Ammonia in traditional HFC territory – Part 2

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5. QUANTIFIABLE PENALTIES ASSOCIATED WITH NH_3

It is a common generalisation that ammonia plants are more maintenance-intensive than HFC systems. These generalisations often originate from proponents of synthetic refrigerants. Traditionally, ammonia has not been used extensively in small systems similar to those described here. In addition, ammonia plants are often also subjected to strict maintenance regimes due to the properties of the fluid. Thirdly, there is of course a return associated with spending money on good maintenance – this in part explains the much lower refrigerant leakage rates of NH_3 plants compared with HFC systems.

It is therefore relatively difficult to verify such generalisations in relation to maintenance costs on the basis of practical experience. Most competent ammonia practitioners will most likely be sufficiently commercially courageous to offer five years warranty on the refrigerant charge, provided the prescribed maintenance regime is complied with. Although this is far from common practice, it is proposed as a relatively low-risk way (for the contractor) of providing an additional competitive advantage over proponents of less capital-cost-intensive HFC systems. It is unlikely that providers of HFC systems are in a position to match this.

The lack of miscibility between traditional refrigeration machine oils and ammonia is, however, an issue if ammonia is to compete with HFCs in small to medium-size systems such as those described here. Owners and operators of such systems do generally not have full-time maintenance staff employed, and regular oil drainage is therefore a significant operational cost.

Figure 3 shows an automatic oil drainage and distribution system for the small dual-stage ammonia refrigeration plant, with five compressors servicing the facility shown in plan view in Appendix 1, figure 4.

Based on experience to date, this system can extend the time intervals between service visits to three months. During normal operation solenoid valve #1 that supplies hot gas to the oil transfer vessel ODV 1:1 is closed. The same applies to solenoid valve #2, which transfers oil from the oil- transfer vessel back to the second-stage compressor oil separator. The ball valve #3 and the solenoid valve #4 are both open during normal operation. This permits refrigerant circulation through the oil drain vessel by means of the thermosyphon effect.

The automatic oil transfer is initiated by means of a temperature sensor in the top of the oil transfer vessel. Oil transfer occurs by closing ball valve #3, initiating and maintaining oil transfer vessel electric heater operation until all refrigerant is vapourised and returned to the intercooler (timer- controlled), closing solenoid valve #4, closing solenoid valve#5, opening solenoid valve #1 and opening solenoid valve #2.

During oil transfer from the oil transfer vessel to the second-stage compressor oil separator, a differential pressure regulator in the second-stage compressor discharge line (not shown) establishes a small differential pressure between the oil drain vessel and the second-stage oil separator. Transfer of oil from the second-stage compressor oil separator to the booster oil separator is initiated by means of a level sensor in the booster oil separator.

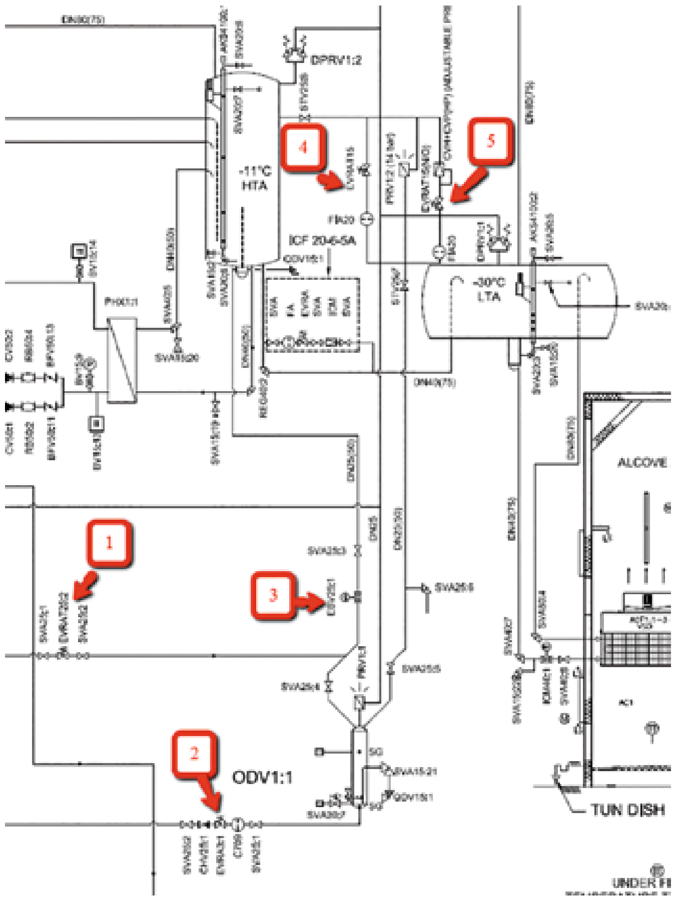

Figure 3: Automatic oil return system.

