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Abstract

Fishing vessels and fish transporting well-boats have varying cooling demand depending on operational mode. There is a possible benefit of peak shaving and energy saving with the use of cold thermal energy storage (CTES), which has been explored in this paper. Fishing vessels have limited space availability and the focus is therefore on compact and efficient systems. A CO_2 system is suitable for that purpose due to its compactness and high volumetric refrigeration capacity. One application is to use ice slurry systems, which can be used to reduce the storage temperature of the fish and thereby keep the fish quality longer, compared with no chilling or chilling in refrigerated sea water (RSW). The chilling rates are faster, and it results in no significant damage to the fish surface.

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1 Introduction

Fishing vessels and fish transporting well-boats have varying cooling demand depending on operational mode. There is a possible benefit of peak shaving and energy saving with the use of PCM-CTES which will be explored in this task (cooperation with RA3.3). Maritime vessels have limited space availability and the focus is therefore on compact system design. The requirements can be transferred to onshore installation as well, especially for retrofitting on brown field installations.

The fishery sector consists of many players from catch to table and the largest user of fossil fuels in the fishery sector is the fishing vessels during the capture (FAO, 2015). Even though the greenhouse gas emission (GHG), in fuel consumption and refrigeration leakage is low per kg landed fish (Gabrielii and Jafarzadeh, 2020) there are potential for improvement. The simplest way to reduce the GHG would be to electrify the fishing vessel fleet. However, the transition would not be realistic with current battery technology. The operation of the vessels requires a lightweight, dense fuel with capacity for long trips. There are currently put in a great effort to find the next green fuel to replace fossil fuel. Two potential fuels are hydrogen and ammonia, while biofuels or carbon neutral fuels could also be an alternative. There is currently no clear solution for a permanent future proof fuel. Today, some of the most technological advanced new fishing vessels use liquid natural gas (LNG). LNG is a more climate and environmentally friendly fuel compared to diesel, with lower CO_2 and NOx emissions. Thus, focus on reducing fuel consumption is one of the most important steps the fishery sector could make to reduce their climate footprint. One of the processes that can be improved is running the refrigeration system closer to the optimal refrigeration load. The refrigeration process is important to the quality and an energy intensive process. (Widell et al., 2021)

The refrigeration process on board fishing vessels is using electricity produced in the engine, thus indirectly using fossil fuels. The cooling demand will vary from boat to boat and trip to trip. Operating the system ideal is difficult due to the unpredictable nature of fishing. Weather, catch size, cooling demand are some of the factors playing a part in efficient use of the refrigeration system. These factors and the system design of the refrigeration system makes the system run on part load, which is resulting in unnecessary GHG emissions. One possible solution to counteract the part load operation is the integration of a cold thermal energy storage (CTES). CTES could assist the refiguration system by reducing the high loads by discharging stored energy and charging cold during low loads, which give leeway to the refrigeration system.

1.1 The Norwegian fishing fleet

The fishing fleet in Norway is highly diverse, varying from factory trawlers to one-person inshore fishing vessels. The main species are pelagic, whitefish, demersal, and crustaceans, while the most used fishing gears are trawl, seine, hook and line, Danish seine, pots and traps, and gillnet (Widell et al., 2021). According to the Norwegian Directorate of Fisheries[1] had trawl a 54% share of the total catch, seine has 24%, while hook and line, Danish seine, and pots and trap where all around 5% each.

Following is a simplified operation of a trawl described. A trawl is pulling a fishing net through the water behind the boat and sweeps up herds of fish. When the net is filled the boat drags in the net and puts the fish in receiving bins. On board the fish is further sorted, bled, gutted, and headed. Depending on the product, the fish could be filleted or sorted whole and packed. The final steps on board are cooling or freezing, storage and unloading. Different refrigeration system may be installed depending on the trawler. Trawlers equipped for pelagic fishing may have a refrigerated sea water (RSW) tanks installed, while other trawlers have vertical plate freezers where whole fish are frozen, and some trawlers have horizontal plate freezers for fillets or standardized blocks.

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[1] https://www.fiskeridir.no/Yrkesfiske/Tall-og-analyse/Fangst-og-kvoter/Fangst/Fangst-fordelt-paa-redskap

Purse seine uses hydro-acoustic fish detection technology to locate stims of pelagic fish. A large net is floating on the water, and heavy rings places on the edges of the net, which allows the net to fall over the stims. Then the rope on the edge is tightened, and the catch is pulled toward the boat. Pumps are used to move the fish from the net into the RSW tanks.

1.2 Cold thermal energy storage (CTES)

There are mainly three possible ways to store thermal energy: chemical, sensible, and latent heat storage (Alva et al., 2018). Chemical heat storage use adsorption, which is a reversible reaction, to charge and discharge the material to store thermal energy. This is a promising technology but is still in the laboratory stage and commercial applications need further research. Hence, chemical heat storage will not be further discussed.

