DOI: 10.18462/iir.nh3-co2.2021.0017

# Energy consumption of ammonia refrigeration system on board a fishing vessel

**Eirik Starheim SVENDSEN[(a)*], Kristina Norne WIDELL[(a)], Tom Ståle NORDTVEDT[(a)], Sepideh JAFARZADEH[(a)], Cecilia GABRIELII[(b)]**

[(a)] SINTEF Ocean, 7465 Trondheim, Norway
[(b)]SINTEF Energy Research, 7465 Trondheim, Norway
[*]eirik.starheim.svendsen@sintef.no

## ABSTRACT

When assessing the carbon footprint of seafood from capture fisheries, the fuel use during fishing operation is the major contributor to overall greenhouse gas emissions. While the necessary shift towards low-carbon fuels and advancement in propulsion technology has commenced, also a more efficient use of energy is a key strategy for reduction of the emissions. Furthermore, leakage of high-GWP refrigerants contributes to emissions and a transition towards natural refrigerants ($NH_3$, $CO_2$) is essential. Introducing efficiency measures depends on knowledge of current performance. Due to the wide range of different fishing vessels with different on-board processing equipment and different modes of operation, the performance needs to be evaluated for each fleet segment before proper advise can be given. This paper presents energy measurement results from a research cruise conducted during autumn 2020 on a combined purse seiner/pelagic trawler. The vessel's refrigeration system was instrumented with sensors logging the electrical input to frequency converters (compressors and seawater pumps) and temperatures on the RSW side, while the vessels mode of operation and fuel consumption was logged on a regular basis during the cruise. The results provide insight on the vessel's energy flow, performance of the refrigeration system and fuel intensity of the fishing operation, which gives valuable input for design of efficiency measures.

Keywords: fishing vessel, energy efficiency, natural refrigerants, energy measurements

## 1. INTRODUCTION

Bringing high quality seafood from the sea to the dinner table requires maintenance of a low temperature throughout the cold chain, starting at the fishing vessel (Nordtvedt and Widell, 2020). There are several incentives for shipowners in fisheries to increase energy efficiency. Firstly, all onboard energy is usually generated by fossil fuel, which on a global scale amounts to 30 to 50% of operational expenditures (Parker and Tyedmers, 2015). Secondly, the use of fossil fuels is associated with large amounts of greenhouse gas emissions (Parker et al., 2018), which conflicts with the worldwide need of reducing global warming. Improved fuel efficiency and the switch from high-global warming potential (GWP) refrigerants to natural refrigerants, in particular ammonia ($NH_3$) and carbon dioxide ($CO_2$), have contributed to reducing the overall greenhouse gas (GHG) emission for Norwegian based fishing vessels the last decade. However, there is still room for improvements (Hafner et al., 2019). The first step of introducing energy efficiency measures is conducting an energy flow analysis. The aim of this study was to perform measurements onboard a fishing vessel. The vessel was a combined pelagic trawler/purse seiner with two 1020 kW $NH_3$ refrigeration systems together with a refrigerated seawater (RSW) system. Earlier studies on RSW systems have been concerned with prediction (Kolbe, 1990) and transient simulation (Thorsteinsson et al., 2003) of the chilling process, while more recent work has been focused on adapting $CO_2$ as refrigerant onboard (Brodal et al., 2018). The largest barrier against employing $CO_2$ was pointed out by Widell et al. (2016) to be the lack of industrial sized compressors This paper describes field data from relevant onboard energy systems gathered during a research cruise, and the results will generate insight for efficiency measures.

## 2. SYSTEMS AND OPERATIONAL PROCEDURES

### 2.1. Fishing vessel

The research cruise was conducted on the 67 m long combined fishing vessel Selvåg Senior equipped for purse seining and pelagic trawling. It has a Wärtsilä 12V32 main engine with an output of 5520 kW and has a load capacity of 1960 $m^3$ distributed between 9 RSW tanks. The vessel was built in 1999 and is owned by the shipping company Selvåg Senior AS.

### 2.2. RSW system

The onboard chilling system consists of two similar $NH_3$ refrigeration systems, RSW pumps, piping, and 9 RSW tanks. Valves and system layout allow for a multitude of operational combinations, e.g. only running one refrigeration system to serve all tanks. The modus operandi is that the tanks are organized in sections of three, and system 1 handles chilling loads for the mid-section, and system 2 handles load for the bow and stern sections. Water inlet to the tanks is through perforated pipes at the bottom, while outlet is through partly submerged pipes from the top. Flow direction can be reversed, which is normally done for cleaning/flushing purposes. Figure 1 shows a simplified diagram of the refrigeration system with RSW tanks.

