

# Analysis of existing refrigeration plants onboard fishing vessels and improvement possibilities

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**Abstract**— The refrigeration plant has shown to be at least one of the largest electricity consumer onboard a fishing vessel, usually assuming 50% of the total power plant. It is therefore natural that efforts on improving energy efficiency have to take into account this installation and try to provide solutions for the reduction of consumption.

In this paper a brief overview of the main types of refrigeration plants is made, identifying their characteristics and needs for each of the different types of fishing methods. Also, existing technologies whose implementation would result in energy savings are revised. These solutions have to consider various aspects of the cooling process, as the design and analysis of freezing systems and the holds themselves, control systems, different refrigerants and the influence of environmental regulation in this area, as well as the use of alternative energies such as the use of heat waste, either in absorption systems or Organic Rankine Cycles.

**Keywords**- refrigeration plants; energy efficiency; heat waste recovery.

## I. INTRODUCTION

Within the major energy consumers in a fishing vessel, apart from propulsion, cooling plant represents a significant percentage of the total amount of energy consumed, not only for its high energy demand but by its continuity in time.

Whereas cooling plant processes are demanding more energy due to higher quality fish market demands, onboard processing increases and more room, consumption and facilities are required, the sector is in a delicate balancing, forced to reduce total energy consumption and becoming energy efficiency more and more important.

Also, the attempt to generalize solutions for improving energy efficiency in these systems is difficult, because the

design of these plants is very different for each vessel, making the study difficult to systematize.

The problems that may be faced in ashore refrigeration plants should be added besides other inconveniences caused by the fact of being at sea, like vessel movements, presence of vibrations, the corrosive effect of seawater or space problems.

## II. PROCESSES OF CONSERVATION

Depending on the refrigeration needs, fish can be fresh (0 °C) or frozen (-18 °C).

As special cases, design temperature for tuna is -50 / -55 °C for the freezing process, while -45 / -50 °C is taken as reference temperature for the holds, as it is consumed raw, mostly in the Japanese market [1]; in the case of using live bait, sardines are kept in tanks at 2 - 3 °C, as these temperatures keep the animal weak, but alive.

### A. Fresh

Ice is commonly used for the conservation of fresh fish [2], maintaining the hold temperature slightly above 0 °C to ensure the continuous melting of ice; thus, the temperature is constant, auto-regulated naturally, heat transfer is improved due to the liquid phase and also the humidity of the fish is kept. There is a great dependence between the size of ice pieces and cooling time, opting in most cases to use flake ice. Keeping the fish in ice boxes is very common, although it is usually not an effective method because the correct proportion of ice is rarely used.

Another option is ice made from seawater, with a lower melting temperature than freshwater ice; theoretically, with a salt content of 3.5 %, ice melts around - 2.1 °C. However, it is physically unstable, thereby the overall temperature decreases

and temperature is not properly controlled. Eutectic solutions (23.31 % salt and 76.69 % water in mass) could be another option, being its melting temperature around  $-21\text{ }^{\circ}\text{C}$ .

Pelagic fish is generally better preserved in cold sea water than using ice. Storage in RSW (refrigerated sea water) is a well established practice and has been refined both in theory and in practice since the sixties. Sea water refrigerated with ice is an economic solution, enough to cool fast and uniformly the catch around  $0\text{ }^{\circ}\text{C}$  and to maintain this temperature until the discharge. Within this system, the most popularly variant is called "champagne", on which rapid heat transfer between the fish and ice is obtained using compressed air introduced into the bottom of the tank to shake the content, instead of using circulation pumps [3].

As a special case when handling large catches, or if the catch process can not begin immediately, it should be pre-cooled in tanks on the deck using ice or RSW. Pre-cooling tanks are unloaded by lifting or vacuum pumps, but this can harm the fish.

Currently, liquid ice technology has been developed, which is a suspension of ice crystals within an antifreeze solution. This system is 100 % organic, can be handled using pumps, hygienic and with a high thermal capacity [4].

### B. Frozen

Most used freezing systems are freezing tunnels and plate freezers (both systems can be installed simultaneously in the same vessel), and freezing tanks for particular species.

Freezing systems based on immersion in salt solution at low temperatures (freezing tanks) are used especially for large whole fish (which have not been emptied), but also can be used for pelagic fish for bait.