To minimise refrigeration system energy consumption in most Australian jurisdictions, it is necessary to substitute air-cooled condensers with either water-cooled condensers, evaporative condensers or air-cooled condensers with adiabatic assistance. The water consumption associated with the application of any of these evaporative devices represents an additional operating cost, which partly offsets the energy cost savings.

Following the 10-year drought between 2000 and 2010 and escalations in water costs, it has become common practice to collect rainwater from the roof of refrigerated distribution facilities. In the bottom left-hand corner of Figure 4, an example of these collection and storage systems are shown.

Usually a rainwater storage capacity of four to six weeks evaporative condenser water consumption delivers a reasonable return of tank capital costs in the eastern jurisdictions of the Australian mainland. Areas with longer periods between rainfalls may well justify larger tank storage capacities.

The supply of rain water to the evaporative condenser has priority over the supply of mains water. This is controlled very simply with two automatic ball float valves fitted within the condenser sump. If the top rainwater float fails to supply sufficient water because the rainwater tank is empty, then the bottom float valve supplying mains water will start to make up water as soon as the condenser water level has dropped to the level where this second ball float is fitted.

Figure 4: Rainwater storage tank for evaporative condenser make-up water.

6. PRACTICAL ENERGY PERFORMANCE COMPARISONS

The main focus of any plant owner is verification that the refrigeration system energy consumption that was evaluated theoretically at project commencement is delivered at project conclusion. Table 7 summarises the energy performance comparisons for the four refrigeration systems. For the four systems that are the topic of this paper, two plants enable a "before" and "after" comparison based on electricity meter readings. Both of these systems are described in segment 2 of Table 2 (See June 2014 Ecolibrium).

In the case of the Tweed Heads facility, the plant was, prior to the expansion, serviced by an HFC system. Electricity consumption records exist for the relevant periods immediately prior to the plant expansion and conversion from an HFC to an NH_3 based refrigeration plant. These electricity records are reproduced in Figure 5.

Segment	1		2	
Geographic location →	Brisbane	Mackay	Tweed Heads	Sydney
HFC, annual estimated energy consumption, [MWh]	1248	1200	N/A	881
NH3, annual estimated energy consumption, [MWh]	635	700	N/A	546
HFC, annual measured energy consumption, [MWh]	N/A	N/A	1197	1265
NH3, annual measured energy consumption, [MWh]	611	735	718	579

Table 7: Energy performance comparisons for four plants.

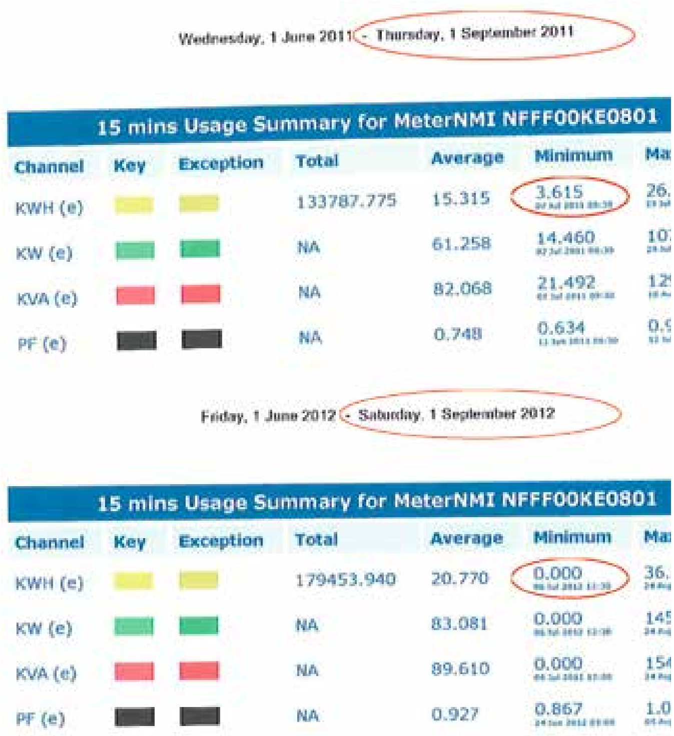

Figure 5: Electrical energy consumption records for Tweed Heads.

The Tweed Heads plant expansion increased the refrigerated volume by a factor of around 2.1 with the freezer store volume being tripled, and the medium temperature volume being increased by a factor of ~1.25.

