COLD STORAGE WAREHOUSE, USING DIRECT EXPANSION AMMONIA REFRIGERANT

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Abstract
This paper presents the design approach adopted for the expansion of a large existing cold storage complex served by a liquid recirculation ammonia refrigeration system. The expansion required the addition of new rooms equivalent to 130% of the volume of existing rooms, as well as providing a means where by the new rooms could be independently operated for either frozen or chilled product storage duty.

Project Description: - The completed complex comprised a total of two existing and three new –25ºC freezer storage rooms (approx 230,000m³) and an associated +4ºC stock transfer annex (approx 58,500m³). The ammonia refrigeration plant capacity is 1700kWR low stage and 2500kWR high stage.

Project Expansion: - Three new 43,000m³ freezer rooms were added, each serviced by two, direct expansion ammonia, air-cooling evaporators. Each is arranged for automatic ambient air defrosting.

Innovation: - The design encompasses the use of supply air duct systems with jet air diffusers; which enables the ammonia evaporators located in alcoves, to be isolated from the stored product in the room. The design had to allow each of the three rooms in the new extension to operate independently for either chilled storage +2ºC or freezer storage –25ºC duty. The objective of the design was to incorporate a direct expansion ammonia system, self draining oil return and ambient air defrosting.

Refrigerant Piping: - For chilled product duty either half of the evaporator capacity is switched off or all evaporators operate at lower temperature differences and fan speed, depending on the room usage plan. The room then operates via the high stage compressors, providing economical energy utilization. A common sub-cooled high pressure liquid feed supplies the evaporators, sseparate dry suction piping for chilled and freezer duty return to the compressors via a suction traps located in the plant room.

Introduction

The key points presented as considered for the system design are, room size and calculated heat load, evaporator design for two-temperature duty, air distribution within the room, ambient air defrosting arrangement and the ammonia system piping.

1. Room Dimensions and Heat Load.

Room	**L**	**W**	**H**	**CUM**	**KWR**
Existing	49	87	11.5	49,000	450
Existing	49	87	11.5	49,000	450
New	76	42	13.5	43,000	320
New	76	42	13.5	43,000	320
New	76	42	13.5	43,000	320
Total				227,000	1860
Annex A-B	128	16.5	11.5	24,300	227
Annex C-E	156	16.5	11.7	30,000	253

Figure 1 – Cold Store Extension, Melbourne Australia.

2. Previous Projects Using Direct Expansion Ammonia Refrigerant.

The concept of direct expansion ammonia for large size freezer and chilled product stores has been developed over several years and several projects. As a lead up to this project, design data from the following projects list items A through D was used. The topic project having three rooms for dual temperature operation is listed as items E and F and the loading annex as G.

Project	Date	Room Duty	Room Temp	Evap kW	Room Vol M3
A- One Room	1997	Freezer	-20ºC	300	18,200
B- One Room	2000	Freezer	-25ºC	366	24,000
C- One Room	2001	Freezer	-23ºC	450	34,000
D- One Room	2001	Chiller	+2ºC	600	50,000
E- Three Rooms	2004	Freezer	-25ºC	945	130,000
F- Three Rooms	2004	Chiller	+2ºC	800	130,000
G- Two Room	2004	Annex	+4ºC	450	54,300

3. Special Features.

The special features attributed to the design of the direct expansion ammonia refrigeration system for this project were: -

- The installation of large size horizontal, vertical airflow direct expansion design evaporators.
- Location of evaporators and fans in external alcoves, automatically isolatable from the storage space, in the event of detection of an ammonia leak.
- Supply air distribution in room via ducts and jet diffusers.
- Self-draining of refrigerant and oil from evaporator headers.
- Use of readily available refrigeration oils (non-miscible semi synthetic oil was used)
- Reverse flow automatic ambient air defrosting of evaporators.
- Extension of the existing liquid recirculation system to accommodate the direct expansion design.
- Conversion of the existing single stage economised system to a two-stage system for increased energy efficiency.
- Refrigerating of the freezer facility loading dock area, using direct expansion ammonia refrigerant.
- Variable speed evaporator fan motors arranged to reduce speed, power consumption and noise as the room set point temperature is reached.

Figure 2 – Freezer room during installation showing air distribution ducts.

Figure 3 – Loading dock operation, showing high speed insulated doors.

4. Project Overview.

The project was for the extension of an existing freezer storage complex. The original two freezer rooms each being 49,000 m³ were completed in 1999, serviced by a liquid recirculation ammonia plant with three economised single stage compressors. At this time the loading dock area was not refrigerated. The system design incorporated ambient air defrost evaporators two per room, each located in external alcoves with air distribution ducting.

