5}$ | 1.204 620 578 3 |
| *H* | – | – | -5.745 835 899 14 E × $10^{-8}$ | -9.659 594 338 13 E × $10^{11}$ | – | -1.915 521 819 66 E × $10^{-8}$ | -4.284 187 939 12 E × $10^{-8}$ |
| *I* | – | – | 4.081 543 317 13 E × $10^{-14}$ | – | – | 1.421 462 570 32 E × $10^{-2}$ | 1.576 537 781 19 E × $10^{-8}$ |
| *J* | – | – | -1.662 913 198 77 E × $10^{-10}$ | – | – | -1.525 277 348 41 | -5.669 529 942 36 E × $10^{-13}$ |
| *K* | – | – | – | – | – | 1.099 941 436 43 E × $10^{-3}$ | -1.204 513 700 06 E × $10^{-4}$ |
| *L* | – | – | – | – | – | -4.157 810 855 13 E × $10^{-11}$ | 8.686 253 230 13 E × $10^{-6}$ |
| *M* | – | – | – | – | – | 474.355 53 | -3.283 429 169 44 E × $10^{-13}$ |
| *N* | – | – | – | – | – | – | 4.256 509 1 1 |

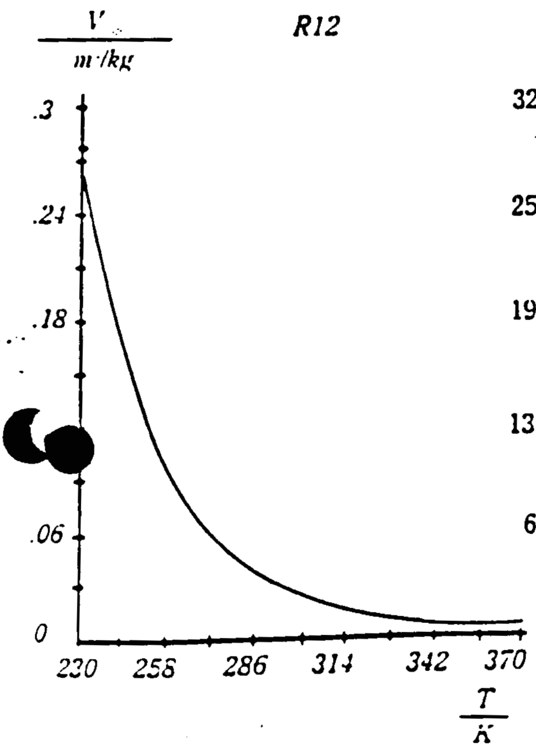


*Figure 1 Specific volume of vapour*

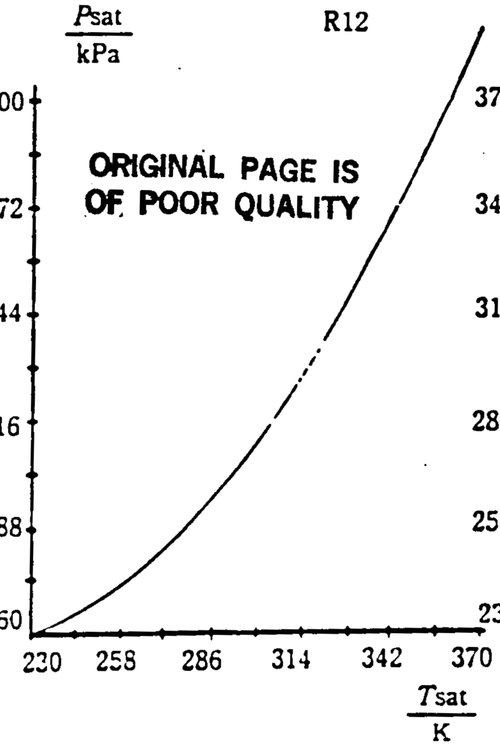


*Figure 2. Saturation pressure*

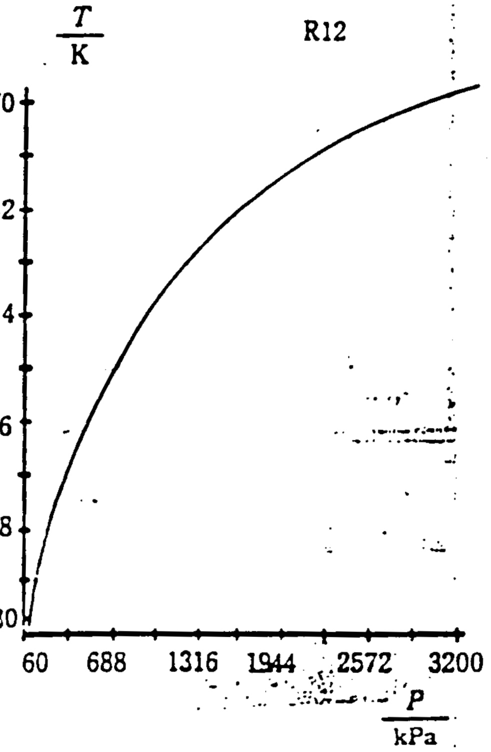


*Figure 3: Saturation temperature*

This equation is valid for the temperature range –40°C to 100°C.

$v_{vap} = aT^b$

where $a$ = 2.715 011 590 43 $E \times 10^{19}$
and $b$ = –8.483 269 769 07

*Vapour pressure:* Two more relations between $P$ and $T$ have been linearized for the smaller temperature range –40°C to 100°C. The constants for these extra equations are given in Table 2.

$P = a + bT + cT^2 + dT^3 + eT^4 + fT^5$

for P in kPa and T in K.

The expression for saturation temperature as a function of saturation pressure is —

$$T = a + bP + cP^2 + dP^3 + eP^4 + fP^5 + gP^6 + hP^7$$

for $T$ in K and $P$ in kPa.

The curves fitted for these two polynomial correlations are shown in Figure 2 and Figure 3.

## Table 2 — Constants for the extra relations

| Equation / Constants | Vapour pressure | Saturation temperature |
|---|---|---|
| *a* | -6806.887 659 72 | 215.410 460 703 |
| *b* | 117.677 711 029 | 0.330 818 041 102 |
| *c* | -0.738 194 091 301 | -6.866 745 530 83 E × 10[illegible] |
| *d* | 2.598 253 373 55 E × 10[illegible] | 9.259 148 089 6 E × 10[illegible] |
| *e* | 4.536 770 457 E × 10[illegible] | -7.166 890 663 18 E × 10[illegible] |
| *f* | 4.000 229 026 67 E × 10[illegible] | 3.094 790 356 7 E × 10[illegible] |
| *g* |  | -6.908 045 655 33 E × 10[illegible] |
| *h* |  | 5.191 631 357 04 E × 10[illegible] |

## References

1. R. C. Downing, "Refrigerant equations" *ASHRAE Transactions*. Vol. 80, Part II, 1974, p. 158).
2. Chapter 17, *1981 Fundamentals Volume*, ASHRAE Handbook.
3. H. A. Sadafi, "Steady-state thermal performance of evaporative plates under varying input heat flux in solar boosted heat pump systems" *M.Eng.Sc. Thesis*, University of Melbourne, 1985.

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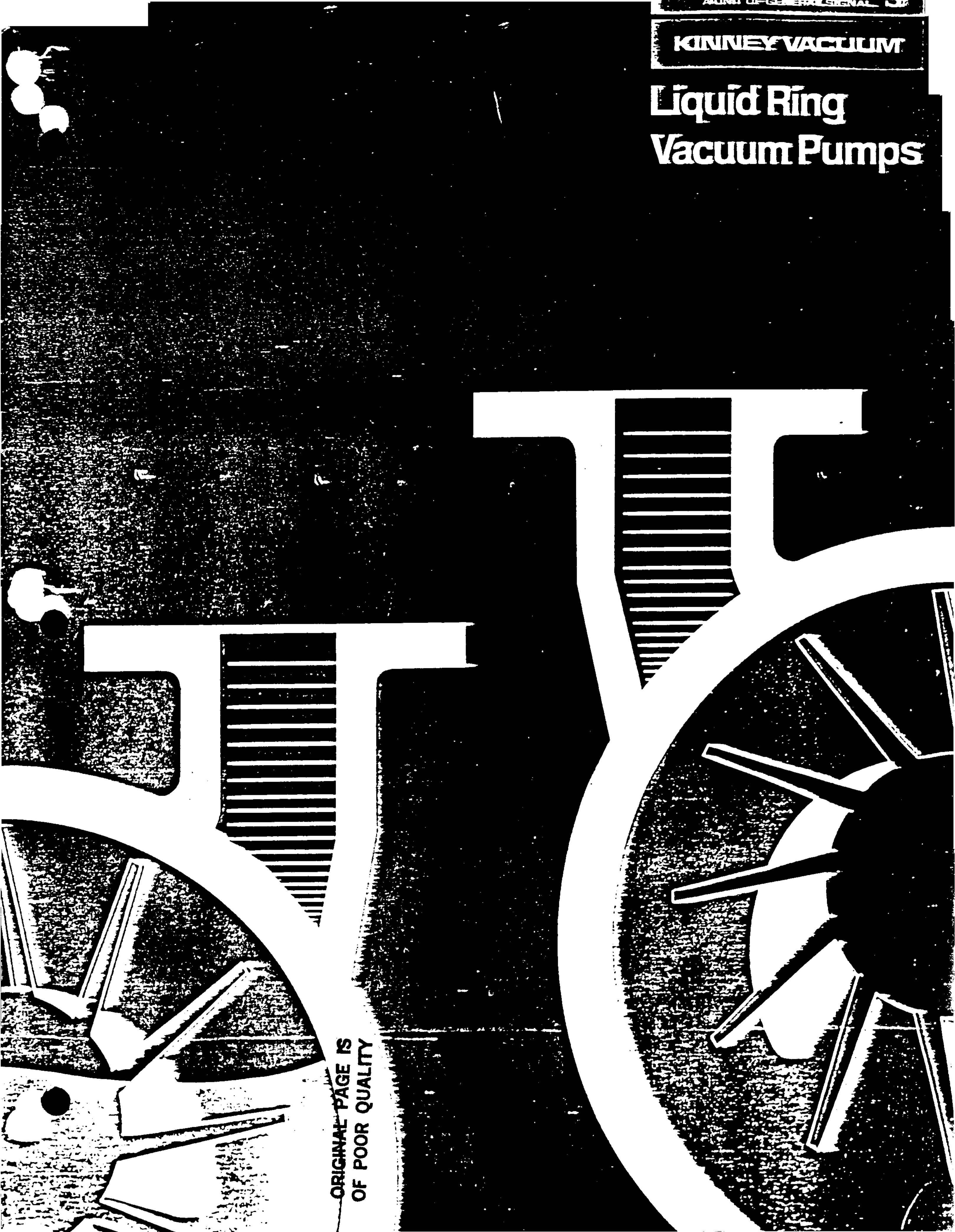
KINNEY VACUUM

# Liquid Ring Vacuum Pumps



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# The Liquid Ring Vacuum Pump

The liquid ring vacuum pump is a nonpulsating pump that removes gases by means of rotating impeller blades which enter and leave a ring of liquid, usually water, but can be a variety of other sealants such as oil or toluene.

When the pump is operating, the sealing liquid is thrown to the periphery of the casing where it forms a moving ring of liquid around a center void. The impeller shaft is mounted above the center line of the casing so that the blades rotate concentrically but are located eccentrically with respect to the casing and the ring of liquid. The axial suction and discharge ports of the pump are exposed to the void but are separated from each other by the impeller blades and the ring of liquid.

As the process fluid (gas or vapor) is drawn into the pump through the suction port, it becomes trapped within the space formed by the impeller blades and the liquid ring. During rotation, the blades enter deeper into the liquid ring, and the trapped space becomes progressively smaller, compressing the gas and exhausting it as it passes the discharge port. The liquid ring acts as a liquid piston, accomplishing the entire pumping operation without vanes, valves, pistons, or any other metal-to-metal contact.

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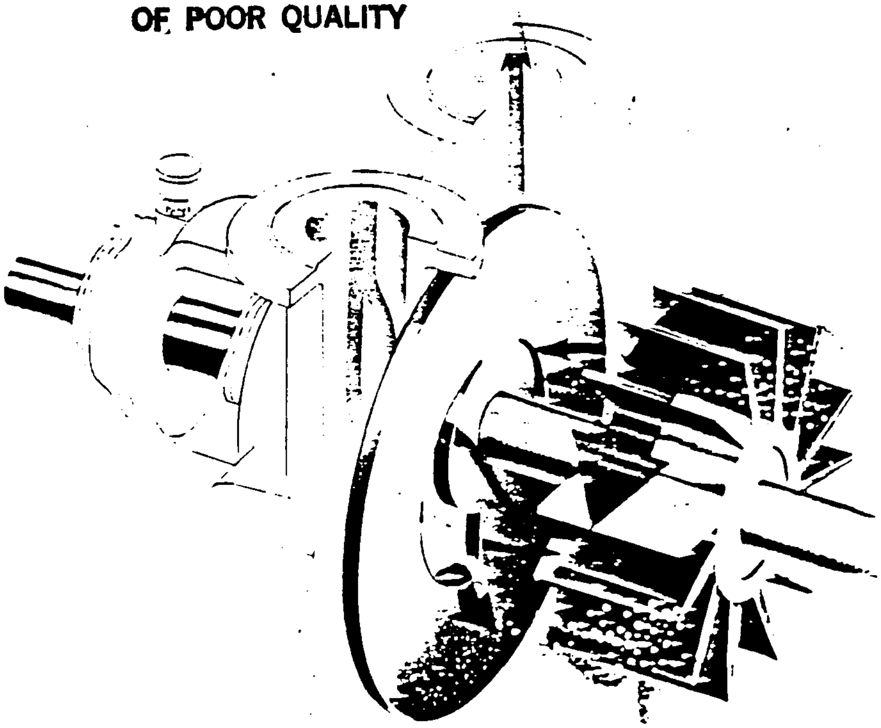

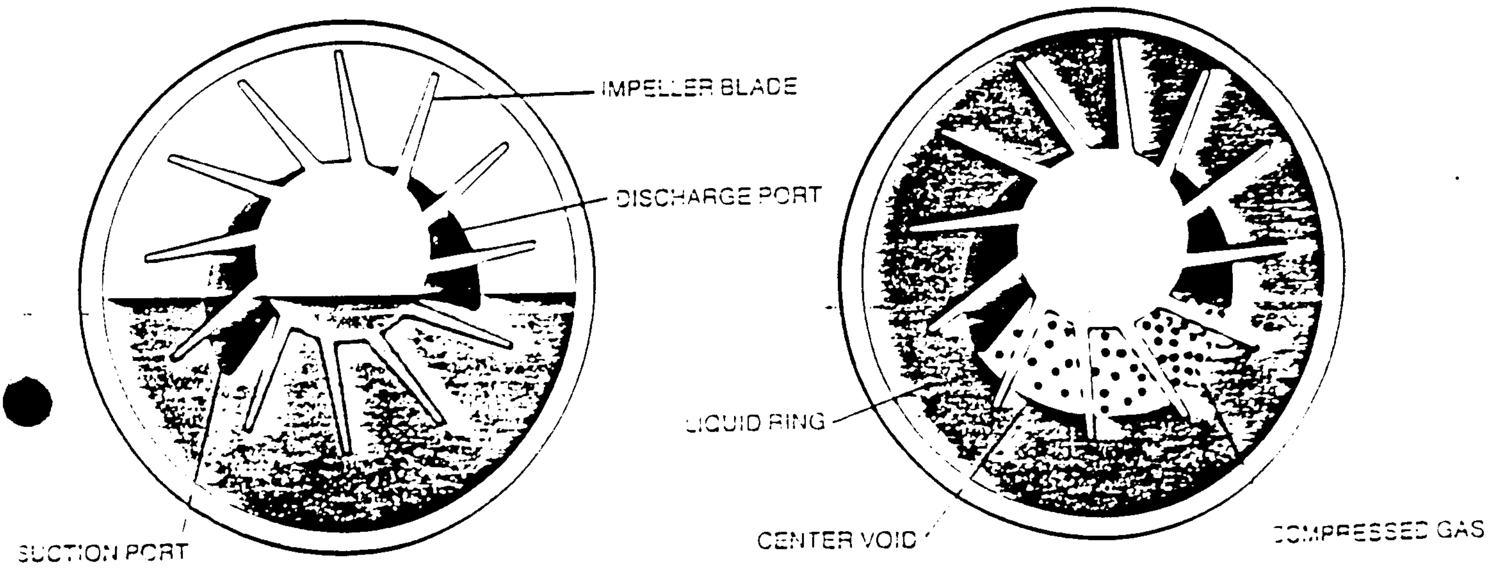
Pump at Rest

Pump in Operation

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# LIQUID RING VACUUM PUMPS

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FEBRUARY 1, 1986

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|---|---|---|---|---|---|---|---|
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| KLRC- 25 | 3 | 795 | 1,285 | 1,135 | 105 | 1,715 | 2,340 |
| KLRC- 40 | 5 | 1,015 | 1,595 | 1,435 | 145 | 2,120 | 2,825 |
| *KLRC- 75 | 5 | 1,115 | 1,700 | 1,525 | 145 | 2,225 | 2,930 |
| KLRC- 100 | 7½ | 1,435 | 2,310 | 2,035 | 145 | 2,935 | 3,690 |
| KLRC- 125 | 10 | 1,630 | 2,545 | 2,250 | 145 | 3,170 | 3,925 |
| *KLRC- 200 | 15 | 2,225 | 3,200 | 2,800 | 145 | 4,085 | 4,830 |
| KLRC- 300 | 25 | 2,490 | 3,800 | 3,225 | 145 | 4,570 | 5,665 |
| KLRC- 525 | 50 | 4,070 | 6,715 | 5,680 | 430 | 7,785 | 9,465 |
| KLRC- 526 | 40 | 4,070 | 6,375 | 5,525 | 430 | 7,445 | 8,900 |
| KLRC- 775 | 75 | 7,600 | 11,500 | 9,715 | 955 | 13,835 | 15,510 |
| KLRC- 776 | 50 | 7,600 | 10,640 | 9,610 | 955 | 12,980 | 14,640 |
| KLRC- 950 | 100 | 8,340 | 13,015 | 10,990 | 955 | 15,350 | 17,335 |
| *KLRC- 951 | 60 | 8,340 | 11,820 | 10,015 | 955 | 14,150 | 15,830 |
| KLRC-1500 | 150 | | ALL | PRICES | ON | REQUEST | |
| KLRC-1501 | 100 | | " | " | " | " | |
| KLRC-2100 | 200 | | " | " | " | " | |
| KLRC-2101 | 125 | | " | " | " | " | |
| | | | | | | | |
| KLR- 45 | 3 | $ 815 | $ 1,305 | $ 1,155 | $ 145 | $ 1,830 | $ 2,535 |
| KLR- 85 | 5 | 1,050 | 1,630 | 1,465 | 145 | 2,155 | 2,860 |
| KLR- 130 | 10 | 1,585 | 2,425 | 2,135 | 145 | 3,025 | 3,780 |
| **KLR- 250 | 15 | 2,405 | 3,435 | 3,025 | 145 | 4,250 | 5,000 |
| **KLR- 360 | 25 | 2,820 | 4,375 | 3,795 | 145 | 5,190 | 6,280 |
| **KLR- 700 | 50 | 4,555 | 7,020 | 5,590 | 430 | 8,275 | 9,955 |
| KLR- 701 | 30 | 4,555 | 6,650 | 5,995 | 430 | 7,340 | 9,390 |
| **KLR-1050 | 75 | 7,835 | 12,255 | 10,475 | 955 | 14,065 | 16,890 |
| KLR-1051 | 50 | 7,835 | 10,790 | 9,755 | 955 | 12,600 | 15,195 |
| **KLR-2000 | 100 | | ALL | PRICES | ON | REQUEST | |
| KLR-2600 | 200 | | " | " | " | " | |
| **KLR-2601 | 150 | | " | " | " | " | |

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CANTON MASSACHUSETTS 02021
TELEPHONE 617 828-9500

| Mod[illegible] | Add for Std. Mech. Shaft Seals | Add for Inlet Check Valve & Elbow (Mounted) | Add for All Iron Pump Construction |
|---|---|---|---|
| KLRC- 11 | $ 370 | $ 85 | $ 85 |
| KLRC- 25 | 370 | 85 | 95 |
| KLRC- 40 | 480 | 100 | 120 |
| KLRC- 75 | 480 | 100 | 130 |
| KLRC- 100 | 545 | 100 | 170 |
| KLRC- 125 | 545 | 100 | 190 |
| KLRC- 200 | 650 | 140 | 260 |
| KLRC- 300 | 650 | 140 | 310 |
| KLRC- 525 | 1,060 | 315 | 510 |
| KLRC- 526 | 1,060 | 315 | 510 |
| KLRC- 775 | 1,555 | 430 | 950 |
| KLRC- 776 | 1,555 | 430 | 950 |
| KLRC- 950 | 1,555 | 430 | 1,040 |
| KLRC- 951 | 1,555 | 430 | 1,040 |
| KLRC-1500 | PRICES | ON | REQUEST |
| KLRC-1501 | " | " | " |
| KLRC-2100 | " | " | " |
| KLRC-2101 | " | " | " |

|  |  |  |  |
|---|---|---|---|
| KLR - 45 | 480 | 100 | 95 |
| KLR - 85 | 480 | 100 | 125 |
| [illegible] 130 | 545 | 140 | 185 |
| KLR 250 | 650 | 190 | 280 |
| KLR 360 | 650 | 190 | 350 |
| KLR - 700 | 1,060 | 430 | 570 |
| KLR - 701 | 1,060 | 430 | 570 |
| KLR -1050 | 1,555 | 590 | 980 |
| KLR -1051 | 1,555 | 590 | 980 |
| KLR -2000 | PRICES | ON | REQUEST |
| KLR- 2600 | " | " | " |
| KLR -2601 | " | " | " |

**NOTES:**

- Requires motor with 1.15 service factor. ODP motors have 1.15 service factor.

