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Challenges of and Options for Refrigerant Selection

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Winner of the 2023 J & E Hall Gold Medal

Why you should attend

- Improve your knowledge of the future of refrigerant options
- Find out about the relative strengths and weakness of current refrigerants available
- Hear how end users are overcoming these barriers to successfully adopt low GWP alternative refrigerants safely

Abstract

Numerous viewpoints exist regarding suitable refrigerants for specific applications. Frequently, a solitary refrigerant hazard is selected, leading to the disqualification of the refrigerant. Nevertheless, utilising the refrigerant safely remains a viable option. Each refrigerant possesses its own set of strengths and weaknesses, requiring a thorough exploration of these aspects. In this paper, we will explain what it takes to overcome refrigerant weaknesses.

Hydrocarbons are some of the most used refrigerants in the industry and have been in constant use since the beginning of refrigeration because they were used by the petrochemical industry. Here they knew how to handle these fluids in a safe manner. Also, ammonia was adopted by the industry relatively early. A little later also CO_2 was introduced to the markets, however, CO_2 went out of use and the last traced installation was onboard a fishing vessel in 1955. Since then new plants were not installed before in the second half of the 1990s where CO_2 was promoted by amongst others Prof. Gustav Lorentzen from the Norwegian Technical University in Trondheim.

This paper describes how the working fluids can be utilised in a safe ways. The future is naturally occurring substances. Further, CO_2 and NH_3 are part of the human body – every human body release CO_2 in every breath and NH_3 is in our cells where it is a vital part of our organisms. We release about 17 gram of NH_3 per day on average. The systems discussed here are larger systems excluding residential and commercial systems placed in areas with no limitations of people e.g. supermarkets or restaurants.

1. Introduction

In discussions about future refrigerants, it is often claimed that this or that refrigerant has some disadvantages, but are these claims all true? That a refrigerant is flammable does not necessarily mean it is impossible to use, that it should be disqualified. In this paper, we will have a look at what it takes to overcome these minor challenges. It is not as difficult as some would like to point out. All working fluids have their strong and less strong sides, and this is the challenge that needs to be explained.

Flammability, toxicity, scarcity and rare earth products, global warming potential and formation of PFAS when breaking down in the atmosphere – all topics are used in different ways both as barriers and for scaring off their use. However, following the standards available will provide guidance through most issues where bans imposed by the surrounding reality, are the real limit that will affect the use of a given working fluid – also called refrigerants.

In this paper different barriers will be looked at and discussed – and solutions will be pointed out. Some prefer one solution over others and that is also OK, just know what you are doing and follow the law.

Currently, there is a significant focus on using non-fluorinated working fluids, which has been the preferred solution for many years up until the signature of the first Montreal Protocol agreement in 1987. The first focus was on phasing out the chlorinated fluids because they had a harmful effect on the ozone layer that protects life on Earth from the harmful ultraviolet (UV) light from the sun. When chlorofluorocarbons (CFC) and hydrochlorofluorocarbons (HCFC) became banned, the chemical industry quickly introduced new series of working fluids called hydrofluorocarbons (HFC). However, these fluids still had one disadvantage that also the earlier CFCs/HCFCs also had – a high global warming potential (GWP). Consequently the industry is now being forced into a new regime where the legislative force is on the GWP. At the same time, we now see a big push from another side effect of the breakdown in the atmosphere – the formation of long-lived per- and polyfluoroalkyls (PFAS). The issue here is that when the substances break down in the biosphere the break down will form some of the most stable molecules with no known natural breakdown path and with an expected life of not under 4999+ years. These substances are also very temperature resistant and can resist temperatures up to about 1300°C. Incinerators very often only burn waste at about 800°C, so when the smoke leaves the chimney the PFAS is effectively sent into the sky and when it comes down with the rain it does not discriminate between ecologically driven fields or conventional fields and beast. Humans all over the world already have smaller and larger amounts of these substances in our bodies. This is currently very much a topic that scares many citizens globally. The European Chemical Agency (ECHA) has opened a case in which 5 countries have asked for regulation of at least the most common of the 10.000+ known substances in question – among these also the latest un-saturated HFC substances named HFO in some standards like ISO 817 which is also used by other standards as reference.