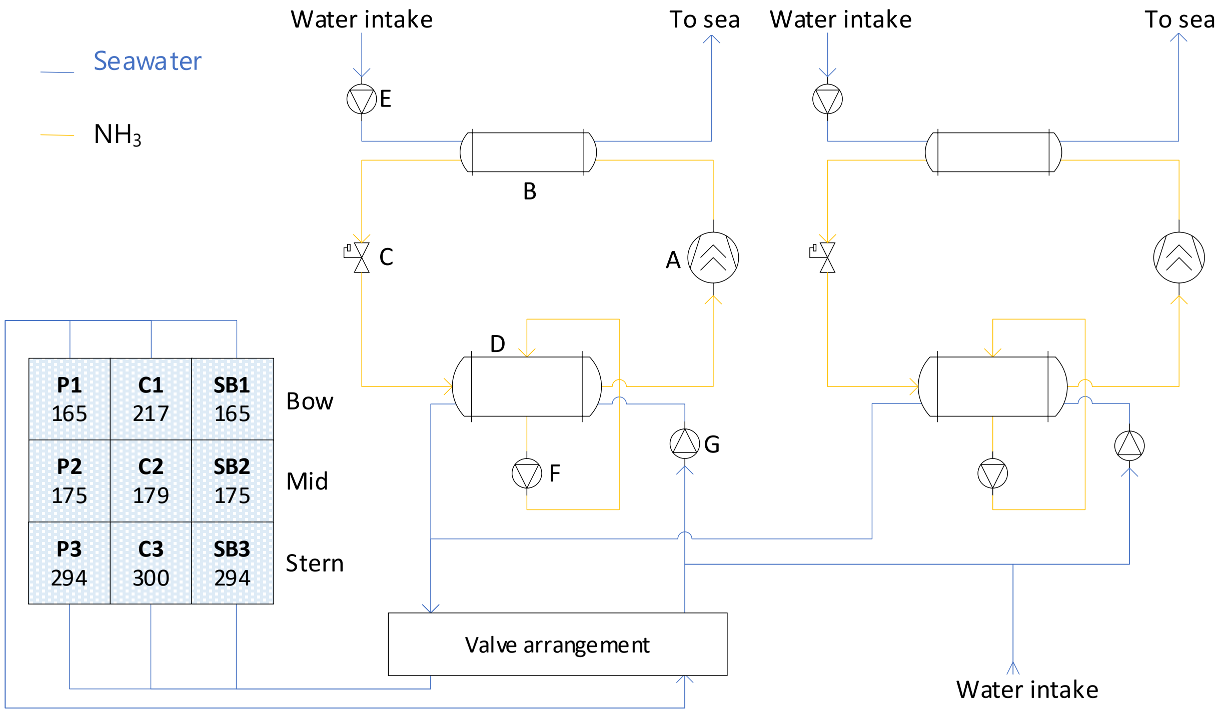


**Figure 1: Simplified diagram of the refrigeration systems and RSW tank layout. A: screw compressor, B: condenser, C: throttle valve, D: evaporator, E: condenser pump (open circuit), F: liquid refrigerant recirculation pump, G: RSW pump. Labelling of RSW tanks denote side (port, center, starboard) and section (1 bow, 2 mid, 3 stern), while numbering denote volumetric size ($m^3$) of each tank.**

Each refrigeration system consists of a Howden screw compressor with cooling capacity of 1020 kW, employing a $NH_3$ charge of approx. 100 kg. The evaporator is a tube&shell design with refrigerant on the shell side. It is equipped with a small refrigerant recirculation pump, drawing liquid from the bottom, and returning it on the top, spraying refrigerant over the tubes and thus increasing heat transfer. Amount of liquid is controlled by a floating device (high-pressure float valve), while condensation heat is handled by an open circuit seawater condenser. Two RSW pumps with each the capacity of 720 $m^3/h$ ensures circulation between the evaporators and the RSW tanks. All the compressors and pumps in the systems are controlled by frequency converters.

## 2.3. Heat loads and operation of RSW system

The heat loads for the RSW system can be divided into primarily two parts: prechilling seawater from an initial temperature ($T_1$) to target temperature ($T_3$) and chilling a mixture of fish and seawater from a mixture temperature ($T_2$) to target temperature ($T_3$) (see graph in Figure 2). The length of each period ($\tau_{1,2,3}$) depends on the amount of seawater, quantity of fish caught and capacity of the refrigeration systems. The systems must handle other heat loads due to transmission losses through the RSW walls and heat added by the circulating pumps (Kolbe, 1990). To ensure efficient and quick chilling of the catch once it is loaded onboard, some of the tanks are filled with seawater and prechilled when steaming towards fishing grounds. Once target temperature is reached (approx. -1.5 °C), refrigeration systems are switched off and not switched on again before either a) tanks are loaded with fish or b) tank temperatures rise above 0 °C. Fish is then loaded onboard to an empty tank together with the prechilled water, which in turn reduces the fish temperature and thus reduces initial heat load for the refrigeration systems. There is usually an intermission period between loading and start of refrigeration. This is partly due to the inability to run refrigeration while using the RSW system to move water between tanks, but also for some species, the fish must be allowed to settle before proper circulation can be achieved. The tanks are loaded according to a plan set by the skipper and chief, and target ratio of fish in each tank is around 40-50%.

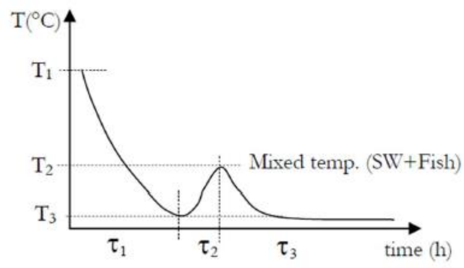


**Figure 2: Characteristic chilling curves for a RSW system showing the prechilling and chilling process. Adapted from Thorsteinsson et al. (2003)**

# 3. MEASUREMENT AND METHODS

To investigate the efficiency of the refrigeration processes onboard, the vessel has been equipped with several sensors as described in this chapter. The results from this investigation will be used as input in the design of energy efficiency measures, which will be continued in further work.

