Ammonia Refrigerant Pressure Vessel Design

By

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Pressure vessels used in Ammonia Refrigeration systems

1. Oil Separators after compressor & before condenser
2. High pressure Liquid Receiver for ammonia storage
3. Inter-stage cooler-open type-two stage system
4. Inter-stage cooler –with closed coil –for two stage system
5. Low pressure Ammonia storage vessel in forced feed pump circulation system (L.P. Vessel)
6. Surge drum mounted on shell & tube flooded chillers
7. Accumulators for gravity flooded cold storage air coolers, PHE, ice bank etc.
8. Knock out drums to protect compressors from liquid
9. Oil Pots for oil draining

DESIGN BASIS PARAMETERS

1. 21 kg/cm^2 g for water cooled Applications-AAR standard

2. 27kg/cm^2 g for air cooled-AAR standard

3. Design Pressure-+17^{0}C above wet Bulb for Water Cooled min.

4. +17^{0}C above Dry Bulb for Air Cooled Minimum- EN/ISO standard

I Prefer Designing for both High and low stage Vessels for above pressures to Reduce Ammonia Charge. Ammonia can be then stored in L.P. vessel & there is no need to pump down if one wants to stop the plant.

DESIGN STANDARDS

1. AAR-1/ANSI-IIAR-2 2014
2. BIS-2825
3. ANSI/ASHRAE-15 2013
4. ASME B31.5 2013
5. ASME Sect V III-Div. 1
6. ISO-5149
7. EN 378
8. IS 665- latest
9. OSHA

DESIGN PRECAUTIONS

1.Use Boiler Quality plates for Receiver Fabrication- IS2002 Gr 2A or SA516/Gr.70 –SA517 Gr-60/70 plates & refer AAR- 1 standard. Do not use Structural steel IS-2062

2. Use proper Thickness of plate as per TEMA standards

Consider joint efficiency as 0.7 if no radiography is done

Add corrosion allowance 0f 1.6mm in calculated thickness.

3. Fabrication as per IS 2825 or ASME sec. VIII-Div. 1 or EC/97/23

Pressure Vessel Thickness Calculations

- MOC: SA 516 Gr. 70-Allowable stress 17500 psi(ASME CODE)
- Vessel Size say: 30" diameter x 12 ft long
- Calculations Based on ASME Sec VIII Div. 1
- t =PR/(SE-0.6P)
- Where,
- t = minimum required thickness (inch.)
- P = Internal design pressure in (psi)
- R = inside Radius
- S= Allowable Stress for material
- E=Joint Efficiency
- E= 0.70 DP Test only
- E=0.85 10% Radiography
- E=1.0 100% Radiography

THICKNESS CALCULATIONS

ITEM	Value	Unit	Value	Unit
P	300	Psi	21.1	Kg/cm²
R	15	Inch	381	Mm
S	17500	Psi	1230.4	Kg/cm²
E	0.7	%	0.7	%

t= 300Px15R/(17500SxE0.7-0.6xP300)
t= 4500/(12250-180)12070= 0.37 inch or 9.47 mm
Add corrosion allowance of 1.6 mm
Thickness required is-11.07 mm
Use next Available size as 12mm thick plate

Recommended Thickness for Various Sizes

Vessel Diameter-inch	Thickness-mm 516 Gr.70	Dish end Thickness-mm
24	10	10
30	12	12
36	14	14
42	16	16
48	18	18

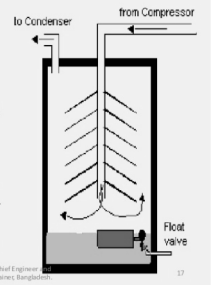
1. OIL SEPARATORS

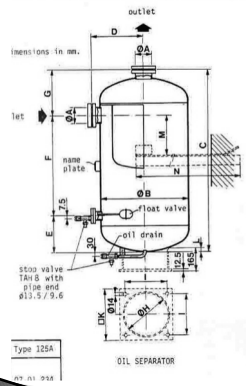
1. Function of oil separator-Ammonia Refrigerant and mineral oils are not miscible with each other.
2. Oil is required primarily for compressor lubrication and oil anywhere else in the system is not desired
3. If oil separator is not efficient, then more oil goes into the system & oil needs to be drained from various other places in the system which is manual process and can lead to problems like accidents.
4. Installing efficient oil separator, even at higher cost, is therefore recommended so that maximum oil is contained in the close loop of compressor and oil separator only

Oil Separator

Oil Separator
It is situated on the compressor discharge line.

