FREON REMOVAL SYSTEM FOR THE CERENKOV COUNTER .

WALTER TUZEL
OCTOBER 15, 1993

INTRODUCTION.

The CLAS spectrometer in end station B includes Cerenkov detectors. These detectors require the use of either Freon 12 (CCl_2F_2) or Freon 114 ($C\ ClF_2\ CClF_2$). This note describes a conceptual design approach for the filling and recovery of the Freon 114 gas.

A design objective is to minimize the release of Freon to the atmosphere during filling and recovery operations.

DESCRIPTION OF THE APPARATUS.

The system uses nitrogen as a carrier gas. During filling operations, the Cerenkov chamber is first filled with nitrogen. The Freon is then introduced and the exhaust from the Cerenkov flows through a cooling system to condensate the Freon. The remaining gas (nitrogen) is released to the atmosphere. The recirculation continues until the required purity of Freon is reached within the chamber.

When recovering Freon, nitrogen gas is introduced into the chamber and the exhaust flow passes through the heat exchangers. Freon gas is condensed and collected.

See section 5 for a schematic of the system. The system uses three heat exchangers, the first precools warm nitrogen to the required temperature, the second cools Freon and carrier gas to the temperature at which Freon liquifies and the third freezes the remaining Freon.

The liquid nitrogen is used as the coolant in all three heat exchangers. The system is sized to fill or empty the chamber (volume approx. $12.8m^3$) in approximately 12 hours. The detector maximum working pressure is about 2" of water, so the system must operate with near ambient pressure .

We expect that we would recover at least 99.9 percent of the Freon.

REQUIREMENTS FOR EACH HEAT EXCHANGERS.

1. THE HEAT EXCHANGER TO COOL FREON FROM ROOM TEM-

PERATURE TO -80C.

1.1. Nitrogen requirement to cool the incoming Freon.

1.1.2. Initial Freon flow rate from the system (one Cerenkov counter).

Since system must be empty from Freon within 12 hours, initial volumetric Freon flow rate must be :

$v = \frac{V}{3600t} = 3E - 4m^3/s$ or $18.3in^3/s$ – initial volumetric flow rate of Freon for:

V=$12.8m^3$ – volume of the Cerenkov counter

t=12 hours – time to remove Freon from the system

1.1.3.Flow rate of nitrogen required to cool Freon from ambient temperature (25 C) to -80 C (20 C off the freezing point).

Heat to be removed from the incoming Freon.

$Q = Q_1 + Q_2 + Q_3 = .54kW$

where:

$Q_1 = mc_p(T_1 - T_2) = .036kW$ – heat removed to cool Freon to 3 deg C

$Q_2 = mh_{f-g} = .31kW$ – heat removed to liquify Freon

$Q_3 = mc_{pl}(T_2 - T_3) = .19kW$– heat removed to cool liq. Freon to -80C

for:

$m = v\rho = 2.3E - 3kg/s = 5.1E - 3lb/s$ –mass flow rate of Freon

where:

$\rho = 7kg/m^3$ – density of Freon at 25C and 1atm [1]

$v = 3E - 4m^3/s$ – flow velocity of Freon (sec.1.1.2)

$c_p = .71kJ/kgK$ – specific heat of Freon at 25C and 1atm [1]

$c_{pl} = 1.0kJ/kgK$ – specific heat of liquid Freon at -3 deg C [1]

$h_{f-g} = 135kJ/kg$ – heat of liquification [1]

$T_1 = 25C$ – ambient temperature

$T_2 = 3C$ – liquification temperature

$T_3 = -80C$ – required end temperature of liquid Freon

Required flow rate of -100F=200K nitrogen (assumed value) can be calculated as:

$m = \frac{Q}{c_p dT} = 2.6E - 2kg/s$ or $.015m^3/s$ – flow rate of 200K nitrogen

for:

Q=540 W – heat to be removed (calculated above)

$c_p = 1.043kJ/kgK$ – specific heat of nitrogen [2]

dT= 20K – temperature rise of nitrogen (assumed value)

1.2. Sizing of the heat exchanger .

The heat exchanger is counterflow type, with Freon flowing via .5" dia coiled tube and cooling gas flowing outside . The coiled tube is inserted in between two concentric tubes, forming the passage for the cold gas.

1.2.1.Required surface area of heat exchange to cool incoming Freon to -80C.