The alternatives to fluorinated substances are very well known and described in many ways, often referred to as natural refrigerants. These substances are ammonia (NH_3), carbon dioxide (CO_2), water (H_2O), the family of hydrocarbons and finally air. NH_3 is one of the three most used fluids globally. The other two are R-22, a HCFC, and R-134a, a HFC. It is often discussed in the industry if these natural refrigerants are truly natural – because they can also be produced by industrial processing of natural gas. Therefore, they are also more correctly referred to as naturally occurring substances. In fact, what not everybody is aware of is that the human body uses NH_3 as a breakdown product of amino acids – the human body also uses NH_2 and NH_4 for other processes. Every human on average release about 17 gram of ammonia every day through the kidney. In nature ammonia, apart from being a fertiliser for plants, also serves as a neutraliser for some acids which would otherwise be a problem, ammonia is a strong base.

Currently, we see a competition between the supporters of naturally occurring working fluids to gain market shares. Some parties say one is having the upper hand and some another – truthfully nobody has a complete overview. The market is so vast that there will be more than enough to do for everyone just to get a complete phase-out of all CFC/HCFC and HFC. The applications are many and they are everywhere and the need for refrigeration is growing. It will take years before these fluids are fully phased out of use. The next may well be the unsaturated HFCs because of their decomposition products.

Meanwhile, the proponents of naturally occurring working fluids need to optimise and industrialise future systems but also be aware of the circular economy as not all components and metals will be available forever if the industry does not start to see the benefits of recycling more. Recycling is both good for business and for the environment but also creates new kinds of jobs for those that have less to do in the mining industry.

2. Mastering flammable working fluids

In most countries around the world, it requires technical skills to work with hydrocarbons. The good side of these requirements is that the technology used is not that different from HFC technology. This means that being updated to work on hydrocarbons is relatively easy. The biggest part of skills becoming qualified to work on the pressurized system has been achieved before proceeding to hydrocarbon refrigerants.

When some popular fluorinated refrigerants e.g., R-134a and R-22 are called non-flammable, it is a truth with some modifications. Looking into the ISO 817 it says that they are non-flammable as tested, which also implies that they can be - and they are - flammable under other conditions. This has been seen in the past in both test facilities and chillers in the field. Others are classified as having lower flammability – ISO 817 class A2L, e.g., R-32, are known to be flammable and have caused fatalities in the past. Working with A3, highly flammable according to ISO 817, working fluids should not be that unfamiliar to the trained refrigeration and heat pump technicians. The design is different because you must place ignition sources, like controls and other electric components that are not strictly needed in the safety zone (as defined by ATEX regulations or standards - outside the zone e.g., in a separate cabinet. The safety zone is to be ventilated as described later.

One of the things that make the fluids containing chlorine and/or fluorine is their potential to break down into toxic and corrosive compounds – which cannot happen with hydrocarbons. Only if the concentration becomes high enough both types will deplete oxygen in the air, which is another problem, but with proper ventilation, this issue can be mitigated.

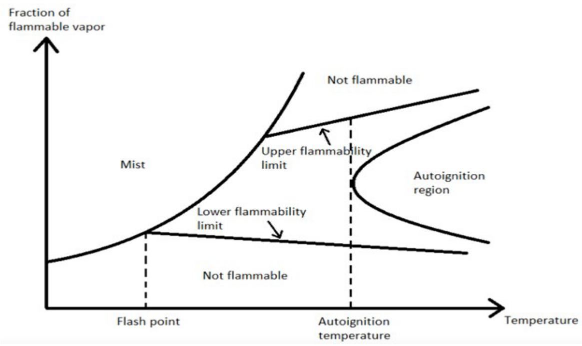
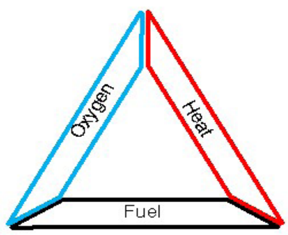