## 3.1. Instrumentation

Some instruments were already installed on the ship as part of the operational system and some instruments were installed specifically for this research cruise. In contrast to controlled lab tests, field experiments are much more challenging due to low influence on the onboard operations. The equipment used during this research cruise were selected based on earlier experience and ease to use in a safe manner.

*Energy/Power consumption*: Instant power consumption of the two compressors, two RSW pumps, two condenser pumps and two liquid recirculation pumps were logged with a 10 s sampling frequency. The loggers were installed on the frequency converters.

*RSW temperature and flow:* Stationary temperature sensors (4-20 mA) are installed on the RSW in- and outlet pipe to the evaporator, logging data every 10 seconds. These were calibrated at the start of the cruise, by comparing the sensors with calibrated handheld instruments (Testo 110 w/12 cm probe, accuracy ±0.2 K) and a thermos with ice/water mixture at 0 °C. RSW flow was measured with two already installed volumetric flowmeters mounted just downstream of the evaporator with a sampling frequency of 10 seconds.

To get an overview of the temperature distribution inside the tanks, temperature loggers were installed inside one of the tanks (P2) with a sampling frequency of 30 seconds. Two ropes with 7 loggers (HOBO Pendant Temperature Logger UA-002-64, accuracy ±0.53 K) were prepared beforehand and installed in the vertical and horizontal direction within the tank (see Figure 3). Distance between loggers on the horizontal rope was 100 cm and 66 cm on the vertical rope. The loggers were calibrated using 4 calibrated sensors (iButton DS1922L, accuracy ±0.5 K) and an ice/water mixture at 0 °C.

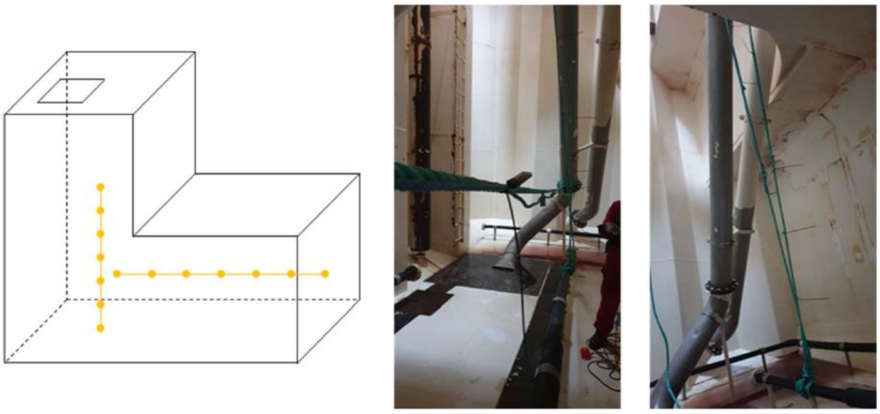

**Figure 3: Left: 3D representation of the RSW tank P2 along with arrangement of temperature sensors. Middle/right: Pictures taken within the tank showing how the ropes were attached inside the tank**

*Fuel consumption:* Fuel consumption (L, litre) was registered manually from the onboard systems at regular intervals every second hour during daytime. The system reported accumulated lifetime fuel consumption of the engine, meaning that calculation of specific fuel consumption was done by dividing the differential between two temporal points by the known distance (L/nautical mile) or period (L/hour). Documentation of the accuracy of the fuel meter was not available. It should also be noted that it is in general difficult to assess the exact consumption on marine engines. However, it was considered that the provided data gave a fair estimation of the fuel consumption.

### 3.2. Data handling and processing

A large amount of data was gathered from different sources in CSV format and analysed using MS Excel. A total of almost 1.4 million data points were gathered only from sensors in the RSW system and P2 tank. Temperature sensors on the RSW in-/outlet had a logging resolution of 0.1 K, which in this case with small temperature differences, created a large amount of noise in the temperature readings and thus the subsequent energy calculations. Therefore, the temperature data was filtered using a moving average filter with a window of 360 s (6 min). Given the large logging period (8 days) and small sampling frequency (10 s) this was considered to maintain the overall trends.

### 3.3. Calculations

Chilling duty of each RSW system was calculated by considering energy removal rate from the seawater in the evaporator, using Eq. (1).

$$\dot{Q}_{RSW} = \dot{V} \cdot \rho_{sw} \cdot c_{p,sw} \cdot \Delta T \ [kW] \qquad Eq.(1)$$

Where $\dot{V}$ is the measured volumetric RSW flow ($m^3 \cdot hr^{-1}$), $\rho_{sw}$ is the density of seawater ($kg \cdot m^{-3}$), $c_{p,sw}$ is the specific heat of seawater ($kJ \cdot kg^{-1} \cdot K^{-1}$), $\Delta T$ is the seawater temperature difference over the evaporator (K) and $\dot{Q}_{RSW}$ is the chilling duty (kW).