The following assumption are made:

– inside diameter of the tube for Freon flow (coiled to 2in radii) – 0.5"

– inside diameter of the nitrogen container – 3"

– outside diameter of the nitrogen container – 5"

1.2.1.2. Heat transfer coefficient inside of the Freon tube.

$h = \frac{N_u k}{d} = .0156 \frac{W}{in^2 F}$ – heat transfer coefficient [3]

where:

$N_u = .023 Re^{.8} Pr^{.3} = 53$ – Nusselt number [3]

$Re = \frac{123.9 d v \rho}{\mu} = 21000$ – Reynolds number [4]

for:

d=.5 in – tube diameter

$\rho = .486 \frac{lb}{ft^3}$ – density of Freon at 25C [1]

$\mu = .011 cPoise$ – dynamic viscosity of Freon at 25C [1]

$v = 7.7 \frac{ft}{s}$ – calculated flow velocity of Freon inside of the .5" tube (calculated as a ration of volumetric flow velocity over the tube cross section area)

Pr=.5 – Prandtl number for freon at 25C [1]

$k = 1.46E - 4 \frac{W}{inF}$ – thermal conductivity of Freon at 25C [1]

1.2.1.3 Heat transfer coefficient outside of the .5in tube – nitrogen passage.

Velocity of nitrogen within passage (the ring 3in ID and 5" OD with .5" tube inside coiled to 2in radii).

$v = \frac{V}{A} = 146 in/s$

for:

$V = 1.5E - 2m^3/s = 915 in^3/s$ – required volumetric flow rate of nitrogen (sec.1.1)

$A = 6.28 in^3$ – cross section area of the nitrogen passage (area in between 3' and 5"dia tubes minus 4" dia coil of .5"tube)

Hydraulic diameter of the cooling passage.

r= A/P= .153" – hydraulic radii

for:
$A = 6.28 in^3$ – calculated flow area
P=40.8 in – calculated perimeter of the ring and the tube inside
Calculated hydraulic diameter is d=4r=1.3 in.

The heat transfer coefficient can be calculated from the following formula:
$h = \frac{.683 k_f}{d} Re^{.466} Pr^{.33} = .0167 \frac{W}{in^2 F}$ [3]
where:
$Re = \frac{v d \rho}{\mu} = 7970$ – Reynolds number [3]
$\rho = .1099 lb/ft^3$ – density of nitrogen at 200K [2]
$\mu = 8.5E-6 lb/fts$ – dynamic viscosity of nitrogen at 200K [2]
$k_f = 2.5E-4 W/inF$ – thermal conductivity of nitrogen at 200K [2]
d= .61 in= .051 ft – calculated hydraulic diameter of the cooling passage
$v = 146 in/s = 12.1 ft/s$ – calculated flow velocity
Pr= .722 – Prandtl number for nitrogen at 200K [2]

Required length of the Freon tube.
Since both nitrogen and Freon temperature are known, an effective heat transfer area can be found from the following formula:
$Q = UA\delta T_{log}$[3]
where:
$U = \frac{h_i h_o}{h_o + h_i} = .0081 W/in^2 F$ – overall heat transfer coefficient
$A = 3.14 dl$ – heat transfer area to be calculated
$Q = 540W$ – heat to be removed (sec.1.1.3.1)
$\delta T_{log} = \frac{dT_1 - dT_2}{ln(dT_1/dT_2)} = 77.4F$ – average temperature across the films
for:
$h_i = 1.56E-2 W/in^2 F$ – heat transfer coef. within the Freon tube
$h_o = 1.67E-2 W/in^2 F$ – heat transfer coef. outside the Freon tube
$dT_1 = 300 - 220 = 80K$ – temperature difference at the entrance of the Freon and exit of N_2
$dT_2 = 220 - 200 = 20K$ – temperature difference at the exit of the Freon and entrance of N_2
The calculated required surface area of the Freon tube is $861 in^2$ or or 548 in of .5" dia tube or 44 turns , coiled to 2in radii.

In summary, the heat exchanger used to cool Freon from 300 to 220K or

-80C can be built from two concentric 5" and 3" tubes, with volume in between those two cylinders filled with .5" Cu tube, coiled to 2in radii with 44 turns.