Sensible heat storage uses the specific heat capacity of the material in combination with the temperature difference to store energy. The amount of energy stored per kg material is low compared to chemical and latent heat storage. To increase the energy stored there are two possibilities, either the mass or the temperature difference must increase. Neither is ideal for a system on board a fishing vessel. The most widespread material used as sensible heat storage is water. For cold storage is RSW used and for stored heat are hot water tanks used. There are also available system solutions in the marked today using concrete as sensible heat material, however this solution is applied mainly for high temperature storage. This form of TES could be relevant for fish processing on land.

The third way to store energy is latent heat. This is the heat required to phase change materials and occurs at constant temperature. The most well-known example is ice, a large amount of heat is required to melt ice to water. This is known as a solid-liquid phase change. Other phase changes are possible i.e., liquid-gas and solid-gas, but the large change in volume involving gas makes solid-liquid favourable. Of the three possible thermal energy storages is the most realistic use of CTES on fishing vessels is phase change materials (PCM).

There are several ways to operate a CTES system to deal with the heat loads in refrigeration system. In Figure 1 three possible operation modes are shown. Figure a) shows charging of the CTES system during low load periods and discharging the cold during high load periods. The discharge covers the complete heat load; hence the refrigeration system could be turned off. This configuration could be beneficial with high electrical prices during peak load hours. However, this configuration requires the capacity of the CTES to be able to cover the complete cooling demand, which will result in an impractical large unit.

Figure b) shows a configuration that have constant refrigeration capacity. In the periods the heat load is smaller than the refrigeration capacity the CTES are charged up. While during the peak load the CTES discharges and takes care of the difference of the load and refrigeration capacity. This configuration is ideally from the perspective of the load of the refrigeration system because the system is working at the same refrigeration capacity all day. This system configuration will result in the lowest refrigeration capacity requirement.

Figure c) shows charging of the system during off peak load hours and runs with limiting operation during peak hours. Of the three operating strategies are the partial storage the most realistic use of CTES in most industrial applications. The example to the left could be relevant for certain special cases.

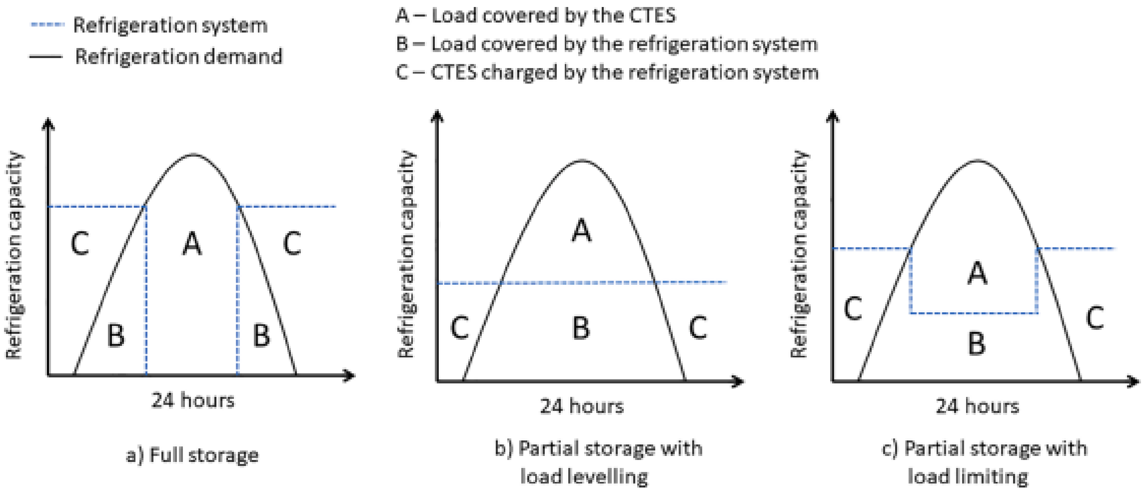

Figure 1: Different strategies for operation a CTES system integrated into a refrigeration system (Selvnes et al., 2021)

1.3 CTES in fishing vessels

The refrigeration load demand in fishing vessels varies from boat to boat, and is highly dependent on the fishing gear, species, and quantity. While one operating strategy could work well for some catches, it could be inefficient for others. The usage of trawl, purse- and Danish seine will result in a large number of fish brought on board at the same time, which leads to one large heat load on the refrigeration system. The uncertainty around how much and when cold is needed, makes the integration of CTES harder than compared to industry process running in predictable cycles. This could lead to over dimensioning of CTES or inefficient use, which the user must be beware of.

Due to the perishable nature of seafood, fish begins to deteriorate as soon as it dies. The deterioration rate is temperature depended, and without freezing the product, the best way to preserve fish is keeping the temperature slightly above the freezing point. And it is essential to maintain the same temperature through the whole cold chain to the consumer. If any parts of the cold chain are compromised, bacterial, enzymatic, and chemical processes will reduce shelf life (Kauffeld et al., 2010).