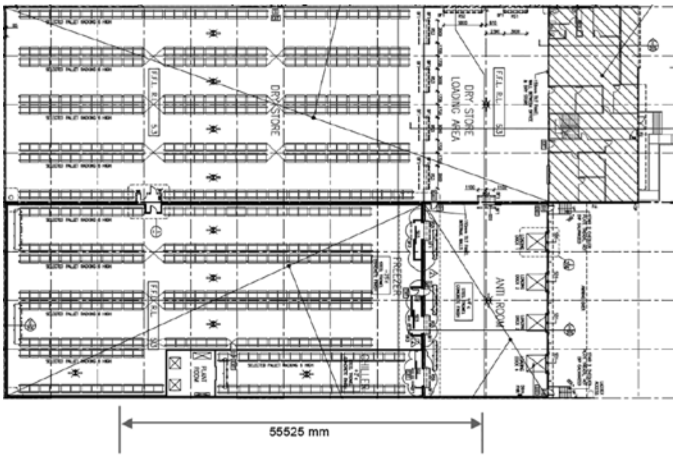

Figure 6: Cold store identical to the Sydney facility, but serviced by an HFC plant.

The Sydney facility owner has another very similar facility elsewhere that is serviced by an HFC-based system of conventional design generally in line with concept "C" in Table 6. This HFC-based cold store is shown in plan view in Figure 6.

For the Tweed Heads facility, the measured annual electricity consumption is calculated on the basis of the electricity consumption records prior to the plant expansion and conversion to NH_3. These records were for a freezer design heat load of around 32kW and medium-temperature rooms with combined design loads of 42kW. The quarterly electricity consumption of 135MWh (Figure 5) is simply allocated to freezer and medium-temperature duties on the basis of loads and system coefficients of performance, which are 0.90 and 1.45 for the freezer and the medium-temperature segments, respectively.

The refrigerated volumes prior to the extension were approximately 1400/1400m³ for freezer/medium-temperature segments, respectively.

The annual electrical energy allocations for the freezer and medium temperature segments hence become:

135 x 4/(32/0.90 + 42/1.45) x 32/0.90 = 298MWh (freezer duty)

135 x 4/(32/0.90 + 42/1.45) x 42/1.45 = 242MWh (medium temperature duty)

Increasing the medium-temperature volume by a factor of 1.25 and tripling the freezer volume would therefore, if the existing HFC systems had been simply added to, have given rise to an approximate annual electricity consumption of:

242 x 1.25 + 298 x 3 = 1197MWh

This is the value inserted in Table 7 under the heading "measured annual HFC system energy consumption". The annual measured NH_3 system energy consumption for comparison is derived from Figure 5 by multiplying the quarterly record of 179.5MWh by four.

The annual measured HFC system energy consumption for the Sydney facility is based on the electricity consumption records for the cold store shown in Figure 6 corrected for the difference in floor area.

For the period June 1, 2011 to June 30, 2011, the electrical energy consumption was 115.2MWh; for July 1, 2011 to July 31, 2011, the consumption was 116.1MWh and for August 1, 2011 to August 31, 2011, the consumption was 121.8MWh – the total consumption for that quarter was therefore 353MWh. Annualising these results and allowing a 5% per month increase for September to November 2011 (spring approaching summer) yields:

(115.2 + 116.1 + 121.8 + 127 + 133 + 139 x 4 + 133 + 127 + 122)/1385 x 1130 = 1265MWh.

The measured annual NH_3 system energy consumption for the Sydney system is based on electricity consumption records for November 2012. The plant was commissioned end of August 2012. Figure 7 shows electricity records from August 2012 to March 2013.

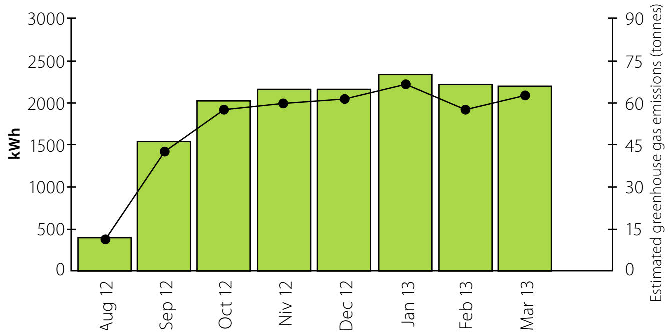

Figure 7: Electricity consumption records for Sydney system.