The new project was to extend this system to cater for an additional three rooms each having a volume of 43,000 m³ as well as to refrigerate the loading dock adjoining the existing freezers and the new rooms; the total loading dock volume being 58,500 m³.

As the freezer complex is used for external clients the three new rooms had to be designed so that they could independently operate for either chilled product or frozen product storage. The overall dimensions of the completed refrigerated enclosure are approximately 400m long x 200m wide x 13.5m high. The refrigeration plant room is located at one end. During this extension the existing refrigeration plant and two freezer rooms had to be retained in operation.

The design concept developed to cater for the project requirements was to convert the existing plant to a two-stage system, by installing two low stage compressors and converting the three existing compressors for high stage duty. The existing low temperature accumulator and pumps were retained for the existing rooms, however the low temperature suction was interconnected to a new low temperature suction trap for the new rooms when operating on freezer duty. An intercooler was installed which also served as the liquid sub cooler vessel for the high pressure liquid supply to the new rooms, this vessel also acted as the chilled product duty suction trap serving the new rooms when operating on chilled product storage duty, and also as the suction trap for the loading dock units.

Each of the new rooms was fitted with two direct expansion ammonia evaporators. Two electronic expansion valves control the liquid supply to each evaporator. Each evaporator is connected with individual freezer and chiller duty dry suction lines. These are piped back to the plant room suction traps. With this arrangement the suction valving for either room can be manually changed between freezer and chiller duty to suit the room operating conditions. Sub cooled liquid supply from the plant high-pressure receiver, via the intercooler / sub-cooler is constant for either application.

Figure 4 – Dry suction and HP liquid piping at rear of freezer rooms and evaporator alcoves. Note: Alcoves form expansion loops for long low temperature pipe runs.

Figure 5 – Low temperature suction trap located in plant room.

5. Ammonia Piping Schematic.

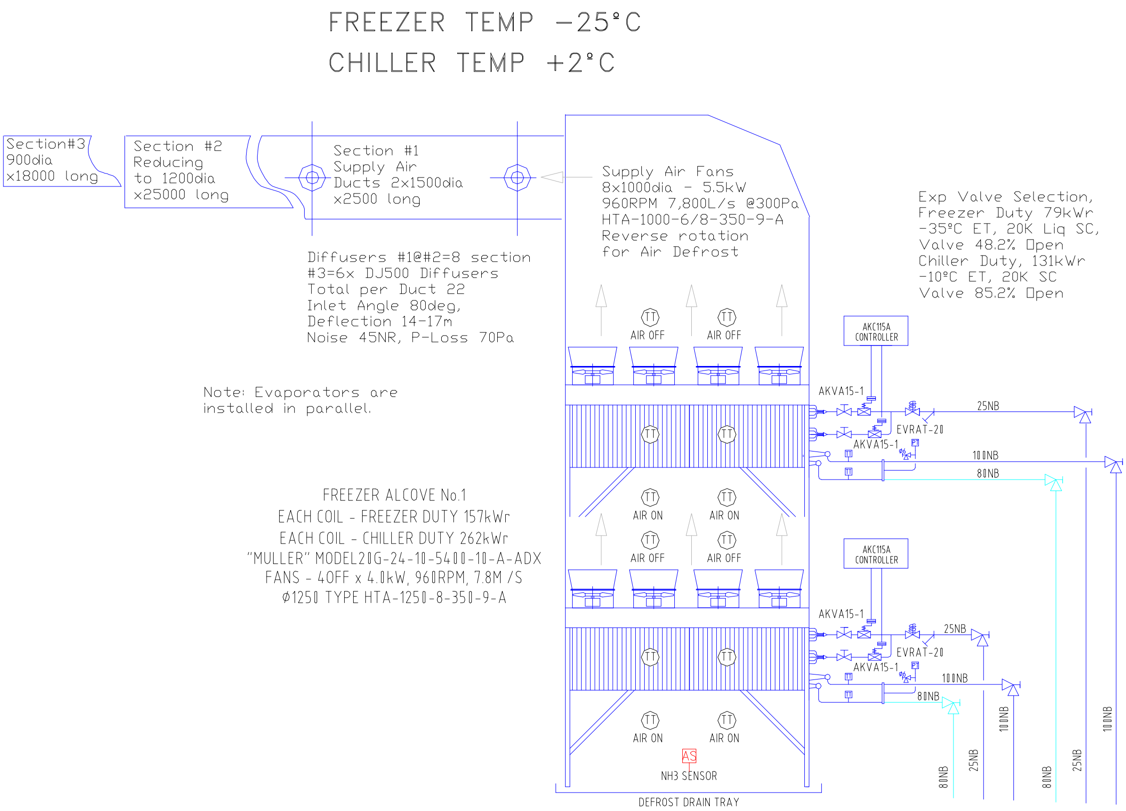

Figure – 6 Alcove air-cooling evaporator arrangement and piping.

