Air as the ultimate green refrigerant

Cooling, freezing and heating with the air cycle

Due to the recent concern about the damage that CFCs cause to the environment (ozone layer, global warming) and the absence of commonly acceptable alternative refrigerants, the search for alternative refrigeration concepts is going on. Air as refrigerant in the Joule-Brayton cycle (air cycle) is one of the most natural refrigerants, and it meets all criteria for a refrigerant being environmentally benign. For this reason the air cycle is one of the most promising long-term alternatives for refrigeration machines, air conditioners and heat pumps. TNO has gained much knowledge and experience on the air cycle concept within the framework of European research projects.

Air cycles can fulfil the functions of HVAC in office buildings.

With simple technology air can be used for cooling or heating purposes. Such air cycles are characterised as simple, reliable and environmentally friendly. Really a long-term survivor, as air is one of the very few refrigerants that will never be phased out!

How it works

Although several configurations are possible (depending on the application), an air cycle always consists of a combination of one or more compressors (fans), turbines (expanders) and heat exchangers, interconnected with air ducts.

TNO developed and built a special version of the air cycle for industrial freezing applications. Figure 1 shows the pilot plant, including some typical operational figures. Experimental results show an excellent performance of the plant, confirming the value and benefit of the concept. The pilot plant proved that air

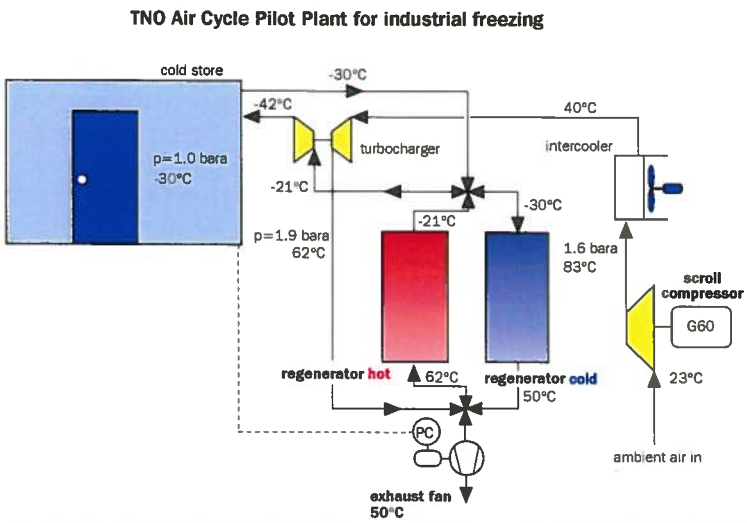

Figure 1
TNO Air Cycle Pilot Plant for freezing applications.

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cycle systems can be easily operated and are reliable. The working principle is as follows.
Ambient air is compressed in two stages, with an intercooler in between to improve the energy efficiency. The first compression stage is taken care of by a motor driven compressor, and the second by the compression wheel of a turbo-charger. Before expanding to atmospheric pressure in the expander of the turbo-charger, the air is cooled down in a heat exchanger by the return flow from the cold room. During this cooling process, the air is losing a lot of its humidity content in the form of moisture and ice. The return flow has to absorb both the heat and the moisture and ice, and therefore a regenerative heat exchanger is necessary. This regenerator is one of the main innovative parts of the pilot plant. As the airflow (the actual refrigerant) is supplied to the cold room directly (no heat exchanger), there is no need for periodic defrosting, which is one of the disadvantages of conventional refrigeration systems.

General advantages

- Air is the refrigerant: inflammable; therefore non-toxic; ODP and GWP equal zero; everywhere available and for free; leak tightness is of lower importance.
- The cooling capacity is less sensitive to changes in the desired cooling temperature.
- It is easy to realise very low temperatures.
- Simple technology to maintain; therefore cheap maintenance and no need for highly qualified personnel for maintenance and operation.
- Simple technology; therefore reliable.
- No need for periodic defrosting of heat exchangers (if air cycle is open to the application; i.e. no heat exchanger at the application's side).
- Low pressure ratios and absolute pressures; therefore simple and cheap piping and vessel constructions.

Promising applications

Industrial (blast) freezing

Air cycles perfectly fill the gap between systems based on liquid nitrogen (in fact -200 °C) and vapour compression systems (air temperatures down to -40 °C). The air cycle can be designed to meet the specific product and process conditions. With currently available technology, an air cycle according to the system shown in Figure 1 can produce air of -50 °C at a COP of 0.72. The COP includes the energy consumption for both compressing and transporting the air to and from the cold room (e.g., the freezing tunnel).

Air conditioning

Air cycles can fulfil all the functions of HVAC systems: heating/cooling, humidification/dehumidification and ventilation (air movement). In that case the air cycle replaces a boiler (hot water production), refrigeration machine (cold water production), humidifier, and supply and return fans. Figure 2 shows an appropriate configuration of an air cycle for this application. The figure shows the heating mode of the system; in the cooling mode (with dehumidification) the airflows are connected to the components in a different way (as with reversible air conditioners).

The TNO Environment, Energy and Process Innovation is a recognised contract research institute for industry and government with expertise in sustainable development and environmentally and energy oriented process innovation.

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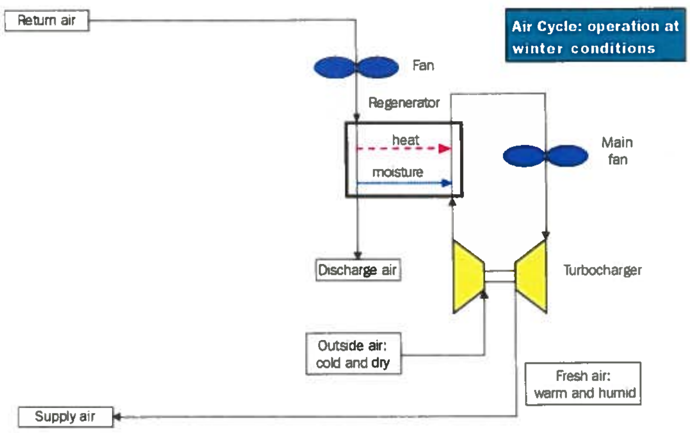

Figure 2
Open Air Cycle for air conditioning.

Currently TNO is building a pilot plant according to this configuration. The pilot plant will produce some 1,000 m^3/h of fresh and conditioned air to two lunch-rooms (total area 7 x 7.5 m) in the TNO building in Apeldoorn. Components applied in building air conditioning systems will be used as much as possible. The plant will come into operation early 2001.

Transport refrigeration

Reliability and little maintenance are very important, since the operating conditions are rough (shocks, climate). Any time lost by system failure or maintenance means a lost of earnings. The expected reliability and simple maintenance requirement of air cycles are advantageous.
Another beneficial aspect of the air cycle is its flexibility in easily achieving different cooling temperatures.
Also the relatively small influence of the required cooling temperature on the cooling capacity can be mentioned. This leads to higher part-load percentages or less on-off switches.