Freezing tunnels are defined as any refrigerated space which gets a temperature range of  $-25 / -32\text{ }^{\circ}\text{C}$  and it is used for fast freezing of a product. It may be continuous, where the fish is moved along the freezing chamber in a direction opposite to the forced flow of cool air, or discontinuous, in which the chamber is filled and emptied completely in cycles. This latter type is more versatile and less expensive, but it requires more labor and energy consumption is higher than in plate system.

In a plate freezer, packed fillets or small trunks are frozen by contact between two plates with some pressure applied on them. Nowadays, the market requires a lot of packaged frozen fish, this is wrapped in plastic, but it should be noted that this practice results in a decrease in energy efficiency. This is due to the drop in heat transmission coefficient due to the air (if not controlled atmosphere) that remains in the package, considerably increasing the time required for freezing.

## III. COOLING PRODUCTION

Onboard refrigeration currently consists in a compression system, with reciprocating or screw compressors, and isolated holds equipped with finned coils [5].

The following figure represents a typical diagram for a compression system:

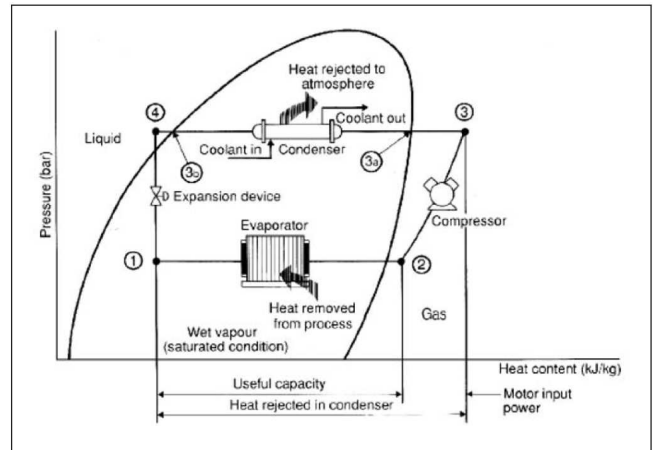


Figure 1. Compression refrigeration system diagram

In this system, a circulating refrigerant goes into the evaporator in liquid state, taking the heat from the ambience to evaporate. Then, it enters into the compressor as saturated vapor and has its temperature and pressure increased, to enter the condenser refrigerated normally with sea water, where the resulting liquid is conducted to the expansion valve to complete the refrigeration cycle.

### A. Compressors

Most existing installations have reciprocating compressors for low power, or screw compressors for higher cooling requirements.

Designs vary greatly for reciprocating compressors (with V, W or star cylinder configuration, with or without valves in the pistons, crank or eccentric-operated...). The main classification within reciprocating compressors is based in the number of active faces of the piston: single-acting compressor, where a single face of the piston is activated, or double acting, with two active sides of the piston (two compressions per revolution). Furthermore, compressors could have a single step or 'multiple compressors'.

Screw compressors, also called helical compressors, are used to obtain very high cooling power. To achieve compression ratios up to 1:20, oil cooling is necessary, so effective oil separators should be provided; it must be taken into account that this oil pressure reduces the system efficiency, increasing the compressor power requirements and reducing capacity. The use of external oil coolers (thermosiphon or refrigerated liquid) can produce savings in the range from 3% to 10%.

Apart from these two types, positive displacement rotary compressor (blade or eccentric compressors) can be used with both all fluorocarbon refrigerants and ammonia. Best results were obtained with fluids having a relatively high boiling point at atmospheric pressure ( $-5\text{ }^{\circ}\text{C}$  to  $+15\text{ }^{\circ}\text{C}$ ). These compressors

are available in a wide range of power with a huge vacuum level, but its use is normally reduced to medium pressure. Compared to reciprocating compressors, rotary compressors are more compact and simple in construction with fewer parts and excellent efficiency. The disadvantages are related to their construction as one part requiring high precision because no joint is fitted between high and low pressure zones. High wear resistance is required between mating parts, so lubrication under pressure is very important in this type of compressors.

Also, to mention that there are also membrane, centrifugal and axial compressors.

