



COLD CHAIN TECHNOLOGY BRIEF

FISHING VESSEL APPLICATION



Acknowledgement: This Cold Chain Brief was prepared by Paul de Larminat (IIR Expert), has been reviewed by Artie Dubrie and Alvin Jose, experts from the UN Environment OzonAction and also several experts from the IIR commissions.

IIR-UN Environment Cold Chain Brief on Fishing Vessel Applications



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Summary

Fishing vessels are primarily intended to catch fish, but must also provide an adequate cold chain until the fish is unloaded. When not consumed fresh, fish is processed in different ways, like in prepared dishes, freezing and canning. This processing can be done in land-based factories or on board large factory ships. These steps involve refrigeration, with implementations depending on the modes of fishing and processing. The applications of refrigeration for the various process needs in fishing vessels are presented, with technologies currently in use. HCFC-22 (R-22) is still the widely dominant refrigerant, but it is among the ODS substances that parties to the Montreal protocol are required to phase-out. Under the Kigali agreement, all countries will also have to gradually phase down the use of hydrofluorocarbons (HFC's) (UNEP, 2017¹). Supporting the Montreal Protocol, controlled substances used in mobile marine systems will have to be addressed.

Alternatives that are not ozone layer depleting and having zero or low global warming potential are commercially available for new refrigeration systems. But for the existing R-22 fleets, the challenges are on the servicing of existing R-22 systems requiring continued cost-effective availability of R-22 refrigerants and equipment supplies. For small capacity direct expansion (D-X) systems, it is generally possible to retrofit to non-ODS substances. But for large flooded systems, retrofitting to R-22 alternatives is not a recommended option.

¹UNEP, 2017: https://ozone.unep.org/sites/default/files/2019-08/ratification_kigali.pdf

1 Introduction

This brief will present the process needs and applications of refrigeration on board refrigerated fishing vessels. Currently used technologies and refrigerants will be presented, along with the possible alternatives for new systems. The issues related to the management of existing fleets and implications to the Montreal Protocol on ozone depleting substances will also be presented.

2 Overview of Refrigerated Fishing Vessels

2.1. Types of fishing vessels

Fishing and the related industry are highly diversified, depending on the mode of catching fish and the circuit between catch and consumption. When not consumed locally, fish can be processed in different ways: frozen as fresh catch, or fillets, prepared dishes, and canning. This can be done in land-based factories, or at sea on board “factory ships”.

The total number of fishing vessels in the world is estimated at about 4.4 million, from which over 80% are less than 12 m long. Overall, Asia and the Pacific have the largest fleet, accounting for 73% of the world total. About 2% of all motorized fishing vessels are industrialized fishing vessels of 24 m or more (UNEP, 2016²). Fishing vessels are also different by the kind of fishing gear they are using. For large scale fishing, the most widely used methods are purse seine and long lines, illustrated in Figures 5 and 6.

Small artisanal fishing vessels as the type seen in Figure 3 do not have installed refrigerated systems. Motorized small-scale fishing vessels load up ice every morning from the harbour as the duration of fishing is for few hours and the catch is preserved during that period with the ice as shown on Figure 2. Medium to Large commercial scale vessels going out for mid distance (of the order of two weeks sailing) typically have Refrigerated Sea Water (RSW) tanks and ice making machines on board. Large industrial-scale vessels going out for long distance and/or time (typically several months sailing) need deep freezing for fish conservation. Depending on species of fish caught, fishing gear and process needs, these vessels often have complete factory installations with various combinations of blast freezers, plate freezers, RSW tanks and ice machines.

2.2. Refrigeration Technologies

2.2.1. Brine cooling and RSW

Some species of fish are mostly preferred for canning like tuna, sardines or anchovies. Canning is often done in land-based seafood processing factories. A common practice is to quickly freeze the whole fish on board by immersion in a brine tank at around -20°C, as soon as it has been caught. Afterwards, it can be stored in the tank or in cold rooms. Brine tanks are also widely used for purse seine fishing, because the method is ideal to quickly freeze large batches of simultaneous catch inherent to this fishing mode (Awira, 2015³).

In warm climates, a quick pre-cooling of catches is needed before putting the fish in ice; this is carried out by immersing the fish in sea water chilled by RSW chillers. Sea water is generally cooled close to or slightly above its freezing point (-2°C). In small boats without chillers on board, water can be chilled by melting stored ice in a seawater tank.



