8-9 GIUGNO 2023 | POLITECNICO DI MILANO

DEMONSTRATING TECHNOLOGIES TOWARDS A CARBON NEUTRAL FOOD BUSINESS WITHIN THE ENOUGH PROJECT. THE BLAST FREEZING CASE STUDY

AUTHORS

Muhammad Mubashir Ahsan(1)*, Antonio Rossetti(2), Silvia Minetto* (3), Francesco Fabris(2), Sergio Girotto(3)

(1) Università degli Studi di Padova, Via Gradenigo, 6/a - 35131 Padova, (Italy)

(2) National Research Council, Construction Technologies Institute, Corso Stati Uniti 4, 35127 Padova (Italy)

(3) Enex srl, Via delle Industrie 7 31030 Vacil di Breda di Piave (TV), Italy

* Corresponding author: muhammadmubashir.ahsan@phd.unipd.it

ABSTRACT

The EU project ENOUGH aims at supporting the EU farm to fork sustainable strategy by providing technical, financial, and political tools and solutions to reduce GHG emissions (by 2030) and achieve carbon neutrality (by 2050) in the food industry. Technological solutions are currently under demonstration at several locations in Europe to show different actors how to limit the emissions covering different links and products along the food chain. All ENOUGH technologies use natural refrigerants to avoid direct emissions and negative impacts on human health and ecosystems. To this extent, blast freezing with very low air temperature is being demonstrated by prototyping and testing a CO_2 unit for food blast freezing. Fast freezing is assured by extremely low evaporation temperature (close to -50°C) and high air volume flow. In this paper, the performance of the system in terms of coefficient of performance and cooling power is simulated and discussed.

INTRODUCTION

Food chain is one of the main characteristics of ecological communities that has drawn significant attention in recent years, owing to its strong influence on community structure, ecosystem processes, and pollutant concentrations. A food supply chain refers to the processes involved in bringing the food from farms to the tables, mainly including production, processing, distribution, consumption, and disposal. Preserving the safety and quality of food on its way from the fields to the table is the key aspect of food chain as the degradation of food results in economic and food losses. The Cold chain refers to the set of processes that ensures this by uninterrupted sequence of events including production, storage, packaging, and distribution at the desired temperatures, which vary as a function of the product considered. From the global annual food production, 1800 metric ton needs refrigeration, and from which 526 metric ton is lost due to the lack of refrigeration *[1]*.

According to FAO *[2]*, about 70% of the energy consumption related to the food chain happens after the farm, related to processing, transportation, packaging, marketing, and consumption. On the other hand, food systems are also responsible for the 20-40 % of global greenhouse gas emissions. So, the situation demands the development of sustainable food chain that is socially, economically, and environmentally sustainable and has a neutral impact on the natural environment. Pre-cooling and freezing represent key links in the food chain, as they impact on the quality of the product as well as on the thermal load related to the next step of the chain. The quality of the product determines its commercial value and impacts on its shelf life.

The EU project ENOUGH *[3]* has the main objective of supporting the EU farm to fork sustainable strategy by providing technical, financial, and political tools and solutions to reduce GHG emissions (by 2030) and achieve carbon neutrality (by 2050) in the food industry. Technological solutions will be demonstrated at several locations in Europe to show different actors how to limit the emissions. The actions taken to reduce emissions are related to energy production and use, including thermal flow management, integration of cooling and heating by direct heat recovery, use of heat pumps and high temperature heat pumps to replace fossil fuel burners, implementation of thermal energy storage to decouple energy offer and demand and to actively interact with the grid, to the use of long -term sustainable fluids and materials, all ENOUGH technologies use natural refrigerants to avoid direct emissions and negative impacts on human health and ecosystems, and finally to improve processing and preservation conditions, so to prolong product shelf life.

Demonstrators are being developed in key points of the food chain covering different links of the chain and different products. The bast freezing, is one of the processes identified to guarantee quality and safety during the product life. Blast freezing is achieved by exposing the product to extremely low temperatures (-40°C to -30°C) to reduce the freezing time, modifying the way the ice crystals interact with the food.

