Evaluation of the environmentally friendly refrigerant ammonia according to the TEWI concept

“The combination of a unique level of temperature increase in the late 20th century and improved constraints on the role of variability provides further evidence that the greenhouse effect has already established itself above the level of natural variability in the climate system. A 21st-century global warming projection far exceeds the natural variability of the past 1000 years and is greater than the best estimate of global temperature change for the last interglacial period.” [1]

There is strong evidence that human emissions of greenhouse gases are changing the world's climate, and that is why climate change is one of the most important issues facing mankind today. The largest contributor to the problem is carbon dioxide (CO_2), produced when we burn fossil fuels like coal, oil and gas for energy generation. Considering that developed countries use approximately a sixth of their total electricity supply for refrigeration and air conditioning [2], there are a number of challenges presented to this industry:

- Increasing the energy efficiency of cooling systems to reduce the amount of greenhouse gases produced by energy generation.
- Reducing the direct emissions of high global warming potential (GWP) refrigerants through improved service practices and better system integrity in the design and manufacture of refrigeration and air conditioning systems using refrigerants with high global warming potential or the use of alternatives with low global warming potential.
- Avoidance of further depletion of the stratospheric ozone layer by globally eliminating the use of refrigerants with ozone depleting potential (ODP).

The final point is already being addressed through the incremental phase-out outlined in the Montreal Protocol, whereas the first two points are only beginning to be tackled through the Kyoto Protocol and supporting national legislation. It is widely accepted that, on average, 20% of the global warming impact of RAC systems can be attributed to direct emissions of F-gases, with the remaining 80% a result of energy consumption and the associated indirect emissions.[2] These are the two areas that are considered in the most popular approach to the assessment and comparison of cooling systems: the **T**otal **E**quivalent **W**arming **I**mpact, or **T**EWI. Whilst there are additional amounts of energy used in the fabrication, installation and decommissioning of cooling systems, and these may be taken into account through more complex **L**ife **C**ycle **Cl**imate **P**erformance (LCCP) analyses, their relative weighting in comparison to direct and indirect emissions is often negligible.

Although the TEWI calculation centres on one simple equation, the result is dependent on a number of assumptions about equipment performance and load profiles, leakage rates, refrigerant properties and electricity generation efficiencies, i.e. specific CO_2 emissions per kWh. For this reason the calculation needs to be guided by supporting documentation.[3] As the outcome of the analysis is a numerical value, it must also be stressed that the results of two or more systems are only comparable when the refrigeration capacity, function and seasonal use are similar.

In broad terms, the factor that has the greatest influence on the outcome of a TEWI calculatin is the relative energy efficiencies of the various systems. A refrigeration system possessing inherently efficient design features such as:

- A refrigerant with good exergetic efficiency
- A compressor with good efficiency at full- and part-load (through techniques such as the use of variable speed drives)
- Evaporator and condenser with low approach temperatures
- Floating head (condenser) pressure to minimise compressor at low ambient temperatures and under part-load conditions

will display a far higher coefficient of system performance (COP) than, for example, a system with artificially inflated head pressure or undersized evaporators and condensers. Although these provide initial cost savings, they result in higher condensing temperatures and lower evaporating temperatures and thus to increased energy consumption – for every K of increased condensing and evaporating temperature, the energy consumption of a refrigeration system increases by around two to three per cent. A similar scenario applies to systems where over-sizing or the inefficient control of processes result in compressors operating at part-load for extended periods.

The refrigerant influences the energy efficiency of the refrigeration system. The thermodynamic properties define the size of the compressor and the associated losses, which also contribute to the total power demand of the refrigeration system. The refrigerant has an effect on the temperature differences necessary for transmitting heat in heat exchangers as well as the power demand for the auxiliary drives like pumps and fans.

Under equal conditions, vapour-compression systems designed to operate with ammonia will excel in reducing indirect emissions (i.e. CO_2 due to energy generation). Ammonia possesses a tremendously high latent heat and therefore a far lower refrigerant mass flow rate is required to service a given heat load when compared to synthetic refrigerants. In addition, ammonia has better heat transfer during evaporation and condensation in relation to synthetics. Ammonia is very economic over its whole operating range (−40°C to +40°C).This reduces the amount of energy consumed by the refrigeration system needs.

Three liquid chilling units with different refrigerants and 300 kW full-load refrigeration capacity were assessed using the seasonal energy performance ratio (SEPR), a seasonal energy KPI. SEPR is calculated from the total refrigeration demand divided by the total electrical energy demand of a year. Details of the annual temperature curve and the load profile of a year, which is dependent on outside temperatures, have been taken together and following the corresponding calculation method from Commission Regulation (EU) 2015/1095 [4] on process chillers for medium-temperature (MT) applications, i.e. for a brine outlet temperature of −8°C at the evaporator.

TEWI is expressed in kilograms CO_2 equivalent. This figure includes the complete life cycle of a refrigeration system through to recycling.

TEWI encompasses the sum of the direct global warming potential of refrigerants emitted into the atmosphere throughout the life cycle of the refrigeration system, and the indirect global warming potential caused as a consequence of transforming fossil fuels into electrical energy to operate the system.