** For sustained operation below 200 torr, a motor with a 1.15 service factor may be required. See Catalog Bulletin 4105 for BHP.

**SPECIAL NOTES:**

1. When ordering, exact operating voltage must be specified.
2. Standard motors through 50 HP are 3/60/230-460; 60 HP and over are single voltage (3/60/460). No additional charge for 200 or 575 volt motors. Consult factory for other voltages.
3. Motor brand is selected by Kinney. Customer-specified brand is additional. If customer furnishes motor for Kinney to mount, consult factory for additional charge.
4. Consult factory for prices on stainless steel and bronze construction and for pumps fitted with stainless steel impellers.
5. For v-belt driven units, motor prices include motor rails.
6. Separator tank is fabricated from mild steel. Consult factory for prices for protective coatings such as galvanizing, teflon, etc.
7. Standard mechanical shaft seals are suitable when sealant has properties similar to water, light oil, glycol solutions, etc. For shaft seals for other type sealants, consult factory.

Supersedes Price List 4202-17, dated 3/4/85.
Minimum Billing: $50. Terms: Net 30 days.
All prices F.O.B. Factory, Canton, MA.
For prices F.O.B. El Segundo, CA, phone
(213) 772-6191.

# Advantages of Liquid Ring Vacuum

### Vapor Handling Capacity

The liquid ring vacuum pump has a decided advantage in vacuum systems that liberate condensable vapor or slugs of liquid. The pump produces a vacuum by hurling a liquid, usually water. When vapors entrained in the gas flow contact this liquid, some condensing action takes place. Thus the liquid functions as a direct contact condenser increasing the pumping speed for vapor without appreciably impairing the pumping speed for air. This characteristic offers functional, as well as economic, advantages over oil-sealed pumps which may have to depend on water-cooled condensers or refrigerated traps to maintain their operating efficiency. With the liquid ring pump, it is frequently possible to eliminate expensive supplementary condensing equipment.

### Insensitivity to Contamination

The pumping mechanism of the liquid ring vacuum pump is insensitive to contamination by liquids and vapors if they are compatible with the sealing fluid. Liquid slugs do no mechanical harm. Some corrosion resistance can be achieved by selection of sealing fluid, temperature control, pH control, and sometimes by dilution. Where additional resistance to corrosion is required, pumps are available with special materials of construction and protective coatings.

### Economy

First cost and operating cost are low in relation to other types of vacuum devices. Economical installation and maintenance costs combine to make liquid ring pumps the first choice in many vacuum applications.

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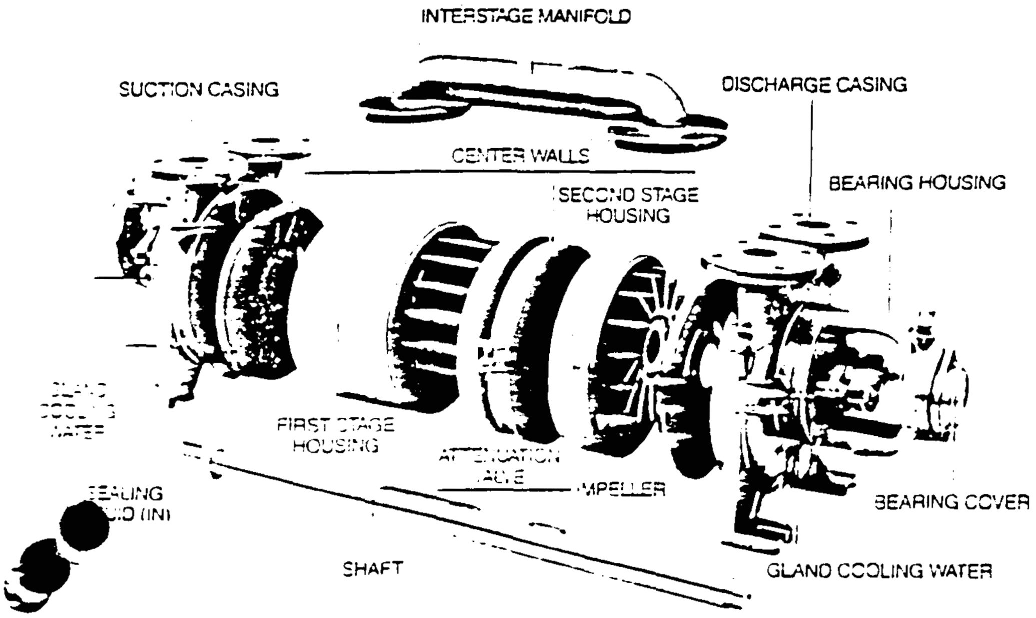


### Ease of Installation and Maintenance

Kinney liquid ring vacuum pumps are quiet, nonpulsating, and relatively vibration free, making them simple and inexpensive to install. Special foundations are generally not required. There are no rubbing surfaces to wear, so maintenance is minimal. Pumps are available in a selection of materials and can use a wide range of sealant liquids, thus providing a relative tolerance for corrosives which may enter the pump from the process stream.

### Single-Stage and Two-Stage Pumps

Single-stage units, indicated by the model prefix "KLR", provide efficient, economical service in the pressure range from atmosphere to (approximately) 150 torr. Two-stage (compound) pumps designated "KLRC", have a lower pressure capability, producing absolute pressures down to 30 torr using water as a sealant and substantially lower with low vapor pressure fluids.

### Optional Sealing Fluids

A distinctive feature of the liquid ring vacuum pump is its ability to use fluids other than water as a sealant. This permits selection of a fluid which has a lower vapor pressure or is compatible with process gases and, in the case of vacuum distillation, the distillate itself can frequently be used as a sealant.

### Combinations to Extend Service Range

Liquid ring vacuum pumps may be "staged" in combination with lobe-type blowers, air ejectors, and steam ejectors to extend the operating pressure range downward or amplify the pumping speed. These combinations are described in a separate brochure.

### Adaptability

Liquid ring vacuum pumps are adaptable to a broad range of industrial processes as described on page 7 of this brochure. Contact your nearest Kinney sales office to determine the suitability of liquid ring pumps for your process or application.

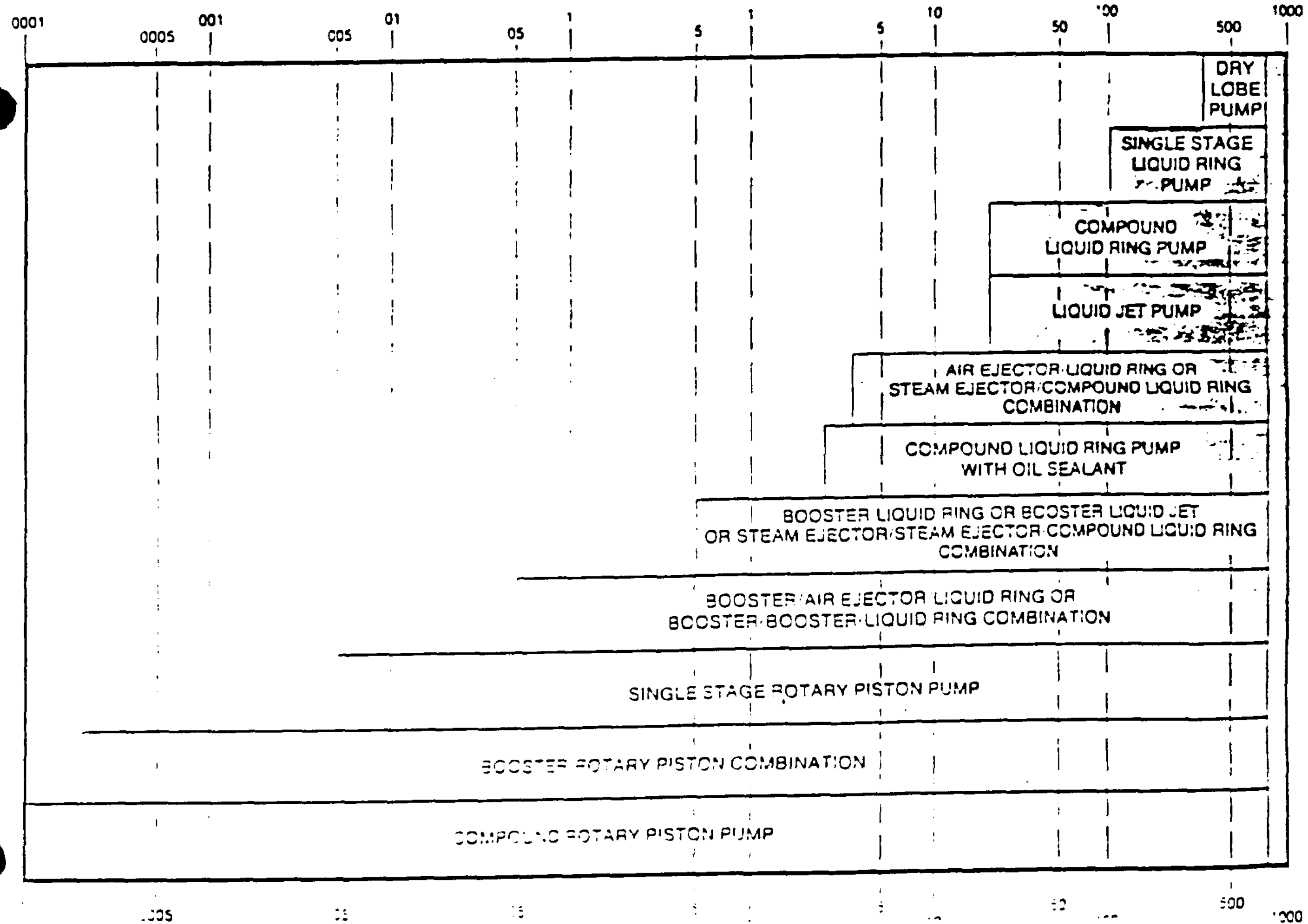
# Pump Sizing and Selection

**Factors Determining Type and Size of Pump Required**
The following factors should be considered in selecting the proper size pump:

1. **Required Operating Pressure** This determines whether a Kinney single-stage pump or a compound pump is required. The practical lower pressure limit for single-stage pumps is 150 torr. Below this pressure, compound pumps should be considered. When compound pumps are not large enough, or the inlet pressure is beyond the range of liquid ring pumps, staging with boosters, air ejectors, or steam ejectors should be considered.

The chart below illustrates the operating pressure ranges for the most commonly used pumps and systems.

2. **Operating Altitude** The pumping capacities shown in this brochure, when stated in inches of vacuum, are based on operation at sea level. When operating at higher altitudes, pumping capacity in inches of vacuum will be limited by the existing barometric pressure.
3. **Pumpdown Time** from the initial pressure to the final desired pressure.
4. **Volume of the System** to be evacuated.
5. **Gas Load** in terms of condensable and permanent-type gases that will evolve from the process and leak into the vessel. Gas load includes either that of deliberate nature or that existing as a result of the vessel not being vacuum tight.
6. **Vacuum Manifold** and its effect on reducing pump speed as related to length, diameter, configuration, entrance, and fittings.
7. **Economic Priorities** such as:
   - a. Utilization of existing equipment.
   - b. Process recovery (noncontamination of air and water).
   - c. Allowable noise level.
   - d. First cost.
   - e. Operating cost as determined by:
     - 1) Pump selection.
     - 2) Manpower (installation, operation, and service).
     - 3) Duty cycle (hours/day, days/week, weeks/year).
     - 4) Cost of electricity and water (sealing and/or cooling).
     - 5) Payback period.



Typical Pressure Ranges for Various Vacuum Pumping Devices

# Sealant System Selection

Early in the planning of a liquid ring vacuum pump installation, the design of the sealant system and its effect on the performance of the pump should be considered. There are several elements of pump sizing and selection, as well as system design, that will be affected by the choice of the sealant system.

Of the seven basic factors shown on the facing page, which help to determine the type and size of pump required, several are affected by the selection of a sealant system.

- Operating pressure is affected by sealant temperature, which in turn is affected by flow rate, specific heat, density, and viscosity.
- Gas load may influence the selection of the sealant and the sealant circulating system.
- Economic and other priorities may indicate a system where process recovery can be accomplished for purposes of water conservation and/or pollution control.
- Operating costs for cooling will almost always have an influence on design decisions.

Although there are variations, there are three basic types of sealant systems from which to choose.

- Once through, no sealant recovery system
- Partial sealant recovery system
- Full sealant recovery system

Piping schematics and brief descriptions of each of the three systems are shown on this page.

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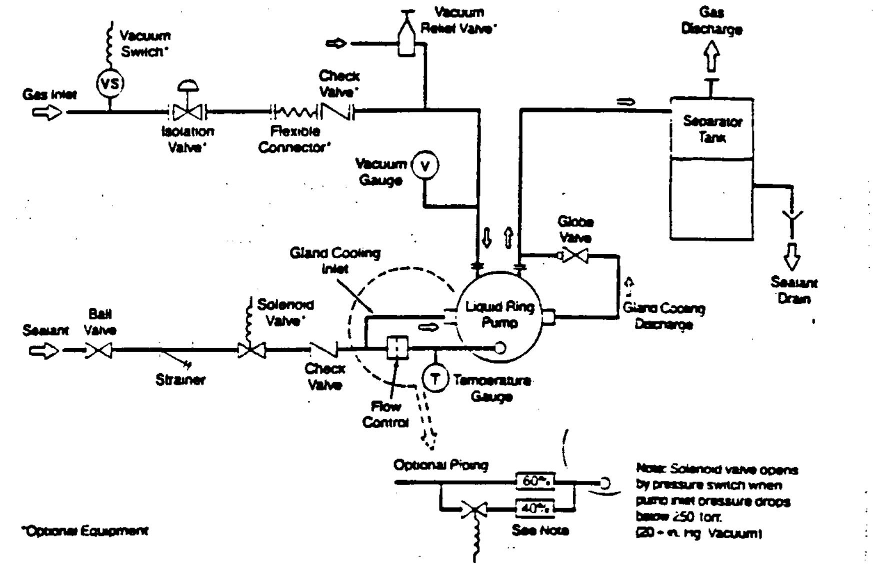
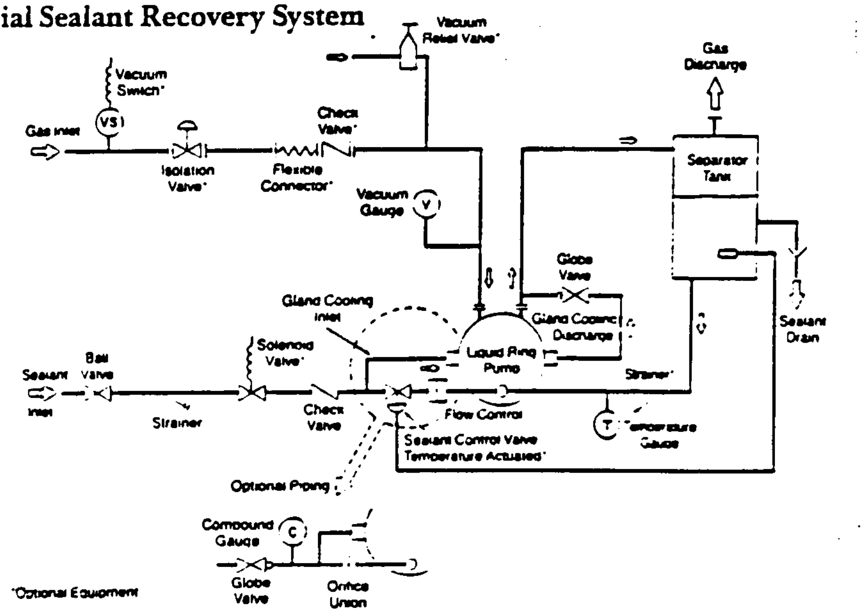
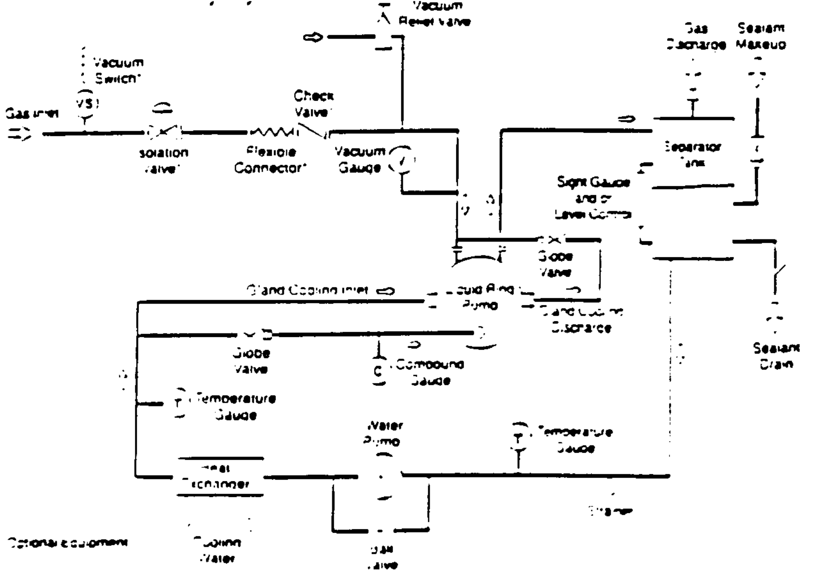
### Once Through, No Sealant Recovery System



### Partial Sealant Recovery System



### Full Sealant Recovery System



**Inlet Elbow.** Adapts vertical pump inlet to horizontal for mounting of inlet check valve. Also used to connect pump discharge separator tank.