The purpose of the oil seperator:
- To return oil entrained in the gas, back to the compressor sump.
The oil return may be float controlled as shown, electric solenoid controlled on a timer, or uncontrolled with a small bore capillary tube allowing continuous return.
With all of these methods a shut off valve is fitted between separator and compressor to allow for maintenance.
The oil gas mix enters the separator where it is made to change direction, the heavier oil droplets tend to fall to the bottom.



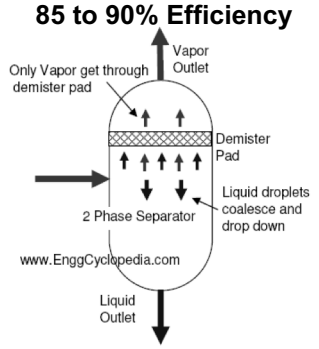


OIL SEPARATOR-65 T0 75% Efficiency

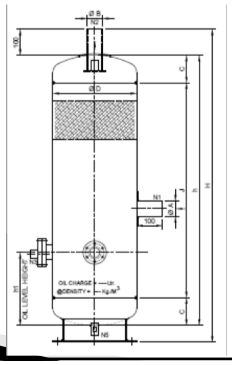
OIL SEPARATOR SELECTION

Di min. =C x $\sqrt{\emptyset p}$
Di min.= minimum inside shell diameter in mm
C=constant-26.6 for single stage and H.P. of two stage C=21.03 for Booster and L.P. Of two stage systems
Øp= compressor discharge volume flow rate in m3/h
Let us take KC3 compressor with volume as 398CMH at 1000RPM & single stage selection
Di min. =26.6 x $\sqrt{398}$ =26.6x19.93=530mm
Select Type 100 with 600x1397x8mm shell Thickness
For Booster or two stage KC31=21.03x $\sqrt{398}$=419mmdia
Select Type 80=419x1039x8mm shell Thickness

OIL SEPARATOR WITH DEMISTER PAD- 85 to 90% Efficiency



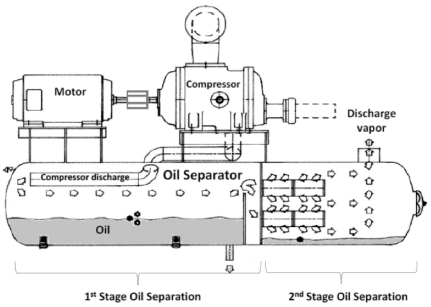
Oil Separator with Demister Pad of S.S.-85-90% Efficiency



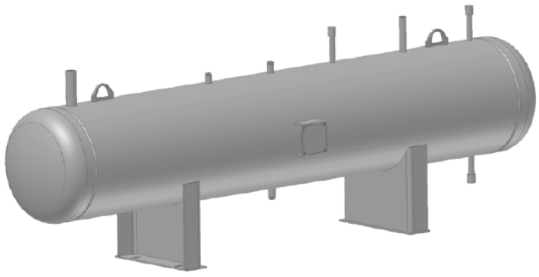
Oil Separator with spiral design

Oil Separator with spiral Design

SCREW COMPRESSOR- OIL SEPARATOR WITH COALESCENT FILTERS



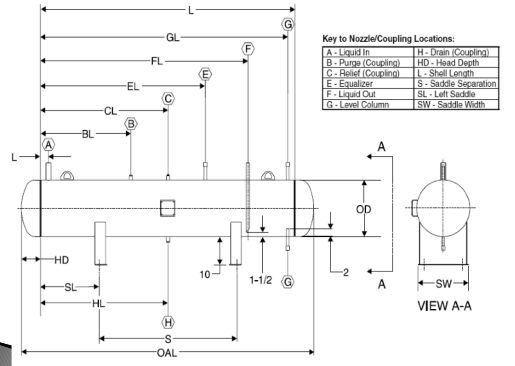
2. High Pressure ammonia receivers



2. High Pressure Liquid Receiver

1. Selection of receiver is done based on the assumption that it should be able to accommodate entire charge of refrigeration system.
2. This is essential as if one wants to do some repairs, attend leakages, do some piping welding etc. one should be able to pump entire refrigeration system in this receiver, close the king valve and then carry the modifications/repairs.
3. The receiver should be selected so that when ammonia is pumped down, the level of liquid should be not more than 80- 85%.
4. Many times a standby receiver is provided as per requirement