2.THE HEAT EXCHANGER TO PRECOOL ROOM TEMPERATURE NITROGEN TO 200K .

This heat exchanger is used to cool warm nitrogen flowing thru the coiled Cu tube, immersed within liquid nitrogen bath. The cold nitrogen from this device is fed into heat exchanger evaluated in sec.1.

Requested exit temperature of warm nitrogen (200K) will executed by adjusting level of liquid nitrogen. Nitrogen temperature will be adjusted according to a temperature sensor reading attached to the exit of the warm nitrogen tube.

Assumption for the calculation of the required tube length:

– tube diameter .5"

– warm nitrogen flow rate .026 kg/s or .057 lb/s or $.67ft^3/s$ (at 250K), sec.1.1

– temperature of a warm nitrogen at the entrance – 300K

– temperature of a warm nitrogen at the exit – 200K

2.1 Heat transfer coefficient inside of the tube.

The same formulas as used in sec. 1 can be used with datas for a nitrogen.

$h = \frac{N_u k}{d} = 55.2\frac{mW}{cm^2K}$ [3]

where:

$N_u = .023Re^{.8}Pr^{.3} = 317$ – Nusselt number [3]

$Re = \frac{vd\rho}{\mu} = 1.68E5$ – Reynolds number [3]

for:

$\rho = .0853lb^3$ – density of nitrogen at 250K [2]

$v = 491ft/s$ –flow velocity of warm nitrogen within .5" tube, for required mass flow rate .057 lb/s (sec.1.1)

$\mu = 1.04E - 5\frac{lb}{fts}$ – dynamic viscosity of nitrogen at 250K [2]

d= .5in – tube diameter

Pr= .733 – Prandtl number for nitrogen at 250K [2]

$k = .221\frac{mW}{cmK}$ – thermal conductivity of nitrogen at 250K [2]

The required tube length, inside of the heat exchanger, can be evaluated under the initial assumption that heat transfer coefficient outside of this tube (within the liquid) is large. The correction for finite heat transfer outside (within the liquid) will be done at the final step.

Heat transferred across the boundary is:
$Q_1 = hA\delta T_{log}$
Heat removed from the flowing nitrogen is:
$Q_2 = mc_p(T_1 - T_2) = 2693W$
for:
$\delta T_{log} = \frac{dT_1 - dT_2}{ln(dT_1/dT_2)} = 165K$ – log mean temperature
$dT_1 = T_1 - 80 = 300 - 80 = 220K$ – temperature difference in between warm nitrogen and a liquid at the entrance to the heat exchange
$dT_2 = T_2 - 80 = 200 - 80 = 120K$ – temperature difference in between cold nitrogen and the liquid at the exit for the heat exchange
$c_p = 1.042\frac{kJ}{kgK}$ – specific heat of nitrogen at 250K [2]
$m = .026\frac{kg}{s}$ or.$0571\frac{lb}{s}$ – required mass flow rate of nitrogen (sec.1.1)
A= 3.14dL – heat transfer area of the cooled tube to be calculated
For steady state $Q_1 = Q_2$; calculated .5" dia tube length must be 74 cm for heat transferred across the boundary of 2693 W (calculated from Q_2).

Since heat transfer coefficient from LN_2 was taken infinitely large, correction at this stage mast be taken. Heat flux from the wall to the liquid nitrogen:
$\frac{Q}{A} = \frac{2693}{3.14*2.54*.5*74} = 9.1\frac{W}{cm^2}$
Since boiling heat transfer of the nitrogen (for temperature difference 120 K) is $2\frac{W}{cm^2}$ [5], the correction of 9.1/2 for tube length must be taken; the final .5" tube length must be about 674 cm.
If one assume bend radii of 2" required number of turns must be 22.

In summary nitrogen precooler can be made from 5in tube with 22 turns of .5" Cu tube coiled to 2in radii.