**Inlet Vacuum Gauge.** Shows pump inlet vacuum. Standard 3½-inch dial gauge comes with shut-off valve, has brass Bourdon tube, and reads 0-30 in. Hg vacuum. Gauge is normally mounted to pump suction tapping. Stainless steel tube is available at additional cost. Precision gauges are also available.

**Inlet Vacuum Relief Valve.** Controls pump inlet and system vacuum. If pump capacity exceeds the system requirements at the preset vacuum, the valve will open and admit ambient air or connected gas source to the pump inlet. Valve selection depends on desired vacuum setting and pump size. Standard valve is sized for typical vacuum setting range of 15 in. Hg vacuum for single-stage pumps and 20 in. Hg vacuum or more for compound pumps.

**Inlet Check Valve.** Automatically isolates pump from inlet system when vacuum pump is shut down. Permits inlet system to stay at vacuum and protects system from backflow of air and sealant. Standard valve is of special low pressure differential design with stainless steel disc, elastomeric seat, and bronze body. Models through KLRC-300 have threaded connections. Model KLR-360 and larger have cast iron valve body with flange connections. Inlet elbow option is required for horizontal operation.

**Inlet Shut-Off Valve.** Postively isolates pump from inlet system. Standard valves are full passage cast iron body with flanges and Buna-N diaphragm for all pump models through KLRC-300. For KLR-360 and larger, cast iron butterfly valves with O-ring seals are used. The latter mount between mating flanges.

**Connector, Flexible, Type I.** Accommodates some motion and misalignment between pump and system. This type is relatively low cost and is recommended for most installations. It consists of flanged ends with a short length of flexible vacuum hose.

**Connector, Flexible, Type II.** Used where considerable relative motion exists between pump inlet and/or discharge and system piping. Standard connector is steel flanged with stainless steel bellows.

**Connector, Self-Aligning.** Corrects for misalignment between pump and system piping. This type will support a normal amount of piping. Some vibration isolation is also achieved. Standard connector has flanged ends with corrosion-resistant plated steel and Buna-N gaskets. Connector is also available with stainless steel sleeve and Viton gaskets at extra cost.

**Mechanical Shaft Seals.** Used in place of standard gland packing to control sealant leakage and to protect shaft. Standard is chemical-type (carbon, ceramic, teflon, and stainless steel). Alternate designs and materials are available.

**Sealant Supply Flow Control.** Establishes the sealant flow rate to the vacuum pump sealing liquid connection. The type of control used depends upon the type of sealant system used, pump size, and individual preference.

**Discharge Separator Tank.** Collects the gas-liquid discharge from the pump, separates liquid sealant from gas, provides liquid storage for sealant recovery systems, and has fittings for mounting of optional sealant level sight and control devices, etc. Additional air discharge silencing is not required for normal noise limits.

Standard tank is steel. Galvanized and stainless steel tanks are available at extra cost. Tanks are included in standard sealant recovery systems.

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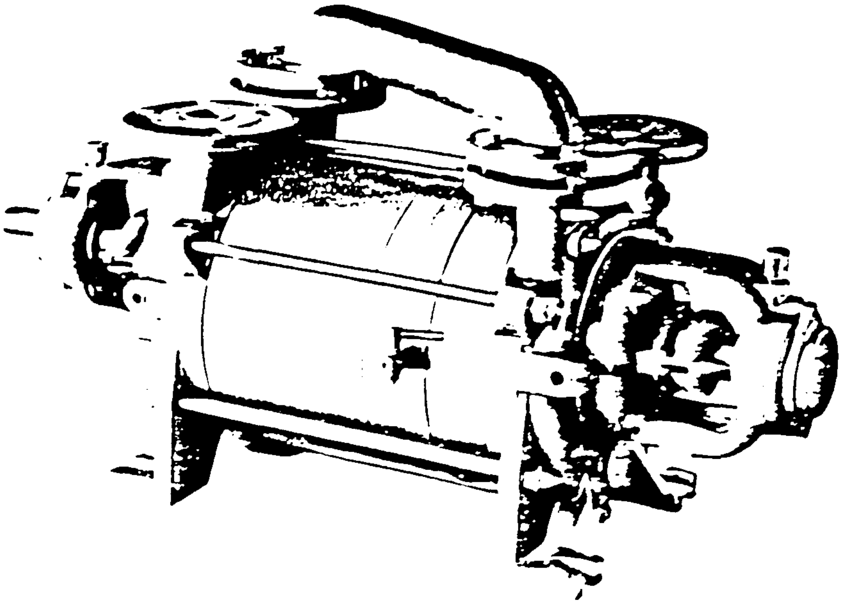

| Application | Function of Liquid Ring Pump | Examples of Use |
|---|---|---|
| Casting, Molding, and Forming | Evacuation of molds, degasification of molten materials | Rubber, plastics, metals, wood products, veneers |
| Chucking | Vacuum pickup, handling, positioning, and holding | Glass, sheet products, small parts, auto windshields, aircraft surfaces, beverage cans, sawmill operations |
| Cooling and Chilling | Rapid evaporation of moisture content | Fruits and vegetables |
| Deaeration and Degasification | Removal of gases | Water, rubber products, oils, plastics, molten metals, beverages |
| Dehydration | Removal of condensable vapors | Transformers, refrigeration systems, foods, chemicals, electrical cables and conduits, grain, textiles, ink and dyes, rotary dryers |
| Deodorization | Removal of offensive gases | Chemicals, food products, effluent processing |
| Distillation | Vacuum extraction of fractions | Chemicals, petroleum, petrochemicals, pharmaceuticals, food products |
| Evacuation | Removal of vapors and gases | Environmental chambers, steam condensers, lasers, leak test chambers, reactors, process vessels, central vacuum systems |
| Evisceration | Removal of viscera | Poultry, fish, shellfish |
| Filling | Removal of trapped air, increased filling speed | Cooling and hydraulic systems, food and beverage containers, electrical transformers, liquid transfer systems |
| Filtration | Increase flow of filtrate by reducing pressure on discharge side of filter | Chemicals, food products, pharmaceuticals |
| Freeze Drying | Removal of moisture by sublimation under vacuum | Coffee, fruits and vegetables, pharmaceuticals, food products |
| Impregnation | Removal of vapors and gases | Cables, metal products, wood products |
| Packaging and Sealing | Evacuation of film and blister packages, bottles, cans and jars | Meat, poultry, hardware, food products, canned and bottled products |
| Puffing | Increase volume of plastic materials by evolution of volatiles or expansion of trapped bubbles | Plastics, rubber, food products |
| Vacuum Cooking | Reduction of cooking or boiling temperature by lowering pressure in vessel | Food, candy, chemicals |

# Specifications

## Compound Liquid Ring Vacuum Pumps

| | | KLRC 11 | KLRC 25 | KLRC 40 |
|---|---|---|---|---|
| Rotational Speed | RPM | 1750 | 1750 | 1750 |
| Standard Motor* | HP | 2 | 3 | 5 |
| 60°F Sealing Water Required W/Partial Water Recovery | GPM<br>Litre/Min. | ** | ** | ** |
| 60°F Sealing Water Required W/No Water Recovery | GPM<br>Litre/Min. | 1.5<br>5.7 | 2.5<br>9.5 | 5<br>18.9 |
| Sealing Water Connection | NPT | ⅜ | ⅜ | ½ |
| Inlet/Outlet Connections*** | Inches | 1¼ | 1¼ | 1½ |
| Height, Bare Shaft Pump | Inches<br>mm | 10½<br>267 | 10½<br>267 | 12⅝<br>321 |
| Width, Bare Shaft Pump | Inches<br>mm | 8 11/16<br>221 | 8 11/16<br>221 | 9⅞<br>251 |
| Length, Bare Shaft Pump | Inches<br>mm | 21 9/16<br>548 | 22¾<br>578 | 26<br>660 |
| Weight, Bare Shaft Pump | Pounds<br>Kg | 75<br>34 | 84<br>38 | 139<br>63 |
| Weight, Compl. Pump Ass'y | Pounds<br>Kg | 145<br>66 | 179<br>81 | 257<br>117 |
| Drive | | | Direct Drive | |
| Standard Shaft Seal | | | Stuffing Box | |
| Standard Materials of Construction | | | | |

# Performance Data

Typical pumping capacity in acfm of air (50% R.H., water inlet temperature 60°F, barometric pressure 14.696 psia)

| Pressure mm Hg Abs. | Vacuum Inches Hg | KLRC 11 | KLRC 25 | KLRC 40 |
|---|---|---|---|---|
| 760 | 0 | 7.0 | 18.5 | 34 |
| 632 | 5 | 7.8 | 19.0 | 34 |
| 507 | 10 | 8.7 | 21.0 | 35 |
| 380 | 15 | 9.7 | 22.0 | 35 |
| 254 | 20 | 11.0 | 24.0 | 36 |
| 126 | 25 | 12.0 | 26.0 | 35 |
| 100 | 26 | 12.0 | 25.8 | 34 |
| 74 | 27 | 11.7 | 24.0 | 31 |
| 49 | 28 | 9.3 | 18.5 | 23 |
| 30 | 28.8 | 3.0 | 7.0 | 10 |
| 25 | 29 | — | — | 5.5 |

# Brake Horsepower

| | KLRC 11 | KLRC 25 | KLRC 40 |
|---|---|---|---|
| Peak BHP–No Water Recovery | 1.8 | 2.8 | 4 |
| Peak BHP–Partial Water Recovery | — | — | — |
| BHP @ 75 mm Hg Abs.–Either System | — | — | — |

Notes

*Standard motor is open, drip proof for standard operating conditions. Smaller or larger motors may be used on some models when chosen sealant system and/or operating conditions permit.

**For sealed water recovery requirements on Models KLRC-11 through KLRC-75, consult factory.

***Models KLRC-11 & 25 have NPT connections. All other models have flange connections with 150# USASI drillings.

| L | LRC | KLRC | KLRC | KLRC | KLRC | KLRC | KLRC | KLRC | KLRC | KLRC | KLRC | KLRC | KLRC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 100 | 125 | 200 | 300 | 525 | 526 | 775 | 776 | 950 | 951 | 1500 | 1501 | 2100 | 2101 |
| 750 | 1750 | 1750 | 1750 | 1750 | 1500 | 1150 | 880 | 1150 | 880 | 870 | 680 | 870 | 690 |
| 7½ | 10 | 15 | 25 | 50 | 40 | 75 | 50 | 100 | 60 | 150 | 100 | 200 | 125 |
| 3 | 3.5 | 5 | 7 | 12 | 8 | 15 | 12 | 20 | 15 | 30 | 25 | 40 | 30 |
| 12 | 13.2 | 18.9 | 26.5 | 45.5 | 30.2 | 57 | 45.5 | 76 | 57 | 113.6 | 95 | 152 | 113.6 |
| 6 | 7 | 10 | 14 | 24 | 16 | 30 | 24 | 40 | 30 | 60 | 50 | 75 | 60 |
| 23 | 26.5 | 37.9 | 53 | 91 | 60 | 113 | 91 | 151 | 113 | 227 | 189 | 285 | 227 |
| ¾ | ¾ | 1 | 1 | 1¼ | 1¼ | 1½ | 1½ | 1½ | 1½ | 2½ | 2½ | 2½ | 2½ |
| 1½ | 1½ | 2 | 2 | 3 | 3 | 4 | 4 | 4 | 4 | 6 | 6 | 6 | 6 |
| 15/16 | 15 15/16 | 18 13/16 | 18 13/16 | 23 1/16 | 23 1/16 | 29¼ | 29¼ | 29¼ | 29¼ | 39 7/16 | 39 7/16 | 39 7/16 | 39 7/16 |
| 05 | 405 | 478 | 478 | 586 | 586 | 743 | 743 | 743 | 743 | 1002 | 1002 | 1002 | 1002 |
| 1 9/16 | 11 9/16 | 15 9/16 | 15 9/16 | 19¼ | 19¼ | 23¼ | 23¼ | 23¼ | 23¼ | 30 15/16 | 30 15/16 | 30 15/16 | 30 15/16 |
| 94 | 294 | 395 | 395 | 489 | 489 | 591 | 591 | 591 | 591 | 786 | 786 | 786 | 786 |
| 9/16 | 31 15/16 | 35¼ | 39 | 46 | 46 | 56 9/16 | 56 9/16 | 60½ | 60½ | 82½ | 82½ | 86 7/16 | 86 7/16 |
| 51 | 811 | 895 | 991 | 1168 | 1168 | 1437 | 1437 | 1537 | 1537 | 2096 | 2096 | 2196 | 2196 |
| 15 | 245 | 342 | 399 | 613 | 613 | 1323 | 1323 | 1510 | 1510 | 3484 | 3484 | 3749 | 3749 |
| 98 | 111 | 155 | 180 | 278 | 278 | 600 | 600 | 685 | 685 | 1580 | 1580 | 1700 | 1700 |
| 18 | 481 | 626 | 820 | 1315 | 1328 | 2287 | 2167 | 2778 | 2496 | 5636 | 5229 | 6168 | 5549 |
| 90 | 218 | 284 | 372 | 596 | 602 | 1037 | 983 | 1260 | 1132 | 2556 | 2372 | 2798 | 2517 |

V-Belt Drive

Stuffing Box with Lantern Ring

Iron Pump, Bronze Impeller, Stainless Steel Shaft

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 70 | 95 | 150 | 160 | 350 | 320 | 600 | 490 | 630 | 600 | 920 | 1125 | 1075 | 1170 |
| 70 | 95 | 162 | 180 | 380 | 340 | 630 | 510 | 670 | 630 | 1000 | 1125 | 1200 | 1200 |
| 73 | 98 | 174 | 210 | 420 | 360 | 675 | 545 | 730 | 650 | 1100 | 1150 | 1325 | 1240 |
| 77 | 103 | 185 | 245 | 460 | 380 | 730 | 600 | 800 | 700 | 1225 | 1180 | 1500 | 1330 |
| 35 | 114 | 200 | 280 | 510 | 420 | 800 | 650 | 890 | 770 | 1400 | 1300 | 1750 | 1460 |
| 00 | 130 | 205 | 300 | 560 | 430 | 830 | 670 | 990 | 810 | 1675 | 1400 | 2150 | 1540 |
| 00 | 130 | 200 | 290 | 540 | 420 | 825 | 660 | 1000 | 810 | 1700 | 1390 | 2200 | 1540 |
| 93 | 125 | 190 | 280 | 520 | 380 | 800 | 650 | 985 | 790 | 1680 | 1320 | 2150 | 1500 |
| 6 | 115 | 170 | 240 | 450 | 325 | 700 | 560 | 900 | 675 | 1450 | 1140 | 1850 | 1230 |
| 0 | 80 | 120 | 160 | 275 | 170 | 380 | 300 | 630 | 365 | 870 | 770 | 1150 | 660 |
| 1 | 55 | 75 | — | — | — | — | — | — | — | — | — | — | — |
| .5 | 10 | 14.5 | 27 | 53 | 37 | 78 | 48 | 100 | 65 | 147 | 102 | 200 | 125 |
| .5 | 10 | 14 | 25 | 50 | 33 | 72 | 45 | 92 | 60 | 137 | 95 | 190 | 120 |
| .0 | 9.5 | 14 | 23.5 | 46 | 30 | 68 | 40 | 83 | 50 | 128 | 89 | 150 | 94 |

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# Specifications

## Single-Stage Liquid Ring Vacuum Pumps

| | | KLR 45 | KLR 85 | KLR 130 | KLR 250 | KLR 360 | KLR 700 | KLR 701 | KLR 1050 | KLR 1051 | KLR 2000 | KLR 2600 | KLR 2601 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rotational Speed | RPM | 1750 | 1750 | 1750 | 1750 | 1750 | 1750 | 1300 | 1150 | 900 | 680 | 870 | 780 |
| Standard Motor* | HP | 3 | 5 | 10 | 15 | 25 | 50 | 30 | 75 | 50 | 100 | 200 | 150 |
| 60° F Sealing Water Required W/Partial Water Recovery | GPM<br>Litre/Min. | ** | ** | 3<br>11.5 | 5<br>19 | 6<br>23 | 11<br>41.8 | 7<br>26.5 | 18<br>68 | 12<br>45 | 30<br>114 | 60<br>228 | 30<br>114 |
| 60°F Sealing Water Required W/No Water Recovery | GPM<br>Litre/Min. | 4<br>15.2 | 5<br>19.0 | 7<br>26.5 | 10<br>38 | 15<br>57 | 22<br>83.6 | 20<br>76 | 30<br>114 | 25<br>95 | 40<br>150 | 70<br>265 | 50<br>190 |
| Sealing Water Connection | NPT | ½ | ½ | ¾ | 1 | 1 | 1¼ | 1¼ | 1½ | 1½ | 2½ | 2½ | 2½ |
| Inlet/Outlet Connections*** | Inches | 1½ | 1½ | 2 | 2½ | 2½ | 4 | 4 | 5 | 5 | 8 | 8 | 8 |
| Height, Bare Shaft Pump | Inches<br>mm | 12⅝<br>321 | 12⅝<br>321 | 17¾<br>450 | 20 7/16<br>519 | 20 7/16<br>519 | 24 13/16<br>630 | 24 13/16<br>630 | 31 5/16<br>795 | 31 3/16<br>795 | 41¾<br>1060 | 41¾<br>1060 | 41¾<br>1060 |
| Width, Bare Shaft Pump | Inches<br>mm | 9⅞<br>251 | 9⅞<br>251 | 12 5/16<br>312 | 16 3/16<br>414 | 16 3/16<br>414 | 20⅛<br>511 | 20⅛<br>511 | 24⅜<br>619 | 24⅜<br>619 | 33 1/16<br>840 | 33 1/16<br>840 | 33 1/16<br>840 |
| Length, Bare Shaft Pump | Inches<br>mm | 22½<br>572 | 24 1/16<br>611 | 27⅜<br>701 | 38⅝<br>981 | 38⅝<br>981 | 42¾<br>1086 | 42¾<br>1086 | 52½<br>1334 | 52½<br>1334 | 75⅞<br>1927 | 88 3/16<br>2240 | 88 3/16<br>2240 |
| Weight, Bare Shaft Pump | Pounds<br>Kg | 97<br>44 | 106<br>48 | 198<br>90 | 375<br>170 | 463<br>210 | 706<br>320 | 706<br>320 | 1323<br>600 | 1323<br>600 | 3749<br>1700 | 4190<br>1900 | 4190<br>1900 |
| Weight, Compl. Pump Ass'y | Pounds<br>Kg | 192<br>87 | 224<br>102 | 434<br>197 | 746<br>338 | 882<br>400 | 1441<br>654 | 1309<br>594 | 2414<br>1095 | 2196<br>996 | 5488<br>2489 | 6609<br>2998 | 6415<br>2910 |

Drive — Direct Drive — V-Belt Drive

Standard Shaft Seal — Stuffing Box — Stuffing Box with Lantern Ring

Standard Materials of Construction — Iron Pump, Bronze Impeller, Stainless Steel Shaft

# Performance Data

Typical pumping capacity in acfm of air (50% R.H., water inlet temperature 60°F, barometric pressure 14.696 psia)

| Pressure mm Hg Abs. | Vacuum Inches Hg | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 760 | 0 | 33 | 68 | 130 | 250 | 360 | 650 | 490 | 1030 | 853 | 1650 | 2500 | 2300 |
| 632 | 5 | 35 | 71 | 130 | 250 | 360 | 650 | 490 | 1030 | 860 | 1720 | 2500 | 2300 |
| 507 | 10 | 36 | 73 | 130 | 250 | 360 | 650 | 490 | 1030 | 840 | 1710 | 2500 | 2300 |
| 380 | 15 | 36 | 74 | 130 | 250 | 360 | 650 | 490 | 1030 | 820 | 1620 | 2500 | 2250 |
| 254 | 20 | 34 | 71 | 124 | 245 | 360 | 620 | 460 | 1000 | 760 | 1450 | 2200 | 2000 |
| 126 | 25 | 23 | 52 | 80 | 173 | 250 | 410 | 300 | 700 | 450 | 850 | 1900 | 1070 |

# Brake Horsepower

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Peak BHP–No Water Recovery @ 126 mm Hg Abs. | 3.2 | 5.0 | 10 | 16 | 26 | 52 | 30 | 78 | 48 | 105 | 200 | 157 |
| BHP Operating @ 250 mm Hg Abs. | 3.0 | 4.1 | 9 | 15 | 24 | 50 | 28 | 75 | 47 | 100 | 190 | 150 |
| BHP Operating @ 500 mm Hg Abs. | 2.5 | 3.7 | 7 | 13 | 19 | 45 | 25 | 72 | 41 | 90 | 170 | 135 |

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NOTES:

*Standard motor is open, drip proof for standard operating conditions to 25 in. Hg Vacuum (126 mm Hg Abs.). Smaller or larger motors may be used on some models when chosen sealant system and/or operating conditions permit.