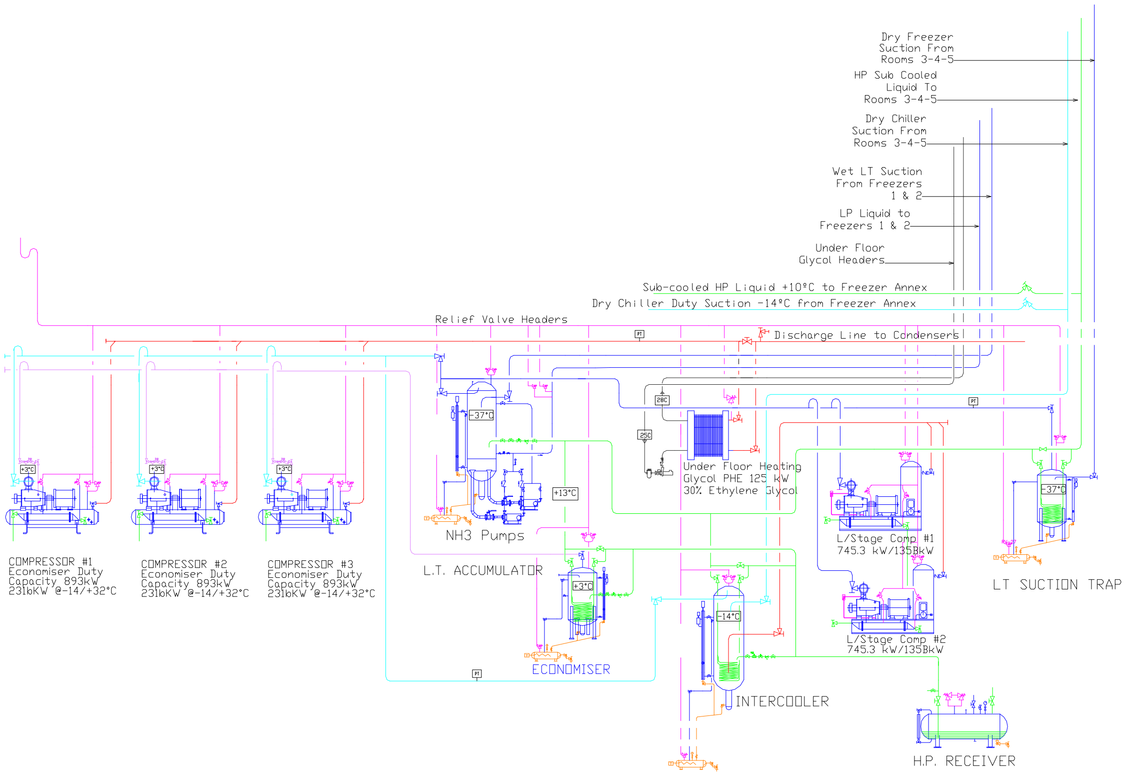

Figure – 7 Plant room main ammonia piping

6. Evaporator Design.

The following table summarises the evaporator design for freezer and chilling duty. Two evaporators
were installed in each alcove, each having two electronic expansion valves.

Coil Design	**Units**	**Freezer Duty**	**Chilling Duty**
Air On Data			
Air Temperature	ºC	-25	2
Relative Humidity	%	80	80
Absolute Moisture Content	g/kg	0.31	3.49
Coil Face Velocity	m/s	4.0	4.0
Air Flow	m^3/s	31.1	31.1
Air Off Data			
Air Temperature	ºC	-28.3	-2.6
Air Temp - Diffusion	ºC	3.3	4.6
Relative Humidity	%	91	91
Absolute Moisture Content	g/kg	0.25	2.75
Capacities			
Total Cooling Capacity	kW	157.7	262.2
Sensible Heat Capacity	kW	151.3	197.9
Refrigerant Pressure Drop	K	1.7	0.6
Heat Transfer Coefficient	$W/m^2.K$	27	35.7
Evaporating Temperature	ºC	-35	-10
Technical Data			
Total Surface Area	m^2	806.66	806.66
Internal Volume	m^3	0.36	0..36
No Tube Passes	Number	10	10

Tube Length	mm	5400	5400
No Rows High	Number	10	10
No Rows Deep	Number	24	24
No Tube Passes	Number	10	10
Fin Spacing	mm	10	10
Tube Diameter	mm	19	19
Tube Pitch	mm	60 x 60	60 x 60
Tube Geometry	type	Equilateral	Equilateral
Coil Construction	type	Galvanised	Galvanised

Figure 8 – Ammonia air-cooling evaporator Showing two liquid distributors and suction headers.