Important locations of receiver Nozzles



MODEL NUMBER	MAWP (psig)	VESSEL		Dry Weight (lb)	VOLUME (2) (ft³)	R-717 (3) (lbf)	L	HD
		OD (in.)	OAL (in.)					
HR-20-110	300	20	110⅜	850	17.9	592	96	7⅜
HR-20-134	300	20	134⅜	1,030	22.0	726	120	7⅜
HR-24-136	300	24	136⅜	1,260	32.4	1,069	120	8⅜
HR-24-160	300	24	160⅜	1,480	38.3	1,264	144	8⅜
HR-24-184	300	24	184⅜	1,700	44.2	1,459	168	8⅜
HR-30-163	250	30	163⅜	1,880	61.3	2,027	144	9 11⁄16
HR-30-187	250	30	187⅜	2,160	70.7	2,336	168	9 11⁄16
HR-30-207	250	30	207⅜	2,390	78.5	2,593	188	9 11⁄16
HR-36-166	250	36	166⅜	2,300	90.2	2,982	144	11⅜
HR-36-190	250	36	190⅜	2,630	103.8	3,430	168	11⅜
HR-36-210	250	36	210⅜	2,910	115.1	3,803	188	11⅜
HR-42-193	250	42	193⅜	3,120	143.7	4,748	168	12 11⁄16
HR-42-213	250	42	213⅜	3,440	159.1	5,259	188	12 11⁄16
HR-48-196	250	48	196½	4,820	188.4	6,228	168	14¼
HR-48-216	250	48	216½	5,310	208.5	6,891	188	14¼
HR-54-199	250	54	199½	5,500	242.2	8,004	168	15¾
HR-54-219	250	54	219½	6,060	267.7	8,848	188	15¾
HR-60-202	250	60	202½	6,210	303.2	10,023	168	17¼
HR-60-222	250	60	222½	6,820	334.9	11,069	188	17¼
HR-60-246	250	60	246½	7,560	372.9	12,324	212	17¼
HR-72-232	250	72	232⅝	10,690	499.6	16,512	192	20 5⁄16
HR-72-256	250	72	256⅝	11,800	554.2	18,317	216	20 5⁄16
HR-72-276	250	72	276⅝	12,720	599.7	19,821	236	20 5⁄16
HR-84-238	250	84	238¾	15,340	691.4	22,853	192	23⅜
HR-84-262	250	84	262¾	16,890	765.6	25,307	216	23⅜
HR-84-282	250	84	282¾	18,190	827.5	27,352	236	23⅜
HR-96-244	250	96	244¾	17,980	923.4	30,521	192	26⅜
HR-96-268	250	96	268¾	19,750	1,020.8	33,741	216	26⅜

3. Open Inter-stage cooler

3. Inter-stage cooler selection

1. Inter-stage coolers are required for two stage ammonia systems. The open type coolers are most efficient and consume minimum power.
2. Installation and operation requires skilled man power.
3. The vessel should be installed above the inlet connection of L.P. vessel to get ammonia liquid flowing in the L.P. vessel due to very low pressure difference and help of gravity is needed many times
4. It is also essential that compressor cylinders are loaded cautiously so as to ensure that inter-stage pressure does not exceed manufacturer's allowable limit.

SELECTION OF OPEN INTER-STAGE COOLER

For velocity of w=0.3m/s, the following equation to be used:

D_i, min. in mm= D_i, min. in mm= $11.2\sqrt{n\,x\,Zh}$

Zh is no of cylinders &*n* is RPM

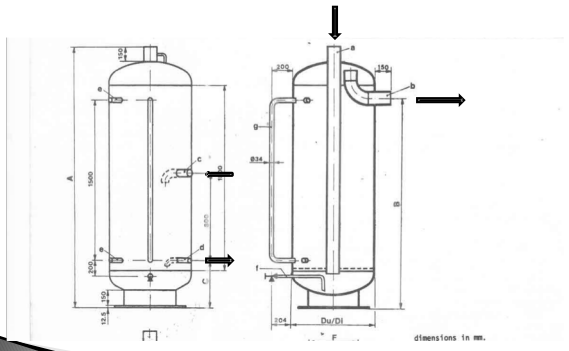
For example, if we take two KC42 compressors running at 965RPM then

Zh would be 2+2=4-

Di, min would be = $11.2\sqrt{965x4}$ = 695.84 mm

If we select FTO-800 with inner shell diameter of 786mm then actual velocity in the cooler at full load would be 0.3x $(695.84/786)^2$= 0.235 m/s which is OK,