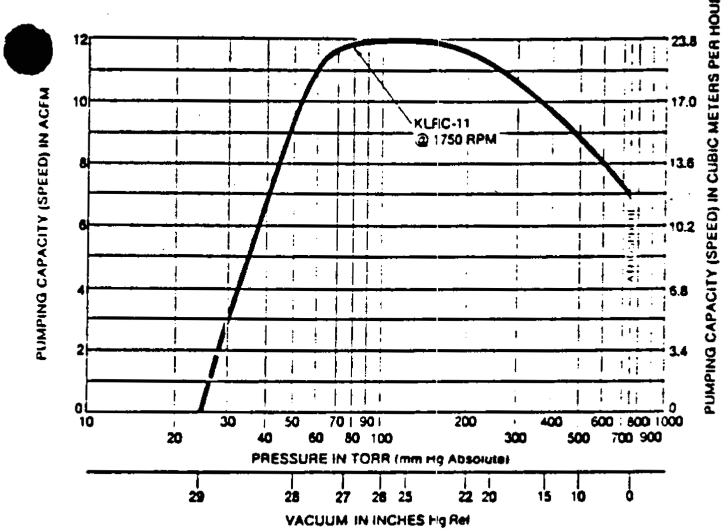
**For sealed water recovery requirements on Models KLR-45 and KLR-85, consult factory.

***Flange connections with 150# USASI drillings.

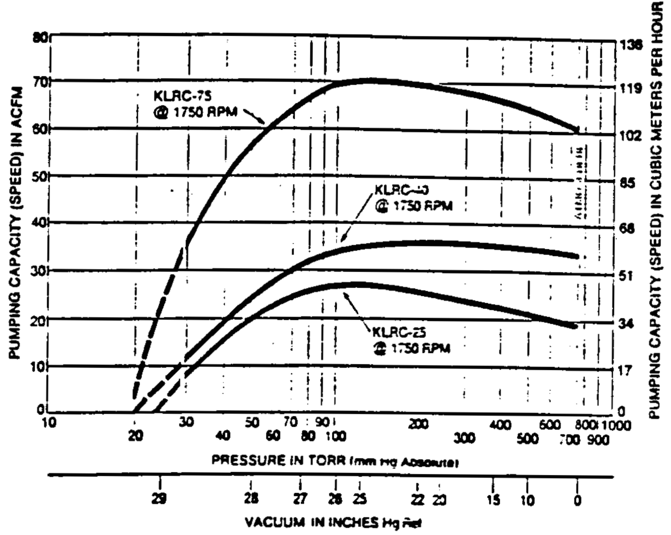
# Pumping Capacity Curves

## Compound Liquid Ring Vacuum Pumps

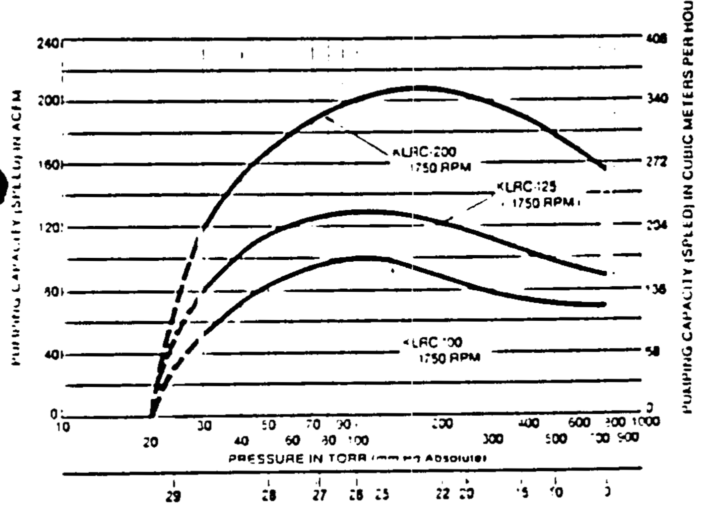
Model KLRC-11



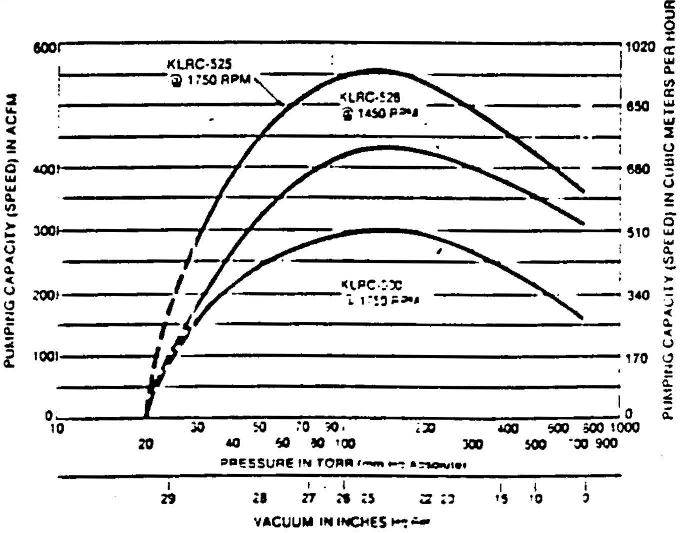
Models KLRC-25, KLRC-40, and KLRC-75



Models KLRC-100, KLRC-125, and KLRC-200



Models KLRC-300, KLRC-525, and KLRC-526



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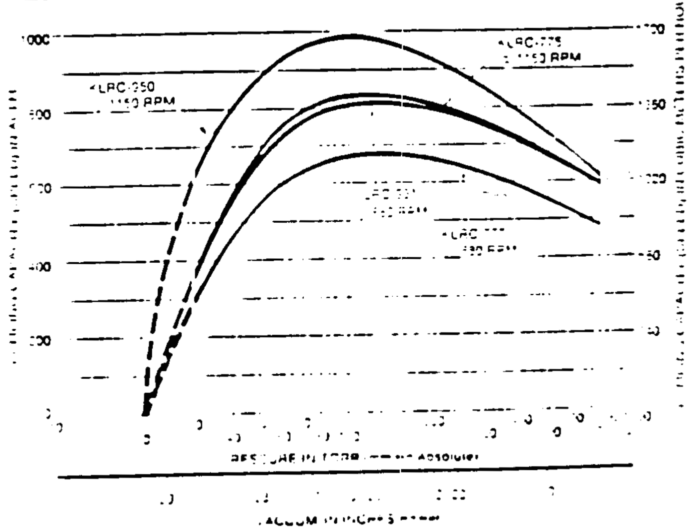
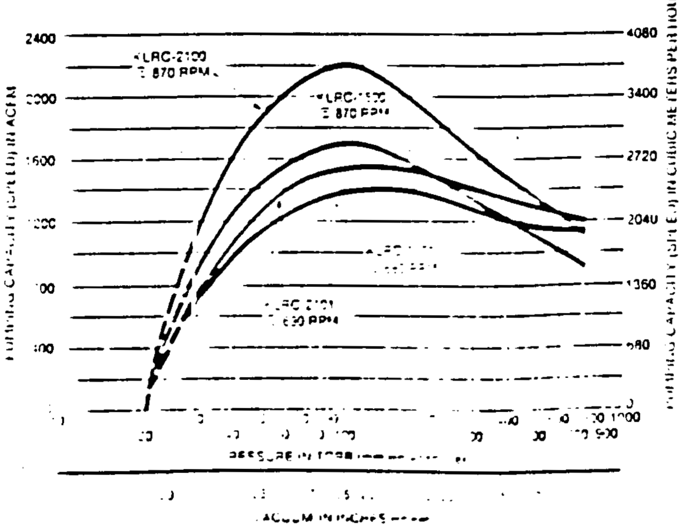
Models KLRC-775, KLRC-776,
KLRC-950, and KLRC-951



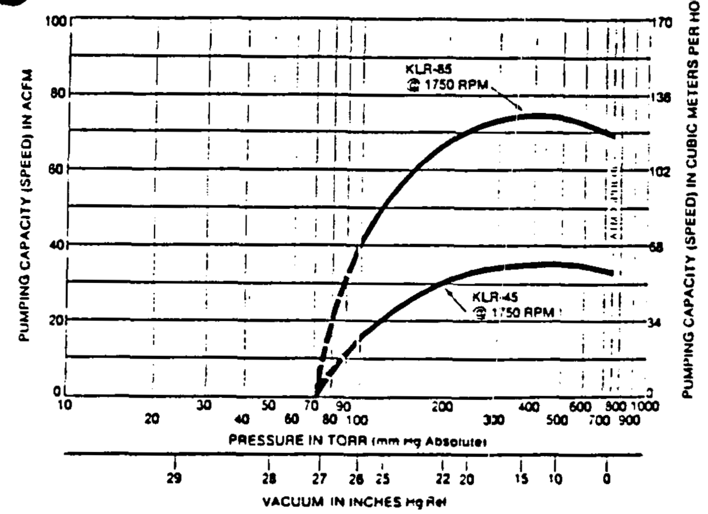
Models KLRC-1500, KLRC-1501,
KLRC-2100, and KLRC-2101



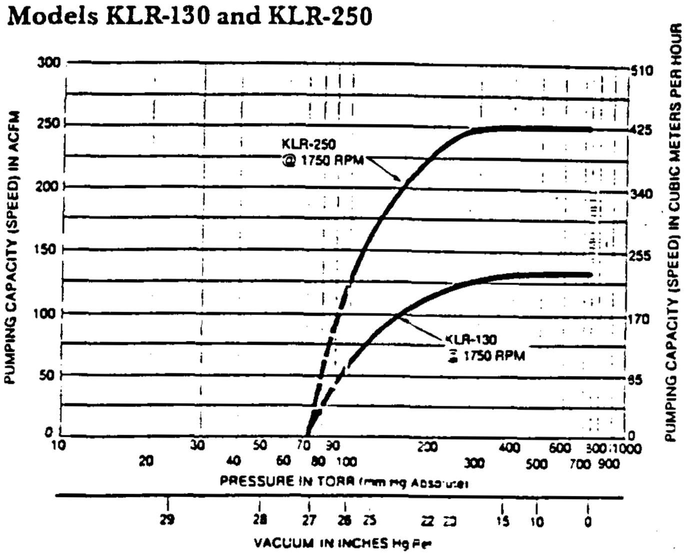
# Pumping Capacity Curves

## Single Stage Liquid Ring Vacuum Pumps

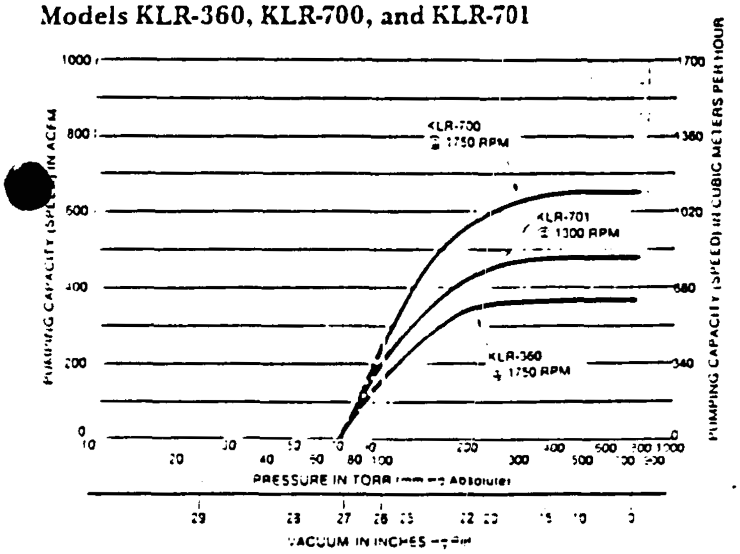
### Models KLR-45 and KLR-85



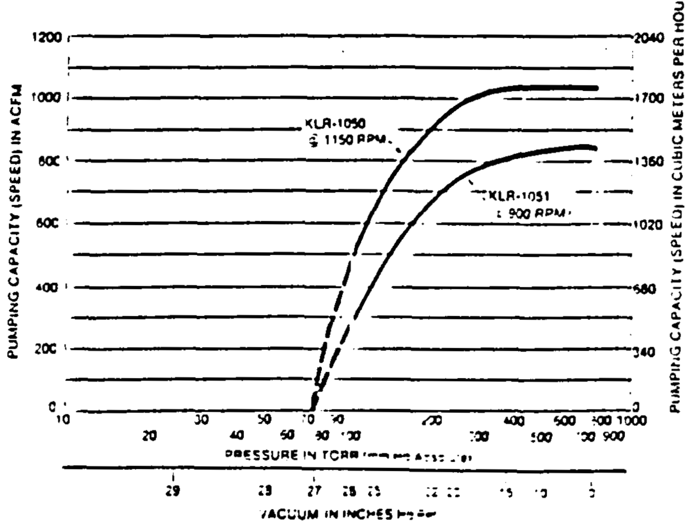
### Models KLR-130 and KLR-250



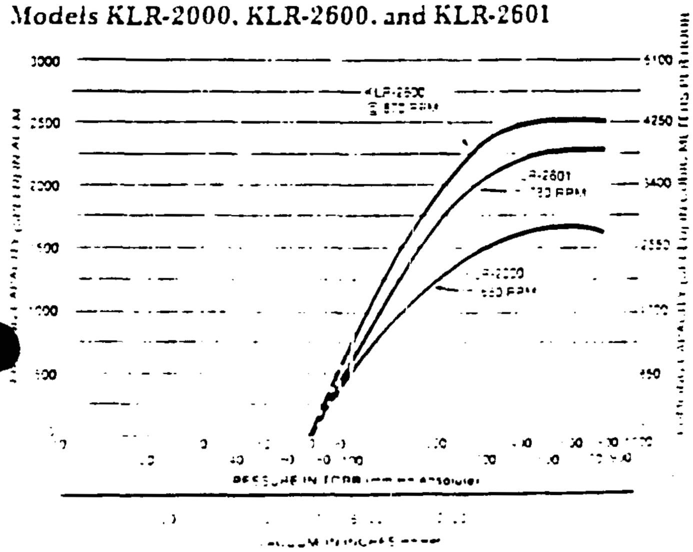
### Models KLR-360, KLR-700, and KLR-701



### Models KLR-1050 and KLR-1051



### Models KLR-2000, KLR-2600, and KLR-2601



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# Compound Liquid Ring Vacuum Pumps

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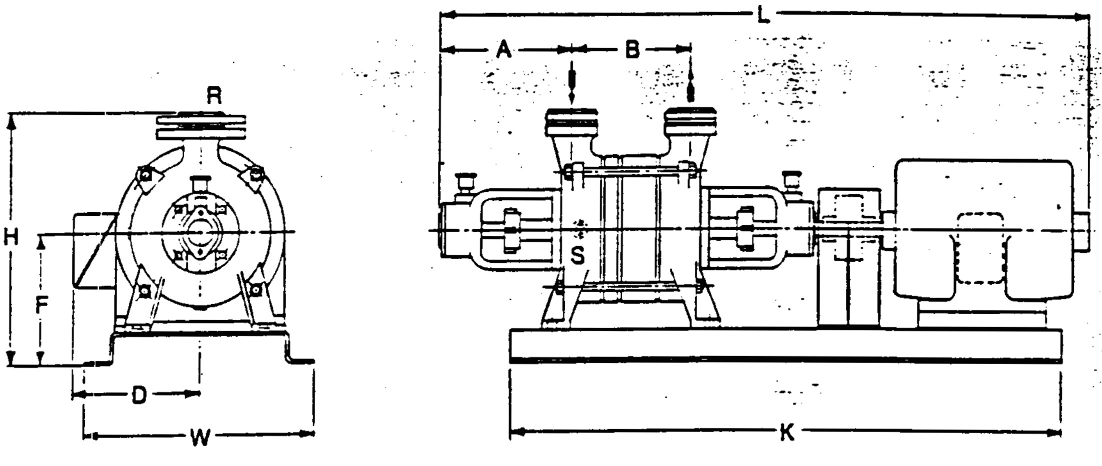
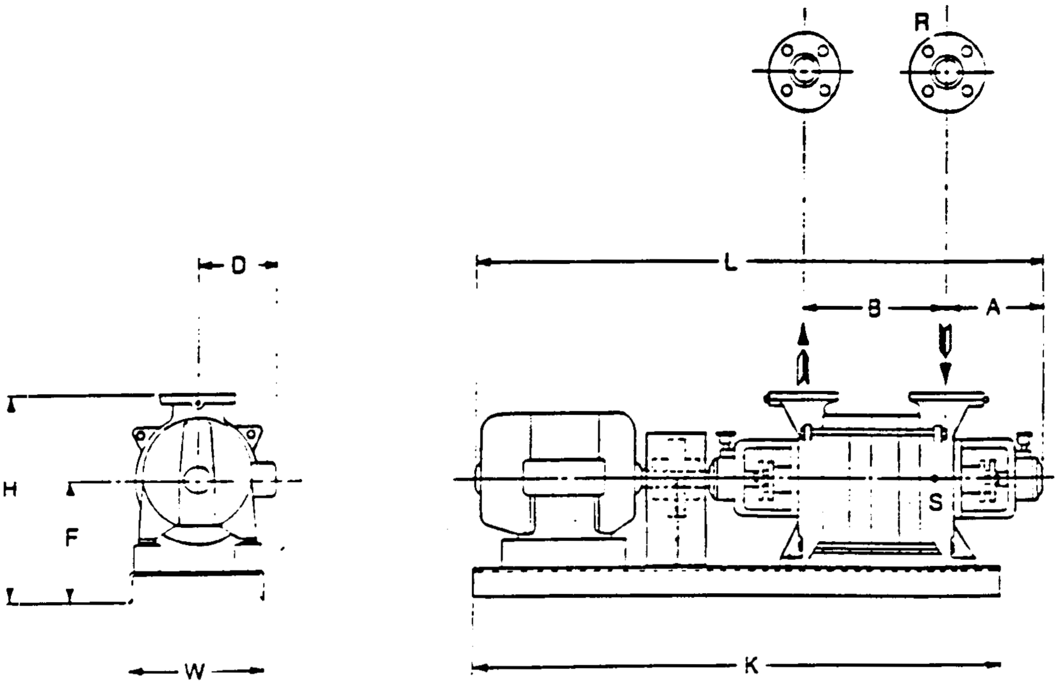