To achieve the best quality, the faster the fish is cooled down, the better it is. The amount of heat removed from the catch is still the same regardless of the time used to remove it. Thus, to achieve a shorter cool down time, a higher refrigeration capacity is needed, which would require the system to work outside of the designed/ideal working range during the rest of the time. This part of the cooling process has potential of utilization of CTES and will positively impact the quality of product and the energy consumption.

There are mainly two different mechanical refrigeration systems on fishing vessels that are in widespread use today: refrigerated seawater and on board freezing (Nordtvedt and Widell, 2020). Different configurations of these systems will be discussed later. However, the compressors for these systems are often dimensioned for the average heat load to avoid over dimensioning, which leads to insufficient compressors during peak heat load. For refrigerated seawater system is the main load brought on board in mainly one batch, while for the freezing process there will be many smaller batches due to the limited freezing capacity. Some of the benefits of implementing a CTES system are that cold could be stored before peak loads, increase the time period cold is produced, and improve operations conditions for the compressors.

1.4 Refrigeration systems and natural working fluids

There are many possible different designs of refrigeration systems for fishing vessels. Space availability on board is limited and the focus is therefore on compact and efficient systems. Since the Montreal protocol was signed, ozone depleting working fluids has been phased out and replaced with fluids with no ozone depletion potential (ODP). These fluids have a high global warming potential (GWP), which is an important contributor to the global warming of the planet. Today, the problem is replacing working fluids with high GWP with working fluids with low GWP. This is especially important for refrigeration system on board of fishing vessels, due to the harsh environment there are higher refrigerant leakages. The industry is pushing new developed working fluids, while there are natural working fluids on the marked. Introducing new refrigerants may come with unintended consequences to nature and health of humans. Therefore, the new generation of system should use natural working fluids.

Propane (C_3H_8), ammonia (NH_3), and carbon dioxide (CO_2) are the natural working fluids matching the temperature range required for a system on board a fishing vessel. Consider the strict rules regarding flammable working fluids on boats, is propane not an acceptable choice. Ammonia is widely used in industry and some larger fishing boats, while being toxic and poisonous it is not a great choice. Extra safety precautions are required, such as a secondary refrigerant loop to avoid leakage

Direct contact between ammonia and product will spoil the product, which limits the use of ammonia to only large fishing vessels. Carbon dioxide is an environmentally friendly, nontoxic, non-flammable natural fluid. A CO_2 system is suitable for fishing vessels due to its compactness and high volumetric refrigeration capacity and is competitive in colder climate, while the efficiency is severely reduced in warmer climate due to the low critical point temperature (Brodal et al., 2018)

2 Current solutions

2.1 Using ice brought from land (pure water) as CTES

The most common use of thermal energy storage in small fishing vessels without mechanical refrigeration, is in the form of ice. The most widespread method for small fishing vessels, is to bring ice from shore in isolated boxes. The fish is put on ice when caught or the ice could be mixed in sea water to create chilled sea water (CSW). The heat transfer rate by only using ice is limited due to the air between the ice and product. The solid ice creates small air pockets which will work as isolation due to the low heat transfer coefficient of air. Crushed ice will reduce the air gaps and increases the surface contact.

Using CSW will increase the heat transfer by replacing the air with water. Unless the seawater is already refrigerated from land, will the seawater brought on board introduce an extra heat load. Consequently, more ice is required compared to use only ice. Other limitations with this way of operating are the space limitation on board, and the temperature will increase when the ice has melted.

2.2 Using ice production as CTES

Another way to utilize ice as CTES is to produce ice in an icemaker. This configuration could be used to distribute the peak refrigeration loads by making ice during low periods and supplement with ice when the chilling tank loads are high. This system requires some extra components, mainly a separate ice maker, crusher, and storage for the ice before use, illustrated in Figure 2.

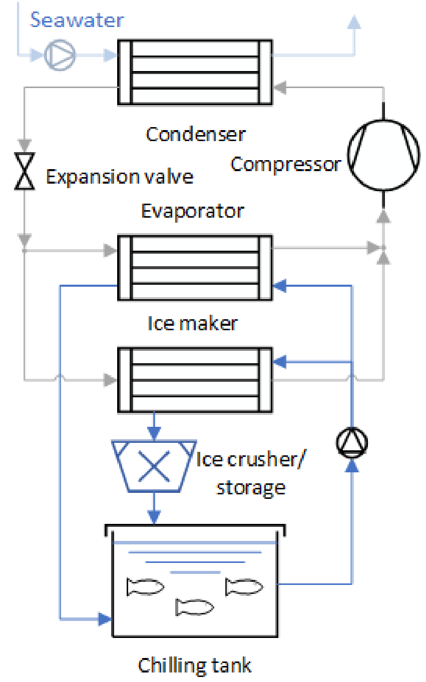

Figure 2. Illustration of refrigeration system with ice maker

2.3 Using RSW as CTES

RSW is a sensible thermal energy storage and one of the most widespread cooling methods in use today. Sea water is chilled down in large tanks, before the fish is brought on board, to the lowest feasible temperature. The temperature of the catch is higher than the temperature in the tank, so when the fish is pumped on board, the temperature in the tank will increase. As a result, will the refrigeration system start to cool down the temperature in the tank again, as shown in Figure 3.