3.OPEN INTER-STAGE COOLER



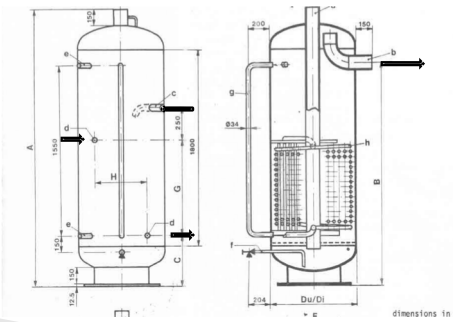
4. Closed Inter-stage cooler with coil

1. Closed inter-stage cooler for two stage systems is many times preferred alternative
2. The cooler can be mounted in the machine room and not required to be mounted at height since the pressure of liquid in the coil is high
3. Operation and loading unloading of compressor is easier
4. The drawback is it is not as efficient as open inter-stage cooler system.

COIL FOR CLOSED INTER STAGE COOLER

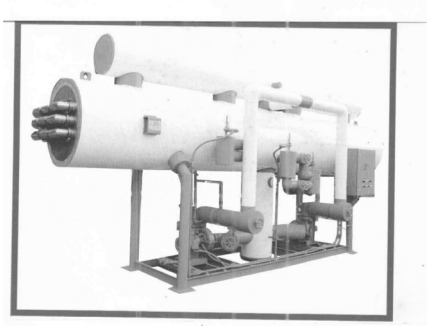
For +40˚C and -25˚C operation with 10K Sub - Cooling - Intermediate temperature from KC42 chart would be – minus 3.5^{0}C with capacity of 162kW each, for two compressors, it would be 324kW
Qs (sub cooling)required would be 12.33kW or 12330W
LMTD would be [40-10+3.5] /ln [(40+3.5) /10] = 33.5/ln (43.5/10) = 22.78 K
Coil area Fn-required would be =12330/ (3568 x 22.78) = 0.151m^2
Select coil VS1 having area as 0.75m^2 with diameter of 197mm