S = Sealed Liquid Flush

Models KLRC-11 & 25

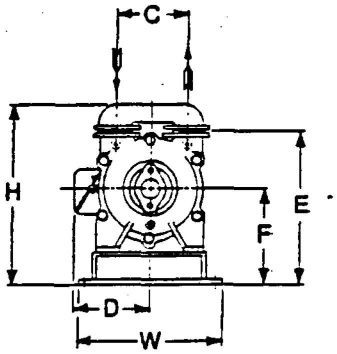


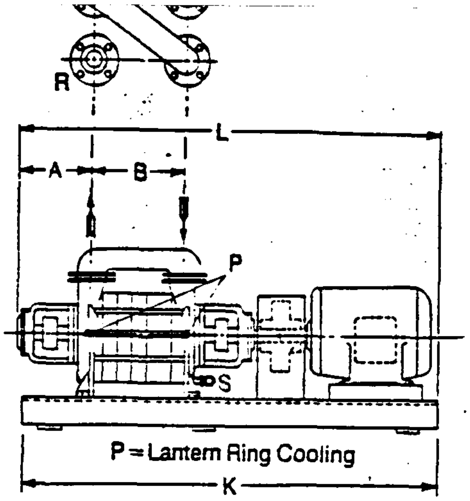
Models KLRC-40 & 75

| | | A | B | D | F | H | K | L | R | S | W | Standard Motor HP | Standard Motor Frame |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| KLRC-11 | Inches | 7³⁄₁₆ | 5¼ | 6 | 6¹¹⁄₁₆ | 12¾ | 34¼ | 36¾ | 1¼* | ¾ | 12⅝ | 2 | 145 |
| | mm | 183 | 133 | 152 | 170 | 324 | 870 | 933 | | | 321 | | |
| KLRC-25 | Inches | 7³⁄₁₆ | 6⁷⁄₁₆ | 8¼ | 6¹¹⁄₁₆ | 12¾ | 34¼ | 37⅞ | 1¼* | ¾ | 13⅜ | 3 | 182 |
| | mm | 183 | 164 | 210 | 170 | 324 | 870 | 962 | | | 340 | | |
| KLRC-40 | Inches | 7¹⁄₁₆ | 9⁹⁄₁₆ | 8¼ | 8 | 14⅛ | 34⅜ | 42³⁄₁₆ | 1½ | ½ | 10 | 5 | 184 |
| | mm | 180 | 243 | 210 | 203 | 359 | 873 | 1072 | | | 254 | | |
| KLRC-75 | Inches | 7¹⁄₁₆ | 11³⁄₁₆ | 8¼ | 8 | 14⅛ | 36 | 43¹³⁄₁₆ | 1½ | ½ | 10 | 5 | 184 |
| | mm | 180 | 284 | 210 | 203 | 359 | 914 | 1113 | | | 254 | | |

*NPT flange. All others are ANSI flange.

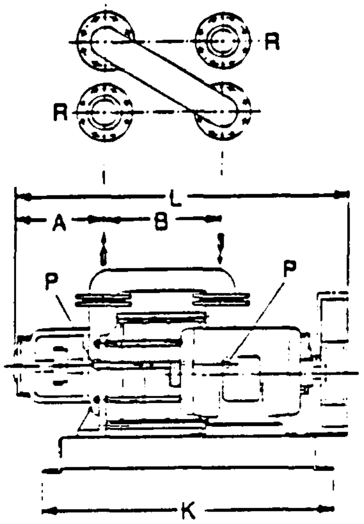
## Models KLRC – 100, 125, 300, 525

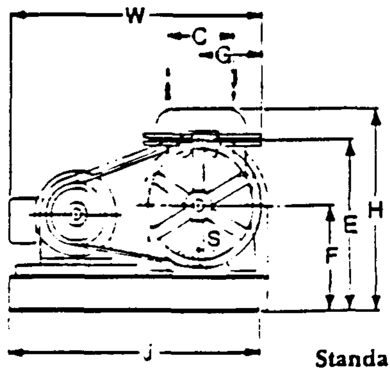




| | | A | B | C | D | E | F | H | K | L | P | R | S | W | Standard Motor HP | Standard Motor Frame |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| KLRC-100 | Inches | 8⅛ | 10⅝ | 6⁵⁄₁₆ | 9⅛ | 17¼ | 10⅜ | 19⅞ | 50 | 50 | ¼ | 1½ | ¾ | 15 | 7½ | 215 |
| | mm | 206 | 270 | 160 | 232 | 438 | 264 | 505 | 1270 | 1270 | | | | 381 | | |
| KLRC-125 | Inches | 8⅛ | 13 | 6⁵⁄₁₆ | 9⅛ | 17¼ | 10⅜ | 19⅞ | 50 | 54 | ¼ | 1½ | ¾ | 15 | 10 | 215 |
| | mm | 206 | 330 | 160 | 232 | 438 | 264 | 505 | 1270 | 1370 | | | | 381 | | |
| KLRC-200 | Inches | 9¾ | 13 | 9¹⁄₁₆ | 11 | 20 | 11¾ | 22¾ | 58 | 58 | ⅜ | 2 | ¾ | 19 | 15 | 254 |
| | mm | 248 | 330 | 230 | 279 | 508 | 298 | 578 | 1473 | 1473 | | | | 483 | | |
| KLRC-300 | Inches | 9¾ | 16⁷⁄₁₆ | 9¹⁄₁₆ | 12 | 20 | 11¾ | 22¾ | 58 | 65 | ⅜ | 2 | ¾ | 19 | 25 | 284 |
| | mm | 248 | 418 | 230 | 305 | 508 | 298 | 578 | 1473 | 1651 | | | | 438 | | |
| KLRC-525 | Inches | 10 | 22 | 11⅜ | 15 | 23 | 14⁵⁄₁₆ | 27½ | 68½ | 75½ | ½ | 3 | 1¼ | 19¼ | 50 | 326 |
| | mm | 254 | 559 | 289 | 381 | 584 | 364 | 699 | 1740 | 1918 | | | | 489 | | |

## Models KLRC – 526, 775, 776, 950, 951, 1500, 1501, 2100, 2101





| | | A | B | C | E | F | G | H | J | K | L | P | R | S | W | Standard Motor HP | Standard Motor Frame |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| KLRC-526 | Inches | 10 | 22 | 11⅜ | 22½ | 13¹⁄₁₆ | 9⅝ | 26⅞ | 39½ | 41¼ | 46⅞ | ½ | 3 | 1¼ | 44 | 40 | 324 |
| | mm | 254 | 559 | 289 | 572 | 332 | 244 | 683 | 1003 | 1048 | 1191 | | | | 1118 | | |
| KLRC-775 | Inches | 12³⁄₁₆ | 27⁵⁄₁₆ | 14⁹⁄₁₆ | 27⁷⁄₁₆ | 16⅝ | 11⅝ | 33¼ | 51⅝ | 53¾ | 57⁵⁄₁₆ | ½ | 4 | 1½ | 57½ | 60 | 364 |
| | mm | 310 | 694 | 370 | 697 | 422 | 295 | 845 | 1311 | 1365 | 1456 | | | | 1461 | | |
| KLRC-776 | Inches | 12³⁄₁₆ | 27⁵⁄₁₆ | 14⁹⁄₁₆ | 27⁷⁄₁₆ | 16⅝ | 11⅝ | 33¼ | 51⅝ | 53¾ | 57⁵⁄₁₆ | ½ | 4 | 1½ | 52³⁄₁₆ | 50 | 326 |
| | mm | 310 | 694 | 370 | 697 | 422 | 295 | 845 | 1311 | 1365 | 1456 | | | | 1326 | | |
| KLRC-950 | Inches | 12³⁄₁₆ | 31¼ | 14⁹⁄₁₆ | 27⁷⁄₁₆ | 16⅝ | 11⅝ | 33¼ | 51⅝ | 53¾ | 61¼ | ½ | 4 | 1½ | 61¼ | 100 | 404 |
| | mm | 310 | 794 | 370 | 697 | 422 | 295 | 845 | 1311 | 1365 | 1556 | | | | 1556 | | |
| KLRC-951 | Inches | 12³⁄₁₆ | 31¼ | 14⁹⁄₁₆ | 27⁷⁄₁₆ | 16⅝ | 11⅝ | 33¼ | 51⅝ | 53¾ | 61¼ | ½ | 4 | 1½ | 59⅞ | 60 | 364 |
| | mm | 310 | 794 | 370 | 697 | 422 | 295 | 845 | 1311 | 1365 | 1556 | | | | 1521 | | |
| KLRC-1500 | Inches | 18¹¹⁄₁₆ | 38⁹⁄₁₆ | 19¹¹⁄₁₆ | 37½ | 22¹⁵⁄₁₆ | 15½ | 45⁷⁄₁₆ | 59¾ | 79½ | 83¼ | ¾ | 6 | 2½ | 70⅞ | 150 | 444 |
| | mm | 475 | 979 | 500 | 953 | 583 | 394 | 1154 | 1518 | 2019 | 2115 | | | | 1800 | | |
| KLRC-1501 | Inches | 18¹¹⁄₁₆ | 38⁹⁄₁₆ | 19¹¹⁄₁₆ | 37½ | 22¹⁵⁄₁₆ | 15½ | 45⁷⁄₁₆ | 59¾ | 79½ | 83¼ | ¾ | 6 | 2½ | 69¾ | 100 | 404 |
| | mm | 475 | 979 | 500 | 953 | 583 | 394 | 1154 | 1518 | 2019 | 2115 | | | | 1772 | | |
| KLRC-2100 | Inches | 18¹¹⁄₁₆ | 42½ | 19¹¹⁄₁₆ | 37½ | 22¹⁵⁄₁₆ | 15½ | 45⁷⁄₁₆ | 59¾ | 79½ | 87³⁄₁₆ | ¾ | 6 | 2½ | 70⅞ | 200 | 445 |
| | mm | 475 | 1080 | 500 | 953 | 583 | 394 | 1154 | 1518 | 2019 | 2215 | | | | 1800 | | |
| KLRC-2101 | Inches | 18¹¹⁄₁₆ | 42½ | 19¹¹⁄₁₆ | 37½ | 22¹⁵⁄₁₆ | 15½ | 45⁷⁄₁₆ | 59¾ | 79½ | 87³⁄₁₆ | ¾ | 6 | 2½ | 69¾ | 125 | 405 |
| | mm | 475 | 1080 | 500 | 953 | 583 | 394 | 1154 | 1518 | 2019 | 2215 | | | | 1772 | | |

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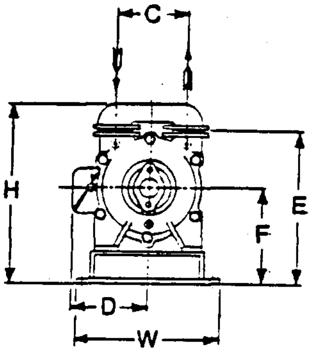
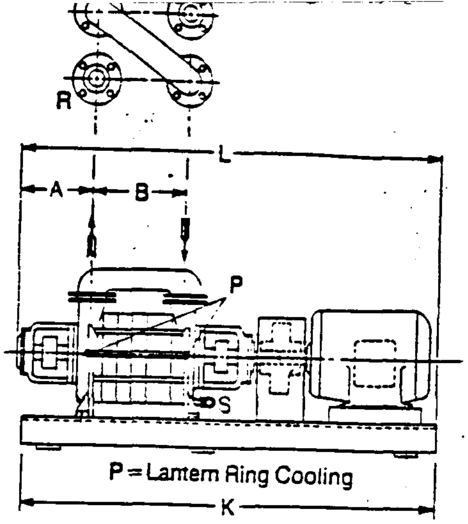
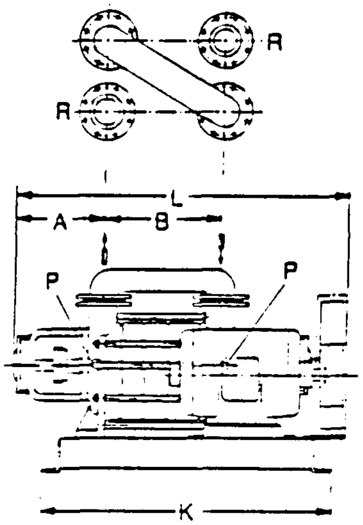
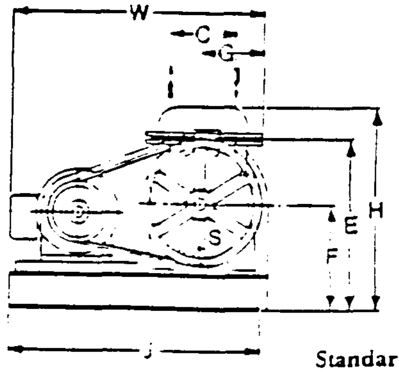




## Models KLRC – 100, 125, 300, 525

| | | A | B | C | D | E | F | H | K | L | P | R | S | W | Standard Motor HP | Standard Motor Frame |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| KLRC-100 | Inches | 8⅛ | 10⅝ | 6⁵⁄₁₆ | 9⅛ | 17¼ | 10⅜ | 19⅞ | 50 | 50 | ¼ | 1½ | ¾ | 15 | 7½ | 215 |
| | mm | 206 | 270 | 160 | 232 | 438 | 264 | 505 | 1270 | 1270 | | | | 381 | | |
| KLRC-125 | Inches | 8⅛ | 13 | 6⁵⁄₁₆ | 9⅛ | 17¼ | 10⅜ | 19⅞ | 50 | 54 | ¼ | 1½ | ¾ | 15 | 10 | 215 |
| | mm | 206 | 330 | 160 | 232 | 438 | 264 | 505 | 1270 | 1370 | | | | 381 | | |
| KLRC-200 | Inches | 9¾ | 13 | 9¹⁄₁₆ | 11 | 20 | 11¾ | 22¾ | 58 | 58 | ⅜ | 2 | ¾ | 19 | 15 | 254 |
| | mm | 248 | 330 | 230 | 279 | 508 | 298 | 578 | 1473 | 1473 | | | | 483 | | |
| KLRC-300 | Inches | 9¾ | 16⁷⁄₁₆ | 9¹⁄₁₆ | 12 | 20 | 11¾ | 22¾ | 58 | 65 | ⅜ | 2 | ¾ | 19 | 25 | 284 |
| | mm | 248 | 418 | 230 | 305 | 508 | 298 | 578 | 1473 | 1651 | | | | 438 | | |
| KLRC-525 | Inches | 10 | 22 | 11⅜ | 15 | 23 | 14⁵⁄₁₆ | 27½ | 68½ | 75½ | ½ | 3 | 1¼ | 19¼ | 50 | 326 |
| | mm | 254 | 559 | 289 | 381 | 584 | 364 | 699 | 1740 | 1918 | | | | 489 | | |





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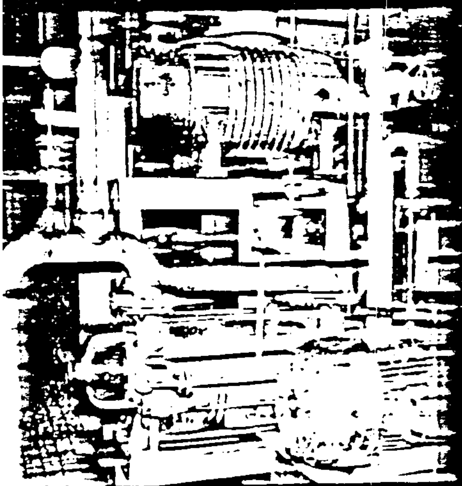
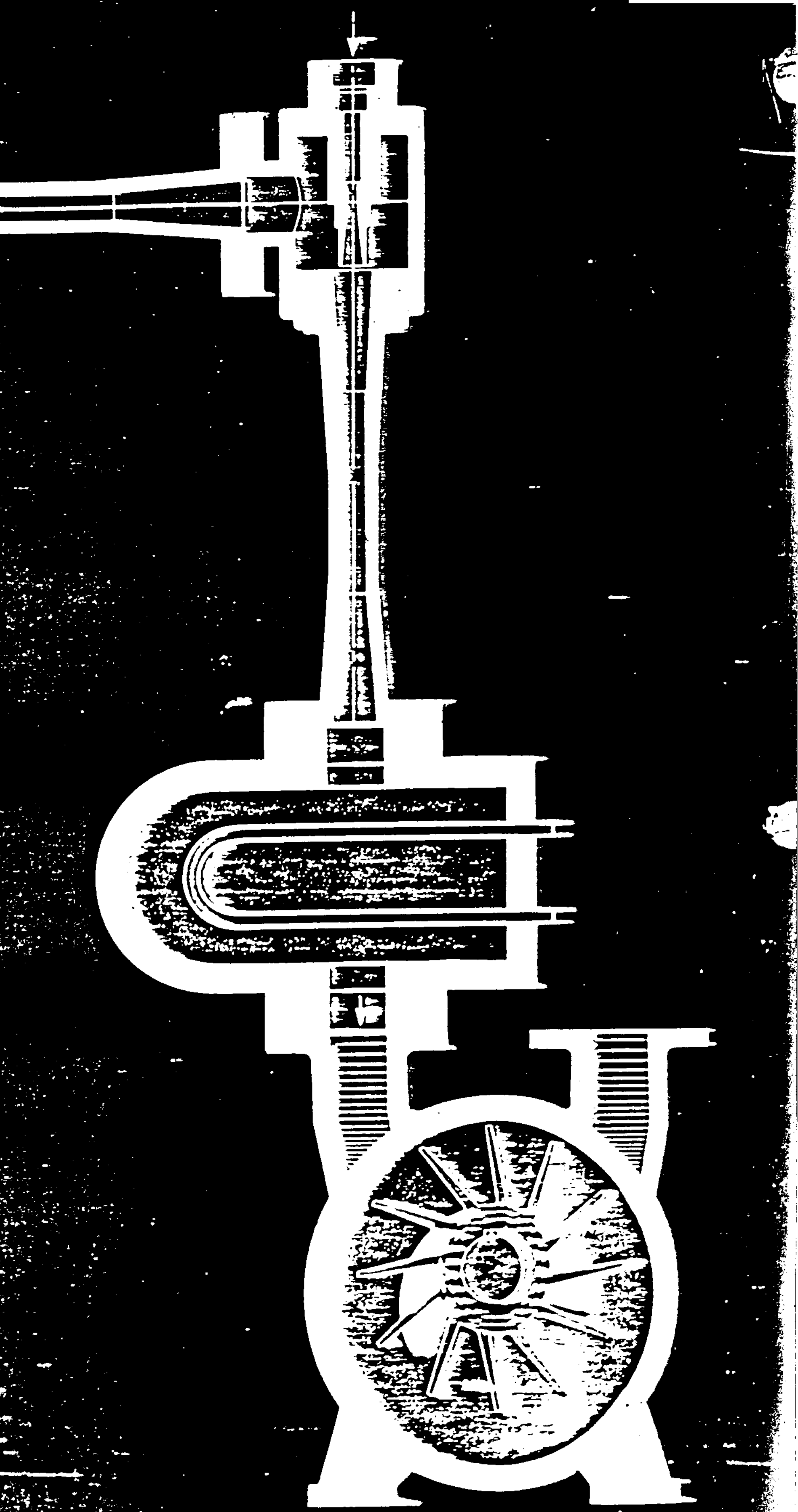
## Models KLRC – 526, 775, 776, 950, 951, 1500, 1501, 2100, 2101