The ratio between fish and water in the RSW tank is important for the mixing temperature. Too much fish will reduce the amount of water flowing between the fish, thus reduce the heat transfer and increase the cooling time. In some cases, the fish will lump together and the heat transfer will reduce drastically, which will influence the quality (Widell and Nordtvedt, 2016).

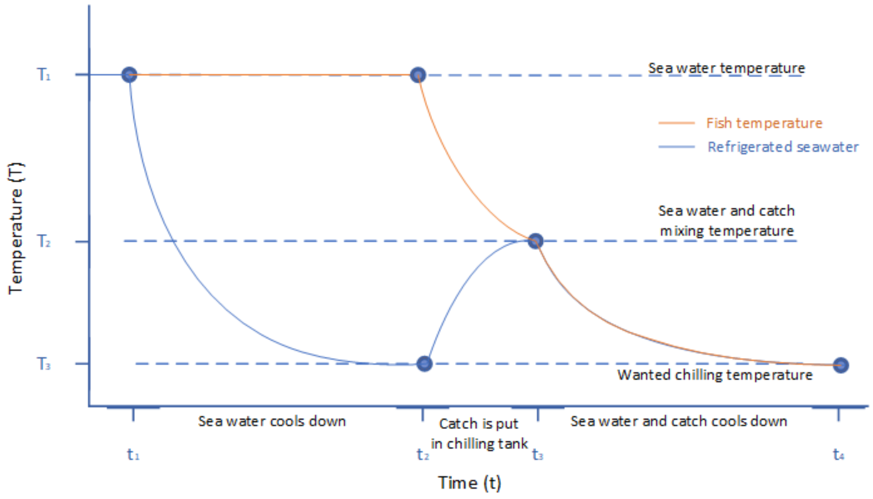

Figure 1: Temperature profile in a RSW tank throughout the cooling process

There are several possibilities to reduce the peak load the system experience after the catch is brought on board. Probably the simplest is adding ice brought from land in the cool down period of the fish. This does not require extra system complexity, but some space requirements are necessary to store the ice. Another solution is to have an icemaker on board, but this increases the system complexity with an extra system.

2.4 Ice slurry

Ice slurry is a mixture of liquid and ice. The slurry could be pure water or a binary solution for lower freezing point. The most used freezing point depressant are sodium chloride, ethanol, ethylene glycol and propylene glycol (Kauffeld et al., 2010).

In the ice slurry, there are many microscopical spherical ice crystals mixed with the liquid, thus the slurry appears liquid while some of the liquid has become solid. This property is favourable for a working fluid for cooling applications. Due to the latent heat of ice, a larger amount of cold could be stored in the same volume as RSW. And it could to some degree be handled as a liquid, thus be pumped and moved around without clogging the pipes. This could ease the manual job of handling ice while still retain the benefits of using ice.

The structure of ice crystals in ice slurry are spherical or oval, while the form of ice made of large crystals – typical flake or block ice – have rougher edges. The shape of the ice impact the handling of the product, rough edges in the ice could damage the product thus reduce the quality and lifespan of the product. Another benefit with small ice crystals is the increased contact with product, the numerous crystals create a large heat transfer area. While with regular ice there are limited contact and the airgaps between the ice and product work as isolation thus reducing the heat transfer. Therefore, the use of ice slurry result in more rapid cooling of the product.

In most cases of cooling fish would the use of ice slurry be beneficial due to the pros mentioned above. However, the temperature of the slurry is below 0°C, and seabass are reported to exhibit cloudy eyes which could affect the appearance and quality negatively (Piñeiro et al., 2004). So, the user of an ice slurry system should know which fish could be negatively impacted by the low temperature.

Rayhan et al., (2018) investigated experimentally the effect of the initial salt concentration of seawater for the forming of ice slurry. The study experimented with concentrations of 1, 1.5, 2, 2.5 and 3 wt%, and they observed the diameter of particle ice increase with decreased concentration. Whereas Melinder and Ignatowicz, (2015) found the optimal initial salt concentration to be 2-3 %, with an ice fraction up to 60%. Any higher salt concentration would require a lower temperature in the ice slurry generator which result in a higher power consumption, while a lower salt concentration increase the problem of clogging.

Akse et al., (2011) compared the salt uptake in cod in RSW, CSW and iced boxes. The results showed raw material refrigerated in RSW and CSW had a higher uptake in salt and water than iced boxes. They also measured lower fillet quality in RSW and CSW compared to ice.