Figure 9 – Ammonia air-cooling evaporator under construction.

7. Ambient air defrosting.

The evaporators and fans are all contained in an external room alcove, which is fitted with two sets of vertical sliding doors each connected with cables. One set of 6600 wide x 18000 high doors is used for room cooling duty, i.e. one supply air door and one return air door. The other set of 4200 wide x 1800 high doors are used for defrosting duty, i.e. one supply air door and one exhaust air door.

The doors are connected by cables and driven by an electric winch. When on room cooling duty the room air doors are open and the defrost air doors closed. For defrost duty this is reversed as the room air doors close the defrost doors open. The fans then operate in reverse rotation drawing ambient air into the alcove chamber and exhausting it out the lower door aperture. When the fans run in reverse rotation the air quantity reduces by about one third, on this basis the defrost doors can be smaller. While the width is reduced the height has to be the same as the room air doors to match the cable movements and line up the doors to a fully open position when in cooling mode or fully closed position when in defrost mode.

Air Flow Design

Room Air	**l/s**	**Air Side PD - Pa**	**Velocity m/s**
Evaporators x 2	62,200	76	4.0
Door Aperture	62,200	10	6.5
Supply Ducts - A	62,200	42	17.6
Supply Ducts - B	19,200	51	17.0
Supply Ducts - C	7,200	26	11.3
Supply Diffusers	1,500	70	7.5

System Losses		25	
Total Supply Air		300	
Room Air Circ Rate			5.2 per hour
Defrost Air			
Evaporators x 2	40,000		2.6
Door Aperture	40,000		6.5

Figure 10 – Section alcove room air and defrost airflow

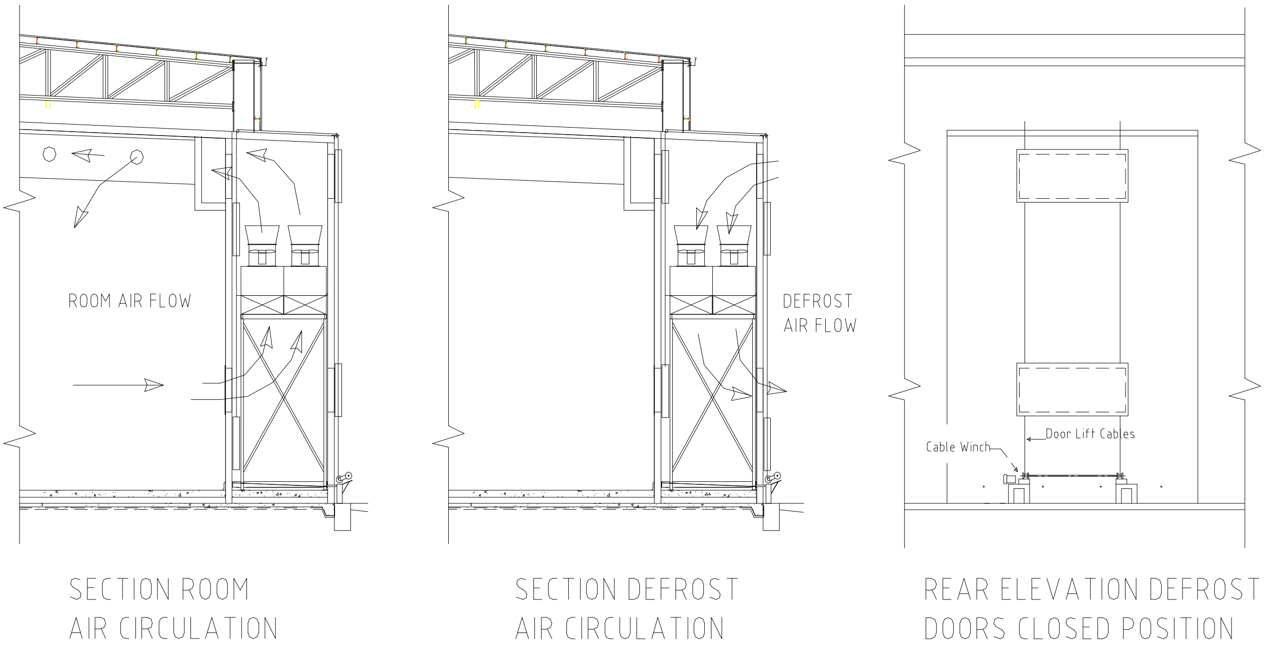

Figure 11 – Room return air aperture and supply air ducting, shown during construction. Racking not yet installed.