TEWI is calculated as defined by (3) using the following equation:

$\text{TEWI} = \text{GWP} \times L \times n + [\text{GWP} \times m \times (1-\alpha_R)] + n \times E\text{a} \times \beta$

The direct global warming potential results from leaks during the life cycle

$\text{GWP} \times \text{L} \times \text{n}$

and from refrigerant losses when recycling the refrigeration system.

$\text{GWP} \times m \times (1-\alpha_R)$

where:

- *GWP* is the global warming potential of the refrigerant in kg CO_2 equivalent per kg refrigerant
- *L* is leaks in kg per year
- *n* is the number of operating years in a life cycle
- *m* is the refrigerant charge in kg
- α_R is the recovery rate on decommissioning

The indirect global warming potential, referred to in the table as GWP_E , is expressed as $n \times Ea \times \beta$,

whereby:

- E_{al} is the energy demand required to operate the refrigeration system in kWh per year
- β is the conversion factor for converting energy into kg CO_2 per kWh

Table: Annual energy demand E_a, seasonal energy efficiency SEPR for ammonia, GWP of the respective refrigerant and TEWI in tonnes CO_2 equivalent for 12 years of use

Refrigerant	SEPR/ $SEPR_{ammonia}$	Compressor type	E_a [kWh]	GWP (AR4)	GWP_E [t CO_2]	TEWI [t CO_2]
Ammonia	100%	Screw	612,400	0	2,940	2,940
R410A	90%	Scroll	683,600	2088	3,281	3,354
R407F	91%	Reciprocating	673,400	1825	3,332	3,312

The comparison was based on types of compressor typically used for the respective refrigerant for 300 kW refrigeration capacity.

The TEWI was calculated with the following values:

m = 120 kg for R407F, m = 150 kg for R410A
n=12
$\alpha_R = 0.95$
L=2%
The VDKF (Association of the German Refrigeration and Air Conditioning Industry) states an annual refrigerant loss of just about 3 per cent.[5]
Conversion factor α=0.40.

Ammonia water chilling systems equipped with evaporative condensers or air-cooled condensers exploit ammonia’s huge evaporation enthalpy, i.e. for dissipating heat to the surroundings, as soon as the outside temperature makes this possible. Here the refrigerant circulates between evaporator and condenser using the heat pipe principle, without needing a compressor. This permits clear reductions in the annual energy demand.

Through its thermodynamic properties, ammonia provides the basis for energy-efficient refrigeration plants and, in contrast to synthetic refrigerants, has no direct GWP. Ammonia therefore has a distinct advantage that becomes apparent in the calculation of the TEWI. Whilst leakages of ammonia should be avoided for safety reasons, any emissions that do occur will not contribute to global warming. In addition, due to the high warning effect of ammonia, leakages can be detected and eliminated quickly, thereby minimising the risk of a system running at less than peak efficiency due to low refrigerant charge.

In comparison, the TEWI figure for a system charged with a synthetic refrigerant will, in most cases, be significantly higher. Besides the fact that their indirect emissions due to energy provision are usually higher than those of an ammonia system due to generally lower energy efficiency, even moderate leakage rates contribute considerably to the direct emissions owing to the comparatively high specific GWP of synthetic refrigerants. For example, 1 kg of R404A has the equivalent GWP of 3,922 kg of CO_2 (IPCC IV). Another point to consider is that most (if not all) synthetic refrigerants are odourless and colourless and therefore a large proportion of the system charge might be lost before the operator or maintenance company becomes aware of low levels or declining system performance. It is therefore the aim of recent legislation such as the European F-Gas Regulation to mandate regular leak tests of refrigeration systems and the installation of permanent leak detection systems in the case of large refrigerant charges.

Ammonia is an excellent choice of refrigerant for many applications and its sphere of use has broadened considerably thanks to its excellent energy efficiency and negligible environmental impact. In addition, it is not subject to the uncertainty facing synthetic refrigerants of possible future legislation limiting or even banning its use, making it a future proof application. Key to its successful application has been improvements in component and system design and the appropriate application of safety measures, such as those outlined for ammonia in EN378. Such measures include the design for minimum (critical) charge, contained primary circuit servicing a distributed secondary fluid system, site-specific risk assessments and the provision of safety equipment and emergency procedures.

References

[1] Crowley, Thomas J.; “Causes of Climate Change Over the Past 1000 Years” *Science* 14 July 2000: Vol. 289. no. 5477, pp. 270–277.

[2] International Institute of Refrigeration (IIR) Statement: “Global warming: refrigeration-sector challenges”, Eleventh session of the Conference of the Parties (COP11), First session of the meeting of the Parties to the Kyoto Protocol (COP/MOP1), Montreal, Canada, November 28 – December 9, 2005.

[3] British Refrigeration Association (BRA): “Guideline Methods of Calculating TEWI, Issue 2 (2006)”.

[4] Commission Regulation (EU) 2015/1095 of 5 May 2015 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to Ecodesign requirements for professional refrigerated storage cabinets, blast cabinets, condensing units and process chillers

[5] Zaremski, Wolfgang, “Kältemittel-Emissionen aus deutschen Kälte- und Klimaanlagen” VDKF Information No. 9–10 September–October 2016, pp. 8–10

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