Coefficient of performance (COP) is a unitless performance indicator, which for a refrigeration process is defined as the heat removed over the power input. In this paper, two different methods are applied: $COP_{COMP}$ (Eq. (2)) was calculated by including only power input to the compressors ($\dot{P}_{COMP}$), while $COP_{TOT}$ (Eq. (3)) is calculated including power input to all the pumps ($\sum \dot{P}_{PUMPS}$) in the system as well. The former is useful for comparing with other studies, as this is the common calculation method, while the latter gives a more accurate description of the efficiency of these refrigeration systems.

$$COP_{COMP} = \frac{\dot{Q}_{RSW}}{\dot{P}_{COMP}} \ [-] \qquad Eq.(2)$$

$$COP_{TOT} = \frac{\dot{Q}_{RSW}}{\dot{P}_{COMP} + \sum \dot{P}_{PUMPS}} \ [-] \qquad Eq.(3)$$

The amount of fuel ($Fuel_{REF}$) used to provide electrical power for the refrigeration systems was estimated using data describing specific fuel consumption (sfc) of the engine and measured energy consumption by the refrigeration systems. Knowing the total fuel consumption of the vessel for the relevant periods, the share can be calculated from Eq. (4).

$$Fuel_{REF} = \frac{E_{REF} \cdot \frac{sfc}{\rho_{fuel}}}{FC_{TOT}} \cdot 100\% \ [\%] \qquad Eq.(4)$$

Where $E_{REF}$ is the energy consumption of the refrigeration system (kWh), $FC_{TOT}$ is total fuel consumption for a trip, $\rho_{fuel}$ is the density of fuel (marine gas oil, MGO) and $Fuel_{REF}$ is the share of fuel used by the refrigeration system.

Fuel use intensity (FUI) is an efficiency indicator that describes how much fuel is used to catch and transport one unit of fish, and was calculated from Eq. (5).

$$FUI = \frac{FC_{TOT}}{m_{fish}} \left[\frac{L\ fuel}{kg\ fish}\right] \qquad Eq.(5)$$

Where $FC_{TOT}$ is the total fuel consumption for a trip (L) and $m_{fish}$ is amount of fish (kg).

## 4. RESULTS AND DISCUSSION

The research cruise lasted from 29$^{th}$ of September to 6$^{th}$ of October 2020 and included two trips to fishing grounds south-south east of the Shetland Islands. The first trip lasted 54 hours, covered a distance of 478 nautical miles and resulted in one catch of 187.6 tonnes of Atlantic mackerel (*Scomber scombrus*). The second trip lasted 56 hours, covered 488 nautical miles and resulted in two catches with a total size of 621.8 tonnes of Atlantic mackerel.

Measured and logged data has been divided into 6 cases for the following analyses: 3 prechilling cases and 3 chilling cases. Furthermore, a distinction between initial chilling and maintenance chilling has been made for the chilling cases. Power readings data showed that the compressor was the main energy consumer, having shares of 75% during prechilling and 58% during chilling (of total energy consumption). The RSW pump was the second largest energy consumer, with shares of 20% during prechilling and 38% during chilling, while the condenser and recirculation pumps had a rather low and constant shares of 0-3% and 2-3%.

### 4.1. Prechilling

Table 1 describes characteristics and average values measured during the three prechilling cases. The low initial temperature of case #3 was due to some amount of the water being previously chilled and saved. The amount of heat removed from the seawater in the evaporator compared to estimated heat load calculations, gives an idea of the heat loads due to transmission losses through tank walls and heat added by pumps. The estimated heat loads were calculated using the measured initial and final temperatures for the different cases. For system 1 (#1 and #2) an additional amount of ~2 000 kWh of heat was transferred from the seawater, while for system 2 (#3) there was an additional removal of ~1 300 kWh. This accounts for about 12% to 19% of total load.

Figure 4 shows the development of the chilling duty and COP for each case. As can be seen, chilling duty and COPs start off with initially high values, but steadily decreases as water temperature decreases toward target temperature. Except for a small dip of the compressor power at the 10-hour mark, the compressor and pumps ran at constant speeds, so the decreasing COP was because of the declining temperature difference. The graphs of case #1 and #2 had similar trends of chilling duty and COP, which indicated a consistent performance of system 1. Note that the apparently lower performance in case #3 was due to a lower initial temperature level of the seawater.

**Table 1: Description and data for prechilling cases**

| Case | Description | Averages | | | |
|---|---|---|---|---|---|
| | | $\dot{P}_{sum}$ | $\dot{Q}_{RSW}$ | $COP_{COMP}$ / $COP_{TOT}$ | Measured/Estimated heat load |
| | | *[kW]* | *[kW]* | *[-]* | *[kWh]* |
| #1 | System 1 prechilling 529 m$^3$ of SW from 15.1 to -1.2 °C | 232 | 881 | 5.0 / 3.7 | 11 864 / 9 828 |
| #2 | System 1 prechilling 529 m$^3$ of SW from 14.7 to -1.0 °C | 237 | 931 | 5.2 / 3.9 | 11 633 / 9 466 |
| #3 | System 2 prechilling 630 m$^3$ of SW from 11.7 to -1.1 °C | 239 | 790 | 4.4 / 3.2 | 10 478 / 9 191 |