Fig.1



Fig.2



Fig.3



Fig.4

² UNEP, 2016. TEAP TF-XXVII-4 Report; annex 2 / June 2016

³ Ribanataake Awira, 2015: "Refrigerant Consumption in Fishing Vessels operating in the Waters of Pacific Islands Countries". MOP27 Side event. Nov.1, 2015, Dubai-UAE

2.2.2. Plate and Blast freezers

Thin consumer sized fillets are generally frozen in plate freezers, while larger cuts including large whole fish are frozen in brine tanks or blast freezers. In a plate freezer, trays containing the fillets are typically placed on stacks of plates as shown in Figure 7. These plates are refrigerated by evaporation of refrigerant inside these plates. The heat transfer is essentially achieved by close contact between the refrigerated plates and the goods in the trays. The process is different than blast freezers: in these, cold air is blown onto the goods to be frozen, like in Figure 8. This air is cooled by air cooling coils. In both cases, the operating temperature is around -40°C , either for the plates or for the refrigerated air; but it can be even lower, down to -70° when "ULT" (Ultra Low Temperatures) is desired, like for sushi or sashimi.

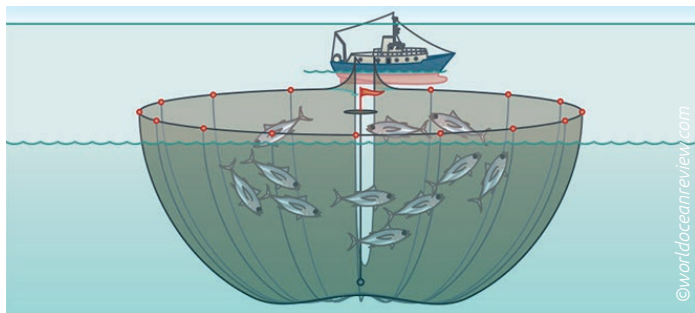


Fig.5

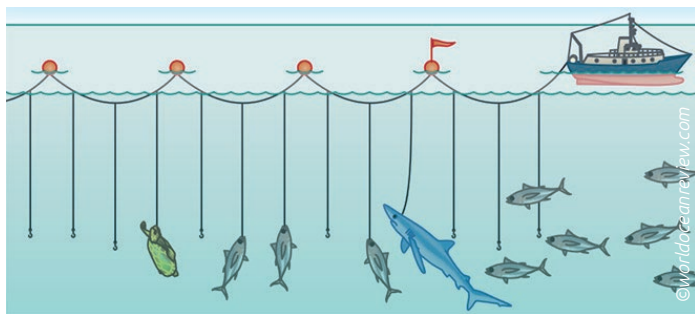


Fig.6

2.2.3. Air cooling

Air cooling is needed at various stages of processing. Working areas need clean rooms with temperature control and hygienic measures. For storage, the air in the hold at positive temperature is also often cooled, especially in warm countries. Frozen goods in factory ships are stored in cold rooms at around -25°C .

Air conditioning for crew comfort and provision stores for the daily life of crews are not addressed in this document, which focuses on "process" applications.



Fig.7



Fig.8

- Fig.1: Frozen fillets
- Fig.2: Fresh fish stored in ice
- Fig.3: Small fishing boats - Thailand
- Fig.4 : Tuna seiner fishing vessel – 90 m long
- Fig.5: Purse seine fishing
- Fig.6: Pelagic Long Line
- Fig.7: Loading a plate freezer
- Fig.8: A blast freezer

3 Current Issues and Market Trends

Fig.9: Centralised flooded system using a single-component fluid: R-22 or ammonia.

Fig. 10: Example of cascade with CO₂ for low temperature and brine for medium temperature.

3.1. Process needs - Similarities and differences with other food industries

Most of the process needs are similar to land-based food processing applications, like cutting and processing in clean rooms, freezing in plate or blast freezers, storage etc. As the process needs are similar, technologies are derived from those used for land-based applications, with specific customisation to the marine environment (“marinization”).

Given the significant constraints specific to the marine environment, very high reliability is expected. Equipment must be suitable for the ship’s motion, and withstand corrosion in the marine environment. There are also material compatibility constraints for seawater cooled condensers. The common practice is to use shell and tube condensers. Copper-nickel tubes are compatible with sea water, and with synthetic fluids such as R-22, but copper alloys are not compatible with ammonia. Titanium is in practice the sole material that is compatible with ammonia and seawater simultaneously.