In the ENOUGH project, blast freezing is under demonstration by prototyping and testing a CO_2 based refrigerated unit, which is described in the following section.

BLAST FREEZER DEMOSTRATOR

The blast freezer demonstrated below is an ultra-low temperature, CO_2 based direct expansion unit for food blast freezing. This system is commonly employed in freezing tunnels, conveyors, spirals, and similar applications. Fast freezing is assured by extremely low evaporation temperature (close to -50°C) and high air volume flow. The key objective of the system is to demonstrate sustainability by reducing energy consumption, minimizing the use of synthetic refrigerants, and enhancing the food quality by demonstrating the feasibility of a two stage CO_2 compression air to air unit system as a reliable and feasible alternative to synthetic refrigerant units. The proposed layout is presented in Fig.1.

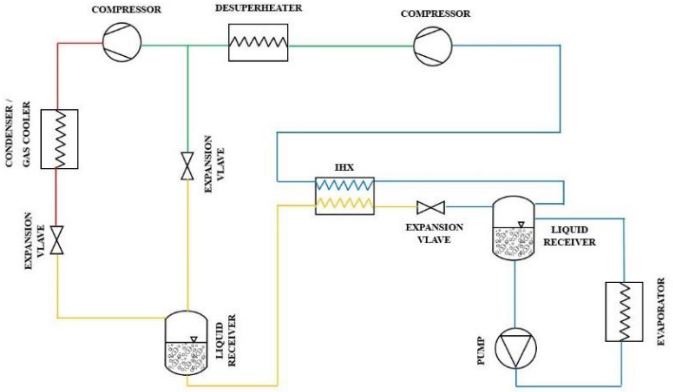

Fig. 1: Layout of two stage CO_2 compression air to air unit system

While the standard application is an air-to-air unit, the first demonstrator prototype will first focus on the low temperature stage to highlight the system dynamics and performance under these low temperature conditions. The prototype presented here then is than a water-to-water unit used to test the low temperature stage under controlled conditions.