Figure 1 Different regions for flammability of gases

Table 1 Table created from standards, REFPROP , product information (MSDS) and Binbin Yu et al

	Flammabilty limit (% vol)		Flash Point (°C)	Auto inition temperature (°C)	LFL (ppm by vol) ISO 817	LFL (g/m3) ASHRAE sdd. 34
Substance	LFL	UFL				
Ammonia (R-171)	15	28	11	651	167000	116
n-Butane (R-600)	1,6	8,4	-60	420-500	16000	48
iso-butane (600a)	1,8	9,6		462	18000	38
Carbon Monioxide	12	75	-191	600		
Ethane (R-170)	3	12-12,4	-135	515	31000	38
Ethylene/Ethene (R-1150)	2,7	36		490	31000	
Ethylene glycol	3	22	111			
n-heptane	1,05	6,7	-4	204-215		
n-Hexane	1,1	7,5	-22	225-233		
n-Pentane (R-601)	1,5	7,8	-40	260	12000	35
iso-Pentane (R-601a)	1,32	9,16		420	10000	38
Propane (R-290)	2,1	9,5		480	21000	38
Propylene (R-1270)	2	11,1	-108	458	27000	46
HFO-1234yf	6,2	12,3		405	62000	289
HFO-1234ze(E)	6,5-7,6			368	65000	303
HFO-1132a	4,7-5,8	20,3	NA	640	47000	131
HFO-1130(E)					65000	258

Different gases have different flammability properties and Figure 1 shows the principle how it works in general. What you will notice is that the lower flammability limit (LFL) and upper flammability limit (UFL) change with the temperature. The auto ignition temperature has a similar trend. This is especially important to know when these fluids are used in a heat pump application because what can be classified as an A1 or A2L can under other conditions become quite like any other flammable gas, e.g., 1234ze(E) is not flammable under 30°C but at higher temperatures it is flammable. In Table 1 you will see that R-1234ze is flammable under the test conditions used for classification in ISO-817, which is 60°. The information at hand can therefore sometimes seem a little limited and must be treated as such. When considering e.g. which pentane to use in high temperature heat pumps, you can select between R-601 and R-601a. In Table 1 you see that the auto ignition of R-601 is given at 260°C and for R-601a is 420°C. This is a consideration to take into account when e.g., the discharge side can reach temperatures over 160°C. It is therefore required to make proper research and alternatively measurements for the fluids in question at the temperatures required – if you need to know more details. With the fire triangle in mind, it makes it easier to understand the science behind the standards. It is always about removing one of the three items. The fuel concentration can be reduced by ventilation – dilution.



EN 378.2:2016 §6.2.14 say: "The temperature of surfaces that may be exposed to leakage of A2, A2L, B2L, A3, B2, or B3 refrigerants shall not exceed the autoignition temperature of the refrigerant reduced by 100 K." This clause can be especially relevant if you have electrical heaters for heating the machine room during winter conditions and other electrical components, but if ventilated according to EN 60079-10-1, more than 0.5 m/s

say EN 60079-10-1, it becomes less according to Figure 1. You, however, need to do the risk assessment and mitigate the loss of ventilation and/or increased levels of flammable gas. The warmest parts of the system are cylinder heads and discharge pipes.

A sufficiently high ventilation rate (Table 3) is defined as being able to keep the concentration below 50 % of LFL at any given condition. The standards also recommend having all non-essential or not strictly needed ignition sources in the safety zone to be placed out of the zone. This is typically electrical components that can be placed in a separate machine room in a non-hazardous area. Electrical components are to be capsulated to withstand the temperatures needed. Pressure transmitters, solenoid valves or switch valves that are temperature sensitive will have to be removed by extended pipe connections to protect against high temperatures.