Calculations and design of a compressor are performed to satisfy a maximum cooling production at the time of greatest refrigeration needs, regulating its power level according to necessity afterwards in such a way that the refrigerant entering the evaporator works at full heat absorbing capacity. Refrigeration systems are typically configured by controlling the compressor capacity, maintaining the suction pressure (which is related to the evaporation temperature) within a margin around a desired reference point. As suction pressure is increased (increased load), capacity is added to the compressor and vice versa. The most common control methods are:

- In screw compressors, acting on its rotational speed, using staggering motors with different speeds, or with mechanical or electrical variable speed systems.
- In multicylinder compressors, varying the number of cylinders in operation. This is achieved automatically, leaving open the corresponding intake valves.
- Using a bypass between the suction and discharge areas.
- Connecting the compressor cylinder to the intake manifold and without direct action on the valves. Thus refrigerant will be driven again to the aspiration area.
- Some screw compressors are equipped with valves for controlling the capacity, placed in openings in the compressor housing along the rotor axis. When a module is opened, provides a path for the refrigerant gas to the suction side of the machine, controlling the capacity in fixed increments (e.g. 100%, 75%, 50% and 25%).
- Using spool valves, which when displaced, the beginning of the compression process is advanced or delayed depending on the gas to fill the screw thread more or less.

### B. Condenser

Refrigerant vapour at high pressure from the compressor is liquefied in the condenser, transferring the heat flow of the refrigerant (corresponding to both the mechanical work of compression as the heat absorbed in the evaporator) to the outside, which in the case of a vessel is sea water, being a free of charge and inexhaustible resource; and thus the pump is dimensioned according to the water flow necessity, calculated taking into account the heat transfer conditions and the seawater temperature. Lower needed room, greater strength

and higher heat transmission are obtained compared to air condensers. As major drawbacks, corrosion, the risk of freezing and scale formation have to be mentioned.

Three areas can be differentiated within the condenser: cooling zone up to the condensation temperature (first quarter of the condenser), condensation zone (next two quarters, where a significant temperature step between the refrigerant and the sea water is also needed), and subcooling zone up to the desired temperature.

Normally, the condenser is countercurrent with high speed cooling water, in order to optimize its dimensions.

### C. Evaporators and defrost

The most commonly used evaporators in holds are fitted with fins. The greatest problem presented in this kind of evaporators is the frost, which appears due to ambient moisture when the temperature of the outer side of the evaporator must be below 0 ° C.

Not only the thermal conductivity of the frost is less than expected for the metal of the evaporator, but also frost causes a dehydration of the stored products reducing the relative humidity of the chamber; therefore, defrosting processes are required, although it must be kept in mind that it will cause a disturbance on temperature and humidity of the hold, the interruption of the cooling cycle and possible pressurizing of the hold caused by the expansion of the air and plus energy required for operation.

To produce the energy needed for defrost, it is possible to recover heat from discharge gas in high-stage compressors. However, a more effective heat recovery is from the oil cooling heat exchangers in the screw compressor packages [9]. Heat available from oil cooling heat exchangers is available in reasonable quantities and at a higher temperature compared to the heat from the gas discharge.

## IV. ALTERNATIVES FOR IMPROVEMENT

As it was shown, several factors are involved in the energy demand and energy efficiency in refrigeration plants; therefore, to achieve an optimal configuration, changes in each of the different areas where improvements can be applied must be considered. Diagram in Fig. 2 presents a summary of this idea:

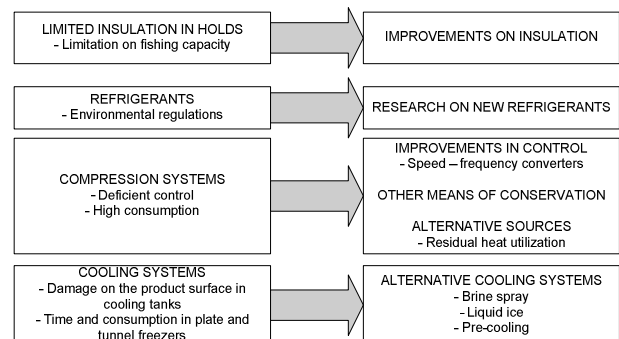


Figure 2. Approach for improving energy efficiency

It must be kept in mind that the viability of these solutions will depend largely on the type of vessel and its operational profile, needs for fish conservation, etc.