| | | A | B | C | E | F | G | H | J | K | L | P | R | S | W | Standard Motor HP | Standard Motor Frame |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| KLRC-526 | Inches | 10 | 22 | 11⅜ | 22½ | 13¹⁄₁₆ | 9⅝ | 26⅞ | 39½ | 41¼ | 46⅞ | ½ | 3 | 1¼ | 44 | 40 | 324 |
| | mm | 254 | 559 | 289 | 572 | 332 | 244 | 683 | 1003 | 1048 | 1191 | | | | 1118 | | |
| KLRC-775 | Inches | 12³⁄₁₆ | 27⁵⁄₁₆ | 14⁹⁄₁₆ | 27⁷⁄₁₆ | 16⅝ | 11⅝ | 33¼ | 51⅝ | 53¾ | 57⁷⁄₁₆ | ½ | 4 | 1½ | 57½ | 60 | 364 |
| | mm | 310 | 694 | 370 | 697 | 422 | 295 | 845 | 1311 | 1365 | 1456 | | | | 1461 | | |
| KLRC-776 | Inches | 12³⁄₁₆ | 27⁵⁄₁₆ | 14⁹⁄₁₆ | 27⁷⁄₁₆ | 16⅝ | 11⅝ | 33¼ | 51⅝ | 53¾ | 57⁷⁄₁₆ | ½ | 4 | [illegible] | 52³⁄₁₆ | 50 | 326 |
| | mm | 310 | 694 | 370 | 697 | 422 | 295 | 845 | 1311 | 1365 | 1456 | | | | 1326 | | |
| KLRC-950 | Inches | 12³⁄₁₆ | 31¼ | 14⁹⁄₁₆ | 27⁷⁄₁₆ | 16⅝ | 11⅝ | 33¼ | 51⅝ | 53¾ | 61¼ | ½ | 4 | [illegible] | 61¼ | 100 | 404 |
| | mm | 310 | 794 | 370 | 697 | 422 | 295 | 845 | 1311 | 1365 | 1556 | | | | 1556 | | |
| KLRC-951 | Inches | 12³⁄₁₆ | 31¼ | 14⁹⁄₁₆ | 27⁷⁄₁₆ | 16⅝ | 11⅝ | 33¼ | 51⅝ | 53¾ | 61¼ | ½ | 4 | [illegible] | 59⅞ | 60 | 364 |
| | mm | 310 | 794 | 370 | 697 | 422 | 295 | 845 | 1311 | 1365 | 1556 | | | | 1521 | | |
| KLRC-1500 | Inches | 18¹¹⁄₁₆ | 38⁹⁄₁₆ | 19¹¹⁄₁₆ | 37½ | 22¹⁵⁄₁₆ | 15½ | 45⁷⁄₁₆ | 59¾ | 79½ | 83¼ | ¾ | [illegible] | 2 | 70⅞ | 150 | 444 |
| | mm | 475 | 979 | 500 | 953 | 583 | 394 | 1154 | 1518 | 2019 | 2115 | | | | 1800 | | |
| KLRC-1501 | Inches | 18¹¹⁄₁₆ | 38⁹⁄₁₆ | 19¹¹⁄₁₆ | 37½ | 22¹⁵⁄₁₆ | 15½ | 45⁷⁄₁₆ | 59¾ | 79½ | 83¼ | ¾ | [illegible] | 2 | 69¾ | 100 | 404 |
| | mm | 475 | 979 | 500 | 953 | 583 | 394 | 1154 | 1518 | 2019 | 2115 | | | | 1772 | | |
| KLRC-2100 | Inches | 18¹¹⁄₁₆ | 42½ | 19¹¹⁄₁₆ | 37½ | 22¹⁵⁄₁₆ | 15½ | 45⁷⁄₁₆ | 59¾ | 79½ | 87³⁄₁₆ | ¾ | [illegible] | [illegible] | 70⅞ | 200 | 445 |
| | mm | 475 | 1080 | 500 | 953 | 583 | 394 | 1154 | 1518 | 2019 | 2215 | | | | 1800 | | |
| KLRC-2101 | Inches | 18¹¹⁄₁₆ | 42½ | 19¹¹⁄₁₆ | 37½ | 22¹⁵⁄₁₆ | 15½ | 45⁷⁄₁₆ | 59¾ | 79½ | 87³⁄₁₆ | ¾ | [illegible] | [illegible] | 69¾ | 125 | 405 |
| | mm | 475 | 1080 | 500 | 953 | 583 | 394 | 1154 | 1518 | 2019 | 2215 | | | | 1772 | | |

# inney Multiple-Stage Vacuum Pumping Systems





Kinney multiple-stage vacuum
umping systems consist of liquid
ng vacuum pumps in combination
ith lobe-type mechanical boosters,
r ejectors or steam ejectors. These
tems offer the advantage of
quid ring pump design with much
gher pumping speeds and lower
essures than can be achieved with
ngle-stage systems.

Representative examples of
mmon multi-stage combinations
e shown in our Bulletin 4104.
pecific details are available on
quest.

Experienced Kinney field sales
gineers are available to assist in
e selection and specification of
quid ring pumps and multiple-
age liquid ring pump systems for
ur specific applications.

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# DESIGN OUTLINE

I. INTRODUCTION

II. DISCUSSION OF ALTERNATIVES

III. CONCEPT CHOSEN FOR DESIGN

IV. OPERATION OF SYSTEM DURING RECOVERY

V. OPERATION OF SYSTEM DURING PRESSURIZATION

VI. DISCUSSION OF SYSTEM

VII. APPENDICES

## INTRODUCTION:

THE 12 FOOT WIND TUNNEL AT NASA AMES IS GOING TO BE RECONSTRUCTED TO HANDLE A PRESSURE OF 7 ATMOSPHERES ABSOLUTE PRESSURE. THE NEW CONSTRUCTION WILL MAKE THE TUNNEL CAPABLE OF BEING PRESSURIZED UP TO 7 ATMOSPHERES AND TAKEN DOWN CLOSE TO 0.1 ATMOSPHERES. IN ADDITION IT WILL BE ABLE TO REPLACE EXISTING AIR IN THE TUNNEL WITH A REFRIGERANT OF SOME SORT. USING A REFRIGERANT WILL INCREASE DENSITY AND PROVIDE GREATER REYNOLD'S NUMBER THUS SIMULATING NEARLY EXACT CONDITIONS OF HIGH ALTITUDES DURING TESTING OPERATIONS. THE NEW DESIGN WILL ALSO BE CAPABLE OF RECOVERING AND STORING THE REFRIGERANT WITH ONLY A MINIMAL AMOUNT OF DISCHARGE INTO THE ATMOSPHERE.

## DESIGN ALTERNATIVES:

VARIOUS METHODS ARE UNDER CONSIDERATION FOR THE DEVELOPMENT OF THE SYSTEM FOR THE 12 FOOT WIND TUNNEL. THE COMPLETE SYSTEM SHOULD CONTAIN A METHOD OF REMOVING THE REFRIGERANT FROM THE TUNNEL, PUTTING THE REFRIGERANT BACK INTO THE TUNNEL. SOME OF THE METHODS CONSIDERED ARE THE FOLLOWING:

1. REMOVING AND STORING REFRIGERANT IN VAPOR FORM.
2. REMOVING REFRIGERANT AND STORING IT IN LIQUID FORM BY LIQUEFYING WITH A REFRIGERATION SYSTEM

REMOVING REFRIGERANT BY FLOWING THE VAPOR THROUGH AN ADSORBENT MATERIAL.

4. LIQUEFYING REFRIGERANT IN THE TUNNEL USING COOLING COILS, THEN DRAINING FROM THE TUNNEL FLOOR.

THIS REPORT WILL DEVELOP AND ANALYZE METHOD NUMBER TWO (SEE FIGURE 3). ANOTHER ALTERNATIVE TO BE CONSIDERED IS WHAT REFRIGERANT TO USE IN THE 12 FOOT WIND TUNNEL. CONSIDERING THE CONTROVERSY SURROUNDING THE USE OF FLOUROCARBONS AND THE POSSIBLE FREEZE IN PRODUCTION OF MANY COMMON REFRIGERANTS BY THE YEAR 1989, FREON 22 WAS CHOSEN AS A SUITABLE REFRIGERANT FOR METHOD NUMBER TWO. CHLORODIFLOUROMETHANE, OR FREON 22, IS NOT PRESENTLY CONSIDERED TOXIC TO THE UPPER ATMOSPHERE AND THERE ARE NO EXISTING PLANS TO LIMIT ITS PRODUCTION. FREON 22 MAY ALSO BE HANDLED AND SHIPPED AS EASILY AS FREON 12. CONSIDERING THE PREDICTED GLOBAL FREEZE ON COMMON REFRIGERANTS, FREON 22 SEEMS THE MOST ECONOMICALLY AND ENVIRONMENTALLY SOUND CHOICE OF AVAILABLE REFRIGERANTS. FREON 22 HAS A THRESHOLD LIMIT VALUE (TLV-TWA) OF 1000 PARTS PER MILLION, A VERY LOW TOXICITY RATING OF 5A, AND IS CONSIDERED NONFLAMMABLE AND NON-EXPLOSIVE AT ORDINARY TEMPERATURES.

CONCEPT OF DESIGN:

THE GENERAL CONCEPT BEHIND THIS RECOVERY SYSTEM IS TO EXTRACT THE REFRIGERANT IN VAPOR FORM AND LIQUEFY IT USING REFRIGERATION UNIT (SEE FIGURE 10). THE MAIN BULK OF THE LIQUID REFRIGERANT WILL PUMPED INTO A LIQUID STORAGE TANK UNIT.

VAPORIZED FOR REUSE. AS THE PRESSURE IS DECREASED IN THE TUNNEL, AIR IS INTRODUCED INTO THE TUNNEL AS A CARRIER FOR THE RESIDUAL REFRIGERANT. THE AIR AND REFRIGERANT MIXTURE IS PUMPED FROM THE TUNNEL THROUGH THE REFRIGERATION SYSTEM AND INTO A LIQUID NITROGEN SEPARATOR. THIS SEPARATOR WILL LIQUEFY THE REMAINING REFRIGERANT AND PASS THE AIR TO THE ATMOSPHERE. THIS LIQUID REFRIGERANT WILL THEN ALSO BE PUMPED INTO THE MAIN STORAGE TANK.

TO PRESSURIZE THE TUNNEL AGAIN WITH REFRIGERANT FROM THE LIQUID STORAGE TANK A REVERSE PROCESS IS USED. THE LIQUID REFRIGERANT IS PUMPED FROM THE STORAGE TANK INTO A HEAT EXCHANGER TO OBTAIN VAPOR FORM FOR THE TUNNEL. THE HEAT EXCHANGER USES WATER AT AMBIENT CONDITIONS TO VAPORIZE THE LIQUID REFRIGERANT. AS A SECONDARY VAPORIZATION UNIT A STEAM JACKET IS USED TO LIQUEFY ANY REFRIGERANT NOT VAPORIZED BY THE HEAT EXCHANGER. A PUMP IS USED IN THE LIQUID STATE TO PUMP THE TUNNEL UP TO REQUIRED CONDITIONS AND IF NECESSARY A COMPRESSOR WILL BE ADDED IN THE VAPOR STATE BEFORE ENTERING THE TUNNEL.

RECOVERY OPERATIONS OF SYSTEM:

THE FREON 22 IS EXTRACTED IN VAPOR FORM AND LIQUEFIED USING A REFRIGERANT UNIT. DURING THIS PROCESS THE TUNNEL IS PUMPED FROM 7 TO .25 ATMOSPHERES AND THE LIQUID IS TRANSFERRED TO A STORAGE TANK. AIR IS THEN INTRODUCED INTO THE TUNNEL MIXING WITH FREON 22 AND CONTINUOUSLY PUMPED THROUGH A SEPARATOR. THE SEPARATOR USES LIQUID NITROGEN TO LIQUEFY THE REMAINING FREON IN THE ADDED AIR WHICH IS ALSO PUMPED TO THE STORAGE TANK. THE

EXACT PROCEDURE OF THE RECOVERY OPERATION IS THE FOLLOWING USING FIGURE 2:

1. THE REFRIGERATION UNIT IS ACTIVATED AND VALVES 1 AND 2 ARE OPENED.

2. VALVE 6 IS OPENED AS LIQUID IS DETECTED IN HEAT EXCHANGER 2.

3. VALVE 11 IS OPENED ONCE THE LIQUID HAS REACHED A SENSOR IN THE SEPARATOR TANK.

4. PUMP 1 WILL BE ACTIVATED AND FREON 22 WILL FLOW THROUGH HEAT EXCHANGER 1 INTO STORAGE TANK.

5. WHEN TUNNEL PRESSURE EQUALS 1 ATMOSPHERE, VALVE 2 WILL BE CLOSED AND VALVES 3 AND 4 OPENED.

6. COMPRESSOR WILL BE ACTIVATED UNTIL PRESSURE EQUALS .23 ATMOSPHERE. AIR IS THEN INTRODUCED OPENING VALVES 22 AND 23 AS A CARRIER FLUID FOR FREON 22.

7. 1 ATMOSPHERE IS REACHED AND VALVE 22 IS CLOSED.

8. VALVE 7 IS OPENED AND SECONDARY SEPARATOR ACTIVATED

9. VALVES [illegible], [illegible], [illegible] 27 ARE OPENED TO THE [illegible] [illegible] [illegible]

ESCAPE.

10. VALVE 10 IS OPENED AS LIQUID FREON REACHES SENSOR IN SECONDARY SEPARATOR.

11. THE LIQUID IS THEN PUMPED TO THE STORAGE TANK THROUGH PUMP 1.

12. STEPS 6, 7, AND 11 ARE REPEATED FOR UNTIL THE TUNNEL IS EMPTY OF FREON 22.

13. ALL THE FREON WILL BE STORED IN THE MAIN STORAGE TANK AND ALL VALVES ARE CLOSED.

PRESSURIZATION OPERATION OF SYSTEM:

THE TUNNEL IS FILLED WITH THE STORED FREON 22 USING A REVERSE PROCESS OF THE RECOVERY OPERATION. THE LIQUID FREON 22 IS VAPORIZED IN HEAT EXCHANGER 3 AND THEN LET INTO THE TUNNEL IN VAPOR FORM. THE PRESSURE IN THE TUNNEL IS PUMPED UP TO 7 ATMOSPHERES USING A LIQUID PUMP. THE EXACT PROCEDURE IS DESCRIBED BELOW (SEE FIGURE 3):

1. VALVES 1, 3, AND 5 IS OPENED AND COMPRESSOR 1 ACTIVATED.

2. THE TUNNEL IS PRE-PUMPED DOWN CLOSE TO VACUUM.

3. VALVES 1, 3, AND 5 IS CLOSED AND VALVES 19, 20, AND 21 IS OPENED.

4. PUMP 3 IS ACTIVATED AS VALVES 14, 15, 17, AND 18 ARE OPENED LETTING THE FREON 22 OUT OF THE STORAGE TANK.

5. PUMP 2 IS ACTIVATED TO KEEP A MINIMUM FLOW RATE IN LINE AND THE FREON 22 PASSES THROUGH HEAT EXCHANGER 3.

6. THE LIQUID FREON 22 IS VAPORIZED IN THE HEAT EXCHANGER 3.

7. THE STEAM JACKET WILL ONLY BE ACTIVATED IF CONDENSATION IS SENSED AT VALVE 17.

8. THE PROCESS CONTINUOUS UNTIL A PRESSURE OF 7 ATMOSPHERES IS REACHED IN THE TUNNEL.

DISCUSSION:

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THE SYSTEM WILL RECOVER AND STORE FREON-22 FROM THE TUNNEL AS WELL AS FILLING THE TUNNEL WITH THE STORED FREON-22 UP TO SEVEN ATMOSPHERES. IN THE DESIGN IT TAKES 12 HOURS TO PUMP FREON-22 FROM SEVEN ATMOSPHERES DOWN TO 0.25 ATMOSPHERES AND ANOTHER TWELVE HOURS TO EXTRACT THE REMAINING FREON-22 FROM TUNNEL. TWELVE HOURS IS USED TO MINIMIZE THE SIZE OF THE REFRIGERATION UNIT USE TO INITIALLY LIQUEFY THE FREON-22. THE REFRIGERATION SHOULD BE CAPABLE OF HANDLING CAPACITY UP TO 5.08 MW (1400 TONS) WHICH IS AVAILABLE FROM CARRIER.

IN THE DESIGN THE WORST POSSIBLE CASE WERE USED TO CALCULATE THE VARIOUS STATES. THESE VARIOUS STATES CAN BE IMPROVED IF A GOOD CONTROL SYSTEM IS USED. THE CAPACITY OF THE REFRIGERATION UNIT CAN BE VARIED AS THE PRESSURE IN THE TUNNEL CHANGES. THE SAME COULD GO FOR PRESSURIZING THE SYSTEM USING A CONTROL SYSTEM TO VARY FLOW RATE OF WATER AS THE PRESSURE OF FREON-22 CHANGES.

THE SECONDARY SEPARATOR USES LIQUID NITROGEN TO LIQUEFY THE REMAINING FREON-22 IN THE TUNNEL. APPROXIMATELY 20000 POUNDS OF LIQUID NITROGEN IS USED FOR EACH RECOVERY CYCLE. THE COST OF LIQUID NITROGEN IS ESTIMATED TO BE $100/ton THUS, THE TOTAL COST FOR EACH RECOVERY CYCLE IS APPROXIMATELY $1000.

SENSORS AND PRESSURE RELIEF VALVES SHOULD BE PLACED IN HIGH PRESSURE LINES. FURTHERMORE, IF AMBIENT TEMPERATURE DROP BELOW SEVENTY DEGREE FAHRENHEIT THE STEAM JACKET SHOULD BE ACTIVATED TO PROVIDE APPROXIMATELY 4.2 KW OF HEAT TO VAPORIZED THE FREON-22 IN THE PRESSURIZING CYCLE. ALSO, THE TUNNEL HAS TO BE HEATED TO MAKE SURE NO CONDENSATION TAKE PLACE.