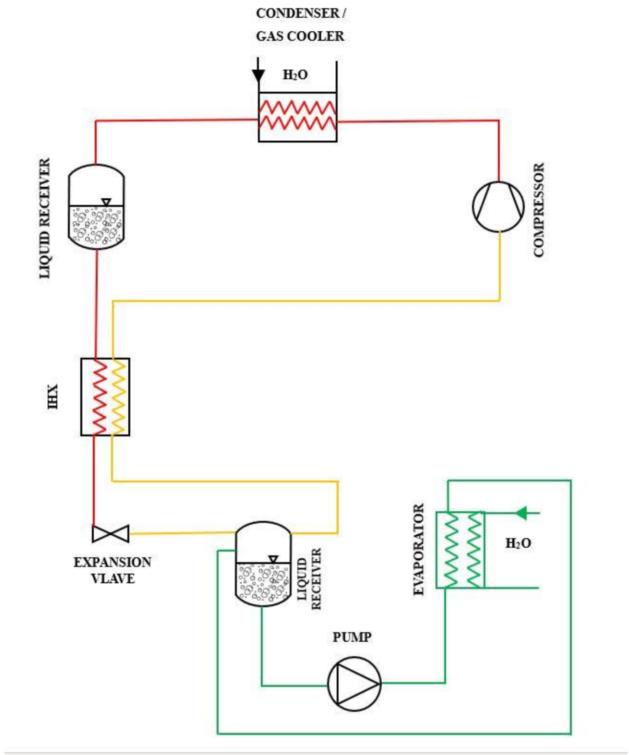

Fig. 2 (a): Demonstrator layout

Fig. 2 (b): Demonstrator prototype

The overall layout of the system is illustrated in Fig. 2 and is briefly described hereafter. The compressor used is a transcritical semi-hermetic compressor. While the low temperature stage is not expected to discharge above the critical pressure, the transcritical model was preferred to the subcritical thanks to its wider envelope. After the compressor the refrigerant reaches the condenser, which is a brazed flat plate heat exchanger consisting of 50 plates and with a nominal capacity of 6.5 kW. The secondary loop of the condenser consists of 60% - 40% ethyl glycol-water mixture that enters the condenser at -4°C. From the condenser, the refrigerant is accumulated in a liquid receiver, which helps to manage charge variations in the low-pressure side of the circuit with a maximum capacity of 15 liters and maximum operating pressure of 80 bars. The refrigerant then passes through the internal heat exchanger and is expanded through a motorized expansion valve reaching the low-pressure receiver (LPR). The valve opening is adjusted according to the reading of a level indicator in order to maintain stable the vapor-liquid free surface in the LPR. and the liquid refrigerant is then pumped from the bottom of the LPR to the evaporator which is a brazed flat plate heat exchanger with 30 plates and nominal capacity of 4.32kW, then returns into the LPR. The secondary loop of the evaporator is also 60% - 40% ethyl glycol-water mixture entering the exchanger at temperature of -25°C with an expected outlet temperature of–35 °C. From the top of the LPR the vapor is directed to the low-pressure side of the internal heat exchanger and then flows back to the compressor suction.

Secondary loop inlet temperatures on both the evaporator and the condenser are controlled by three-way valves recirculating some of the flow rate exiting the heat exchangers to the inlet. The loop is then closed on a tank kept at constant temperature of -7°C by an auxiliary chiller.

The system is fully equipped with measuring instruments, for pressure, temperature on both the refrigerant and secondary loop sides, thus allowing for operations monitoring and performances measurement.

Enex has developed the first unit at their site for the exploration of technological aspects, especially related to the ultra-low evaporation level. The actual prototype blast freezer developed is shown in Fig. 3 below. Experimental tests are expected to start in the next months.

The first tests are planned to investigate operations in the oil-liquid phase inversion range i.e., when the evaporator secondary fluid is in the range -25°C-35°C.

NUMERICAL MODEL

Based on the actual demonstrator unit built by Enex, an equivalent numerical model of the unit has been developed by using Simcenter Amesim *[4]* and is shown in Fig. 3 below.

The numerical model includes the main components of the refrigeration unit and the secondary loop as well as the main control system actuation the refrigerant high-pressure valve and the three-way valves on the water secondary loops.

The software offers libraries to model the dynamic behavior of both refrigerant and secondary fluid flows. The model includes both mass flow devices (compressor, pump, and expansion valve) and energy flow devices (heat exchangers); the mass flow devices were modeled by steady-state empirical equations, while for evaporator and condenser a discretization approach was adopted, divided them into lumped parameters elements. The compressor is characterized on the basis of the manufacturer's performance maps, while the heat exchangers have been set up on the basis of their geometrical features. The resulting numerical model is then fully capable of realizing the actual operating conditions in both steady and dynamic condition.

The final goal of the model will be the description of the dynamic behavior of the system, with transient operation conditions when the system is switched on to perform pull downs, as well as when the system is operating in on-off cycling. Such a model also offers the possibility to test control strategies.

At this stage, the numerical model is used in this work to map the expected performance of the units under different operating conditions, to verify the actual sizing of components through the entire application field as well as to identify potential critical components.

RESULTS

The coefficient of performance (COP) and Cooling Power are plotted as a function of evaporation temperature between the temperature range of -50°C to -33°C as shown in Fig. 4. Figure 5 reports instead the expected inlet and outlet temperature on the water loop. The numerical model was also useful to test the sizing of the pump recirculating the liquid CO_2 on the evaporator, confirming that the flow rate is sufficient to maintain the evaporator flooded for all the tested conditions.

As the first unit has already been built by Enex and is ready for the experiments, the numerical results would be validated with the experimental results in upcoming months and design and parametric optimization would be performed accordingly to achieve the best performance.