### A. Cooling needs /cooling systems

It seems obvious that one way for energy saving approach would be to reduce refrigeration requirements from the source. Some projects currently carried out [6] address the development of conservant products and define concentrations and appropriate conditions of use for inhibiting properties alteration and extend the useful life of important commercial products of fish, lowering the cooling requirements. For example, the use of traditional ice on board prepared from an aqueous solution containing natural organic acids (citric, lactic, ascorbic acid) in order to provide a preservative medium is studied to improve the quality of certain species.

Research in packaging systems not only improves hygiene, but also the development of a system interface (between the flake ice and the fish) based on films produced with natural biodegradable matrices, in which various substances (seaweeds) that improve fish quality will be incorporated.

It should be mentioned as example cases such as the development of a cooker installed onboard in a Grand Sole vessel, so when the crayfish is boiled and then frozen the roe is better preserved, improving marketing.

Moreover, energy spent for the preservation of fish would be minimized improving the insulation of the hold. However, under current legislation fishery is limited by the volume of holds (GTs) measured to the structure [7]; thus an increase in thickness in the insulation would reduce the usable space for cargo with the same GTs. Therefore, one solution would be the use of better insulation material.

Irrigation with cold brine was used for cooling in the first half of the past century; closed boxes were placed under tubes where the brine was distributed without direct contact with the fish, preserving its quality. This system had a number of drawbacks (uneven irrigation, foam formation...) so it was displaced by the use of immersion systems; however, it must be taken into account that irrigation systems are more and more used in land, so it could be considered for future installations.

### B. Refrigerants

Regulations related to refrigerants indicate that since January 1st 2004 the manufacture of all kinds of equipment with HCFCs is banned. From January 1st 2010, import, produce, sell and / or use virgin R-22 is prohibited, according to Regulation (EC) No 2037/2000 on substances that deplete the ozone layer, although reclaimed R-22 can still be used until 2015. To meet the demand for R-22 in existing facilities, several substitute products such as R-427A, R-134a and R-410A (Puron ®) have been developed. Main classification of refrigerants, as well as their present validity, can be found in the diagram below:

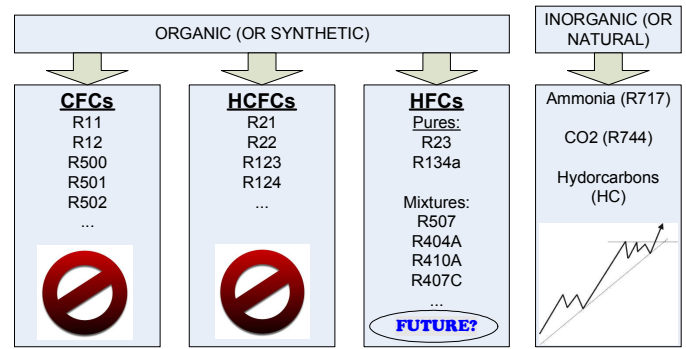


Figure 3. Types of refrigerant and their validity.

In order to choose a refrigerant, not only thermal properties (latent heat, temperatures of work ...) must be considered, but also levels of security classification (if explosive or toxic) and environmental impact, in order to ensure compliance with current and upcoming regulation [8].

In the following lines, security levels and the characteristics of the most common refrigerants can be found.