EN 60079-0 divides the maximum space/application temperature into different classes for electronic components:

Table 2: EN 60079-0 classification for electronic components

Temperature Class	Maximum surface temperature (°C)
T1	≤ 450
T2	≤ 300
T3	≤ 200
T4	≤ 135
T5	≤ 100
T6	≤ 85

These temperature classes are used for selecting electrical equipment, sensors, transmitters etc.

When it comes to autoignition temperature, small surfaces can have higher temperatures without being a problem, because small objects, e.g., transistors with very small surfaces do not tend to ignite so easily the gas as a larger surface1. However, it is not recommendable to go there if avoidable. The problem with some sensors is the printed circuit board (PCB) in them, which can have a short service life if exposed to very high temperatures. If placed in the air inlet, this can be mitigated.

EN 1127-1 also discuss hot surfaces. Equipment used in areas, e.g., in a special machine room or closed cabinet, in which you can have an explosive gas/air, vapour/air and mist/air atmosphere:

- Category 1: The temperature of all equipment, protective systems and components surfaces which can come into contact with the hazardous atmosphere shall not even in the case of a malfunction – exceed 80 % of the auto ignition temperature of the flammable substance in °C.
- Category 2: The temperature of all equipment which can come in contact with the flammable substance shall not exceed the minimum ignition temperature of the gas or liquid in °C during normal operation and in the case of a malfunction. Where it cannot be excluded that the gas or vapour can be heated to the auto ignition temperature, the surface temperatures shall not exceed 80 % of this temperature measured in °C.
- Category 3: The temperatures of all equipment, protective systems and components surfaces which can come into contact with hazardous atmospheres shall not exceed the auto ignition temperatures of the gas or liquid in normal operation

Following the EN 60079-10-1, you can estimate the leakage rate of your system. Very often you will find that the potential leakage rate is far less than you can even measure with normal detectors or soap water bubbles, which in praxis is about 50 kg/year. Large systems, lose some charge over the years, but following the ventilation required by the standard, you will always find yourself in a non-hazardous atmosphere. In large machine rooms removal of air to cool motors and other equipment can be much more than required for gas removal.

Table 3 Effectiveness of ventilation as given by EN 60079-10-1 (D.1)

Grade of release	**Effectiveness of Ventilation**						
	High Dilution			**Medium Dilution**			**Low Dilution**
	Availability of ventilation						
	Good	Fair	Poor	Good	Fair	Poor	Good, fair or poor
Continuous	Non-hazardous (Zone 0 NE)[a]	Zone 2 (Zone 0 NE)[a]	Zone 1 (Zone 0 NE)[a]	Zone 0	Zone 0 + Zone 2[c]	Zone 0 + Zone 1	Zone 0
Primary	Non-hazardous (Zone 1 NE)[a]	Zone 2 (Zone 1 NE)[a]	Zone 2 (Zone 1 NE)[a]	Zone 1	Zone 1 + Zone 2	Zone 1 + Zone 2	Zone 1 or Zone 0[c]
Secondary[b]	Non-hazardous (Zone 2 NE)[a]	Non-hazardous (Zone 2 NE)[a]	Zone 2	Zone 2	Zone 2	Zone 2	Zone 1 and even Zone 0[d]

[a] Zone 0 NE 1 NE or 2 NE indicates a theoretical zone which would be of negligible extent under normal conditions

[b] The Zone 2 area created by a secondary grade of release may exceed that attributable to a primaryor continuous grade of release: in this case, the greater distance should be taken

[c] Zone 1 is not needed hree i.e. small Zone 0 is int he area where the release is not controlled by the ventilation and larger Zone 2 for when ventilation fails.

[d] Will be Zone 0 if the ventilation is so weak and the release is such that in practice an explosive gas atmosphere exists virtually continuously (i.e. approaching a 'no ventilation condition).

'+' signifies 'surrounded by'
Availability of ventilation in naturally ventilated enclosed spaces is commonly not considered as good.

The standard EN 60079-10-1 in figure (D.1) above gives some good guidance on how to achieve the non-hazardous classification. A heat pump will be a secondary Zone 2 with poor ventilation and a non-hazardous area with good ventilation. Ventilation is key to the chillers and heat pumps based on hydrocarbons (HC). Annex C in the standard provides many good tips on the topic. Secondary is used because the leaks are not part of normal operation and only one leak is expected at a time.

