Refrigeration System Based on Natural Refrigerants for Fish Processing

Dr. Arun B.S[a], Mr. Sumit Kumar[b], Dr. Murali, S[a]

[a]Engineering Section, ICAR-CIFT, Cochin, Kerala - 682029

[b]School of Energy Science & Engg., IIT Kharagpur- 721302

E-mail: bsarun.indee.cift@gmail.com

Introduction

Refrigeration plays a vital role to ensure quality and safety of fish. In a tropical country like India, the fish processing industry has relatively larger cooling load throughout the supply chain due to higher temperature differences between ambient and chilled fish. The cooling demands in a fish processing plant are typically at four different temperature levels. Supply of chilled water at 2°C, ice at -5°C, cold storage maintained at -25°C, and a plate or blast freezer at -40°C. Commonly a multi-evaporator multi-stage refrigeration system with refrigerants like NH_3, R404A, or R22 are used in India. However, R404A, and R22 have harmful effect on environment due to their high GWP. Instead, an all-natural CO_2-NH_3 cascade refrigeration system with multi-evaporators for different temperature can be used in fish processing. Moreover, the cascade refrigeration system has the highest coefficient of performance.

The concerns regarding high ozone depletion potential (ODP) and high global warming potential (GWP) from various synthetic refrigerants were proposed to be mitigated through their restricted usage under the Montreal and Kyoto Protocols. Long term alternatives are natural refrigerants or refrigerants with nearly zero ODP and low GWP. However, these options need to be extensively tested for various applications to establish their suitability and overall impact on environment. Over the years, the design of refrigeration systems and components has undergone considerable improvement leading to enhancement in their efficiency, safety and durability. There are significant environmental and economic benefits of using low GWP alternatives and to explore possible design changes to suit the demand. Several studies have been reported about use of low GWP refrigerants for specific applications, some of them also highlighted concerns about their limitations, the technology readiness level and safety issues.

India is a prominent producer and exporter of fish and expects to improve supply chain infrastructure to support potential growth in this field. Fish require low temperature to be maintained throughout the supply chain in order to reduce food losses and to ensure food quality. The temperature requirements are varied. For example, the fresh harvest is maintained near 0°C with ice slurry, while quick freezing of processed seafood requires deep freezing at -40°C and for long term storage and reefer transport, maintaining temperature around -20°C is recommended. The energy demand in refrigeration during processing and long-term storage accounts for about 50-70% of total energy consumption in the seafood cold chain. In India, most of the seafood processing sites are located near the coastal areas which also have ambient conditions around 35°C for a prolonged duration in a year. In such operating conditions, two-stage vapor compression refrigeration systems are mostly deployed to cater the cooling demands matching the high compression ratio. Most of the seafood processing industries in India use NH_3, R404A and R22 as refrigerants. NH_3 is one of the most abundantly used refrigerants in industries due to its high efficiency and low cost. NH_3 also have zero ODP and GWP. However, there are some limitations of using NH_3 as a refrigerant. Since the normal boiling point of NH_3 is -33.4°C, therefore, the saturation pressure of NH_3 is lower than atmospheric pressure when used as refrigerant below this temperature. Seafood industry have refrigeration demand below -40°C which results in an increased risk of intake of non-condensable fluids such as air, water etc. into the system. The compressor performance can be reduced due to requirement of higher compression ratio and increased volumetric displacement. The toxicity and flammability of NH_3 also add to the restrictions of usage in proximity with food and operation in highly populated areas.

Table 1 List of selected refrigerants and ODP, GWP

Name	Type	ODP	GWP
R12	CFC	1	10900
R22	HCFC	0.055	1810
R404A	HFC	0	3922
R410A	HFC	0	2088
R134a	HFC	0	1430
R32	HFC	0	675
R1234yf	HFO	0	4

R1234ze	HFO	0	6
R717	Natural	0	0
R744	Natural	0	1
R290	Natural	0	3

A method of reducing hazards is to use NH_3 in the higher end of a cascaded refrigeration systems. This arrangement potentially reduces amount of NH_3 charge in the system, uses the fluid in the temperature range in which its performance is better and also isolates NH_3 from proximity to food being processed. While the other commonly used refrigerants R404A & R22 have high GWP and are better to be replaced with alternative refrigerants. Cascade refrigeration system has NH_3 in high temperature circuit (HTC) and CO_2 in low temperature circuit (LTC). CO_2 has high volumetric refrigeration capacity and better heat transfer properties resulting in compact system and high heat transfer rates in heat exchangers.

1. Natural refrigerants

Natural working fluids do have favourable thermodynamic and fluid properties enabling energy efficient refrigeration system configurations. In addition, their environmental impact is well known, and safety standards are established. R717 (ammonia, NH_3; GWP = 0) has been used as a refrigerant during the last 140 years and is still widely used, especially for large industrial plants for food processing. It has neither a global warming potential nor does it deplete the Ozone layer. Because R717 has low molar mass it can have much higher particle velocity than all other refrigerants and therefore small pipe sizes can be used. It is important to avoid copper components, because R717 and water will corrode copper, zinc and their alloys. R744 (carbon dioxide CO_2; GWP = 1) is a working fluid in refrigeration systems since the late 19th century. It disappeared from marine applications in the 1950's mainly due to technical difficulties and the introduction of synthetic working fluids, operating at lower working pressures. R744 is the only non-flammable working fluid classified as A1. R744 is non-toxicity and will not be restricted under the Freon gas regulation. R290 (propane, C_3H_8; GWP = 3) is an example of another group of natural working fluids, the hydrocarbons. It has a very low GWP. Systems with R290 have been in operation globally for many years.