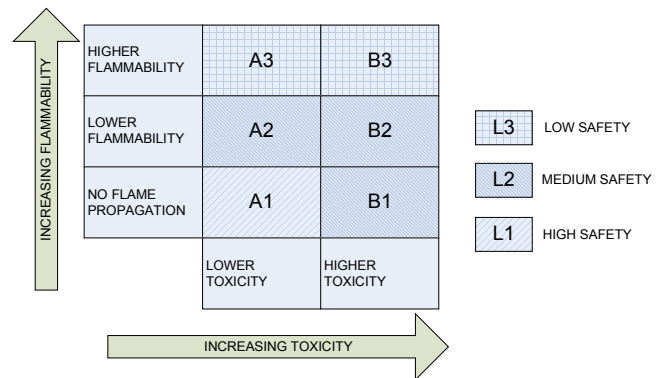


Figure 4. Security levels for refrigerants

TABLE I. REFRIGERANT CHARACTERISTICS

| Refrigerant | Latent heat @ 0°C (kJ/kg) | Flammable / explosive | Practical limit ASHRAE 15-2004(ppm) | Global warming potentials (GWP) | Class | Comments                   |
|-------------|---------------------------|-----------------------|-------------------------------------|---------------------------------|-------|----------------------------|
| R22         | 205                       | No                    | 42000                               | 1700                            | A1 L1 | Withdrawal from the market |
| R134a       | 199                       | No                    | 60000                               | 1300                            | A1 L1 | Candidate for R-22         |
| R404A       | 165                       | No                    | -                                   | 3850                            | A1 L1 |                            |
| R407C       | 209                       | No                    | -                                   | 1370                            | A1 L1 |                            |
| R507        | 162                       | No                    | -                                   | 3900                            | A1 L1 |                            |
| R410A       | 221                       | No                    | -                                   | 1370                            | A1 L1 | Candidate for R-22         |
| R-717 (NH3) | 1262                      | Yes                   | 500                                 | 0                               | L2 B2 |                            |

The practical limit is defined as the maximum concentration of the refrigerant not to cause damage on health. The Global warming potential (GWP) represents how much a

given mass of a chemical contributes to global warming over a given time period compared to the same mass of carbon dioxide [9].

It should be noted that some refrigerants show incompatibilities with the materials of the installation (ammonia reacts with the copper and copper alloys in the presence of water, etc.)

### C. Improvements in compression systems

There are many techniques for controlling the capacity of screw compressors, as already described. The option of using multiple compressors operating with a common aspiration is not estimated as starting and stopping can reduce engine life and generate problems in the power plant.

Thanks to the advances in power electronics, the use of variable speed drives (or variable frequency, VFD) has become popular, proving to be a profitable option in the case of screw compressors at half load [10].

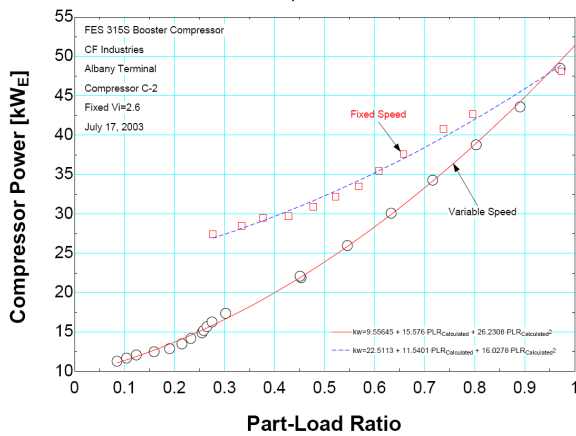


Figure 5. Power – load curves for screw compressor with fixed and variable speed.

The results of experimental work with screw compressors, carried out by monitoring and analyzing the results obtained with two identical compressors with variable frequency installation in one of them, are shown in the Fig. 5. Despite the great difference in power for low and medium loads (around 25% less for half load), it must be taken into account that when the compressor operates near full load, the performance of variable speed compressor is a bit worse than the fixed speed (losses attributable to the unit itself, about 3%).

A typical value of return on investment is estimated to be about five years, depending on the case and regardless of improvements in the quality of fish due to process control and maintenance savings potential. In addition, a very important side effect in the installation onboard is produced by the soft start; on many ships with several auxiliary engines installed, common operation is carried out with several of these generators with very low load and hence high specific fuel consumption, facing the possibility of a peak demand that can shut down the power plant. Soft start drives in important

consumers as compressors could allow operation with a smaller number of gensets adjusted to the real power needed.

Moreover, the efficient operation of a compressor requires the compression ratio to be kept low to reduce the discharge pressure, so multiple stages installation can be used for low temperature. These systems can be of two types, compound and cascade, applicable to all types of compressors.

Another option is using variable displacement compressors, having a dish shaped crankshaft inside to vary the angle relative to the shaft of the compressor, rotating around a point [11]. The greater the angle, the greater the displacement of the pistons and hence the greater the capacity of the compressor. This type of regulation does not need a temperature sensor at the outlet of the evaporator, because it is self-regulated, using a control valve that balances the suction, output and the crankcase pressures. This system gives a reduction in fuel consumption, a linear evolution of the hold temperature and eliminates abrupt starting of the compressor, increasing the lifespan of the compressor. However, its application is currently only used in the automotive sector.