3.The FREON FREEZER.
A freezer tank is an container used to freeze a vapor released from the liquid Freon.
3.1. The required freezer volume to contain frozen Freon.
The vapor pressure of the Freon at required liquid temperature of -63F(220K) is 27.9 in Hg [1]. With ambient pressure of 29.92 in Hg, a portion of Freon vapor escaping the liquid Freon container is proportional to a difference in between these two pressure divided by an ambient pressure.
The portion of incoming gas escaping a liquid phase is:

$m = \frac{p_1 - p_2}{p_1}$
$m = \frac{29.92-27.9}{27.92} = .067$
For the total liquid volume of the Freon within the one Cerenkov counter, a volume of the freezer for complete removal of the Freon from one counter should be:
$V_{fr} = .067 V_l$
for Freon liquid volume used for one Cerenkov counter eq. to $4400 in^3$, required volume of the freezer should be $300 in^3$ to contain the frozen freon.
3.2 Min liquid nitrogen flow to the freezer to freeze the vapor:
3.2.1 Heat to be removed from the Freon.
$Q = Q_1 + Q_2 = 31W$
where: $Q_1 = mc_p(T - T_s) = 2.25W$ – heat removed to cool freon down to freezing point
$Q_2 = mH_{fs} = 28.5W$ – heat removed to solidify Freon
for:
m =1.5E-4kg/s – flow rate of freon vapor (for flow rate of Freon from the counter 2.3E-3kg/s (sec.1.1))
$c_p = 1.0 kJ/kgK$ – specific heat of liquid [1]
$H_{fs} = 1.358E5 J/kg$ – heat of fusion of Freon [1]
T=220K – vapor temperature, equal to liquid temperature
T=205K – freezing temperature of Freon at 1atm [1]
3.2.2. Required flow of the nitrogen.
$m_n = \frac{Q}{H_{vl}}$
for:
Q= 31 W – heat removal rate
$H_{vl} = 199 kJ/kg$ – heat of vaporization of LN
Calculated flow rate of the nitrogen to the freezing tank must be .16 g/s or $.13 cm^3/s$
Probably reserve of 2h nitrogen flow interruption should be kept within the freezer eq. to $56 in^3$.

The total volume of the freezer should be about $500 in^3$, to contain all frozen Freon and reserve of liquid nitrogen for 2 hours.

4. Estimated pressure drop for Freon within the pipework.
Pipes length form the Cerenkov counter to the exit from the freezer:

- pipe length from the counter to the Freon removal station – 10 feet
- pipe length within the Freon removal station – 68ft
- addition unknown length 5ft. Pressure drop can be calculated according to 'Crane' formula:

$dP = \frac{.001294 f l \rho v^2}{d}$ [4]

where:

$f = .316 Re^{-.25} = .026$

for:

Re=21000 – Reynold number calculated in sec.2

v=7.7 ft/s – flow velocity calculated in sec.2

$\rho = .486 \frac{lb}{ft^3}$ – Freon density at 300K and 1atm

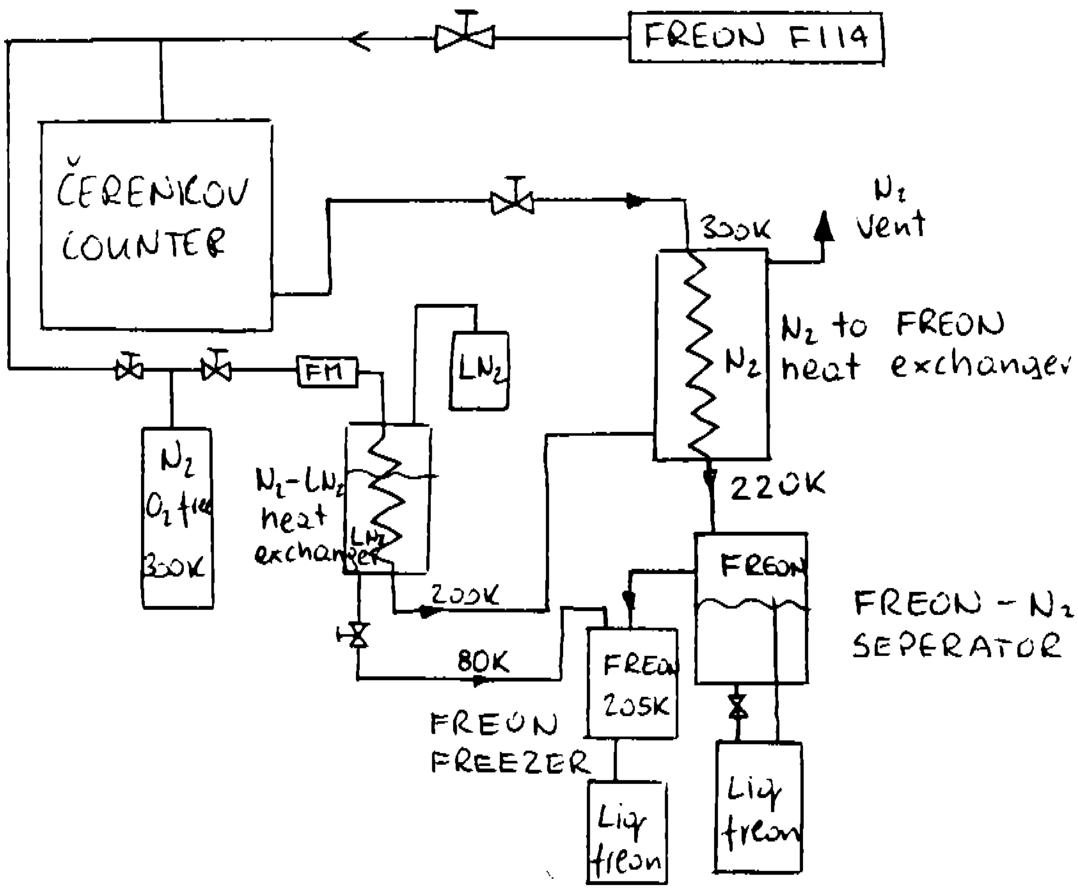
l= 83 ft – estimated tube length

d=.5in – tube diameter

Calculated pressure drop over entire system is .16 psi or 4.3 in of water. This pressure drop in on pessimistic side, since during the cooldown process, gas density increase very rapidly decreasing flow rate and pressure drop.

If the system can't tolerate such "high" pressure , small pump may be necessary to drive gas through system

5.System schematic.



References:

1. Du Pont – Properties of Freon
2. R. Barron – Cryogenic System
3. J.P Holman – Heat Transfer
4. Crane Catalog
5. NBS TN317 – Boiling Heat Transfer of Nitrogen