7. FINANCIAL CONSIDERATIONS

For medium to large refrigeration plants it is, to a great extent, superfluous to attempt to convince any user to favour ammonia refrigerant – in most cases one would be preaching to the converted. In that area of application, ammonia has a proven track record of being able to deliver safe, efficient, reliable and long-lasting service. In the small-to-medium capacity plant categories that are the topic of this paper, the use of ammonia needs to be "sold" to a much greater extent. This is because this area up until now to a very great extent has been reserved for HFC-based plants. The most prominent argument to be presented to users that may be novices to the introduction of ammonia within their facility is financial. An example of a financial argument is presented in Table 8, which applies to the Sydney installation. The table reflects year 2010 price levels.

The annual average refrigerant loss for the HFC plant of 16% is empirically based for plants servicing refrigerated warehouse facilities. Supermarket systems, which are similar in refrigeration capacity to the systems that are described in this paper, feature losses of up to one-third of the total charge annually. Fully sealed systems such as household refrigerators have much lower losses of <1% annually; all these system losses combine and result in the annual average service rate of 9% nominated in chapter 4.

The difference in annual operating costs of approximately $85,000 is the annual income change that must provide the return on the differential investment between the HFC and the NH_3 based system. In 2010 price levels that differential investment is $323,300; this delivers a simple pay-back period for the differential investment of 323,300/85,000 = 3.8 years.

Refrigerant	NH_3	HFC
Total engine room shaft power, [kW]	114.2	264.2
Comparison of annual energy consumption:		
Annual engine room energy consumption, [MWh/a]	546	881
Power factor	0.85	0.85
Electric motor efficiency	0.85	0.85
Unit electrical energy costs, [$/MWh]	150	150
Annual electricity costs, [$/a]	113,314	182,953
Comparison of annual electrical emission costs:		
CO_2 emission per kWh, [kg/kWh]	1.1	1.1
Annual CO_2 emission, [metric tons/a]	706	1140
Carbon Tax charge, [$/t of CO_2e] (1.7.2012-30.6.2013)	23	23
Annual emission penalty post 1.7.2012, [$]	16,245	26,229
Annual energy costs including emission penalties post July 1, 2012, [$]	129,560	209,182
Refrigerant loss comparison:		
Approximate system charge(s), [kg]	500	500
Annual average loss, [%/a]	1	16
Annual loss, [kg/a]	5	80
Global Warming Potential of refrigerant (GWP)	0	3300
Unit refrigerant costs post July 1, 2012 (CO_2e cost $23/t), [$/kg]	7	101
Annual refrigerant loss costs, [$/a]	35	8,072
Annual water treatment costs, [$]	3,000	0
Total annual operating costs excl. maintenance and water costs, [$]	132,595	217,254

Table 8: Financial comparison between HFC and NH_3 for Sydney installation.

The financial viability of all four systems based on the value of the electrical energy savings associated with switching to ammonia refrigerant is summarised in Table 9. These simple pay-back periods are to be considered in conjunction with the simultaneous mitigation of the commercial risks associated with HFC losses that an ammonia alternative offers the plant owner.

Following the introduction of the carbon-equivalent HFC levy such commercial risks are significant, and in some cases bordering on extreme depending on the HFC refrigerant in question. For the plant sizes discussed in this paper, the HFC charges would have ranged from ~400 to ~600kg. At the current unit list price for HFC 404A in Australia of approximately $373/kg, a catastrophic loss of charge could cost the plant owner $149,000 to $224,000. Considering contractor discounting and common supply chain margins, the cost of a catastrophic loss of charge could reduce to $80,000 to $120,000, but this remains a very considerable commercial risk. A decision in favour of an ammonia alternative builds in an insurance against this commercial risk, and this has a tendency to encourage decision makers to accept longer pay-back times than would otherwise have been the case.

The unit electricity cost used is $150/MWh. The additional cost of a dual-stage ammonia plant over and above the equivalent single-stage, economised HFC-based refrigeration system is in 1000s of dollars. All cost comparisons have been brought forward to the month of September in the 2012 calendar year by applying a CPI (Consumer Price Index) of 3.5% per annum from the time of the cost estimate to September 2012. In those cases where measured energy consumption cost reductions are not available, the simple pay-back period calculation has been based on estimated energy consumption cost reductions using the methodology described in Appendix 2.

Segment	1		2	
Geographic location →	Brisbane	Mackay	Tweed Heads	Sydney
Differential capital cost between the NH_3 and the HFC system (+ represents a more expensive NH_3 system), [$/1000]	+499	+454	+264	+311
Approximate value of the measured energy consumption cost reduction associated with NH_3 (- represents energy saving associated with NH_3), [$/1000]	-92	-70	-72	-50
Simple pay-back period for the differential capital cost of the NH_3 system based on energy consumption cost reductions only, [Years]	5.4	6.5	3.7	6.2

Table 9: Simple pay-back period for the additional NH3 system capital cost based on energy- consumption cost reductions.