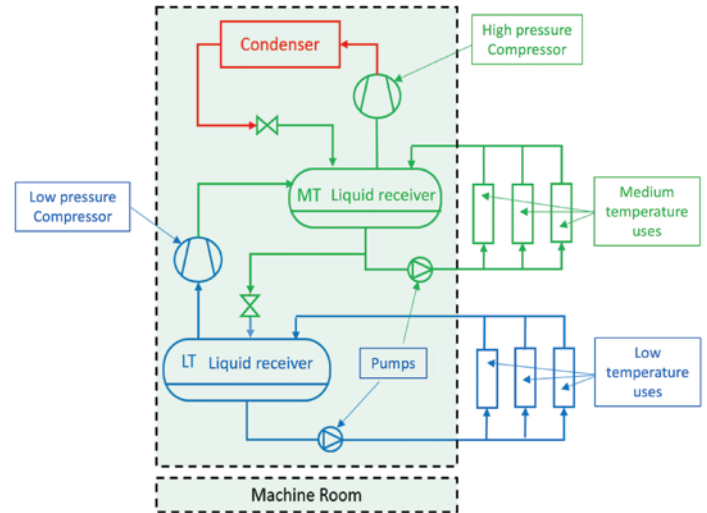
3.2. Systems architecture

There are many possible systems architectures for process applications. The different needs may be fulfilled by independent systems, or the systems may be centralised, meaning that a combined system is serving all refrigeration demands (RSW, cooling, freezing) from a central machine room (Norden, 2000⁴). In general, larger vessels tend to have a higher degree of integration. They typically have a centralised system providing refrigeration at two different levels of evaporation temperature, around -38°C for freezing (Low Temperature, “LT”), and about -8°C for other needs like air cooling in working areas and holds, seawater cooling etc., (“Medium Temperature, “MT”). Large systems are generally pumped flooded systems, as per Figure 9. They currently use single-component refrigerant, usually R-22, but the use of ammonia is increasing. In such systems, the refrigerant charge is large (several tonnes), with long piping and many connections, often causing relatively high refrigerant leakage. Smaller systems are often D-X systems. They are mostly used in air-cooling applications (in holds and cold rooms), but they are inadequate for plate freezers. They are less energy efficient than flooded systems, but the initial cost is lower, and they require a lower refrigerant charge (of the order of a few hundred kilograms).

3.3. Climate considerations

Given the nature of the industry, fishing vessels can be found to be working in extreme and varying climates. But refrigeration systems are inside the vessel and condensers are generally cooled with seawater. Even in warmer climates, seawater temperature practically never exceeds 32°C, which is still rather simple to design for. Therefore, although a hot climate must be taken into account in the design when applicable, it is not a major technical issue.

⁴Norden, 2000. “Alternatives to HCFC as refrigerant in Fishing Vessels”, ISBN 92-893-0504-5.



©Diagram: Paul de Larminat

Fig.9

3.4. Safety Management on board

Refrigeration machinery must be built according to an approved existing equipment safety standard such as that of the EN-378 or equivalent. For on board refrigerated systems, there are currently no international agreed vessel-building codes. In keeping with industry practices, design decisions should be based on robust risk analyses conducted in coordination with classification societies, insurance companies and other key industry and public sectors stakeholders. This standard safety management approach is required for all types of refrigerant and technologies. It is to be noted also that some countries have required national legislatively enforceable maritime standards that can be applicable also to fishing vessels.

In a design per Figure 9, most of the refrigerant charge is in the machine room, installed with leak detectors and adequate ventilation and very restricted access, especially if the refrigerant is flammable. Yet, although to a lesser amount, there is also some refrigerant in the working or storing (“use”) areas. Although non-flammable fluids are preferred, experience with ammonia has shown that such designs can be implemented with acceptable safety, providing the system is designed accordingly, with proper training of crew, and adequate operational procedures and maintenance.

Having only non-flammable fluids, especially in working areas, is always preferred for safety. In addition to its high efficiency, it is a reason why CO₂ is now widely acknowledged as suitable in marine, especially for the low temperature stage of cascade systems. When combined with ammonia for the high stage, using CO₂ facilitates the elimination of ammonia from working areas, with confinement in the machine room. Figure 10 is an example of design for a centralised system without ammonia in working areas. It combines ammonia / CO₂ cascade for low temperature, and indirect system for medium temperature uses. Noting however that many other system architectures are feasible.

While the above is focusing on ammonia, A2L refrigerants are also likely to have some applications, like HFOs for brine chillers, blends for D-X systems, or R-32 for some process needs. Hydrocarbons based refrigeration technologies are currently not considered acceptable in fishing vessels.