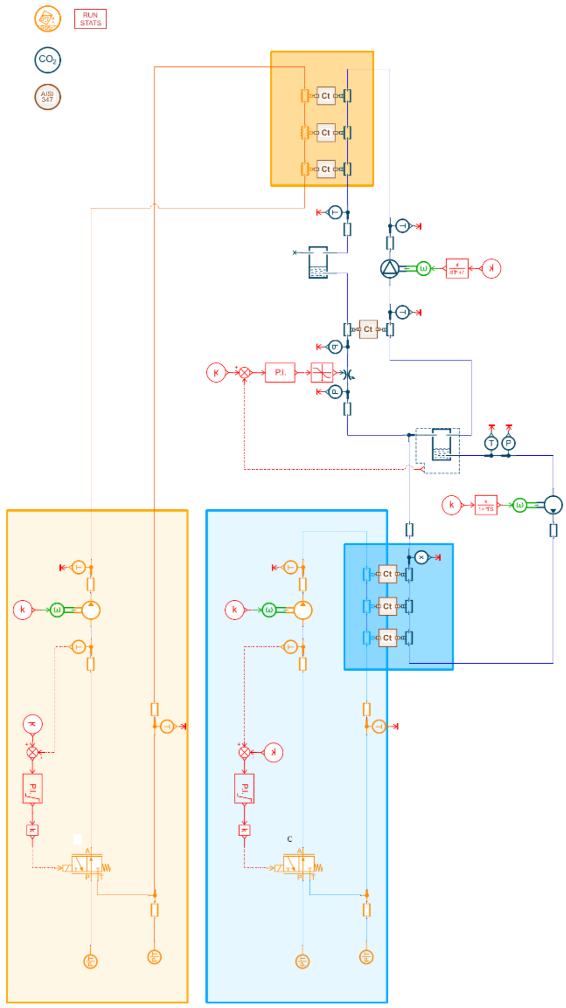

Fig. 3: Numerical model of demonstrator

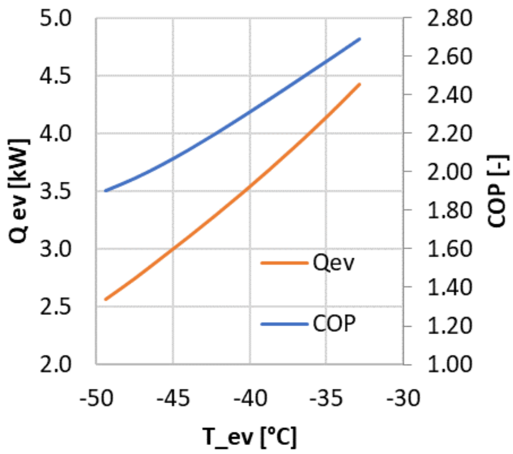

Fig. 4: Cooling Power and COP vs T_{evap}

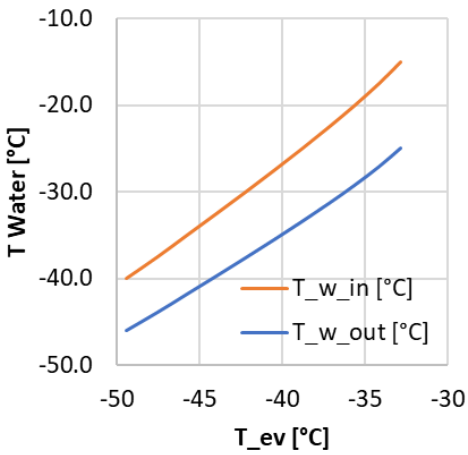

Fig. 5: Water temperatures vs T_{evap}

ACKNOWLEDGEMENTS

The activity described in this manuscript has been performed within the project ENOUGH. ENOUGH has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101036588.

REFERENCES

1. https://iifiir.org/en/fridoc/the-carbon-footprint-of-the-cold-chain-7-lt-sup-gt-th-lt-sup-gt-informatory-143457.
2. https://www.fao.org/news/story/it/item/146971/icode/
3. https://enough-emissions.eu/
4. https://plm.sw.siemens.com/en-US/simcenter/systems-simulation/amesim/