Natural refrigerants and heat exchanger applications

As the demand for green energy increases so does the need for natural refrigerants and heat exchangers to accommodate their operation. This article discusses examples of real applications for Pillow Plates and natural refrigerants. Using Pillow Plate heat exchangers with natural refrigerants for large-scale heating and cooling cuts down on the use of CFCs (Chlorofluorocarbons) and reduces environmental impact. This article will explore a few different types of Pillow Plate heat exchangers and how they have been used in conjunction with natural refrigerants.

By Robert du Pree, Sales Engineer at Omega Thermo Products B.V. & Chelsey Kemper, Sales Engineer at Omega Thermo Products LLC

Regulations

Over the last few decades, synthetic refrigerants such as CFCs and HCFCs are being phased out by regulation. In the U.S. the Environmental Protection Agency (EPA) regulations issued under Sections 601–607 of the Clean Air Act phase out the production and import of ozone-depleting substances (ODS), consistent with the schedules developed under the Montreal Protocol. In stages, the U.S. phaseout has reduced the amount of ODS that may be legally produced or imported into the country. The Montreal Protocol is a global agreement designed to stop the production and use of refrigerants that deplete the ozone layer in an effort to protect it. The Parties to the Montreal Protocol have changed the phaseout schedule over time through adjustments and amendments. The EPA has accelerated the phaseout in the United States under its Clean Air Act authority. Within the EU, ozone-depleting substances are covered by Regulation (EC) No 1005/2009 (known as the ODS Regulation). The EU ODS Regulation is more stringent than the rules of the Montreal Protocol and also encompasses additional substances.

https://www.epa.gov/ods-phaseout/what-phaseout-ozone-depleting-substances
https://www.state.gov/key-topics-office-of-environmental-quality-and-transboundary-issues/the-montreal-protocol-on-substances-that-deplete-the-ozone-layer
https://ec.europa.eu/clima/sites/clima/files/docs/montreal_prot_en.pdf

Ozone-depleting substances are harmful to the ozone layer of the atmosphere. The ozone layer serves an important function in protecting life on Earth as it absorbs the sun's ultraviolet rays, which can pose a danger to the environment and human health.

Use of heat pumps for district heating with seawater and R-1234ze(e)

Heat to power applications such as heat pumps are an exciting possibility to provide power markets with a massive power supply. Heat pumps have been installed throughout the world over the course of the last century. Especially now that the world is looking for

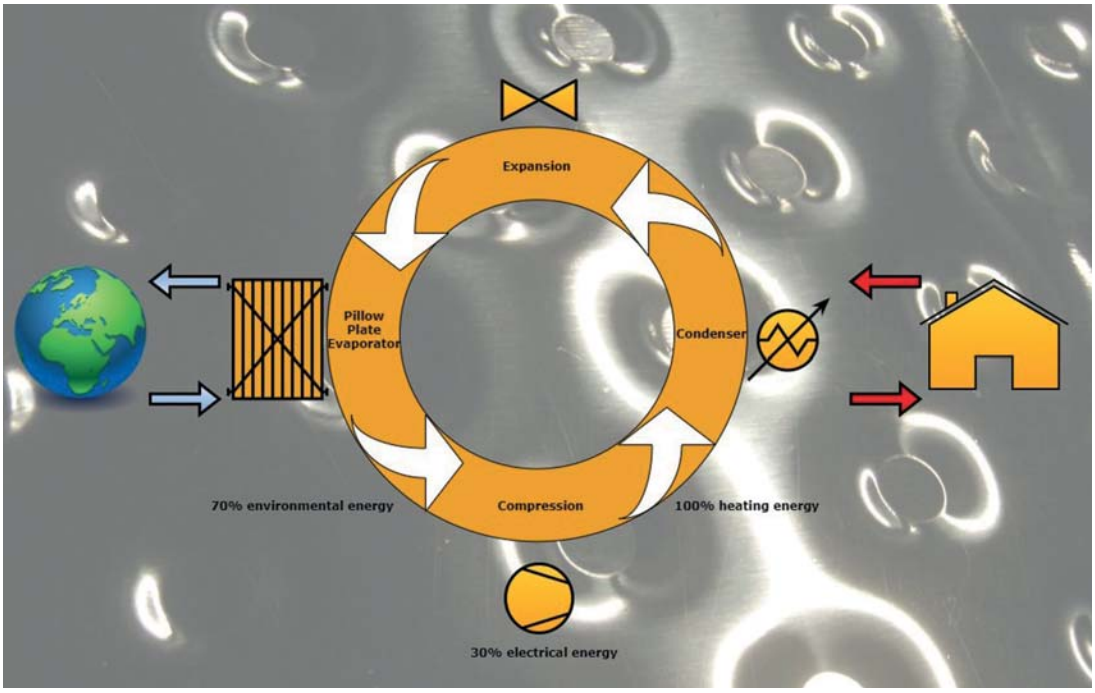

Fig. 1. Refrigeration cycle showing 70% energy savings by using natural heat sinks such as the ocean.