Chillers and heat pumps will be in the secondary grade. In section B.4 of the standard “secondary grade releases are not expected to release in normal operation so, given that it is unlikely that more than one secondary source would release at any one time, only the largest secondary release should be considered”. If you ventilate the machine room efficiently you are having a non-hazardous area. For chillers and heat pumps placed in normal non-hazardous areas, the ambient air can be used to ventilate the machine room. If placed in an ATEX environment the ambient air can be what creates the risk - either a Zone 1 or Zone 0. This situation is very different and difficult to navigate in. Ventilation air from the non-hazardous zone can be far away from where needed. The advice is to follow the guidelines of the site and its risk management team.

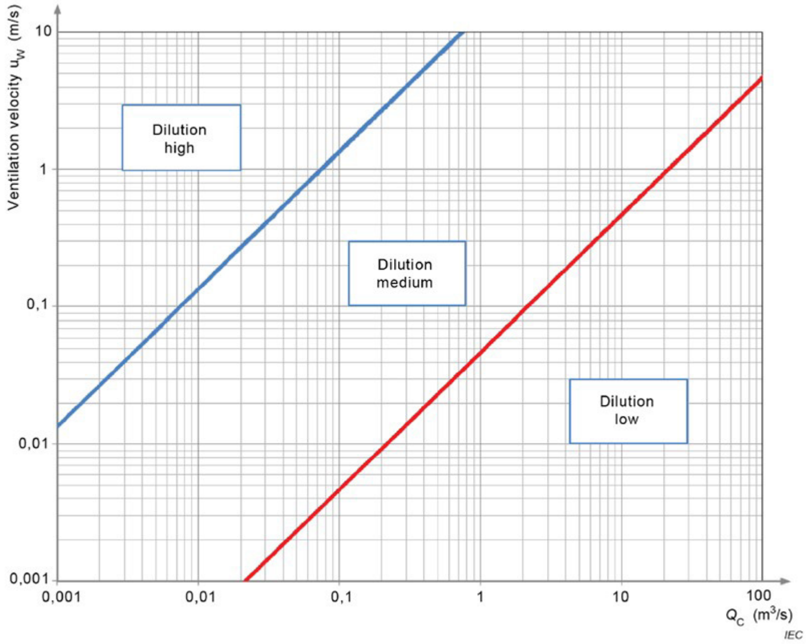


Figure 2 A Chart for assessing the degree of dilution according to EN 60079-10-1 Annex C

Fugitive emissions are small releases of gases or vapours from pressurised equipment due to leaks (generally in an order of magnitude between 10-7 kg/s and 10-9 kg/s, which is about 0,65 kg/year). Though small, these releases can still accumulate in enclosures that are not ventilated. Care must be taken that such emissions are ventilated away so they do no harm, which is not a big deal.

Table 4 Fugitive leaks can be in an order of magnitude between 10-7 kg/s and 10-9 kg/s, here calculated into kg/year

10^-7			10^-9	
0,00911882	g/s		0,0012341	g/sec
4792,85161	g/year		648,64193	g/year
4,79285161	kg/year		0,64864193	kg/year

IEC 60079-13 emphasises that it is important that the air used for ventilating the space is clean in terms of dust that is flammable. If the air comes from a Zone 2 or higher additional measures must be taken to prevent a situation where dust creates an explosive atmosphere. That includes additional detectors so there is one both inlet and exhaust. The ideal is therefore that the air supplied comes from a place outside any zone – a non-hazardous area. The type, quantity and placement of detectors installed shall be based on a process risk evaluation and the specific standard for gas detection. The location of gas detectors depends on the gas properties and applies to all types of refrigerants.

In flammable atmospheres, the gas detectors shall operate to isolate the electrical power supply of flammable substances if the gas concentration exceeds 25 % of the limiting value.