**Error! Reference source not found.**

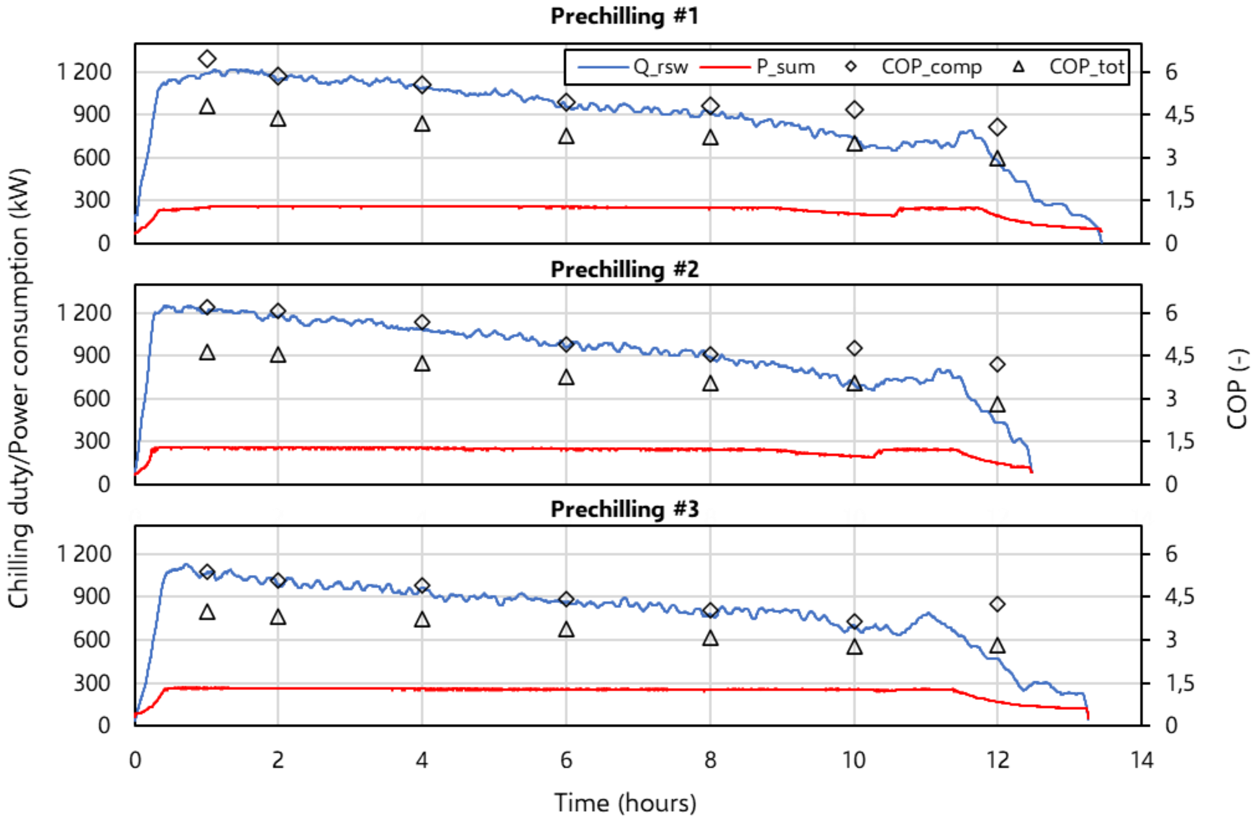


**Figure 4: Chilling duty ($\dot{Q}_{RSW}$ ), sum of power input ($\dot{P}_{SUM}$) and COP values for the three prechilling periods**

## 4.2. Chilling

Characteristics of the chilling cases are described in Table 2 along with average values for power input to the refrigeration systems, chilling duty, measured and estimated heat load, and length of period.

**Table 2: Description and data from chilling periods**

| | | | | Averages | | | | |
|---|---|---|---|---|---|---|---|---|
| **Case Description** | **Fish ratio** | $T_{MIX}$ | **Subperiod** | $\dot{P}_{SUM}$ | $\dot{Q}_{RSW}$ | $COP_{COMP}/COP_{TOT}$ | **Measured/estimated heat load** | **Length** |
| | *[%]* | *[°C]* | | *[kW]* | *[kW]* | *[-]* | *[kWh]* | *[hrs]* |
| #4 System 1, midsection | 33 % | 3.4 | Initial | 195 | 596 | 3.9 / 2.9 | 3 043 / 2 656 | 5.1 |
| | | | Maintenance | 90 | 82 | 1.8 / 0.9 | 1 436 / - | 17.5 |
| | | | *Total* | *114* | *198* | *2.3 / 1.4* | *4 479 / -* | *22.7* |
| #5 System 1, midsection | 38 % | 3.5 | Initial | 198 | 613 | 4.0 / 3.0 | 3 305 / 2 696 | 5.6 |
| | | | Maintenance | 89 | 71 | 1.6 / 0.8 | 2 533 / - | 35.8 |
| | | | *Total* | *103* | *141* | *1.9 / 1.1* | *5 838 / -* | *41.4* |
| #6 System 2, bow and stern section | 46 % | 4.8 | Initial | 222 | 670 | 3.9 / 2.9 | 6 249 / 5 253 | 9.3 |
| | | | Maintenance | 97 | 89 | 2.1 / 0.9 | 2 226 / - | 24.9 |
| | | | *Total* | *131* | *248* | *2.6 / 1.5* | *8 475 / -* | *34.2* |

For each catch there was an intermission period of about 1 hour between loading and start of refrigeration system. Given that the fish holds an initial temperature of roughly 12.5 °C, the effect of prechilling can be seen in the in the measured mixture temperatures, which is a result of fish ratio in the tanks, initial water and fish temperature and length of intermission period. The subperiods of initial and maintenance chilling have very different characteristics. The load is initially high but decreases as the temperature difference decreases. This is reflected in the average COP values between the two periods. During maintenance chilling the average load is around 71-89 kW.