Figure 12 – External view of alcove showing defrost doors in the closed position, with personal access door at side.

8. Advantages and Disadvantages

Ambient Air Defrost Method.

The following table highlights the main advantages and disadvantages associated with the ambient air defrosting method described.

Advantages	Disadvantages
Ammonia system, evaporators, piping, valves etc. These can be isolated from the refrigerated space minimising the risk of product contamination due to an ammonia leak.	Site restrictions. Setback from boundary or other buildings necessary for defrost air relief, also the evaporator has to be adjacent to an external wall.
Refrigeration plant less expensive to construct, no hot gas valves controls etc.	Building costs higher as external alcoves have to be constructed. Requires designing alcoves into building layout from beginning.
Less refrigeration plant maintenance, no hot gas valves.	Door seals and cable linkages have to be maintained.
Maintenance of fans valves etc. This can be carried out at ambient conditions.	Security issues if personnel barriers are not fitted as product can be removed via alcove doors by thieves
Defrost doors can be automated on demand or arranged for manual activation.	Additional cost required for fan reverse rotation control.
The warmer the day, the faster the defrost coinciding with the room load demands.	System can only be effective if ambient conditions are more than 0ºC.
Defrosting does not consume any water.	Defrosting times will vary, dependant on ambient conditions.

9. Advantages and Disadvantages

Direct Expansion Ammonia Air Cooling Evaporators.

The following table highlights the main advantages and disadvantages associated with the direct expansion ammonia refrigeration system and installation as described.

Advantages	Disadvantages
Less expensive to install, one HP liquid line served both low temperature and chilled temperature rooms.	Plant room control more critical, the low pressure and high-pressure compressor operation has to be more consistent to provide stable expansion valve operation.
Easy room duty change over only dry suction line valves to be changes and set points between freezer and chilled temperature room duty.	Commissioning and setting up of electronic valve controls requires a skill level higher than that for the traditional ammonia LR plant.
Reduced refrigerant charge when compared to conventional liquid recirculation overfeed system.	Evaporator circuit design is more critical than traditional ammonia liquid recirculation design.
Reduced service and maintenance, no ammonia pumps and vessel level control valves.	Low temperature plant has to operate at slightly lower suction temperatures 3-5K. This is necessary to compensate for superheat control to achieve the same results at liquid recirculation system, resulting in less energy efficient operation.

	Electronic expansion valves require regular maintenance and cleaning of strainers, valves available are not tolerant of foreign mater as found in many ammonia systems.
	When compared to liquid recirculation systems, direct expansion evaporators require additional coil surface area to compensate for the valve superheat and reduced coil heat transfer coefficient.

10. Conclusion.

This paper describes the design information developed and operating experience gained from the construction of several direct expansion ammonia cold storage systems. From the experience gained from these projects, we conclude that the application of direct expansion ammonia refrigerant for large volume freezer and chilled product storage room applications is practical, achievable and can be successful.

We also conclude that the main advantage of the direct expansion system in comparison to a traditional liquid recirculation ammonia system arranged for the same application is the reduction of refrigerant charge within the system. Our view is that the savings gained from the omission of ammonia pumps and larger liquid supply piping, is off set by the valve and control system costs as well as additional commissioning time required to achieve the optimal system operation.

With respect to ongoing maintenance costs, our experience to date also shows the costs for maintaining the direct expansion valves will be greater than the ongoing costs of maintaining modern liquid ammonia pumps.

In Australia there are no regulations restricting the amount of ammonia charged in refrigeration plants. The reasons direct expansion systems have been applied on the projects described have been to satisfy customer requests based on less ammonia charge less risk to personnel, as well as the duty changeover flexibility as described in this paper.

Reference:

1. ISECO *Direct Expansion Cold Storage*, Construction and installation projects A-D section 2
2. AIRAH Handbook, 2000, Section 4 *Air Distribution systems*.
3. ASHRAE Refrigeration Handbook, 1994, *Separation Velocities Steady Flow Conditions*.