## RECOVERY

TOTAL RECOVERY TIME OF 24 HRS

REFRIGERATION UNIT (R-22)
(SINGLE FLUID, TWO STAGE VAPOR COMPRESSION)

| | |
|---|---|
| EVAPORATOR | -40 F |
| CAPACITY | 5.08 MW<br>(1400 TONS) |
| MASS FLOWRATE (LOWER STAGE) | 3300 LB/MIN |
| CONDENSER | 70 F |
| MASS FLOWRATE (UPPER STAGE) | 811 LB/MIN |
| TOTAL POWER (COP = 4.0) | 1.27 MW |

SECONDARY SEPARATOR (CRYOGENICS)

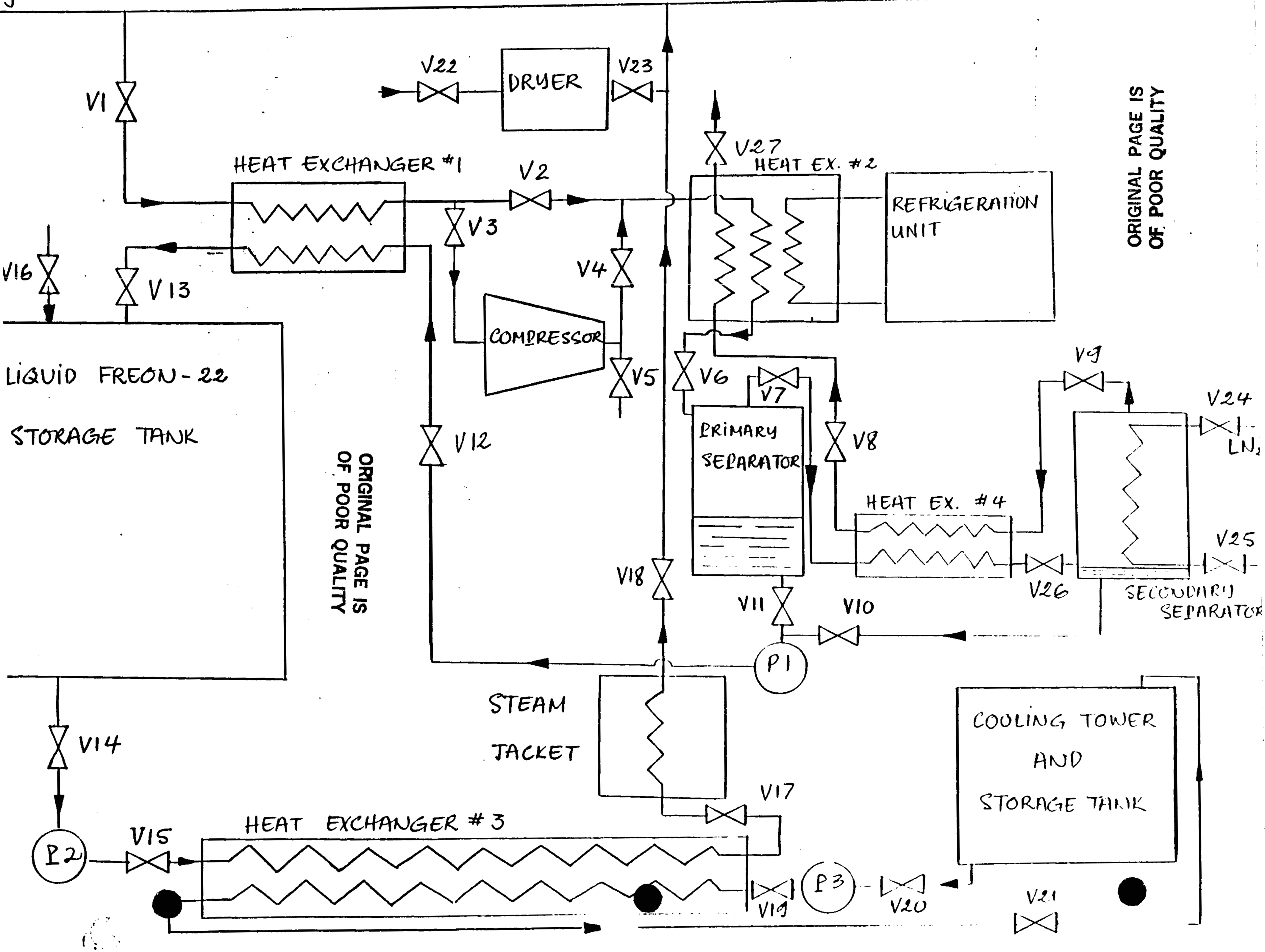
| LIQUID NITROGEN | |
|---|---|
| PRESSURE | 3 ATM |
| TEMPERATURE | 83 K |
| MASS FLOWRATE (INITIALLY) | 120 LB/MIN |
| MASS FLOWRATE (AN HOUR LATER) | 18.3 LB/MIN |
| TOTAL MASS | 20000 LB |

## PRESSURIZING

(TOTAL TIME OF 12 HOURS)

| | |
|---|---|
| TOTAL HEAT REQUIRED TO VAPORIZED | 4.5 MW |
| MASS FLOWRATE OF R-22 | 2500 LB/MIN |
| MASS FLOWRATE OF WATER | 12800 LB/MIN |

ESTIMATED EMMISSION OF R-22 0.037 LB



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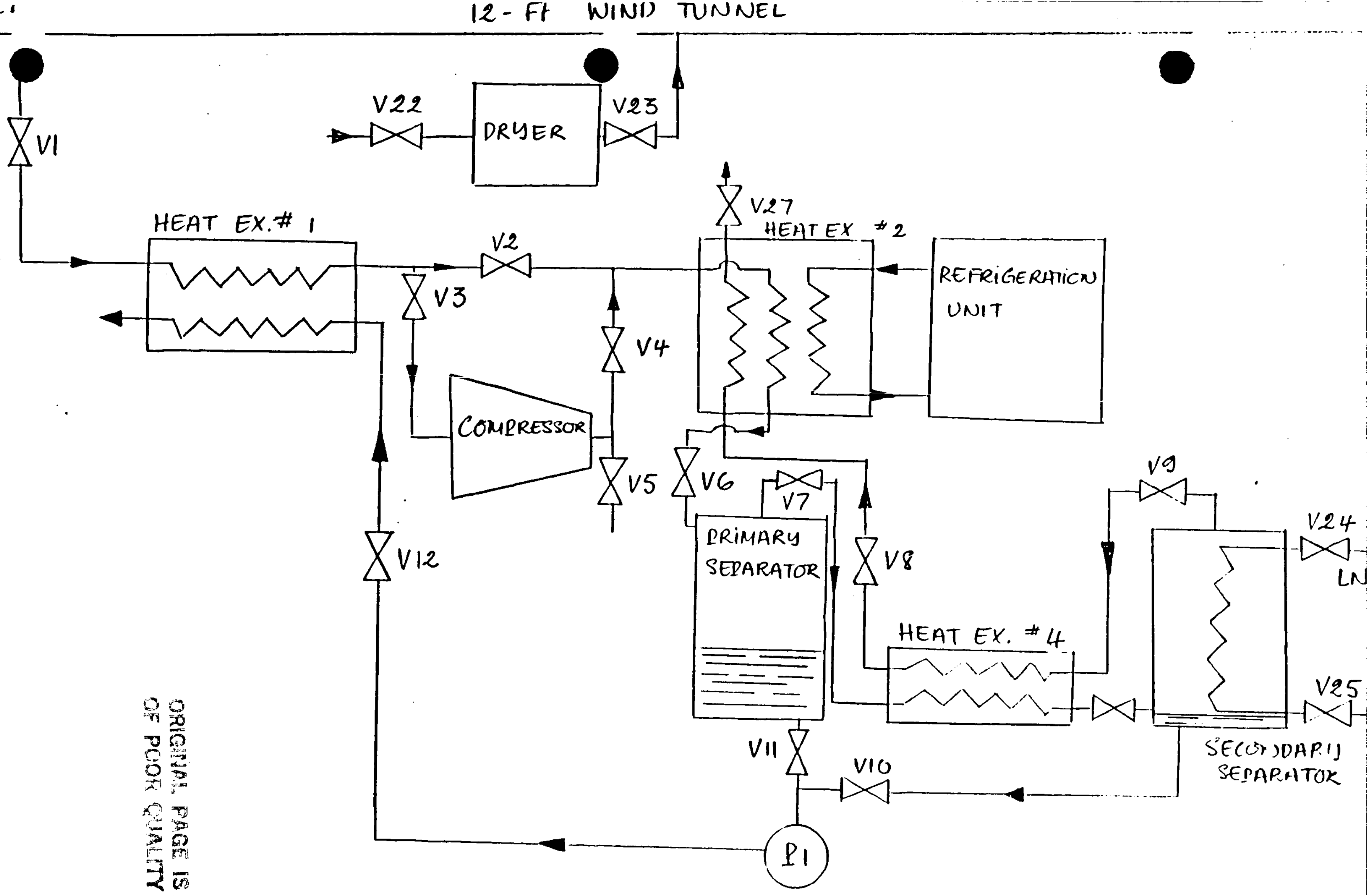
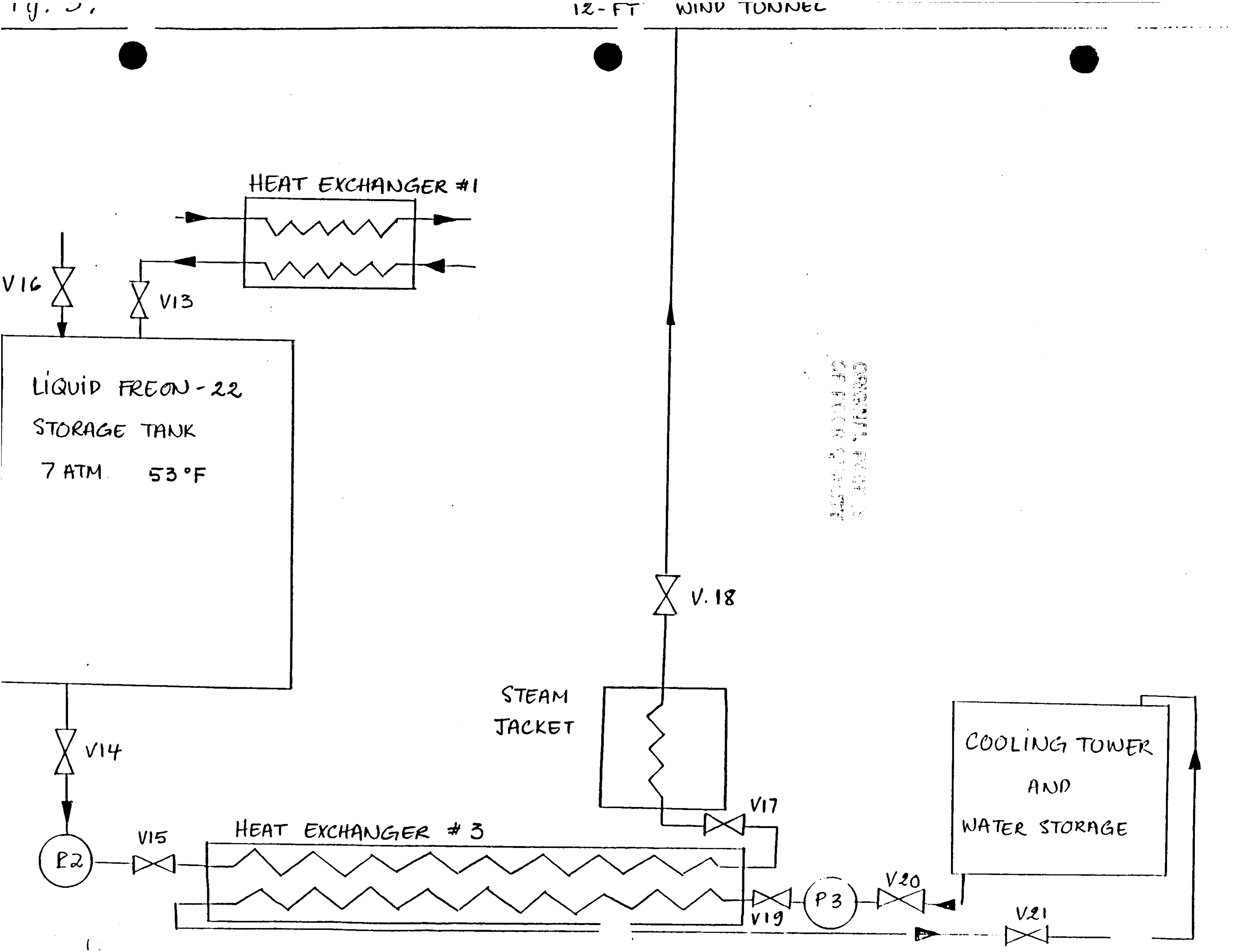

12-Ft WIND TUNNEL
V1
V22
DRYER
V23
HEAT EX.# 1
V2
V3
V4
V27
HEAT EX #2
REFRIGERATICN UNIT
COMPRESSOR
V5
V6
V7
PRIMARY SEPARATOR
V8
HEAT EX. #4
V9
V24
LN
V25
SECONDARY SEPARATOR
V10
V11
V12
P1


12-FT WIND TUNNEL
HEAT EXCHANGER #1
V16
V13
LIQUID FREON-22
STORAGE TANK
7 ATM 53°F
V.18
STEAM
JACKET
V14
V17
P2
V15
HEAT EXCHANGER # 3
COOLING TOWER
AND
WATER STORAGE
V20
P3
V19
V21

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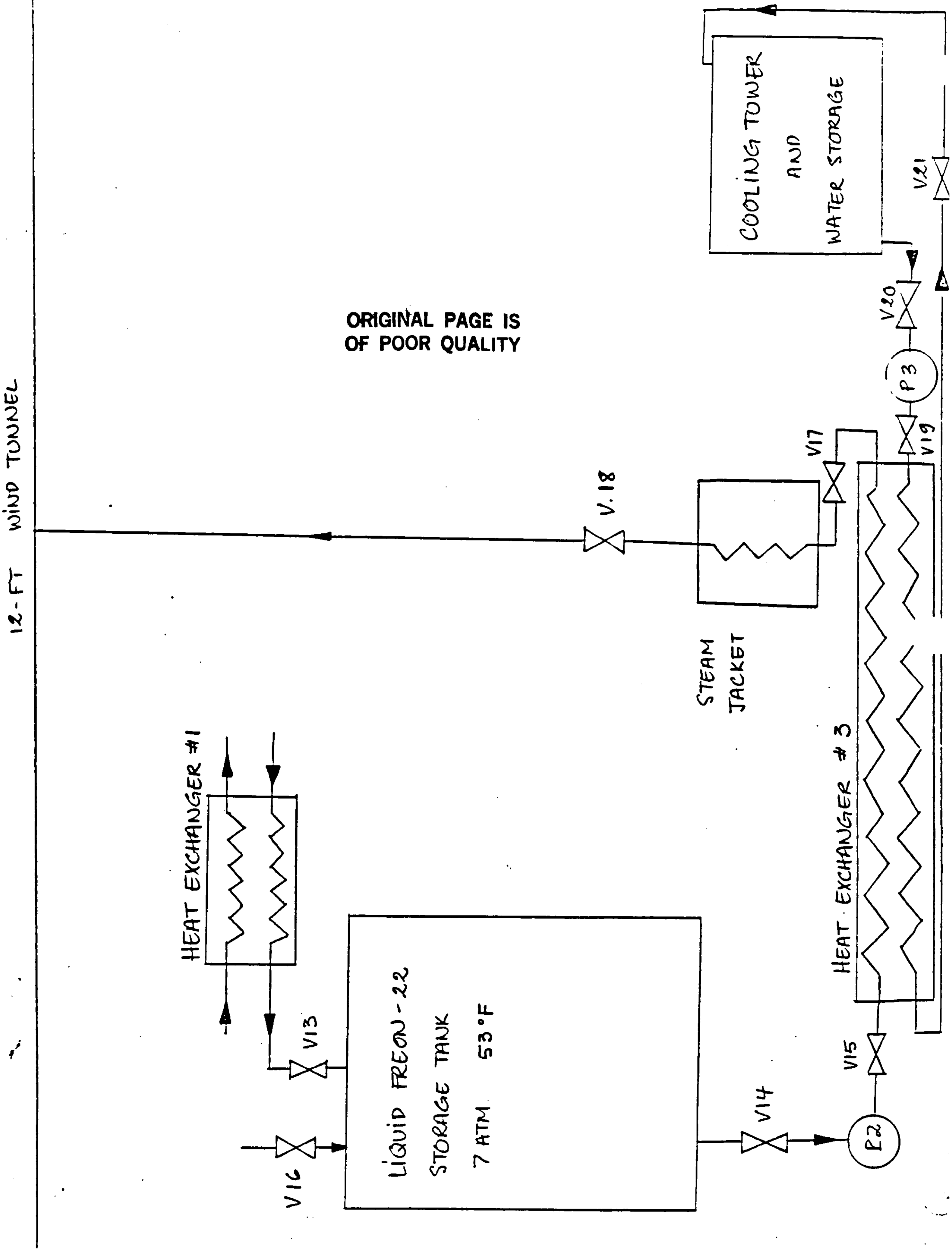

*R-11, R-12 affected*

# Global freeze on certain CFC's in 1989 and 50% cut in 1998

***by Gordon Duffy***

MONTREAL, Canada — In a historic move intended to "send a strong signal to industry," representatives of 49 nations Sept. 16 signed the final act of a Protocol on Substances That Deplete the Ozone Layer that will freeze, then reduce by 50%, the global consumption of five fully halogenated chlorofluorocarbon (CFC) compounds.

Consumption of three bromine compounds used in fighting fires also will be frozen at 1986 production levels.

Of those who signed the final act, 24 nations — including the U.S., the European Economic Community (EEC), and Japan — also signed the protocol. Other nations indicated they will sign later. If ratified by their governments, those who already have signed are more than enough to satisfy the minimum of 11 nations and two-thirds of world consumption required to ratify the [illegible]aty.

[illegible]eralded by many nations as a strong and workable document with effective enforcement provisions, it marks the first time the world community has acted jointly to control a potential environmental hazard with specific remedies. It is scheduled to become effective Jan. 1, 1989.

The protocol provides:

- Consumption of R-11, R-12, R-113, R-114, and R-115 will be frozen at 1986 consumption levels starting July 1, 1989. The ozone-depleting potential of R-11, R-12, and R-114 is listed as one. The potential for R-113 is 0.8 and for R-115 (used in R-502) it's 0.6.
- Effective July 1, 1993, consumption of the above CFC compounds will be reduced to 80% of 1986 consumption levels.
- Effective July 1, 1998, consumption of the same compounds will be reduced to 50% of 1986 consumption levels. This figure can be revised by a two-thirds majority present who represent at least two-thirds of their total consumption.
- Production of three bromine compounds — Halon 1211, Halon 1301, and Halon 2402 — will be frozen at 1986 production levels starting Feb. 1, 1992. No cuts are planned. The ozone depleting potential for Halon 1211 is 3; it's 10 for Halon 1301, and has not been determined for Halon 2402.
- An exemption from the control measures for up to 10 years is available to developing countries provided their level of consumption does not exceed 0.3 kilograms (0.66 lb) per capita.
- The protocol details how plants under construction are to

**U.S. WAS AMONG** the 24 nations that signed the Protocol on Substances That Deplete the Ozone Layer. Here U.S. chief delegate Lee M. Thomas, Environmental Protection Agency administrator, makes it official. Congress still must ratify the treaty.

*(Page 31, Please)*

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be treated. Regional economic organizations such as the EEC are permitted provided each member state is signatory to the treaty. It discourages providing technology to nations not party to the agreement. Any exports to them after Jan. 1, 1993, will not be credited in the calculation of consumption levels (production plus imports minus exports).

- Other control measures will be determined by a conference of participants to be established by 1990. This group also can raise or lower control levels and add or r[illegible] controlled chemicals. It will develop procedures for dealing with noncompliance among both signatories and those that do not sign.
- Starting in 1990, and every four years thereafter, the conference will convene panels of experts to assess scientific knowledge and the impact of control measures.