IEC 60079-13 minimum ventilation flow rate is required to be tested and the test shall be made to verify that the ventilation system can maintain the minimum flow rate required with 50 % of the outlets closed. With flammable working fluids it can also be a solution to build the system into an enclosure and ventilate it to a safe place where you are sure there is no accumulation of gas or potential for gas entering a building air intake. Safety pressure valve outlets should also be vented in the same safe area.

Which standard is the over the over the others as the biggest barrier? EN 378 (ISO 5149) covers some things and IEC standard 60079-10-1 covers the parts where EN 378 is not applicable. You cannot say they stand over one another, but more side by side, supplementing where some things need to be explained better. Otherwise, EN 378 would have to be a very huge document if it had to cover all details of everything. It is very important to remember that local law resides over standards.

Enclosure, cabinet or machine room? Definitions in EN 378 EN 60335-2-24: Particular requirements for refrigerating appliances, ice-cream appliances and ice makers; ".. enclosure, the walls enclosing the appliance as near to all its sides and the top of the appliance as possible, unless the manufacturer indicates in the instructions for installation that a free distance shall be observed from the walls or the ceiling ..". This is the best description of a cabinet we can get.

EN 378-1 §3.2.10 Ventilated enclosure; enclosure containing the refrigeration system that does not enable air to flow from the enclosure to the surrounding space and has a ventilation system that produces airflow from the enclosures to the open air through a ventilation duct.

EN 378-1 §3.2.1 machinery room; enclosed room or space, with mechanical ventilation, sealed from public areas and not accessible to the public, which is intended to contain components of the refrigeration system.

EN 378-1 §3.2.2 separate refrigeration machinery room; machinery room intended to contain only components of the refrigerating system, accessible only to the competent personnel for the purposes of inspection, maintenance, and repair.

One could say that a boxed machine room is a cabinet. This is true when you look in EN 378-2§6.2.15, but this assumes that the main danger of the content comes from electric sparks or components that ignite the gas and therefore EN 60335-2-40 applies.

When you restrict access and remove all controls and place them out of the zone or a safely ventilated cabinet, and reduce electrical components in the zone to an absolute minimum and in a safe construction, e.g. in an ATEX execution, the main danger comes from mechanical vibrations and stress on the pressure system – hence the pressure equipment directive (PED) applies and the EN 378-3§5.14 in which is pointed to EN 60079-10-1 for classification and safety. A machine room includes the entire pressurized system. EN 378-3 §5.14.2.2 is about emergency exhaust ventilation and the requirements for the motors in the ventilation system.

The standards are all connected with references which can make it overwhelming to dig into the different standards. It is therefore important not to be diverted from the actual product/system.

In conclusion, it depends on the application and the safety requirements. If the main danger is electric sparks or components that ignite the gas, then an enclosure is considered a cabinet. If the main danger is mechanical vibrations and stress on the pressure system, then an enclosure is considered a machine room. Since the area is covered by national legislation this must be consulted before considering installation. The law always presides over standards. One should be aware of the fact that some hydrocarbons are more toxic than others or can have other side effects than immediately toxic. Always check the MSDS sheet that comes with the gas in question.

3. Mastering ammonia

Ammonia, NH_3 or R-717, is used globally mostly in larger industrial applications, e.g., abattoirs, dairies, breweries, pharmaceuticals, petrochemical facilities, paper, and wood drying etc. Ammonia is one of the most efficient working fluid for refrigeration and freezing applications[4]. The quality of the ammonia in refrigeration is slightly purer than the ammonia used as fertiliser by farmers worldwide. Ammonia is one of the most produced commodities and the annual global production of ammonia is between 200 and 240 million metric tons[5]. Less than 1 % of this is used for refrigeration, the estimated consumption for refrigeration is between 60.000 and 80.000 tons/year. About 80 % goes as fertiliser, some go to produce explosives and gun ammunition, and some is used for different cleaning products and for colour, e.g., hair colour products.

