Newsletter September 2021

Dear CoolFish participant,

Here you will find a summary of our recent accomplishments in CoolFish as well as our plans for future work.

Webinars

We had a webinar in May about *CO_2 as a refrigerant in fishing vessels* with these presentations:

- Kristina N. Widell (SINTEF, Norway): Introduction to CoolFish and other related projects
- Leif Grimsmo (SINTEF, Norway): Fishing vessels, technology, and methods in Norway
- Malikayil Vijayan Baiju (CIFT, India): Fish storage in commercial fishing vessels of India
- Alexander Pachai (Johnson Control, Denmark): Cascade refrigeration system with NH3 and CO_2
- Yves Ladam (PTG, Norway): Examples of CO_2 refrigeration systems installed onboard
- Thomas Lund (Danfoss, Denmark): Components and controls for CO_2 HVAC&Ref systems
- Terje Nybø (Ullstrøm Fepo AS, Norway): Compressor solutions for the natural refrigerant R744 (CO_2). Availability and development.

We plan to have several shorter webinars in the project. The topics and contents are not finally in place, but here is an overview of our suggestions:

- Thermal energy storage on fishing and passenger vessels – joint webinar with CruiZE and PCM-store projects (Okt/Nov)
- LNG as fuel in fishing vessels
- Integration of cooling and heating onboard fishing vessels

We plan to have the webinars in English and invite participants from other projects and countries as well. If anyone has suggestions for presentations or topics, please contact us.

We will set up physical meetings when it is safe to meet again.

The presentations from earlier webinars are available on the webpage of CoolFish:
www.sintef.no/en/projects/coolfish

Industry cases

We are well into the work of our four industry cases:

Case 1: Energy efficiency on board fishing vessels

We are planning a research cruise with the freezer trawler Ishavet during the autumn. The purpose is to measure the energy flows onboard, with special focus on the refrigeration system. The research cruise will this time be conducted without researchers onboard, but data will be collected and analysed later.

Case 2: Design concepts for cold utilization from LNG driven ships

Based on previous work in the project, we have identified a possible utilization of the "free" cooling which can be available from LNG fuelled fishing vessels. There seem to be a good correlation between the cooling load of the RSW system during maintenance cooling and the amount of available cooling from the LNG. This will be further evaluated by simulation models in Dymola.

Case 3: Freeze concentration

Since spring 2021 NTNU had activities in production of hydrolysate and low temperature concentration:

- 3 students were hired for a summer job
- Production of hydrolysates was conducted in lab-scale from rest raw materials of white fish (heads and backbones 50%50)
- Hydrolysates were filtrated with different filtering methods.
- Differential scanning calorimeter (DSC)/viscosity determination methods were applied to check the properties of hydrolysates
- Freeze-concentration and vacuum concentration methods were applied to filtrated hydrolysates: -1.1^{o}C, 6 L volume, duration 0.5-1.0 hours.

Figures 2 and 3 shows results of experiments.

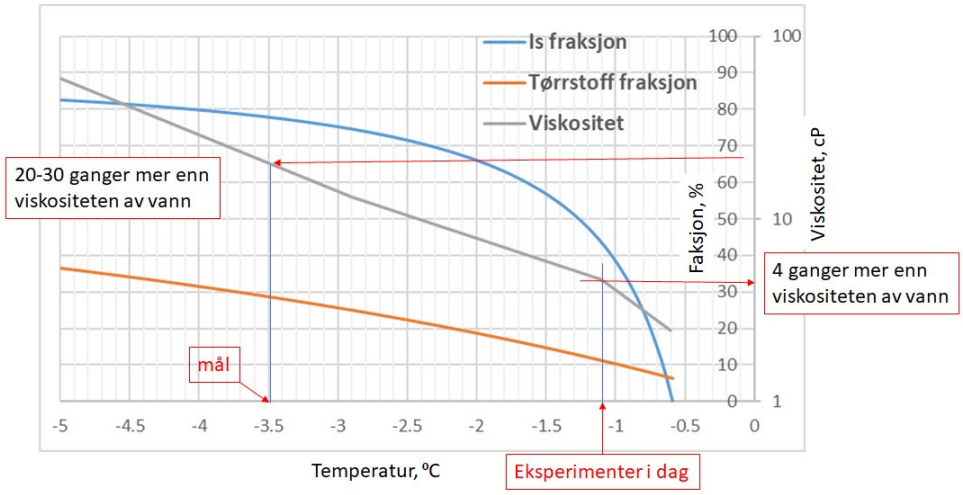


Figure 2: Boundaries for freeze-consentration:- max 30 % solids, max 20-30 cP viscosity

Figure 3: Example of freeze-concentrate hydrolysate (12%) and separated ice (left) and vacuum concentrated hydrolysate (25%) (right)

Conclusion: Freeze-concentration and vacuum concentration are the best methods for sustainable production of concentrated hydrolysates.