4 Current Refrigerants Used and Potential Longer-Term Alternatives

4.1. Existing refrigerated systems

It is estimated that 70% of the global fishing fleet is still using R-22 for all refrigeration applications (UNEP, 2016², §-ES4). Prior to Montreal Protocol compliance requirements, R22 was a preferred option for reasons of efficiency, cost, and safety. Some ships built over the past two decades are using HFCs such as R-404A or R-507. In some recently built or refurbished ships, ammonia or ammonia/CO₂ cascades have been used

4.2. Blends versus single-component refrigerants

The technical acceptability of alternative refrigerants depends on the system architecture. Designers have the choice of using single-component fluids or blends, but all the blends proposed as alternatives to R-22 have some temperature “glide”. Typical examples are the blends R-407A, R-407F, R-438A, R-448A and R-449A, 449B. All of these blends have a GWP in the range of 1300 to 2400, i.e. about half that of R-404A or R-507, but with a glide of approximately 6 to 7 K. This is generally acceptable in D-X systems, but is not desired in large flooded systems, where the glide can induce large performance penalties.

4.3. Lower-GWP Fluids– New systems

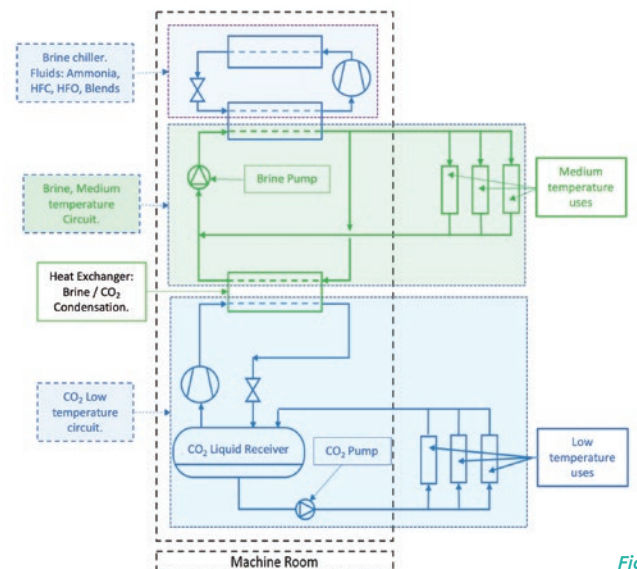
D-X systems: as aforementioned, the refrigerants proposed as alternatives to R-22 are blends with GWP of approximately 1300 to 2400 for non-flammable blends. Because of their glide, they are more complicated to handle than pure fluids. Systems must therefore be carefully designed, but one can generally consider that such blends are viable as alternatives to HCFC however with concerns on the GWP characteristics

Brine and sea water RSW chillers: Most marine chillers are derived from standard land-based chillers, with proper marinization. The choice of the refrigerants is not as critical for chillers as it is for large flooded systems because the refrigerant charge is limited, and the leak rates are much lower. For average temperatures of -10°C, medium to low GWP fluorinated refrigerants (such as R-134A) or lower GWP HFOs or blends like R-513A are used. For temperatures lower than -10°C, the refrigerants used mostly are R-404A or R-507. Suitable substitutes to R-404A or R-507 could be R-410A that has comparatively lower GWP, R-32 could also be suitable medium to low GWP substitute but has flammability concerns to be addressed. Ammonia is also suitable at all temperature levels, provided that the risk management is deemed acceptable considering the toxicity and flammability concerns of Ammonia.

Centralised flooded systems: To provide the cooling needs at medium and low temperature simultaneously with a common low-GWP refrigerant, ammonia is technically a straightforward alternative to R-22; it is cost effective and highly energy efficient, but with safety constraints. A possible alternative is to use two different refrigerants in a cascade, with CO₂ for the low-temperature level. Such CO₂ systems are compact and very efficient. The excellent heat transfer of CO₂ at low temperature improves the performance of freezers, reducing their capital cost and improving their productivity. If CO₂ is used for the LT stage, the remaining question is which fluid

to use for the medium stage. Various options are possible. Trans-critical CO₂ is feasible in theory, but it is not ready for fishing vessels. Other solutions require a different refrigerant for the medium-temperature stage of the cascade. The most widely used so far is ammonia. In ammonia/CO₂ cascade, safety is easier to manage than with 100% ammonia systems, because the ammonia charge is lower and can be contained in machine rooms. R-134a or one of its lower- GWP alternatives can also be used for the medium stage. Another option is to use “indirect” systems. In this case, a chiller cools brine to the desired “medium” temperature around -8°C. This brine chiller is used to serve the needs at this temperature level, and also to condense the CO₂ of the low temperature circuit, as illustrated in Figure 10. Like for RSW, this brine chiller can use a variety of refrigerants like ammonia, HFCs, HFOs, or suitable blends.