CLOSED INTER-STAGE COOLER WITH SUB COOLING COIL

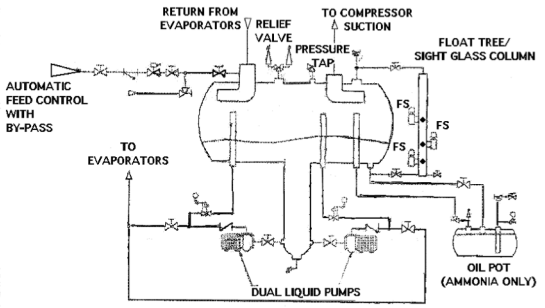


5. Low pressure/low temperature ammonia storage (L.P.) vessel for forced feed pump circulation systems

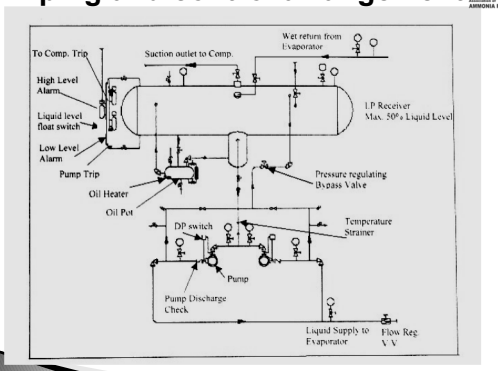
PUMP CIRCULATION SYSTEMS



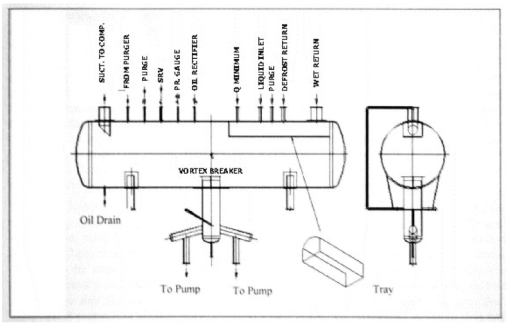
Ammonia Pump circulation Arrangement



Piping and control arrangement



Low Pressure vessel details



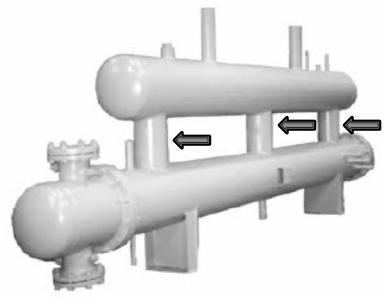
Low Pressure vessel details

Important considerations

1. **Liquid collection channel-very necessary**
2. **Vortex breaker-essential**
3. **Location of inlet and outlet connections-Apart**
4. **Gauge glass or standpipe location**
5. **Insulation of vessel, pumps and mounting of vessel**
6. **Pump by pass line and controls**
7. **Use of flow regulating valves instead hand expansion valve**
8. **Oil pot location**
9. **Most important - selection of diameter and length & to accommodate surge volume.**
10. **Location of liquid level max 405%, high lelve60% and low level pump trip 20% are suggest points**

6.Surge drum on shell and tube flooded chiller

SURGE DRUM ON CHILLER



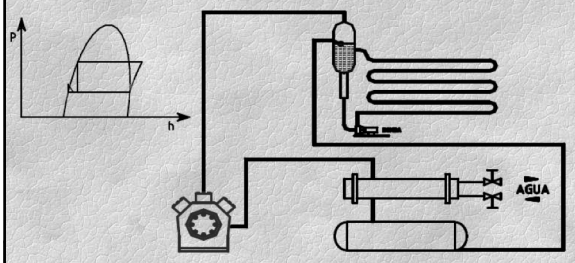
SURGE DRUM ON CHILLER

Important considerations

1. Surge drum is provided to prevent liquid entering the suction line and thereafter in the compressor.
2. The nozzles connections should be selected to maintain very low velocity of vapours likely to enter the suction line
3. Observe the photos and see how many connections have been provided between chiller and surge drum to lower the vapour velocity
4. There is no need to unnecessarily provide large diameter surge drum if proper care is taken in designing the suction velocities-around 0.5 to 0.7m/s

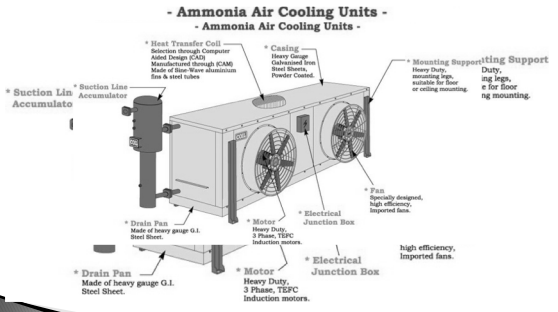
7. Accumulator for gravity flooded cold storage air coolers

Flow Control Methods Recirculated Systems

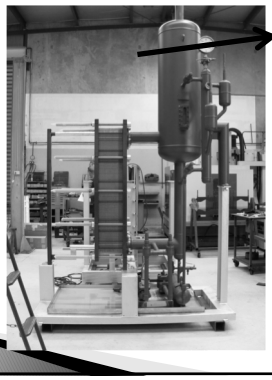


ACCUMULATOT SELECTION FOR AIR COOLER

Accumulator for Air cooler

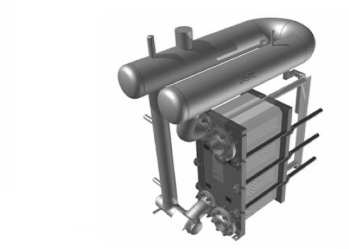


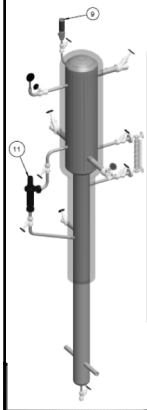
ACCUMULATOR FOR GRAVITY FLOODED SYSTEMS



ACCUMULATOR FOR PHE

'U' Turn Accumulator





ITEM No.	DESCRIPTION	QTY.	REMARKS
1	STRAIGHT SHUT OFF VALVE	ALL VALVES AND ACCUMULATOR ACCESSORIES ARE AVAILABLE ON SITE ON SITE	50 NB
2	STRAIGHT SHUT OFF VALVE		50 NB
3	STRAIGHT SHUT OFF VALVE		25 NB
4	STRAIGHT SHUT OFF VALVE		15 NB
5	STRAIGHT SHUT OFF VALVE		25 NB
6	STRAIGHT SHUT OFF VALVE		25 NB
7	STRAIGHT SHUT OFF VALVE		15 NB
8	STRAIGHT SHUT OFF VALVE		15 NB
9	PRESSURE RELIEF VALVE		15 NB
10	PRESSURE GAUGE		15 NB
11	FLOAT VALVE		25 NB
12	LIQUID LEVEL SWITCH		25 NB
13	PUFF INSULATION		60mm THICK PUFF (UNIFORM THICK ALL AROUND)