Some fishermen have adopted small scale ice slurry system for direct chilling of fish and other catches. Kæling is a producer of these systems in Iceland. Their Cooling K3F Slurry machine[2] is installed on smaller vessels and has production capacity of 930 l/hour. The unit use regular seawater with a minimum salt concentration of 2,5%.

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[2] https://cooling.is/en/new-fishing-boat-equipped-with-cooling-k3f-slurry-machine/

2.4.1 Possible ice slurry system

There are many possible designs to utilize ice slurry in fishing vessels, some imitate the ways ice are used and described earlier. The main difference is the ice slurry generator, which is specialised to make ice crystals in the correct size. There are multiple designs out on the marked i.e., scraped surface generator, direct contact generator, and supercooling generator.

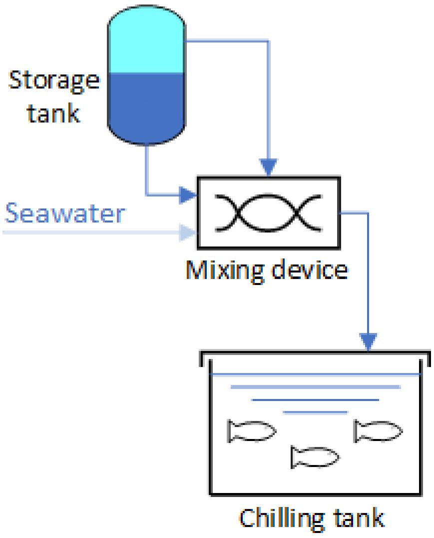

Figure 2: Simplified ice slurry system

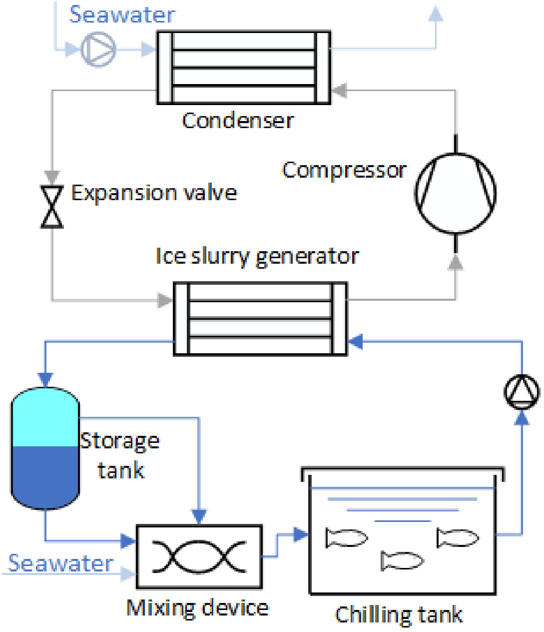

Figure 3: On board ice slurry production

Unless the ice slurry is used in the same rate it is produced, the system requires a storage tank that stores the ice slurry. This tank is the CTES in the system. In the Figure 4 is the storage tank is divided in a poor and rich layer of ice slurry. In the poor layer, the ice concentration is low, and in the rich layer, the ice concentration is high. The ice is rising to the top of the tank due to the density difference between ice and water. To ensure the right mixing ratio of ice and water, the system requires either a separate mixing device or a stir in the storage tank.

2.4.2 Only ice slurry brought from land

This is the easiest use of ice slurry and similar to the use of ice brought from land. The system consists of only two parts: a storage tank and a mixing device, as shown in Figure 4. A big advantage with a system like this compared to ice brought from land is the reduced manual handling of the ice. The mixing device could pump the ice slurry to different tubs with product and easily distributed evenly. This system is mostly relevant for small fishing vessels without existing refrigeration system.

2.4.3 Ice slurry producing system on board

With an ice slurry producing system on board there are some extra components, as shown in Figure 5. The system is quite similar a regular refrigeration system, but evaporator is replaced with an ice slurry generator and there is a storage tank and mixing device for the ice slurry.

2.5 PCM integration in cold room

There are currently land based solutions for thermal energy storage for warehouses. Viking Cold's TES system[3] for warehouses is integrated top of the racks and is easily integrated with existing refrigeration system. Viking Cold claims an 26% improved efficiency on average, with the possibility of cycle off up to 13 hours each day. It is possible to transfer a similar solution to cold room on board fishing vessels, but such a solution will give extra weight onboard and thereby increased fuel consumption.