The major disadvantage is the high flammability and classified as safety group A3.

2. Ammonia-CO_2 Cascade refrigeration system for deep freezers

CO_2 refrigeration system was first very popular from 1920 to 1930. Last recorded installation was in 1955. First NH_3-CO_2 cascade system installed in a seafood processing industry was in 2001. Cascade systems are a solution for industrial freezing applications. The efficiency of the cascade system reduces the energy consumption. The performance of the system at low temperatures increases the daily frozen capacity.

Currently ammonia (VCR) systems are commonly used in seafood industries in major coastal cities like Cochin. Fig. 1 shows the schematic of a simple ammonia refrigeration system consisting of compressor, condenser, expansion device and evaporator.

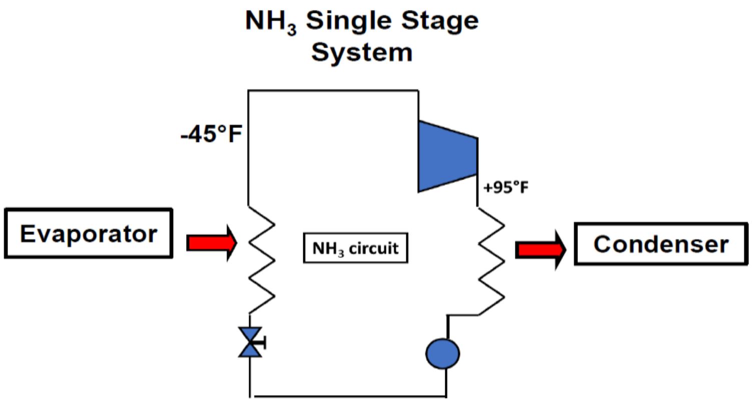

Fig. 1 NH_3 single stage refrigeration system

The reason to choose cascade system for seafood refrigeration is because CO_2 is a green, natural refrigerant and is about 10 times denser than NH_3 and Freon refrigerants. It has improved power and efficiency with freezer temperatures -20°C compared to two stage NH_3 refrigeration systems. CO_2 can be used as low as -50°C evaporator temperature maintaining pressure above atmospheric pressure. It require smaller engine rooms, smaller wet and dry suction lines and discharge lines. On the other hand, low ammonia charge is required for the cascade system and the ammonia unit can be isolated to the engine room.

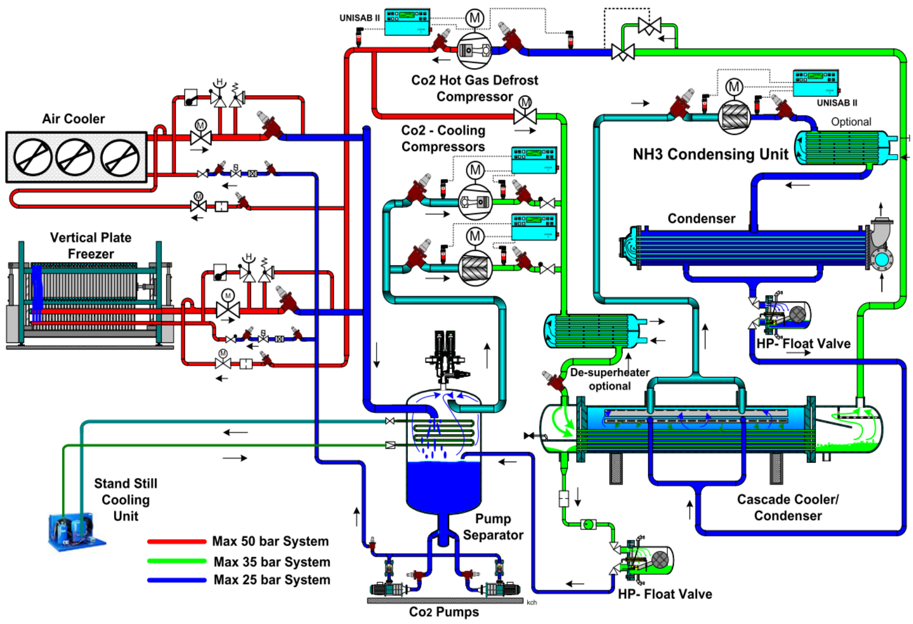

Fig. 2 Example of an R-717/R-744 cascade system for a marine application (Pachai, 2017)

NH_3 cycle (on the right hand side): The high-pressure NH_3 is sent from the screw compressor to the condenser via an optional de-superheater. The NH_3 is condensed as heat is rejected to the cooling water circuit. The liquid NH_3 is expanded by the HP-float valve (expansion device) to the evaporation pressure of the cascade heat exchanger in which NH_3 gains heat and evaporates. The evaporated NH_3 condenses the vapour CO_2 of the low-temperature stage and returns back to the NH_3 screw compressors.

CO_2 cycle (on the left hand side): The CO_2 compressors (screw- and piston type) maintain the pressure/temperature level inside the CO_2 separator. The HP-float valve of the CO_2 circuit supplies the liquid CO_2 to the separator. Pumps are circulating the liquid CO_2 to the various expansion valves where the liquid CO_2 is further throttled to the low temperature level of the air cooler and freezers. The fish products are cooled by the air coolers (storage) and vertical plate freezers (freezing of blocks). A dedicated CO_2 hot gas defrost arrangement is implemented with a separate CO_2 compressor (shown on the top) utilizing vapor of the cascade condenser to deliver heat towards the air coolers and the freezers when defrost or a release of the frozen block is required. A small capacity stand still cooling unit maintains the pressure level inside the CO_2 loop in case of standstill of the main unit by re-condensing the boil-off CO_2 vapour.