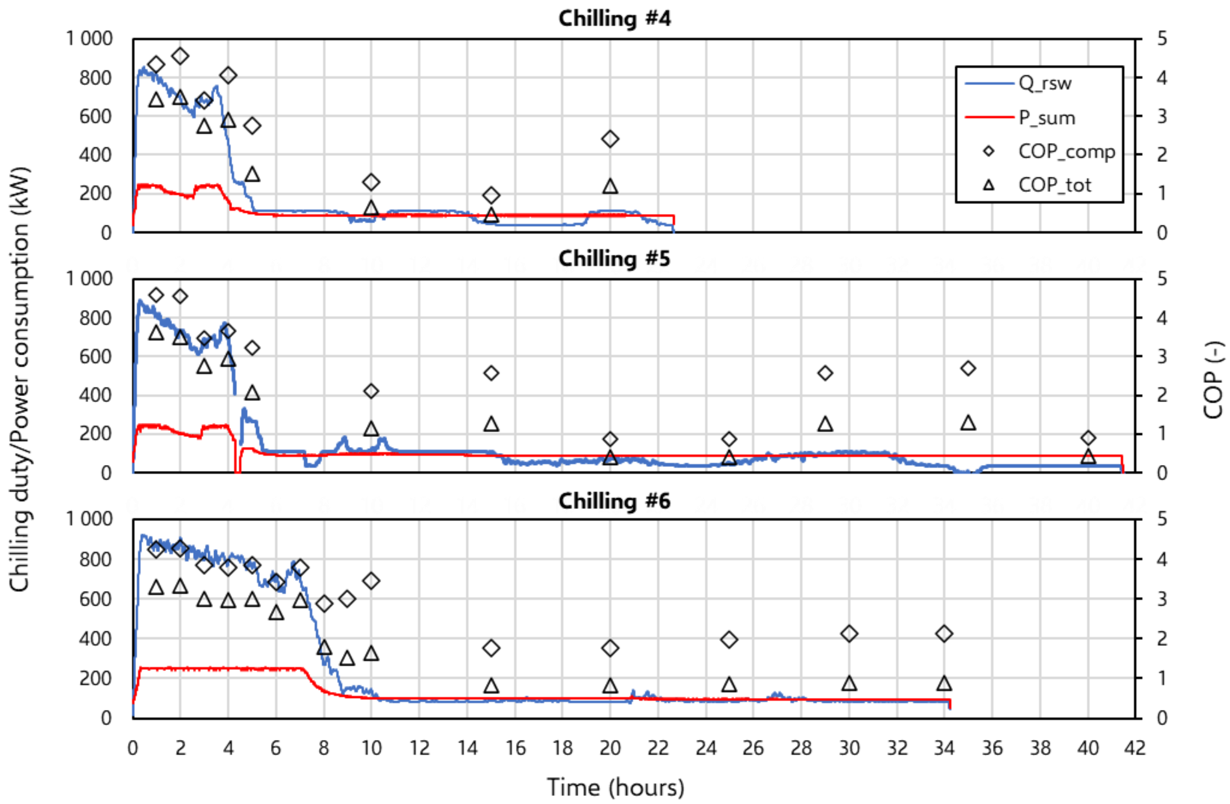


**Figure 5: Chilling duty ($\dot{Q}_{RSW}$), sum of power input ($\dot{P}_{sum}$) and COP values for three cases of chilling. The gap in case #5 curves is because the refrigeration system was switched off for a short period (unknown reason)**

The transition from initial to maintenance period can be seen quite clear in Figure 5 at the 5- and 9-hour mark of the respective cases. The chilling duty has been reduced by 86-88% from initial to maintenance period, while power consumption of the systems only has reduced by 54-56%. Case #4 and #5 are quite similar (catches of 187.6-214.4 tonne) and has thus similar performance, albeit the period for #5 lasted longer because more catch attempts were made during that trip. Case #6 had a much larger amount of fish and water, which explains the prolonged initial chilling phase. By comparing the measured and estimated heat loads like for the prechilling cases, the losses are in a similar range, i.e. 12-18%.