3 Theoretically evaluated solutions

3.1 Using PCM as a CTES in chilled water circuit

Saeed et al., (2021) investigated the possibility of introducing a PCM-CTES unit in the chilling tank loop, shown in Figure 6. This unit will be cooled down before the catch is brought on board and discharged during the peak load. Ideally, the temperature for the phase change is as close to the lowest temperature in the chilling tank. Unfortunately, that will not be possible due to the low temperature difference (the PCM would use an unrealistic long time to charge), so in this example, the phase change temperature is set to 4°C. From the foregoing RSW example with the temperature profile in Figure 3, let's assume that the mixing temperature of chilled water and catch is substantially higher than 4°C. In this case, a simple PCM-CTES unit will reduce the peak load. When the temperature in the chilling tank is below 4°C, a stopping valve could be turned and the PCM does not have to change phase again. This system is simple and can be fitted to already existing systems.

3.2 PCM integration into the walls of chilling tank

Another possible system design is to integrate PCM in the walls of the chilling tank, as shown in Figure 7. To utilize the phase change behaviour, the melting temperature of the PCM is set to 4°C to ensure sufficient temperature difference. A major advantage with this system is the extra heat transfer area the system will introduce when the catch is brought in the tank. With sufficient circulation in the tank, the walls will help to cool down the catch and work as an isolation layer to the surroundings. The disadvantages with this design are the need for new chilling tanks and the phase change of the material must be cooled two times. However, it may be beneficial for the compressors when the system is maintaining the temperature at -1°C, i.e., on the trip back. The PCM will work as a chargeable isolation layer. This way could the compressor run at more efficient loads (on/off) instead of part loads.

Sukoco et al., (2021) investigated the possibility of replacing ice with bags of PCM in boxes with fish. The bags consisted of aluminium-foil zip-lock bags containing 670 grams of eutectic potassium chloride solution, with a melting point of -10.7°C and heat of fusion of 253 kJ/kg. They compared the use of ice vs. PCM. The temperature in the box with PCM showed a steady lower temperature, which resulted in lower quality loss on average compared to the control box.

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[3] https://www.vikingcold.com/

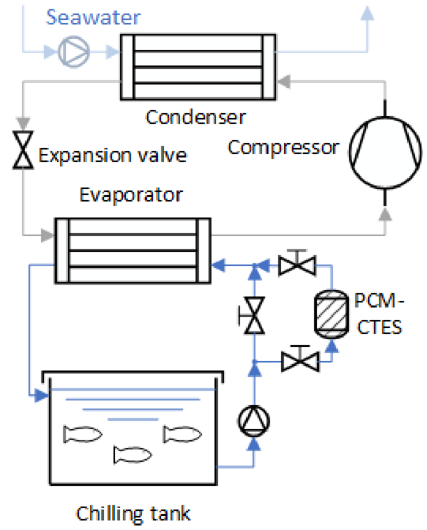

Figure 5 PCM-CTES unit integrated in chilling loop

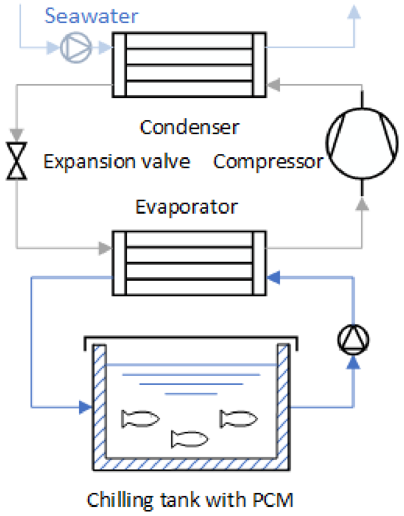

Figure 4 PCM integrated in chilling tank walls

3.3 RSW in combination with LNG-cold vessels

In some of the new larger fishing vessels liquid natural gas (LNG) is used as fuel. LNG is a more environmentally friendly fuel compared to diesel. LNG is stored at -162°C and must be regasified before use. Regasification is a process of converting LNG from -162°C to ambient temperature. This is cold that could be utilized to cooling, rather than go to waste to the ambient. There are two temperature levels the cold from the LNG could be used, the sub-cooler in the CO_2 cycle and chilling of the seawater in the chilling tank. The cold in the subcooler lower the temperature of the CO_2 thus increasing the performance of the refrigeration system. The remaining cold in the LNG is used to chill water.

The pro with this system is the use of free cold. The system efficiency will increase. However, the fuel demand depends on the operation of the vessel, which could cause mismatch between cooling load and available cold from the regasification. Also, extra safety precautions must be in place when LNG is utilized.

3.4 PCM as a CTES in combination with LNG vessels

Another possible design to utilize the cold from LNG, is to introduce a PCM-CTES. This unit would do the same as the sub cooler, but the unit introduce a flexibility of discharging cold. This design could be suitable to pelagic fishing vessels with few and large loads, while the unit size is the limiting factor due to limited available space and weight. However, in fishing vessels with freezers, where the load profile is dominated by many, small loads, a small PCM-CTES system like this could be suitable.