VAPOR PRESSURE

FREON 22

DU PONT FREON® REFRIGERANTS

TEMP. °F	FREON 113	FREON 11	FREON 114	FREON 12	[illegible]		FREON 502	FREON 13B1	FREON 116	FREON 13	FREON 503	
−150		29.9		29.6		29.4	29.1	27.9	22.6	20.9	15.4	71.0
−140		29.9		29.4		29.0	28.5	26.8	19.3	16.8	9.7	77.4
−130		29.9		29.1		28.4	27.8	25.2	14.7	11.5	2.1	102.7
−120		29.9		28.6		27.7	26.7	23.1	8.8	4.5	3.8	132.0
−110		29.8		28.0		26.6	25.3	20.3	1.1	2.1	9.8	168.1
−100		29.8		27.0	26.4	25.0	23.3	16.6	4.3	7.6	17.3	209.1
−90		29.7	29.3	25.7	24.9	23.0	20.6	11.9	10.3	14.3	26.4	271.2
−80		29.6	29.0	24.1	22.9	20.2	17.2	5.9	17.6	22.4	37.5	311.1
−70		29.4	28.5	21.8	20.3	16.6	12.8	.8	26.5	32.3	65.5	373.7
−60		29.2	27.9	19.0	17.0	12.0	7.2	5.3	37.2	43.9	81.3	445.9
−50		28.9	27.1	15.4	12.8	6.2	.2	10.7	49.9	57.5	99.8	
−40		28.4	26.0	11.0	7.6	.5	4.1	17.2	64.8	73.3	106.7	
−35		28.1	25.4	8.4	4.6	2.6	6.5	20.9	73.2	82.2	118.7	
−30	29.3	27.8	24.6	5.4	1.2	4.9	9.2	24.9	82.2	91.6	131.6	
−25	29.2	27.4	23.8	2.3	1.2	7.4	12.1	29.2	91.8	101.7	145.5	
−20	29.1	27.0	22.9	.6	3.2	10.2	15.3	33.9	102.2	112.4	160.3	
−15	28.9	26.5	21.8	2.4	5.4	13.2	18.8	38.9	113.3	123.9	176.1	
−10	28.7	26.0	20.6	4.4	7.8	16.4	22.6	44.4	125.1	136.1	193.0	
−5	28.4	25.4	19.3	6.7	10.4	20.1	26.7	50.2	137.8	149.1	211.0	
0	28.2	24.7	17.8	9.2	13.3	24.0	31.1	56.4	151.2	162.9	230.0	
5	27.9	23.9	16.2	11.8	16.4	28.2	35.9	63.2	165.4	177.4	250.3	
10	27.6	23.1	14.4	14.6	19.7	32.8	41.0	70.3	180.6	192.8	271.8	
15	27.2	22.1	12.4	17.7	23.3	37.7	46.5	77.9	196.6	209.1	294.5	
20	26.8	21.1	10.2	21.0	27.2	43.0	52.4	86.1	213.6	226.3	318.5	
25	26.3	19.9	7.8	24.6	31.4	48.8	58.8	94.7	231.4	244.4	343.9	
30	25.8	18.6	5.2	28.4	36.0	54.9	65.6	103.9	250.1	263.5	370.6	
35	25.2	17.2	2.3	32.6	40.8	61.4	72.8	113.6	269.8	283.6	398.7	
40	24.5	15.6	.4	37.0	46.0	68.5	80.5	123.9	290.4	304.8	428.2	
45	23.8	13.9	2.0	41.7	51.6	76.0	88.7	134.8	311.9	327.1	459.2	
50	22.9	12.0	3.8	46.7	57.5	84.0	97.4	146.3	334.2	350.4	491.7	
55	22.0	10.0	5.8	52.1	63.9	92.6	106.6	158.5	357.3	375.1	525.6	
60	21.0	7.8	7.9	57.7	70.6	101.6	116.4	171.3	381.0	400.9	561.0	
65	19.9	5.4	10.1	63.8	77.8	111.2	126.7	184.8	405.2	428.2	597.7	
70	18.7	2.8	12.6	70.2	85.3	121.4	137.6	199.0		456.9		
75	17.3	0.0	15.2	77.0	93.4	132.2	149.1	214.0		487.2		
80	15.9	1.5	18.0	84.2	101.9	143.6	161.2	229.7		519.4		
85	14.2	3.2	20.9	91.8	111.0	155.7	174.0	246.1				
90	12.5	4.9	24.0	99.8	120.4	168.4	187.4	263.4				
95	10.6	6.8	27.5	108.2	130.5	181.8	201.4	281.6				
100	8.6	8.8	31.2	117.2	141.1	195.9	216.2	300.6				
105	6.3	10.9	35.0	126.6	152.2	210.7	231.7	320.4				
110	4.0	13.1	39.1	136.4	164.0	226.4	247.9	341.2				
115	1.3	15.6	43.4	146.8	176.3	242.7	264.9	363.0				
120	.7	18.3	48.0	157.7	189.2	259.9	282.7	385.7				
125	2.2	21.0	52.8	169.1	202.8	277.9	301.4	409.4				
130	3.7	24.0	58.0	181.0	217.0	296.8	320.8	434.2				
135	5.4	27.1	63.4	193.5	231.8	316.6	341.2	460.1				
140	7.2	30.4	69.1	206.6	247.4	337.2	362.6	487.1				
145	9.2	34.0	75.1	220.3	263.7	358.9	385.0	515.2				
150	11.2	37.7	81.4	234.6	280.7	381.5	408.4	544.5				

FREON 14

¹Vapor pressures are shown as PSIG. Red figures are shown as inches of mercury vacuum.

PROPERTIES

P3 & ...