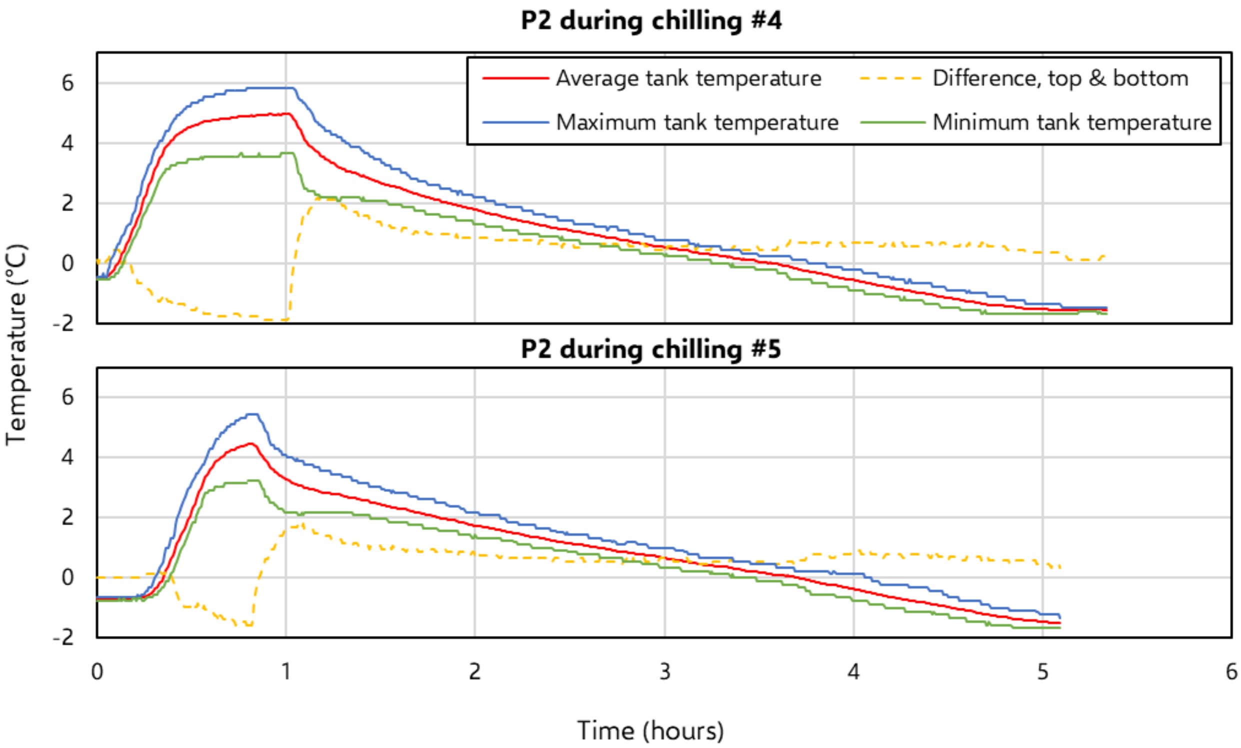


**Figure 6: Temperature development in tank P2 during chilling of fish, cases #4 and #5**

Figure 6 shows temperature development in tank P2 during chilling for cases #4 and #5. Mackerel was loaded onboard (hour 0) while refrigeration systems were off, which resulted in an increased water temperature as the fish and prechilled water moved towards an equilibrium mixture temperature. The plateau that can be seen in case #4 was due to a prolonged intermission period, since this tank was loaded first (refrigeration started after all fish was loaded onboard). For case #5 refrigeration started almost immediately after loading since it was the last tank being loaded, and thus lacks the plateau. The yellow dashed curves show the temperature difference between the topmost and bottommost sensor. During loading and intermission, the negative values indicated that the bottom layer was warmest. This was expected, since the warm mackerel, lacking a swim bladder, sinks straight to the bottom and the tank is filled in the upwards direction. When the RSW circulation started there was an immediate decline of temperature which continued until target temperature was reached. Simultaneously the top-bottom-difference reversed, as cold water was bottom-fed to the tank. The largest temperature difference within the tank during the whole period was right above 2 K, which fell to almost 0 K when transitioned into maintenance chilling.

### 4.3. Overall performance

In the previous analyses it has been shown that the periods of maintenance chilling are normally the longest and those with lowest performance, i.e. low COP values. These periods account for 48-67% of each system's total operational hours, which is then reflected upon the overall performance as shown in Figure 7. The COP values are skewed towards the lower range, e.g. for system 2 during the 2$^{nd}$ trip the system runs with a $COP_{TOT}$ < 1 for over 40% of the time.