APPENDIX 2

					Energy consumption					
Heat load type →					Peak		Shoulder		Minimum	
Hours at prevailing load →					1920		3840		3000	
Temperature level (LT = Low Temperature; HT = High Temperature)					LT	HT	LT	HT	LT	HT
Heat loads [kW] →					121.7	160.1	67.4	59.6	50	40
Heat loads [TR] →					34.7	45.6	19.2	17.0	14.2	11.4
Location	**No. of drives**	**Drive motors**	**Drives installed**	**Nominal power consump-tion**						
		[kW]	[kW]	[kW]	13.0		0		0	
Booster #2 (dual duty)	1	75.0	75.0	10.5	8.5		12.0		9.0	
Compressor #1 (dual duty)	1	90.0	90.0	51.3		42.8		34.7		23.7
Compressor #2	1	45.0	45.0	39.2		38.2		0		0
Evaporative condenser:										
Fan	1	5.5	5.5	5.5		5.5		2.29		1.62
Spray Pump (duty)	1	1.5	1.5	1.5		1.5		1.5		1.5
Ammonia pumps (LT)	2	2.2	4.4	2.2		2.2		2.2		2.2
Ammonia pumps (HT)	2	4.0	8.0	4.0		4.0		4.0		4.0
Freezer evaporator fans	4	3.0	12.0	11.0		8.28		1.40		0.57
Chiller air cooler fan	1	1.4	1.4	1.4		1.15		0.30		0.05
Banana Room air cooler fan	1	1.4	1.4	1.4		1.15		0.06		0.02
Ante Room 1 fan	1	0.9	0.9	0.9		0.82		0.65		0.46
Ante Room 2 fan	1	1.4	1.4	1.4		1.31		0.59		0.43
Subfloor ventilation fan	1	4.0	4.0	4.0		2.0		2.0		2.0
Engine room exhaust fans	2	2.2	4.4	4.4		2.2		1.1		0.88
TOTAL	21		273.4	151.7	21.5 111.1		12	50.8	9	37.4
Electric power drawn, [kW]					132.6		62.8		46.4	
Electrical energy consumption (power drawn x hours), [kWh]					254606		241073		139287	634966
Specific electrical energy consumption [kWh/m³a]										25.3
Annual electricity cost assuming power factor 0.85, electric motor efficiency 0.85 and $0.15/kWh										$131,827

8. DISCUSSION

In a society of rising energy costs, ammonia solutions in the small-to-medium refrigeration capacity range from around 140kW to 300kW present themselves as economically very viable. This statement is based on a unit electricity cost of $150/MWh, actual system capital costs and actual energy consumption costs for small-to-medium size commercial cold storage applications.

For various reasons, ammonia refrigeration systems have not been very common in this capacity/plant size range. Some of these reasons are relative insignificance of energy costs to date; prominence of synthetic refrigerant proponents in this market segment, proliferation of standard HFC-based solutions, natural refrigerant skills shortages, lack of unbiased information for users, government red tape and psychological barriers. The energy performances of ammonia solutions, however, speak for themselves.

It is, of course, a business reality that higher capital cost solutions are not always affordable. However, if governments in many jurisdictions are under pressure to address global warming issues and the conservation of energy is part of addressing this problem, then the next logical step for legislators is to do what is necessary to simplify the implementation of natural refrigerant solutions.

Synthetic HFC refrigerants are powerful contributors to future climate forcing [1]. Owners and operators of refrigerated facilities may not agree that man-made global warming is an issue and may indeed adopt the stance that it is not an issue for them or for the role of their business in society. The introduction of a carbon-equivalent levy on HFC refrigerants in Australia is, however, a prime example of how political reality can force the hands of owner/operators and drive change.

Carbon taxes, which are or will be a prominent feature in many economies world-wide, will impact upon electricity prices. The carbon tax, which is now a reality, increases the unit electricity cost by around $0.025 per kWh. Ammonia solutions have the capacity to address both the issue of fugitive emissions (refrigerant leaks) from refrigeration systems and indirect emissions that are a result of the consumption of electrical energy by refrigeration systems. Ammonia is not subject to any environmental levies. Ammonia has a superior vapour-compression cycle efficiency to synthetic refrigerants. Ammonia is therefore part of the solution to the problems faced by many legislators in many jurisdictions.

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