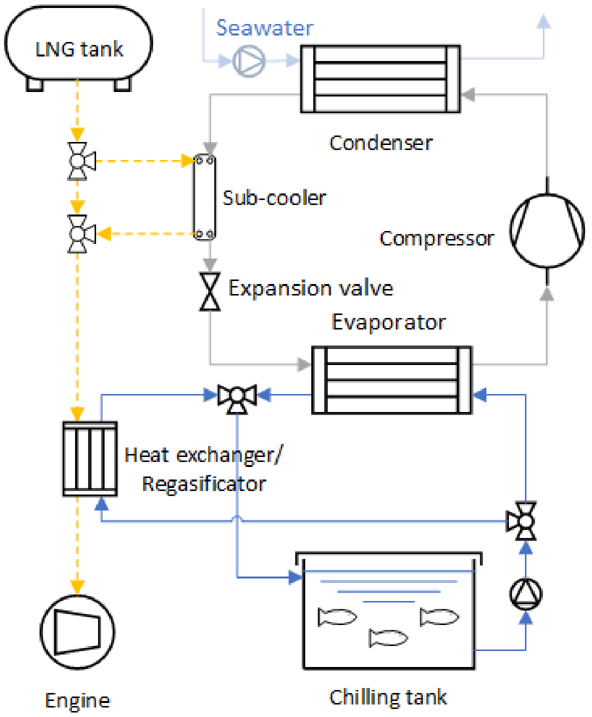

Figure 7 LNG cold utilized in refrigeration system adopted from Saeed et al., (2020a)

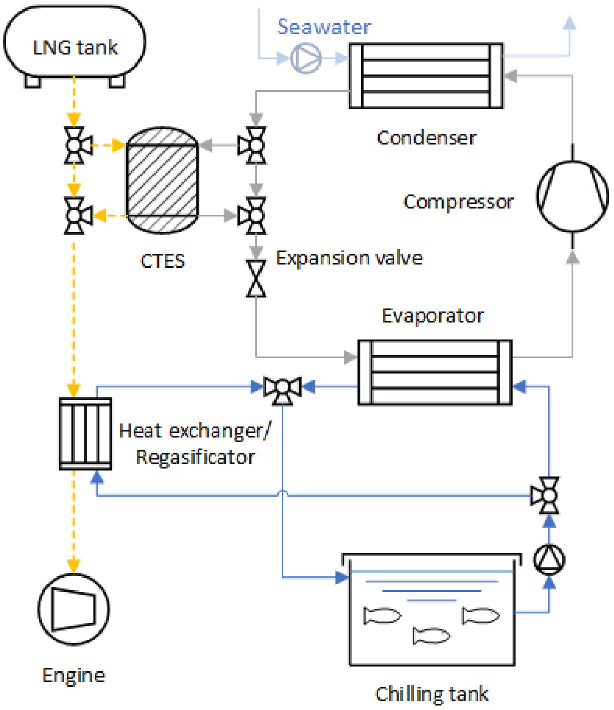

Figure 6 LNG and CTES utilized in refrigeration system

3.5 CTES for freezing applications

There are many ways to integrate a cold storage in a freezing system. With a starting point of a two stage CO_2 system show in Figure 11, the placement of the PCM-CTES could be placed in various places depending on the cooling loads and peaks. Depending on the operation of the freezing system, the temperature of evaporator in the freezer could be -30°C, or lower for faster freezing. For these working temperatures there are limited suitable PCMs, but there are some inorganic and bio-based organic products on the marked (Selvnes et al., 2021).

CO_2 is potential PCM for low temperature CTES systems. The triple point of CO_2 is at -56.6°C, 5.18 bar. Any further reduction of pressure and temperature results in CO_2 going from gas to solid (sublimation) rather than gas-liquid-solid (Hafner et al., 2011). The liquid-solid melting temperature for CO_2 is at -56.6°C for the pressure levels from 5.18 bar and higher. There is limited research on CO_2 in the phase change transition around the triple point, thus more research must be carried out before system based on CO_2 as PCM could be used.

Hafner et al., (2011) analyses the potential of CTES by applying an indirect carbon dioxide system to minimize the part load operation of the main compressor unit. The system investigated was a tunnel freezer (-30°C) for fish product using a cascade process of ammonia and CO_2. The results show a 30% reduction in power consumption by minimizing the part load operation on the main compressor. The system differs to some degree from a regular PCM (liquid-solid) CTES. During the charging process, carbon dioxide evaporates as gas or gas-solid mixture inside the tubes in the cold storage, see Figure 10. The temperature of the gas or gas-solid mixture is lower than the liquid CO_2 (outside the tubes at a higher pressure) which is used as PCM. This liquid freeze and can be used as CTES.