In the case of fans used in forced convection evaporators, installation of variable frequency drives provides a payback less than three years in a system with fans running continuously, four years in case of cycle running. Also installation design must be carefully studied; if the fan is positioned before the evaporator, the airflow would pass through the fan and then by the battery, the cooling capacity is greater than if we locate the fan behind the battery, since the value of  $\Delta T$  is higher in the first case because of the heat from the fan motor.

Increasing fan speed improves heat transfer conditions, so that consumption of a refrigerating machine ( $N_k$ , in Fig. 6) decreases for a given installation. It should be noted that this trend is reversed from a certain fan speed because of the equivalent work of the fans ( $N_v$ ) that has to be compensated. Total consumption is represented as  $N = N_k + N_v$ .

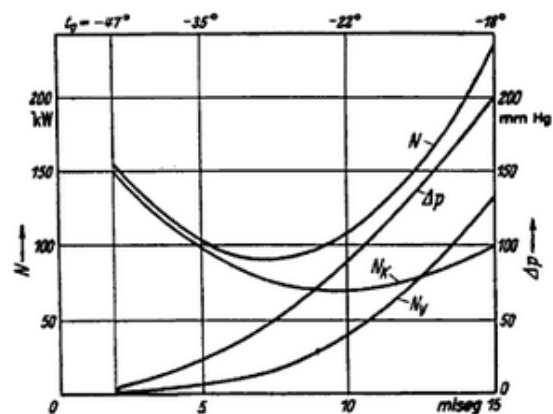


Figure 6. Influence of air speed in pressure drop in the freezing tunnel and the fan consumption.

## V. WASTE HEAT RECOVERY

As a basic requirement for waste heat recovery in any installation, the availability of sufficient waste heat energy and the coincidence in time of this source and the needs of the installation must be taken into account.

On board a fishing vessel, the main engine, and to a lesser extent auxiliary engines, are presented as a source of waste heat primarily through the exhaust gas and cooling water, which is rarely used. In general, the main engine is always running, except specific cases in some longliners. Electric plant is fitted with more than one genset, except in very small vessels, so that at low demands for electrical power they are operated alternately and used together with higher demands. In particular, some ships may have a shaft generator that allows the operation without any of the gensets, although in practice it is rare that at least one auxiliary engine is used simultaneously.

The amount of thermal energy that can be recovered from exhaust gases is limited by the temperature to which they can be cooled, as some components as nitrogen oxides ( $\text{NO}_x$ ) and sulfur dioxide ( $\text{SO}_2$ ) cause corrosive acids if they are condensed, both on the heat recovery system or the exhaust duct. Minimum temperature recommended for exhaust gases cooling, established by Diesel Engine Manufacturers Association, is  $121^\circ\text{C}$ , but in order to prevent risks of corrosion, cooling temperature limit should be  $180^\circ\text{C}$  [12].

In order to obtain data on exhaust gas temperature, measurements carried out in the framework of different projects are taken into account, whose results are presented in Fig. 7. It should be noted that except for very low engine loads, temperatures are kept above  $300^\circ\text{C}$ .

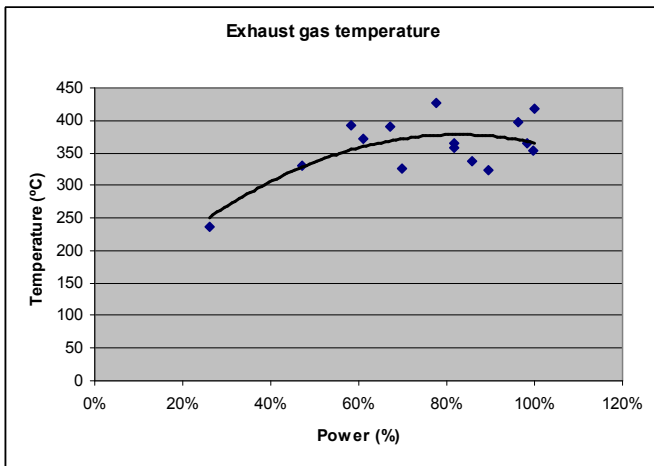


Figure 7. Exhaust gas temperatures.

### A. Absorption system

The difference between absorption and compression systems lies in the procedure followed for the recovery of the refrigerant vapors formed in the evaporator.