Many operators perceive ammonia as safe because of the smell and the human reaction when exposed to it and hence, it makes ammonia self-alarming. Only very few individuals cannot smell ammonia but the reactions with watery eyes and coughing are universal. Because the human body knows ammonia it also tolerates ammonia to a certain level around 1000-1500 ppm for 15 minutes without lasting damage[6] . At these levels, nobody will feel comfortable, not even the most hardcore ammonia technician.

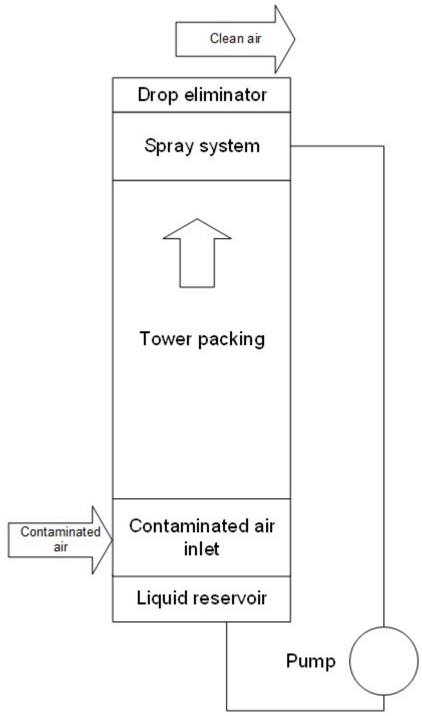


Figure 3 The liquid in the tower is circulated by a pump and the packing insures good exposure of the air to water. To enhance the capacity the water is kept at neutral level (Ph=7) by adding acid to the water.

To avoid emission of ammonia from the machine room you can use a scrubber which can remove the ammonia from the air before it is released to the ambient. This is often used in machine rooms of plants close to rural areas where a major release will cause panic to the public.

A scrubber is a kind of air washing unit. Ammonia vapour is quickly attracted to water when it flows through the shower construction. To increase the capacity of the water, it is possible to maintain a constant neutral pH value by adding acid. However, it will make the water a chemical waste.

Since NH_3 is also a flammable working fluid, a B2L, the ventilation requirements mentioned under hydrocarbons are also applicable here. In many refrigeration and heat pump applications where you use open type compressors and motors, the ventilation requirements are often more related to heat removal than removing the ammonia. Modern and well-serviced ammonia compressors have a negligible leak rate and service technicians rarely have refrigerant cylinders in their service car which is more normal for other markets using other types of fluids. This has to do with generally higher standards such as x-ray of welding's, design of bearings and the system in general. The number of engineering hours in industrial systems are also higher than for commercial systems.

4. Mastering carbon dioxide

Carbon dioxide or CO_2 was one of the early refrigerants and has been around as a working fluid for many years, although it for a period went out of normal use, from about 1955 up to about 1995, where it started to emerge again. Today CO_2 is commonly used both in supermarkets and industrial applications.

Many have asked themselves: CO_2 – but isn't it resulting in the climate change? How can that be a good idea? The simple answers are yes, but as long it is in the refrigeration system, it does no harm to the climate, and should it come out, it has a much lower GWP compared to most alternatives. CO_2 is a by-product from other industrial processes and is just cleaned before it can be used as a refrigerant. GWP of CO_2 is 1 and GWP of flourocarbons from 150 to 4000 or more. Just like ammonia, CO_2 is a natural part of human life, and the body knows CO_2. CO_2 is not toxic but at high levels, the human body reacts to high concentrations and over 10 % of humans will not survive many minutes although there have been examples of recovery after passing out in high concentrations and being there for 30 minutes.

Detectors are available at large in the market and there is no excuse for not installing them to avoid asphyxiation at too high levels. Detectors must have both a visual and acoustic alarm with a sign that says what the alarm is about and what one should do in case it sounds. The same applies for any other working fluid as well.

CO_2 systems have gained a lot of interest since their re-introduction in the middle of the 1990s. In Europe, it has become a kind of standard solution in many applications, especially in supermarkets. Also, heat pumps in district heating are using CO_2 trans-critical heat pumps for temperatures up to about 90ºC. The main advantage of CO_2 is that it is compatible with most materials used in the refrigeration industry, however, in the beginning, the higher operating pressures were a limiting factor, but that has long been solved now.