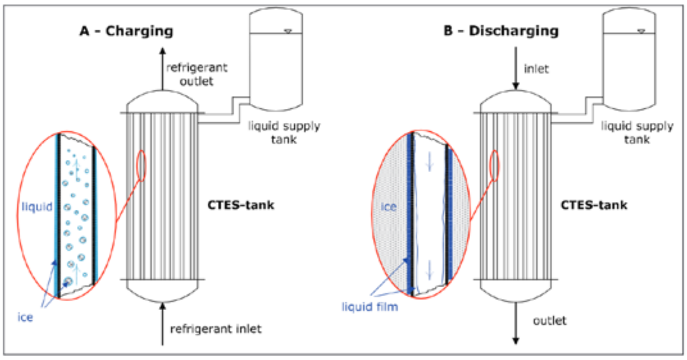

Figure 8 Schematic sketch of a CTES tank for solid CO_2 storage (Hafner et al., 2011)

Verpe et al., (2019) presented the results of a numerical and experimental study of freezing time for fish in plate freezers on board fishing vessels. The temperature range of the evaporation temperature was varied from -30 to -50 °C. The implementation of CTES and the benefits where presented. The system is a two-stage, seawater cooled, flooded evaporator, CO_2 freezer system and showed in Figure 11. The figure to the right is showing the charging and discharging process of the CTES.

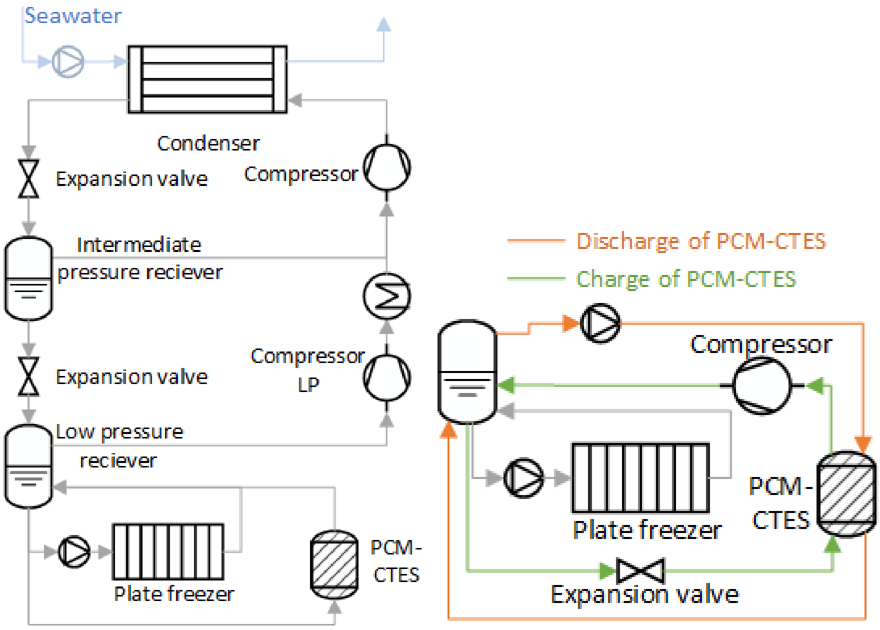

Figure 9 Two stage CO_2 freezer system with integrated CTES

Saeed et al., (2020a) also investigated an integrated CO_2 thermal storage in a two-staged CO_2 freezing system, and additionally heat recovery from the gas cooler. The simulation yields that a 50-kWh stored energy reduces the peak time from 10 to 8 minutes, which increases production capacity with 56 minutes pr day. The heat from the gas cooler was used to heat water to process rest raw materials.

4 Discussion and conclusion

This report aims to give an overview of the possibilities of CTES storage on board fishing vessels. A brief overview of different CTES systems was given, and PCM is the most promising CTES system due to the limited space availability, typical heat loads, and temperature range.

The large range of variety of fishing vessels, in size and technical complexity on board, there is not one solution that will fit all. Depending on the need of refrigeration (e.g., RSW or freezing), the working temperature varies. For desired cooling temperatures around 0°C water is undoubtedly the best PCM. With additives, i.e., sodium chloride, ethanol, ethylene glycol, and propylene glycol, the freezing point could be depressed below 0°C. Due to the availability of seawater on board and possible absorption of the binary solution in the product, sodium chloride is the best solution for depressed freezing point.

In smaller fishing vessels, the use of ice is widespread. The ice is brought from land or made on board. While there are limited possibilities for improvement in some systems, there are other system with room for optimization of the ice production, use, and peak shaving.

Ice slurry systems are discussed as a possible alternative to the use of ice. These systems bring the best from RSW- and ice based-system together. Ice slurry is pumpable, which reduces the manual handling and the energy stored is higher than RSW due to the latent heat in ice.

For fishing vessels with RSW system on board, some possible CTES systems were described. Where some systems require minor interventions and other is more complex to implement.

The use of LNG as fuel in ships is increasing, also for fishing vessels. The cold stored in the LNG could be utilized in the refrigeration system, but since the available cold does not necessary match with the demand, a CTES would be a good solution.

For larger fishing vessels, typical fish factory vessels, there are separate freezing systems on board. Possible systems with CO_2 as PCM was discussed.

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