DUPONT FREON® REFRIGERANTS

FREON 22 | FREON 14

PROPERTIES		FREON 113	FREON 11	FREON 114	FREON 12	500		FREON 502	FREON 13B1	FREON 116	FREON 13	FREON 503	
Chemical Formula		CCl_2CClF_2	CCl_3F	$CClF_2$-$CClF_2$	CCl_2F_2	azeotrope[a]	$CHClF_2$	azeotrope[b]	$CBrF_3$	CF_3-CF_3	$CClF_3$	azeotrope[c]	CF_4
Molecular Weight		187.38	137.37	170.93	120.92	99.31	86.47	111.64	148.92	138.01	104.46	87.28	88.00
Boiling Point (1 atm)	°C	47.57	23.82	3.77	−29.79	−33.5	−40.75	−45.42	−57.75	−78.2	−81.4	−88.7	−127.96
	°F	117.63	74.87	38.78	−21.62	−28.3	−41.36	−49.76	−71.95	−108.8	−114.6	−127.6	−198.32
Critical Temperature	°C	214.1	198.0	145.7	112.0	105.5	96.0	82.2	67.0	19.7	28.9	19.5	−45.67
	°F	417.4	388.4	294.3	233.6	221.9	204.8	179.9	152.6	67.5	83.9	67.1	−50.2
Critical Pressure	atm	33.7	43.5	32.2	40.6	43.67	49.12	40.2	39.1	29.4	38.2	43.0	36.96
	psia	495	639.5	473.2	596.9	641.9	721.9	591.0	575	432	561	632.2	543.2
Density, Liquid	g/cc	1.565	1.476	1.456	1.311	1.156	1.194	1.217	1.538	1.587 (−73°C)	1.298 (−30°C)	1.233 (−30°C)	1.317 (−80°C)
at 25°C (77°F)	lb/ft³	97.69	92.14	90.91	81.84	72.16	74.53	75.95	96.01	99.08 (−73°C)	81.05 (−30°C)	76.95 (−30°C)	82.21 (−80°C)
Heat of Vaporization at B.P.	cal/g	35.07	43.10	32.51	39.47	48.04	55.81	41.21	28.38	27.97	35.47	42.86	32.49
	Btu/lb	63.12	77.51	58.53	71.04	86.47	100.45	74.18	51.08	50.35	63.85	77.15	58.48
Thermal Conductivity:													
Liquid, 25°C (77°F)	Btu/(hr)(ft)(°F)	0.0434	0.0506	0.0372	0.0405	0.0432	0.0507	0.0373	0.0234	0.045 (−73°C)	0.0378 (−30°C)	0.0430 (−30°C)	0.0361 (−80°C)
Vapor (1 atm)	Btu/(hr)(ft)(°F)	0.0044[d]	0.00451	0.0060	0.00557	—	0.00609	0.00670	0.00534	0.0098 (−73°C)	0.00501 (−30°C)		0.00463 (−80°C)
Specific Heat:				1 kJ/kg°C									
Liquid, 25°C (77°F)	cal/g (°C) or	0.218	0.208	0.243	0.232	0.258	0.300	0.293	0.208	0.232 (−73°C)	0.247 (−30°C)	0.287 (−30°C)	0.294 (−80°C)
Vapor, 1 atm, 25°C (77°F)	Btu/lb°F	0.161 (60°C)	0.142 (38°C)	.71 kJ/kg°C 0.170	0.145	0.175	0.157	0.164	0.112	0.182 (@ 0 press)	0.158	0.160	0.169
Viscosity, 25°C (77°F)													
Liquid	centipoise	0.68	0.415	0.36	0.214	0.192	0.198	0.180	0.157	0.300	0.170 (−30°C)	0.144 (−30°C)	0.230 (−80°C)
Vapor (1 atm)	centipoise	0.010 (0.1 atm)	0.011	0.011	0.012	0.012	0.013	0.013	0.015	0.015	0.12 (−30°C)		0.012 (−80°C)
Solubility, 25°C (77°F)													
FREON in water (1 atm)	wt %	0.017[e]	0.11	0.013	0.028	—	0.30	—	0.03	—	0.009	0.042	0.0015
Water in FREON	wt %	0.011	0.011	0.009	0.009	0.056	0.13	0.056	0.0095 (21°C)	—	—	—	—
Quality Specs and Toxicity:													
Max water content	ppm (wt)	10	10	10	10	10	10	10	10	10	10	10	7
Max non-absorbable gas	% (v/v)	—	—	1.5	1.5	1.5	1.5	1.5	1.5	0.20	1.0	1.5	0.40
Max hi-boil impurities	% (v/v)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.05	0.5	0.001
TLV*–TWA	ppm (v/v)	1000	1000[f]	1000	1000	1000	1000.	1000	1000	(FREON 114[g])	(FREON 12[g])	(FREON 12[g])	(FREON 12[g])

a. CCl_2F_2/CH_3CHF_2 (73.8/26.2% by wt).
b. $CHClF_2/CClF_2CF_3$ (48.8/51.2% by wt)
c. $CHF_3/CClF_3$ (40.1/59.9% by wt).
d. At 0.5 atmosphere.
e. At saturation press.
f. Ceiling limit.
g. Relative toxicity based on available data.