Case 4: Design concepts for *integrated thermal energy units*, for cooling and heating

The progress of work related to designing the thermal energy unit is presented here. The primary role of this unit is to cool the seawater (RSW). Besides, it has the capability to fulfil other cooling demands like room cooling and freezing. As reported earlier, the major components for this thermal energy unit have been purchased by MMC. NTNU, in collaboration with SINTEF, has assisted in planning and designing the system.

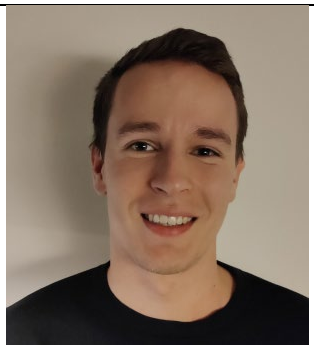
This proposed thermal energy unit will use CO_2 as a working fluid. This unit has three parallel compressors connected to three different pressure levels through flexible valve connections. This solution is adopted to achieve higher energy efficiency. Based on this proposed unit, theoretical studies have been carried out. The thermodynamic models are developed in EES (Engineering equation solver), while the system level models are developed in Modelica for dynamic simulations. This study is carried out considering five different configurations to investigate the use of different throttling options, the use of parallel compressors, and the use of ejector. The results are reported in the master thesis submitted by Pavel Semaev. Results show that the use of ejector and the use of parallel compressors provide superior performance with highest system COP (=3.6). In addition, suitable control strategy is presented to regulate the high-side pressure and cooling capacity to optimize the system performance during operation. Based on these findings, an article is prepared and presented in IIR Ohrid conference 2021.

The theoretical results are helpful in fabricating the right configuration for the proposed thermal energy unit. In this unit, a novel method of using gravity-fed evaporators is introduced to enhance the system performance. The benefits of using gravity-fed evaporators are presented in the theoretical study. These evaporators omit the drawbacks of thermostatic expansion valve and operate independently irrespective of high-side pressure. In addition, better heat transfer and lower pressure drops are achieved during evaporation. However, the theoretical study, carried out before, has limitation with respect to the prediction of the optimum dimensions for gravity-fed evaporator loop. To fulfil this gap, a theoretical model has been developed in EES and then a detailed model has been developed in Modelica for the gravity-fed evaporator loop. To validate the mathematical model, experimental loop for gravity-fed evaporator is fabricated in an existing CO_2 test-rig at NTNU. Next, experimental, and numerical studies will be carried on this gravity-fed evaporator loop. The objectives will be to investigate the effect of loop dimensions and loop arrangements on the performance of the loop. Finally, the optimum dimensions of the loop will be predicted to design optimized gravity-fed evaporator loop. These results will be used in developing optimized gravity-fed evaporator loop in the proposed thermal energy unit.

Based on the experimental and theoretical results obtained for gravity-fed evaporator loop, two articles will be prepared for IIR-Gustav Lorentzen 2022 conference.

Master students

Master student Pavel Semaev finished his master thesis in June. The title of it was “Energy efficient CO_2 refrigeration units for fishing vessels” and it will be available on the project's webpage. The abstract of the thesis is attached to this newsletter.

Muhammad Umar Khan Task: Design and analysis of freeze-concentrator for processing of fish protein hydrolysate	
Prem Kumar Sherman Task: Sustainable production of fish protein hydrolysates: Overall system architecture and footprint	
Zakaria Hajjem Task: Performance investigation of CO_2 heat pump and refrigeration system for hydrolyzation & freeze concentration processes	
Jomar Mandal Leth-Olsen Oppgave: Design of CO_2 heat pump and refrigeration system for hydrolyzation & freeze concentration processes	

We will also recruit master student for CoolFish activities via the project INDEE+, which officially started 1.9.2021, ensuring that we meet the tasks set in the project description. These students are a resource not only for NTNU, but for all partners of the project, since it gives a unique opportunity to follow next generation engineers in their last phase of the master program, with the potential for hiring them as new colleagues.

Reports, publications and visibility

We have published the report "Equipment and systems onboard fishing vessels" which gives an overview of different types of fishing vessels in Norway including equipment and fishing and fish handling methods. It also includes information about energy efficiency, sustainability, and traceability.

We are writing a report on Traceability. The report reviews current methods of data capture and information exchange in the fishery supply chain in Norway. Detailed data on catch, including date, time, area, and quality, are registered electronically on the fishing vessels. Only parts of this information reach the consumers. Significant data gaps include the fuel and energy consumption over the supply chain, as well as detailed transport routes of the fish product from catch to fork.

The conference *Phase-Change Materials and Slurries for Refrigeration and Air Conditioning* was held online 1-3 September.

- Zahid had a presentation and a paper about *Thermal Energy Storage with PCM for Refrigerated Sea Water System of Fishing Vessels*, co-authors were Kristina, Armin, Eirik and Tom Ståle.