CUSTOMER	TITLE		SCALE	DRN BY.
	ACCUMULATOR		NTS	P.JANGRA
VERTICAL SYMBOLS	THIRD ANGLE PROJECTION	JOB NO.	DRG.NO.	DATE
CRITICAL SAFETY			3/3	18.11.10

FLOODED Vertical ACCUMULATOR with connection details

Accumulator for ice bank system used in dairies & for block can ice production

Accumulator selection

The design, selection and installation of accumulator has remained till date a night mare for system designers as there are no clear cut guide lines and evaporator or many air cooler manufacturers indicate their inability to suggest proper size and method for installing the same and indicate that this is a system designer's responsibility.

The accumulator in the flooded system has to serve three functions

1. **To separate liquid from vapour coming from expansion device**
2. **To absorb changes in the volume due to load fluctuations and due to sudden variation in suction pressures.**
3. **To ensure liquid mist or fine droplets are not carried back to compressor**

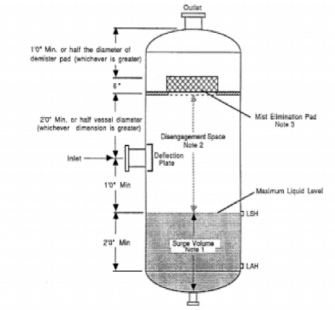
Accumulator sizing

3.There are two forces acting on the liquid droplet-one is gravity pull and other is compressor suction pull.

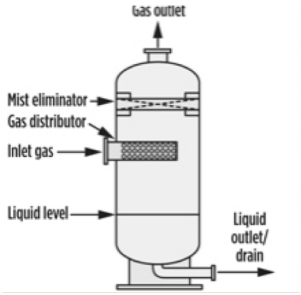
4. Many times if the accumulator design is done on the basis of calculation of droplet size and separation velocity the diameter calculated works out to be quite small, but one must also consider the liquid volume stored in the air cooler which is likely to enter the accumulator if the suction pressure drops suddenly due to load fluctuations. It is therefore essential to accommodate entire internal volume of liquid in the accumulator design over the normal liquid level and hence the diameter or height has to be increased accordingly.

5. Because the static head of the liquid leg results in a higher pressure at the bottom of the leg, the evaporating temperature is higher at the lower section of the evaporator, which reduces heat transfer rate. In low temperature evaporators it becomes more crucial to keep the static head at a minimum.

Knock out drum design



8. Knock out drum-arrangement



KNOCK OUT DRUM/SUCTION TRAP

KNOCK OUT DRUM DESIGN BASICS

1. Surge drum volume is determined by the maximum potential liquid loading and the amount of fill time desired from the high level alarm(LAH) and high level shut down(LSH).
2. Compressor K.O. Pots are recommended to have minimum 5 minute fill time. The distance between maximum liquid level & the inlet pipe is recommended to be minimum 1ft. To minimize splashing and liquid surge.
3. The distance required from disengaging the liquid from gas is determined by the particle size and terminal velocity. 'K' value of 0.15 to 0.17 at a disengagement distance of 24" provides adequate separation for basic gravity separation that do not have mist pads

Mist eliminators are however recommended for all K.O. drums. With mist eliminators the K value can be no more than 0.35 to control liquid carry over.

9.Oil Pot

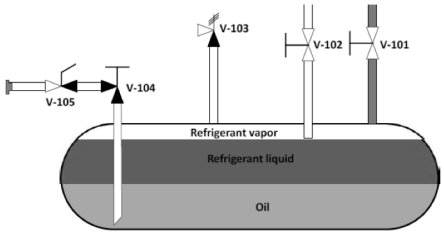


FIGURE 4: Oil pot details.

Various levels in Oil Pot

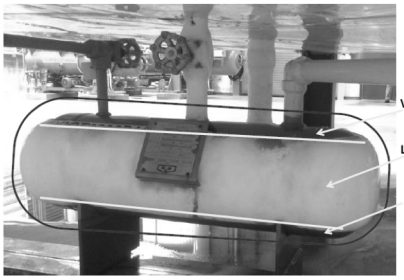


FIGURE 5: Various levels shown on an actual oil pot installed on a recirculator.

THANK YOU
Questions?

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