sustainable and green applications this type of heat supply is becoming increasingly popular. A heat exchanger often used in this application is Pillow Plates with a low GWP (Global Warming Potential) refrigerant as a base. With a Pillow Plate heat exchanger it is possible to make use of the energy storage potential of large bodies of water such as seawater or run-off water. With a low GWP refrigerant such as R-1234ze(e) this is an ideal combination and an energy-efficient alternative to traditional refrigerants in different medium temperature applications. Heat to power installations have been commonly used in district heating systems and found to be competitive due to low capital and operation expenses. Several large-scale heat pumps based on falling film chiller technology were installed in Scandinavian district heating systems during the 1980's, since a national electricity surplus from new nuclear power existed for some years. At the beginning of the 1980's, increasing oil prices and cheap electricity led to a growing interest in heat pump systems. Since water has a high heat capacity it is able to absorb large amounts of energy before there is a temperature change. This makes it a great option to be used as the heat sink in the refrigeration cycle, see Figure 1. In order to keep temperature differences at a minimum, large amounts of sea water are used as the heat sink. Warm surface water is taken during summer. In winter, the water inlet is farther below the surface of the seawater to get warmer more consistent temperatures. In this case a large pump would supply the sea water to the falling film chillers. A thin but constant and continuous film of water flows down the outside plate surface of the heat exchangers while the refrigerant is contained on the inside of the plates. Due to the short contact time of the sea water on the falling film Pillow Plates there is a short amount of time for temperature pick up. The result of this is a minimal temperature difference between the water inlet temperature and water outlet temperature. This alleviates any concern of rising sea water temperatures where these units are in operation for effects on the aquatic environment or surrounding industries.

Furthermore, the R-1234ze(e) refrigerant has a very low GWP. The seawater heat pump converts the existing energy absorbing potential available in seawater into a usable heat transfer liquid. The system has a Coefficient of Performance (COP) of 3, meaning that for every kWh of electricity put into the system to run the system and move the water, it delivers 3 kWh of useful heat to the distribution system.

CO_2 cooling as alternative for freon refrigerant phase-out

Increasing concern and regulatory actions related to the environmental impact of hydro fluorocarbon (HFC) refrigerants has prompted a re-emergence of carbon dioxide (CO_2) based refrigeration systems. CO_2 based refrigeration is of interest due to low GWP, low price, potential for energy reduction, non-toxicity and a positive safety rating. Another benefit is no need for expensive future retrofits due to refrigerant phase out.

Most commonly used feed methods for CO_2 are:

- Pumped liquid
- Direct expansion

While gravity flooded feed is very effective with ammonia, it is not commonly used with CO_2 due to the higher density of CO_2 liquid compared to ammonia.

The thermodynamic properties of CO_2 are excellent when used in a Pillow Plate heat exchanger. Besides the excellent heat transfer coefficient, it is not very sensitive to pressure losses and has a low viscosity. While CO_2 has a low compression pressure compared to regular HFCs, the volumetric efficiency is better. Pillow Plate heat exchangers are very efficient at low volumes. Finally, the temperature glide for CO_2 is negligible, meaning this is very suitable for chillers.

An example of an application for CO_2 water cooling in the food industry is vegetable cooling by taking supply water from 15 °C to 0,5 °C with refrigerant CO_2 based on direct expansion. The chiller is capable of working with a maximum allowable working pressure up to 60 bar(g). During the process the vegetables are cleaned