This heat-powered thermodynamic cycle uses a cooling fluid (refrigerant) and an absorbent fluid. The aspiration of refrigerant vapors is the result of the affinity with the adsorbent (an exothermic process); the increase in pressure to the condensation level is achieved by a pump, so that the electrical power needed is much less than using a compressor.

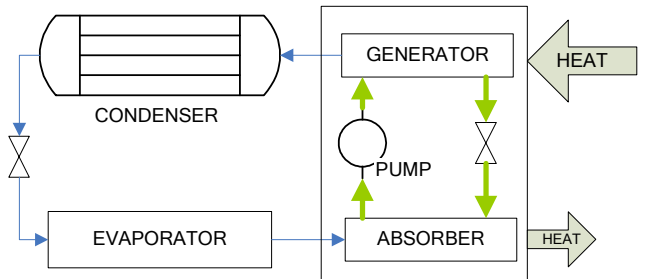


Figure 8. Absorption cycle diagram.

The absorption refrigeration cycle has five phases, being condensation, expansion and evaporation the same as in a compression system; compression is replaced by a set of generation - absorption. After the evaporator, the solution absorbs the refrigerant vapour; being this an exothermic process, the absorber must be cooled to maintain pressure. In order to separate the refrigerant from the absorber fluid, the mixture is pumped to the generator, where (waste) heat is used taking advantage of the refrigerant and absorber properties, so that the vapour generated has a larger proportion of the more volatile component (refrigerant), passing through a separator before entering the condenser. The liquid fraction with a higher proportion of absorbing fluid is returned to the absorber via a pressure valve, ensuring the pressure difference between the generator and absorber.

These pairs of substances must have the following characteristics for their use in absorption systems:

- the adsorbent fluid must have a high affinity with the refrigerant under the conditions in which the absorption is performed
- the refrigerant should be more volatile than the absorbent so that they can easily be separated
- the mixture should have uniform properties and not be separated by mechanical methods, must take place over a wide range of concentrations and temperatures, and should not solidify within the range of working conditions.

It is also preferable that the pressure is kept in a moderate level, to have the refrigerant latent heat of evaporation as large as possible, not to be toxic or flammable, to have low corrosive action, etc.

Among the possible substance pairs there are two widely used in industry: systems with lithium bromide (absorbent) and water (refrigerant) and systems with water (absorbent) and ammonia (refrigerant).

The required temperature level in the heat source for driving these systems is low, between 80 °C and 150 °C, depending on the cooling temperature desired and the absorption system used.

The efficiency is lower than using a compression system (coefficient of performance, COP, between 0.8 and 1.2 for absorption, vs. 3 and 5.5); even though most of the energy used to calculate the COP is the heat supplied to the generator in an absorption system, which is a residual energy, so the comparison of COP is not completely fair between both systems (it is better and more useful to compare through the second law of thermodynamics, to assess the quality of the energy used).

The use of commercial absorption systems is unviable onboard, decreasing the efficiency due to the rupture of the liquid film caused by the movement existing onboard.

The system presented in the references [13-14] is a single-stage cycle using NH<sub>3</sub> as refrigerant and H<sub>2</sub>O as absorbent. The system incorporates a vertical tubular absorber, a pool-type generator and a distillation tower (to avoid the problem of film rupture described above). The study was performed for a trawler with fresh fish, fitted with a 700 kW main engine, although the method of calculation described is general and applicable to other operating profiles. In principle, the recoverable heat level is much higher than would be required to drive the absorption system; the power produced from the exhaust gas is estimated between 11 and 29 kW, used for hold temperature maintenance.

### B. Organic Rankine Cycle

The following transformations take place in a Rankine cycle: vaporization in the boiler up to the saturation pressure, overheating at constant pressure to avoid impacts of liquid droplets against the blades (common practice is to keep the turbine exhaust steam rate not less than 0.9), adiabatic expansion in the turbine or a working cylinder, condensation, increased pressure of the liquid phase at constant volume and preheating until reaching the saturation temperature.