The conference *Ammonia and CO_2 refrigeration Technologies* was held online 16-17 September. This conference is normally conducted every second year in Ohrid, North Macedonia. We had two presentations within the project:

- Eirik has presented a paper with the title "Energy consumption of ammonia refrigeration system on board fishing vessel". It includes results from last year's research cruise with Selvåg Senior. Authors on this paper were Eirik, Kristina, Tom Ståle, Sepideh and Cecilia.
- Engin presented the paper " Simulation of a carbon dioxide (R-744) refrigeration system for fishing vessel ", which is based on the work that was conducted by Pavel Semaev during his master. Authors were Pavel, Engin, Ignat, Armin, Kristina, Thomas Lund, Jostein Øy and Jan Petter Urke.

Cecilia has started on a memo which will give an overview on how the availability and characteristics of surplus heat (and cold) is affected by new types of fuel / propulsion systems.

Next year's conferences within the topics of CoolFish are:

- Sustainability and the cold chain (11-13 April, Newcastle)
- Gustav Lorentzen conference (13-15 June)
    - This conference is arranged by SINTEF and NTNU in Trondheim and we hope many will participate.

We have been contacted by Olivia Daly from ERINN, who works together with Irish Seafood Development Agency (BIM). They are identifying the latest innovative knowledge and technology that could address key challenges and interests of the Irish fisheries sector. We had a meeting with them, where we have described the project, we have sent them reports and papers and also shared who we are working together with in the project. It is possible that other partners of CoolFish also will be contacted by them.

Previous reports are available on the project's webpage.

Information from other relevant projects

Here is some information from other ongoing projects:

CruiZE: In the KPN project CruiZE, which is led by SINTEF Energy Research (Cecilia), we work within similar topics as in CoolFish, but with a focus on hotel operations (cooling and heating) on board cruise ships. The goal is to develop energy-efficient solutions that play well together with new propulsion systems and thereby contribute to zero-emission operations in, for example, ports and fjords. Based on operational data from a cruise ship we are developing dynamic models to be able to evaluate different technologies/concepts and the interaction between them. With new requirements on "zero-

emission" we believe that thermal storage will play a key role. Examples will be presented at a joint webinar between CoolFish and CruiZE, in Oct/Nov.

INDEE+: This is a project led by NTNU where SINTEF Ocean and SINTEF Energy are also participants, together with several institutes and universities in India (more information on project webpage). The goal of the project is to develop refrigeration systems with natural refrigerants, as alternatives to those with high global warming impact. The project will have three pilot plants with CO_2 in India, for testing and education. These will be the primary demonstrator topics:

- Supermarket
- Chiller/hot water heat pump for hotel
- **Seafood refrigeration onboard fishing vessel**

PCM-Store: This is another KPN project, led by SINTEF Energy, where SINTEF Ocean and NTNU are participants. Good solutions for integration of cold thermal storages for different purposes will be discovered in this project. Phase change materials will be used, different types for various temperatures. Objectives of installing a cold thermal storage can be to reduce power peaks, reduce necessary installed refrigeration effect, and to increase the energy efficiency. Activities in the project includes to evaluate different PCM materials and their properties related to thermal storage, to find proper data models for heat exchangers and to make energy measurements at industrial processing plants. This will contribute to finding the best configurations for thermal storage for relevant industrial processes.

Zerocoast is a project that received grant from the Green Platform Initiative, and with both SINTEF Ocean and SINTEF Energi as project partners. The aim is to demonstrate that both new and existing vessels in the seafood industry can be emission free and contribute to decreasing emissions from fishery and aquaculture vessels by 50% before 2030.

Ammonia fuel bunkering network is another project with grant from Green Platform. The ambition is to develop a network of terminals facilitating use of green ammonia as maritime fuel. In this project SINTEF (with Cecilia as project manager) will develop and disseminate knowledge that will contribute to solve technical challenges and safety issues in the value chain for ammonia as a fuel in ships.

INTERPORT – Integrated energy systems in port – is a new KSP project (start-up in October) lead by SINTEF Energi (Cecilia). The aim is to develop sustainable solutions for ports as energy hubs, facilitating the uptake and use of alternative fuels, such as LNG/LBG, hydrogen and ammonia.

ENOUGH is a new project funded by EU Horizon 2020. SINTEF Ocean (Kristina) is coordinator of the project and it will start in October and last four years. The project will provide technologies, tools and methods to contribute to the EU Farm to Fork strategy to achieve climate neutral food businesses. Objectives include reducing GHG emissions by at least 50 % by 2050, increasing the overall sustainability of food systems and to provide selected innovative technological systemic solutions and their potential for uptake at EU.

Project participants

Management group

- SINTEF Ocean
- NTNU
- SINTEF Energy

Industrial reference group

- MMC First Process
- Selvåg Senior/Sørheim Holding

- Danfoss
- Øyangen
- Perfect temperature group (PTG)
- Gasnor
- Bluewild
- Isotherm Inc. (USA)

Scientific reference group

- International Institute of Refrigeration
- London South Bank University
- Johnson Controls Denmark

Project funding

- Norwegian research council ENERGIX
- Industrial partners are contributing with 20 % of total budget

We hope you are staying safe and healthy. Please do not hesitate to contact any of us if you have questions or ideas.

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