How the cuts in CFC production will be accomplished has been left to the individual nations who sign the treaty. In the U.S., EPA is under a court order to issue a proposed rule by Dec. 1. Although it's unlikely to be less stringent than the global accord, it could be more stringent and it could include other refrigerants.

The treaty does not mention R-22, which is not fully halogenated. It mostly breaks down in the lower atmosphere and is seen by many — including some EPA officials — as a solution to the ozone depletion problem rather than a contributor.

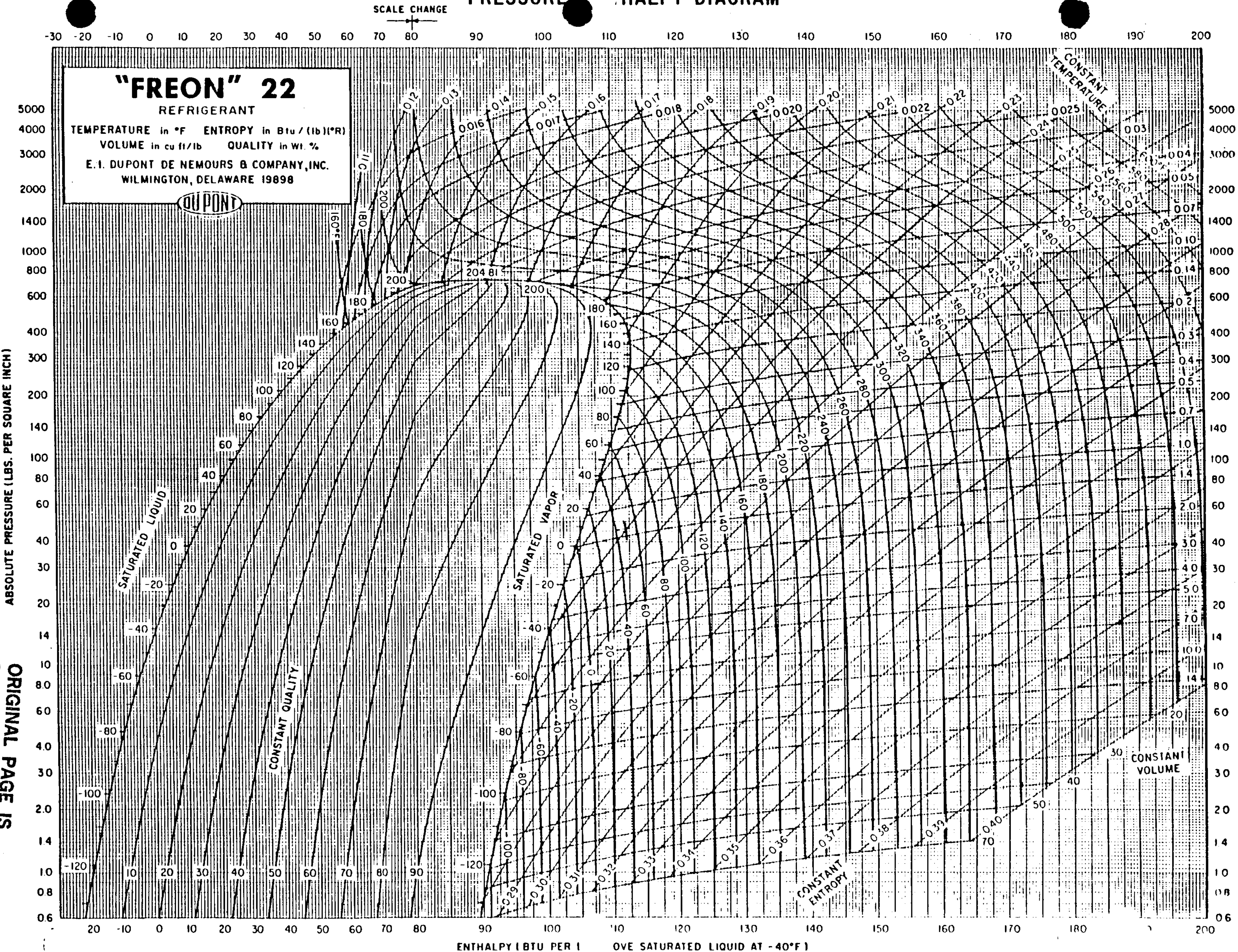
Efforts are being made to organize an international consortium of CFC producers by the end of 1987 to expedite toxicity testing of possible alternatives to the designated CFC's. Supposedly these would include R-123 for R-11 and R-134a for R-12.

In the background is a major race among CFC producers to come up with alternatives for the designated fully halogenated compounds and, just as importantly, to find the lowest cost methods of producing them.

In all, 62 nations were represented at last week's diplomatic conference where the final document was negotiated (see related story).

The British chief delegate, Fiona McConnell, said the protocol should provide a clear signal to industry that the days of fully halogenated CFC's are numbered. Several nations, including Sweden, France, and Japan, reported they are well ahead of the cutbacks scheduled in the accord. Japan reported it concentrating on the devel ment of alternatives and recy ing technology.

# PRESSURE HALPY DIAGRAM



# APPENDIX

A : SEPARATION PROCESS

B : REFRIGERATION UNIT

C : PRESSURIZING PROCESS

D : EMISSION OF FREON-22

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# APPENDIX A

TOTAL VOLUME OF TUNNEL : 1000000 $FT^3$

ASSUME R-22 IN TUNNEL AT 70°F AND 7 ATM

THE SPECIFIC VOLUME : 0.56235 $FT^3/LB$

TOTAL MASS OF R-22 : VOLUME / SPECIFIC VOLUME

$$= 1000000 \ FT^3 / 0.56235 \ FT^3/LB$$

$$= 1.778 \ (10^6) \ lb$$

THE TOTAL TIME OF RECOVERY PROCESS IS 24 HOURS

TIME FOR DECREASING THE PRESSURE INSIDE TUNNEL DROP FROM 7 ATM TO 0.25 ATM EQUALS TO 12 HOURS.

$$\dot{m}_{max} = \frac{m}{t} = \frac{1.778 \ (10\ ) \ 1b}{12 \ hr \ (60 \ min/hr)} = 2470 \ 1b/min$$

EVAPORATOR IS AT T = -40°F

MAXIMUM LATENT HEAT AT T = -40°F, 1 ATM

$$q = 100 \ Btu/1b$$

ENERGY REQUIRED

$$\dot{Q} = q\,\dot{m} = (100 \ Btu/1b)(2470 \ 1b/min)$$

$$= 246780 \ Btu/min \quad (4.32 \ MW)$$

IF THE EFFICIENCY OF THE LATENT HEAT EXCHANGER IS 85%

$$\dot{Q} = \frac{4.32 \ MW}{0.85} = 5.08 \ MW$$

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## STORAGE TANK

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FOR THE MAIN STORAGE TANK

TOTAL VOLUME OF R-22 INSIDE TUNNEL IN LIQUID PHASE AT 7 ATM

FROM FREON TABLE

THE SPECIFIC VOLUME = 0.013251 $FT^3/LB$

VOLUME OF TANK REQUIRED = (MASS)(SPECIFIC VOLUME)

$= 1.778(10^6) LB (0.013251\ FT^3/LB)$

$= 23563.6\ FT^3$

IN ADDITION, ALLOWABLE SPACE FOR EXTRA R-22 AND VAPOR

VOLUME OF TANK = 30,000 $FT^3$

TANK SIZE FOR CYLINDRICAL SHAPE : HEIGHT = 40 FT

DIAMETER = 30 FT

FOR SPHERICAL SHAPE : DIAMETER = 38 FT

## PRIMARY SEPARATOR

AT P = 0.25 ATM AND T = 70°F $\quad v_1 = 18.712\ FT^2/LB$

AT P = 7 ATM AND T - 70°F $\quad v_2 = 0.56233\ FT^3/LB$

PERCENT R-22 LEFT INSIDE TUNNEL AFTER FIRST PHASE

$$\frac{v_2}{v_1} = \frac{0.56233\ ft^3/lb}{18.712\ ft^3/lb}\ 100\% = 3.00\%$$

SINCE R-22 IS RECOVERED CONTINUOUSLY, LET PRIMARY SEPARATOR HOLD 20% OF 97% OF R-22 INSIDE THE TUNNEL IN LIQUID FORM OR 19.4% OF MAIN STORAGE TANK.

$= 0.194 (30000\ FT^3) = 5820\ FT^3$

ALLOWS ROOM FOR SCREENS AND VAPOR

$V = 6000\ ft^3$

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SECONDARY SEPARATOR

AFTER THE PRIMARY RECOVERY THERE ARE 3 % OF VAPOR R-22 AND 97 % AIR IN THE TUNNEL.

MASS OF AIR , FROM AIR TABLE AT 1/4 ATM AND 70°F

THE SPECIFIC VOLUME: $\underline{53.8\ ft^3/lb}$

$$MASS = \frac{\text{VOLUME OCCUPIED BY AIR}}{\text{SPECIFIC VOLUME}}$$

$$= \frac{9.7(10^5)\ ft^3}{53.8\ ft^3/lb}$$

$$= 18042\ lb$$

MASS OF 3 R-22

$$= \frac{3}{100}\ 1.78(10^6)$$

$$= 53,400\ lb$$

TOTAL MASS = MASS OF AIR + MASS OF R-22

$$= 18042 + 53,400$$

$$= 71442\ lb$$

LIQUID NITROGEN IS USE TO LIQUEFY R-22 FROM THE AIR.

LIQUID NITROGEN AT 3 ATM AND 88 K ([illegible]°F) FLOWS THROUGH THE SECONDARY SEPARATOR, USING LATENT HEAT OF CONDENSING R-22 AT -40° F, FROM NITROGEN TABLE

$q = 100$ BTU/lb

THE MASS FLOWRATE OF AIR AND R-22 IS 100 lb/min.

THE ENERGY REQUIRED TO LIQUEFY THE REMAINING R-22

$$\dot{Q} = \dot{m}q$$

$$= (100\ \text{lb/min})(100\ \text{Btu/lb})$$

$$= 10{,}000\ \text{Btu/min} \quad (175\text{KW})$$

ASSUMING THE LATENT OF THE NITROGEN TO SUPPLY THE HEAT TO LIQUEFY THE R-22, FROM NITROGEN DIAGRAM

$$q = 83\ \text{Btu/lb}$$

THE INITIAL MASS FLOW RATE OF LIQUID NITROGEN REQUIRED FOR LIQUEFACTION OF REMAINING R-22

$$\dot{m} = \frac{\dot{Q}}{q} = \frac{10{,}000\ \text{Btu/min}}{83\ \text{Btu/lb}} = 120\ \text{lb/min}$$

THE LATENT HEAT OF CONDENSING R-22 WILL BE CHANGED DUE TO THE HEAT EXCHANGER NO 4 WILL SUBCOOLED R-22 AT -285°F.

FROM AIR TABLE:

$$q = h_{out} - h_{in}$$

$$= \frac{7250 - 6200}{28.96}$$

$$= 36.3\ \text{KJ/Kg}$$

$$= 15.6\ \text{Btu/lb}$$

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ENERGY REQUIRED

$$\dot{Q} = \dot{m}q$$

$$= (100\ \text{lb/min})(15.6\ \text{Btu/lb})$$

$$= 1560\ \text{Btu/min}$$

TOTAL MASS OF LIQUID NITROGEN ASSUMED AT ONE HOUR INITIAL AND 11 HOURS

$m_I$ = (120 lb/min)(60 min) = 7200 lb

$m_{II}$ = (18.8 lb/min)(11 hr)(60 min) = 12408 lb

$m_{Total}$ = 20,000 lb

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APPENDIX B REFRIGERATION CYCLE

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SINGLE FLUID, TWO STAGED VAPOR COMPRESSION CYCLE.

WORKING FLUID : R-22

ENERGY LOAD : 290,565 Btu/min (5.08 MW)

EVAPORATION : 15 psia

CONDENSATION : 140 psia

INTERMEDIATE PRESSURE : 45 psia

$h_g = h_y = h_a = 12.388$ Btu/lb

$h_k = 105.187$ Btu/lb

$h_b = 100.194$ Btu/lb

$h_d = h_j = 30.659$ Btu/lb

$s_b = s_e = 0.23906$ Btu/lb°R $\qquad h_e = 106.985$ Btu/lb

$s_k = s_c = 0.22650$ Btu/lb°R $\qquad h_c = 117.262$ Btu/lb

$$\dot{m}_1 = \frac{\dot{Q}_L}{h_b - h_a} = \frac{290565}{100.194 - 12.388} = 3309.17 \text{ lb/min}$$

$$\dot{m}_2 = \frac{h_e - h_k}{h_k - h_j} = \frac{106.985 - 105.187}{105.187 - 30.659} = 0.0224125 \text{ lb/min}$$

$$\dot{m}_3 = \frac{h_d - h_g}{h_k - h_j}\,\dot{m}_1 = \frac{30.659 - 12.388}{105.187 - 30.659}(3309.17) = 811.263 \text{ lb/min}$$

$$\dot{m}_4 = \dot{m}_1 - \dot{m}_2 - \dot{m}_3 = 4120.43 \text{ lb/min}$$

$$\dot{W}_1 = \dot{m}_1(h_e - h_b) = 3309.17 \text{ lb/min}(106.985 - 100.194)\text{Btu/lb}$$

$$= 22,472.5 \text{ Btu/min}$$

$$\dot{W}_2 = \dot{m}_4(h_c - h_k) = 4120.43 \text{ lb/min} (117.262-105.187 \text{ Btu/lb})$$

$$= 49,754.55 \text{ Btu/min}$$

$$\Sigma \dot{W} = \dot{W}_1 + \dot{W}_2 = 72,227.05 \text{ Btu/min}$$

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## APPENDIX C CALCULATION OF THE PRESSURIZING PROCESS

TOTAL TIME TO PRESSURIZE THE TUNNEL IS 12 HRS.

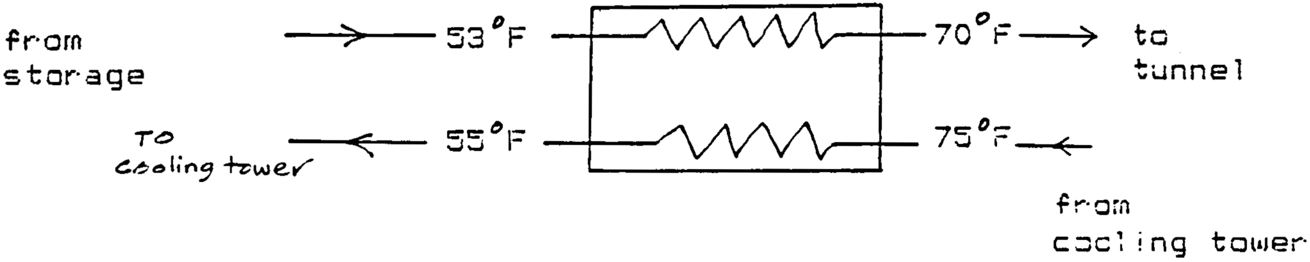
THE AVERAGE MASS FLOWRATE TO PRESSURIZE THE TUNNEL:

$$\dot{m} = \frac{\text{mass required to fill up the tank}}{\text{time for pressurization process}}$$

$$= \frac{1.8 \times 10^{6} \text{ lb}}{12 \times 60 \text{ min}}$$

$$= 2500 \quad \text{lb/min}$$

CONTROL VOLUME OF THE HEAT EXCHANGER



HEAT EXCHANGER EFFECTIVENESS OF 0.85

FROM R-22 TABLE

$$h_{in} = 25.139 \quad \text{BTU/LB}$$
$$h_{out} = 112.349 \quad \text{BTU/LB}$$

FROM STEAM TABLE

$$h_{in} = 43.09 \quad \text{BTU/LB}$$
$$h_{out} = 23.09 \quad \text{BTU/LB}$$

HEAT REQUIRED TO VAPORIZED LIQUID R-22

$$\dot{Q} = \dot{m}\Delta h$$

$$= 2500 \text{ (lb/min)} \times (112.349 - 25.139) \text{ BTU/lb}$$

$$= 218{,}000 \text{ BTU/min (3.8 MW)}$$

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HEAT REQUIRED FROM WATER

$$\dot{Q}_{H_2O} = \dot{Q}_{R-22}$$

$$= 216800 \text{ BTU/MIN}$$

MASS FLOWRATE REQUIRED TO PUMP THE WATER

$$\dot{m} = \frac{Q_{H_2O}}{h_{in} - h_{out}}$$

$$= \frac{\qquad \text{BTU/min}}{(43.09 - 23.09) \text{ BTU/lb}}$$

$$= 10800 \text{ lb/min}$$

$$\text{POWER REQUIRED} = \frac{72{,}227.13\ \text{Btu/min}}{42.2\ \text{Btu/min-hp}}$$

$$= 1700\ \text{hp} \quad (\ 1.27\ \text{MW}\ )$$

## APPENDIX D CALCULATION OF TOTAL MASS OF R-22 EMITTED

VAPOR PRESSURE OF R-22 AT 68 K ( 158°R)

$$\mathrm{LOG}\ P = A - \frac{B}{T} - C\ \mathrm{LOG}_{10} T + DT + \frac{E(F-T)}{FT} \mathrm{LOG}_{10}(F-T)$$

LET $Y_1 = B/T$

$Y_2 = C\ \mathrm{LOG}_{10} T$

$Y_3 = DT$

$$Y_4 = \frac{E(F-T)}{FT} \mathrm{LOG}_{10}(F-T)$$

$$Y_1 = \frac{3845.193152}{158.42} = 24.27214463$$

$Y_2 = 7.86103122\ \mathrm{LOG}\ (158.42)°\mathrm{R} = 17.29277416$

$Y_3 = (0.002190939044)(158.42°\mathrm{R}) = 0.347088556$

$$Y_4 = \frac{305.8268131(686.1 - 158.42)}{(686.1)(158.42)} \mathrm{LOG}_{10}(62.1 - 158.42)$$

$= 4.041997273$

$\mathrm{LOG}_{10} P_{sat} = A - Y_1 - Y_2 + Y_3 + Y_4$

$P_{sat} = 1.51953(10^{-8})$ psi

$$v_a = \frac{R_a T}{P_a} = \frac{(53.34)(158.42°\mathrm{R})}{14.69599} = 575.0\ \mathrm{ft}^3/\mathrm{lb}$$

$(144\ \mathrm{in}^2/\mathrm{ft}^2)$

$$v_{R-22} = \frac{R_a}{P_a} = 1.11019(10^{11})\ \mathrm{ft}^3/\mathrm{lb}$$

$$\frac{\rho_{R-22}}{\rho_a} 100\ \% = 5.1292(10^{-7})$$

$\dot{m}_{air} = 100$ lb/min.

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$$\dot{m}_{R22}\text{emitted} = (\dot{m}_{air})\,(\dot{m}_{R\text{-}22}/\dot{m}_{air})$$

$$= (100\ \text{Lb/min})(5.1393)(10^{-7}\%)$$

$$= 5.1393(10^{-5})\ \text{lb/min}$$

TOTAL MASS OF R-22 FOR THE RECOVERY PROCESS

$$m = \dot{m}(t) = (5.1393\times10^{-5}\ \text{lb/min})(12\ \text{hrs})(60\text{min/hr})$$

$$= 0.037\ \text{lb}$$