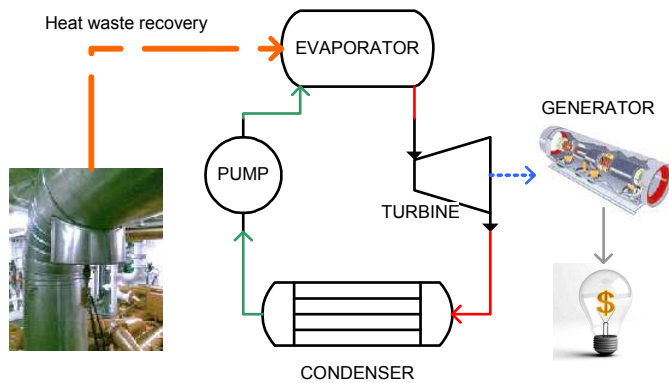


Figure 9. Organic Rankine Cycle diagram.

Energy recovery in ORC is performed with relatively low temperature (< 350 °C).

The organic fluid to be used is defined by the range of temperatures in the process. These commercial fluids are environmentally friendly and operate from 180 °C to 320 °C.

The main advantage of this system is the use of a residual energy for electricity production, allowing the synchronous connection to the vessel electric plant. Main problems with the implementation of ORC are the cost and space needed.

In practice, a system with average power of 180 kWe was developed with exhaust gas recovery at 300 °C and 15000 m<sup>3</sup>/h - 30000 m<sup>3</sup>/h of flow, although it is an onshore installation [15].

## VI. CONCLUSIONS

An overview of the energy problem is achieved by studying all the different aspects involved in the production of cold onboard. This is crucial for an assessment of a refrigeration system from an energy focused point of view, as strategies to improve efficiency not only reside in the use of compressors with better performance, but factors such as insulation, the possibilities of utilization of waste energy or different cooling systems for the fish open the door to a more detailed study on each of the installations.

Although it is not possible to generalize, there are two main groups of technologies based on their current maturity

- Technologies for immediate application: variable frequency drives (both for fans and compressors), liquid ice production, or existing tools to study the airflow in the freezing tunnels.
- Technologies under development for use on board fishing vessels, opening the possibility of research on these subjects: the use systems of waste heat (where is vital to lower the cost and space as well as increasing their efficiency), research on non-polluting refrigerants with optimal thermodynamic properties, or reducing energy needs through conservation by natural alternatives.

As expected, the application of technologies already available will depend on the particular vessel, its operating profile, onboard cooling requirements, etc. Not all of the proposed technologies would be always favorable for all the cases; however, it study of all the possibilities is worthy and it may reveal assumable investments with very short return of investment that can provide significant energy savings.

## REFERENCES

- [1] Institut International du Froid : “Réfrigération et Congélation à Bord des Navire de Pêche”, 1974.
- [2] www.fao.org
- [3] Rudolf Plank. “El empleo del frío en la industria de la alimentación”. Ed. Reverté, 1980
- [4] www.kinarca.com

- [5] Enrique Torrella Alcaraz. "La producción de frío". *Universidad Politécnica de Valencia*, 1996
- [6] [www.arvi.org](http://www.arvi.org)
- [7] IMO. "International Convention on Tonnage Measurement of Ships", 1969
- [8] R. Cabello, E. Torrella, J. Navarro-Esbrí. "Experimental evaluation of a vapour compression plant performance using R134a, R407C and R22 as working fluids", *Applied Thermal Engineering*, 2004
- [9] [www.epa.gov](http://www.epa.gov)
- [10] [www.irc.wisc.edu](http://www.irc.wisc.edu)
- [11] [www.valeoservice.com](http://www.valeoservice.com)
- [12] José Fernández Seara. "Diseño, simulación, construcción y evaluación de un prototipo de sistema de refrigeración por absorción con NH<sub>3</sub>-H<sub>2</sub>O para la producción de frío en barcos de pesca, accionado con la energía térmica residual recuperada de los motores" Universidad de Vigo, 1999
- [13] José Fernández Seara, Alberto Vales, Manuel Vázquez "Heat recovery system to power an onboard NH<sub>3</sub>-H<sub>2</sub>O absorption plant in trawler chiller fishing vessel". *Applied Thermal Engineering*, 1997.
- [14] José Fernández Seara, Manuel Vázquez. "Study and control of the optimal generation temperature in NH<sub>3</sub>-H<sub>2</sub>O absorption refrigeration systems", *Applied Thermal Engineering*, 2000.
- [15] [www.desintec.net](http://www.desintec.net)