A draw-back of CO₂ is that it cannot reach the ultra-low temperatures (below -50°C) that are sometimes desired for specific applications, like premium quality frozen fish for sushi. No technology has gained wide acceptance for these ultra-low temperatures. R-23 could be used in theory but has extremely high GWP. Ethane would be technically suitable but is highly flammable. Not-in-kind technologies like air cycles are feasible, but rather inefficient and still very expensive. High-pressure HFC's like R-32 or R-410A are probably the best acceptable compromises.



©Diagram: Paul de Larminat

Fig.10

4.4. Retrofits

Among various constraints in the retrofit of existing systems, the capacity must remain similar; operating pressures should not be significantly higher than the reference refrigerant, and the efficiency should not be lower, especially as the power supply is limited on board. Compatibility with materials, e.g. oils, must also be considered. For safety, flammable refrigerants cannot be used in systems initially designed for the non-flammable R-22.

Even with these constraints, acceptable blends can normally be found to retrofit small to medium sized D-X systems, but it is highly recommended to perform tests on pilot plants before proceeding to a larger scale.

The situation is much more difficult for large flooded systems. Retrofits from R-22 to ammonia are not feasible for material compatibility and safety reasons. Prior tests to retrofit to R-404A did not prove technically satisfactory, and are not desired anyway because of the very high GWP of this refrigerant. The use of HFC/HFO blends is also highly problematic because their temperature glide is not desired in large flooded systems. So, at this stage, there is no proven solution to retrofit large flooded systems. For this reason, some vessels that still have a long expected life are being completely refurbished with new systems, especially ammonia/CO₂ cascades. The initial cost is high, but it can be cost effective thanks to better energy efficiency and increased productivity.

5 Development Perspectives and Challenges

Whether it be for new vessels, system replacement on existing vessels, or retrofits where feasible, technologies used on fishing vessels will have to shift to refrigerants with lower GWP. For new ships or for the refurbishment of existing vessels, adequate technologies are already available. Incremental vs. operating costs of new technologies compared to conventional ones should be carefully assessed for understanding economics and funding opportunities that can be offered through different international or local platforms.

The real and urgent challenge is the management of the existing fleet using R-22. These fishing vessels often have several tonnes of R-22 on board. Ships have a complex legal status as they can be built, flagged, operated and serviced in different places. Service is a major issue: recharging such large systems can consume a large share of the R-22 allocated to some of the insular countries, causing great difficulties in the implementation of their plan to phase out HCFCs. This raises technical, economic, legal and policy related issues.

Technically, retrofit solutions can be found in most cases for small to medium sized D-X systems, but not for the large flooded systems. Reducing the consumption of R-22 for service can be achieved with a combination of measures: better detection and repairs of leaks, retrofit of systems when possible, retirement of some existing ships, replacement of the systems of large vessels when it makes economic sense considering their remaining lifespan, and possible reclaim and re-use of fluid after end of life or retrofit. But large quantities of R-22 will remain needed anyway.

With more than 1,000 vessels of various nationalities fishing for tuna, in the Pacific Ocean, and even more globally, there is an urgent need to have mechanisms in place to monitor and control the consumption of all refrigerants used (UNEP 2016², p. 120). This would ensure that countries, especially from Pacific Islands, could meet their obligations under the Montreal Protocol as well as other international or regional commitments that might be of relevance to other parties.

Conclusions

R-22 is still the dominant refrigerant in marine off-shore refrigerated vessels. For small to medium sized D-X systems, short term solutions for new systems can be found using fluorinated fluids with medium GWP, mostly blends of HFCs and HFOs, some of which are non-flammable. Proper care must be taken in the design of these systems to account for the “glide” of these blends. These blends can also be considered to retrofit existing R-22 D-X systems.

As an alternative to R-22 for new large flooded systems, cascades using CO₂ at the low-temperature stage are very attractive. For the medium temperature stage of such cascades, ammonia is already widely used and has proven safe provided adequate training and operation procedures are implemented. Non-flammable alternatives, like indirect systems, are also feasible for the medium-temperature stage of cascades, and offer drastic reductions in the CO₂ equivalent of the charges. These technologies are adequate for new systems, but cannot be used to retrofit existing systems; blends with glide also are not a satisfactory option. Therefore, no satisfactory solution has been found yet for the retrofit of large flooded R22 systems. For fishing vessels that have a long lifespan remaining, complete replacement of the existing system is required. For older vessels, consideration can be given to continue using their R-22 systems until end of life.

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