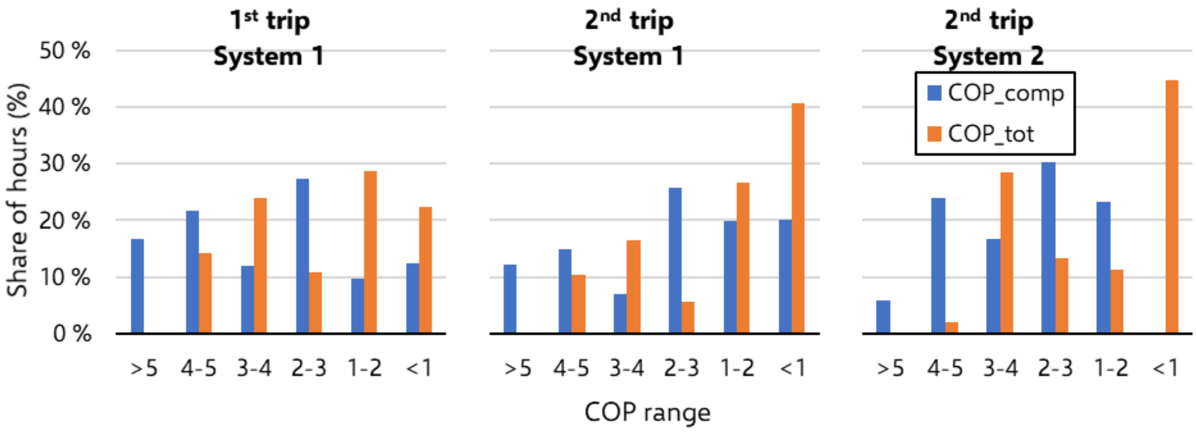


**Figure 7: Share of operational hours for each refrigeration system held at different ranges of COP**

Knowing the amount of electrical energy input to the refrigeration systems, the amount of fuel needed to generate said energy can be estimated using the specific fuel consumption (sfc) factors stated in the engine guide and calculated with Eq. (4). This factor is dependent on engine load and lacking that knowledge the estimations are based on high- and low-limits. Furthermore, it should be noted that the sfc's in engine guides are derived by running lab tests with optimum conditions, and that under real conditions they tend to be higher. The results are listed in Table 3 as mean estimates. No data was found in the literature for comparison.

**Table 3: Fuel consumption by refrigeration systems and FUI for the trips**

| | **Fuel consumption of refrigeration system** (L) | **Share of total consumption** (%) | **FUI** (L fuel/kg fish) |
|---|---|---|---|
| Trip 1, System 1 | 1362 ± 31 | 5.35 ± 0.15 | 0.136 |
| Trip 2, System 1 | 1710 ± 39 | 7.7 ± 0.2 | 0.036 |
| Trip 2, System 2 | 1818.5 ± 41.5 | 8.2 ± 0.2 | |

Fuel use intensities for each trip can also be seen in Table 3 and gives a greater picture of the overall efficiency of each trip, i.e. accounting for total fuel consumption. For comparison Winther et al. (2020) reported that the median FUI for Norwegian purse seiners were 0.09 L fuel/kg fish in 2017. It is easily observed how much the catch amount plays into the reported values.

## 5. CONCLUSION AND FURTHER WORK

A research cruise has been conducted aiming to gather relevant energy data to analyse the onboard refrigeration system energy efficiency. It has been found that high accuracy in measurement instruments is important when measuring temperatures at the evaporator due to large flows and small temperature differences. Analysis of the refrigeration system showed that prechilling of seawater accounted for the largest part of the heat loads. The performance of the system was also greatest during prechilling, with average $COP_{COMP}$'s of 4.4-5.2 for the different cases. The chilling process was characterised by initially high performance ($COP_{COMP}$ 3.9-4.9) followed by a long period of maintenance chilling at low performance ($COP_{COMP}$ 1.6-2.1). As most of the operational hours of the refrigeration system is during maintenance chilling, most effort should be put into increasing energy efficiency for that type of operation. Additional heat loads due to transmission losses and heat added by pump work was estimated to be 12-19%. It was also estimated that each refrigeration system accounts for 5.2-8.4% of the total fuel consumption onboard, which emphasises the importance of focusing on refrigeration as part of overall improvement of energy efficiency and GHG reduction of fishing vessels. Further work will explore efficiency measures targeted at the maintenance chilling period, including the possibility of covering the chilling load during this period by cold recovery of a LNG fuelled engine.

## 6. ACKNOWLEDGEMENTS

The authors gratefully acknowledge the Research Council of Norway for the financial support for carrying out the present research [NFR project No. 294662, CoolFish].

## 7. REFERENCES

Brodal, E., Jackson, S., Eiksund, O., 2018. Transient model of an RSW system with CO2 refrigeration – A study of overall performance. International Journal of Refrigeration 86, 344–355. https://doi.org/10.1016/j.ijrefrig.2017.11.002

Hafner, A., Gabrielii, C.H., Widell, K.N., 2019. Refrigeration units in marine vessels, TemaNord. Nordic Council of Ministers, Copenhagen. https://doi.org/10.6027/TN2019-527

Kolbe, E., 1990. Refrigeration Energy Prediction for Flooded Tanks on Fishing Vessels. Applied Engineering in Agriculture 6, 624–628. https://doi.org/10.13031/2013.26439

Nordtvedt, T.S., Widell, K.N., 2020. Refrigeration and sustainability in the seafood cold chain . https://doi.org/10.18462/iir.iccc.2020.314814

Parker, R.W.R., Blanchard, J.L., Gardner, C., Green, B.S., Hartmann, K., Tyedmers, P.H., Watson, R.A., 2018. Fuel use and greenhouse gas emissions of world fisheries. Nature Climate Change. https://doi.org/10.1038/s41558-018-0117-x

Parker, R.W.R., Tyedmers, P.H., 2015. Fuel consumption of global fishing fleets: current understanding and knowledge gaps. Fish and Fisheries 16, 684–696. https://doi.org/10.1111/faf.12087

Thorsteinsson, J.A., Jensson, P., Condra, T., Valdimarsson, P., 2003. Transient simulation of refrigerated and chilled seawater system. Proceedings of SIMS 2003.

Widell, K.N., Nordtvedt, T.S., Eikevik, T.M., 2016. Natural refrigerants in refrigerated seawater systems on fishing vessels. Refrigeration Science and Technology 933–940. https://doi.org/10.18462/iir.gl.2016.1156

Winther, U., Hognes, E.S., Jafarzadeh, S., Ziegler, F., 2020. Greenhouse gas emissions of Norwegian seafood products in 2017.