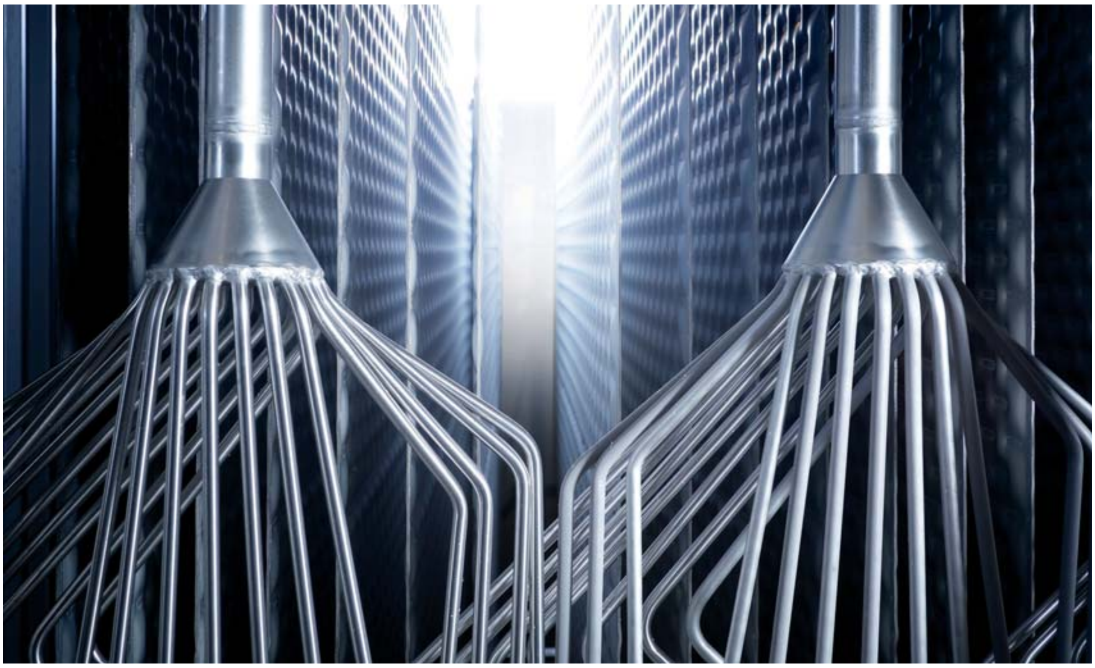

Fig. 2. Pillow Plate Heat exchanger plates with stainless steel distribution tubes for refrigerant.

Fig. 3. Storage tank with Pillow Plate.

with this water, which is then filtered and led back to the pump tank. After the cleaning the vegetables will be stored and transported on a conveyer belt in the cold water for further processing.

Ammonia (R717-NH3) as natural refrigerant

As mentioned earlier in this article, over the last few decades, synthetic refrigerants such as CFCs and HCFCs are being phased out by regulation. The transition to natural refrigeration is enhanced because of these regulations, as they are substances that occur directly in nature. The most commonly used ones are ammonia (NH_3), carbon dioxide (CO_2) and hydrocarbons (propane or isobutane). Ammonia is one of the oldest refrigerants, and has been popular since the start of mechanical cooling. It was used as a refrigerant in the 1930's before fluorinated gases became more common in refrigeration systems. Natural refrigerants such as ammonia are inexpensive to produce, have long-term availability and enable efficient operation of refrigeration.

Ammonia is commonly used in the cooling of milk storage silos. The milk is stored in large outdoor storage tanks and need to be maintained at a temperature colder than ambient. An easy way to do this is by putting integral Pillow Plates on the exterior of the tank and use ammonia as a refrigerant. When milk comes from the farmer it gets off loaded into large storage tanks at cheese plants where it is kept cool until needed to go through the process of becoming cheese.

Principle of falling film chillers

The principle of a falling film chiller is a water cooler based on Pillow Plate technology. A falling film chiller will cool large amounts of water in a short period of time. This (recirculating) water cooler, which supplies large volumes of water at consistent outlet temperatures is a suitable solution for the continuous cooling of almost any product. Due to the design it can easily cool water at temperatures close to freezing. If a water temperature around the freezing point is necessary, an evaporation temperature below the freezing point is indispensable, and forming of ice in the evaporator can be a risk, as this can block the water flow in the evaporator and cause damage. If ice water is produced using a heat exchanger in which the evaporation temperature or the temperature of the cooling medium is below zero degree Celsius, it is possible that the surface temperature on the water side is also below freezing. Even if the water outlet temperature is still well above 0 °C, freezing can occur at points where there is little water flow. An outlet temperature above 0 °C does not necessarily mean that no freezing will take place.

Ice machines

Pillow Plate technology can be used for many cooling applications, such as ice machines. Common applications for this are the food and fish industry as energy storage, transport and industrial ice for concrete production.

Due to the high operating costs of freon based refrigerants the switch to natural refrigerants is becoming increasingly popular. All natural refrigerants that have been discussed for falling film chillers are also a compatible with ice machines. Pillow Plate ice machines have almost no maintenance since there are no moving parts, this is not the case with a scraped surface type ice machine making them an easy choice.

Ice machines utilizing natural refrigerants are a great option for the fish and seafood industry. The operation is the same as a falling film water chiller, where water is flowing on the outside of the plates, using an optimal evaporation temperature of approximately 8 – 10 °C and thus creating a thin layer of ice. Due to the thin layer, which is optimally between 8 and 15 mm the thermal resistance is kept low. After a couple of minutes, the frozen ice can be separated from the plates by using hot gas from the compressor. The ice will fall onto a special

Fig. 4. Cross sectional area of Pillow Plate.

Fig. 5. Chip ice example from Pillow Plate ice machine.

Fig. 6. Pillow Plate ice machine with slide.

designed slide breaking it down into chip ice. This type of ice is ideal in fish and seafood applications, as it does not damage the product and keeps it fresh.

Here are some ways to apply natural refrigerants and heat exchangers. Almost any example of applications where CFCs or HCFCs are being used today would be a candidate to switch to natural refrigerants and use Pillow Plates. Natural refrigerants such as CO_2 require a higher operating pressure and due to the process of laser welding which produces Pillow Plates these higher pressures are achievable. Another advantage of Pillow Plates is that because of the welding pattern a high turbulence is easily achieved, in contrary to many other heat exchange technologies. Due to the low volume in the plate, lower volumes of refrigerant need to be circulated. As a result, less pump capacity is required, with lower (electrical) energy usage as a results. Besides natural refrigerants this is also beneficial to the environment.