CO_2 in refrigeration grade is available on all continents and in most countries. In countries with beer production CO_2 is recovered from the fermentation and after cleaning it is sold for technical purposes. In countries with volcanic activity e.g., Iceland the CO_2 is taken from the ground and after cleaning it can be used for technical uses. CO_2 can also be recovered from natural gas or from the production of ammonia using natural gas as a source. CO_2 is recovered where the quality and content is high. Burning something to produce CO_2 is very rare because it is not CO_2 rich enough and the cleaning process is more complicated.

By the way, note that carbon dioxide is CO_2 – you sometimes see Co2 – Co is Cobalt

5. Education and vocational training

EN 13313 now in transition to become ISO 22712, is a good and internationally accepted standard with the headline: Refrigerating systems and heat pumps – Competence of personnel. This document defines the activities related to refrigerating systems according to ISO 5149:1 4, and other regional equivalent standards, e.g., EN 378:1 4 and ASHRAE standard 15, the associated competence profiles. It also establishes the competence criteria for persons who carry out these activities. Activities concerning electricity are excluded. It is important to understand that the electrical part is covered by local authorities and other international standards. It is therefore very important to follow these rules as well.

EN 13313/ISO 22712 describes the knowledge subjects and depth of knowledge required for different types of work on a pressurized system. It ranges from the design and pre-assembling of a system over various tasks during the operational life of the system and ends with the dismantling of the system. There is also, as required by the F-gas regulations in Europe, a special requirement for persons with the task of leak checking the system. di

The standard can also serve as a framework for an educational system and training grid for different types of specialists working on the systems, e.g., specialists that focus on leak detection, which is a task and is supported by regulations that focus on leak detection. One must remember the certificates required for each of the competencies.

Recovery of refrigerant is another important task which both from a safety point of view but also from an environmental aspect is important. The competent person must at any time be updated on the changes in regulations both nationally but also internationally.

Enforcement of the rules by the authoritative organ in the local country is responsible for maintaining the competence level at high standards and that the people found in the field working the systems are competent according to the standards.

6. Conclusions

From an end user perspective, the change to other working fluids gives no additional worries, because all standards are clear, and the insurance companies do not consider the risk to be higher than any other heating system if you follow the standards.

The worry can be more about the product and the procedures that have been implemented up to the date of change. As an example, if food production changes from boilers to heat pumps, will that affect the taste or the texture of the final product? If yes, it can become an issue to overcome e.g., for the marketing department. Some years ago, a Norwegian salmon producer changed his equipment and started freezing the salmon filets at -47°C instead of the usual -30°C. The meat texture and taste were perfect, but the colour of the flesh was a little paler than the usual rosa. It was taken up as a challenge for the marketing department.

One barrier that is still needed is the publishing of good case studies. Another barrier is that some case studies are too product and sales oriented instead of focusing on end user experience – especially quotes made by the end user are valuable. Smiling end users are priceless.

The aim of this paper was to demonstrate that the standards are in place and are already being used by many manufacturers in the markets. The capacity of education institutions and the capability to make the new workforce interested in working in the field of refrigeration and heat pump technology is lacking in many countries and regions. It is a pity that only few people are interested in this business because it is very challenging and no day is the same as the previous one.

The challenge of selecting the right refrigerant is not the biggest challenge the industry has, but it takes up more discussion time than it deserves. If help is needed to understand the requirements, help is available but hurry, time is short, and the challenge is big. In this discussion, you could consider delivery risks in case of trade limitations.

Enforcement, enforcement, and enforcement is required to maintain safety and keeping the safety of refrigeration and heat pump systems at the highest possible level.

For further reading about the flammability of working fluids it can be recommended to download the document: (Bulletin 627, Burea o Mines) – Flammability Characteristics of combustible gases and vapors. Author Michael G. Zabetakis. 1965. 7328370 (osti.gov)

Declaration of Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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