In focus...

Heat pumps and refrigerant gas technologies

Paving the way for a greener future

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For decades, the basic heating process has remained the same: fossil fuels have been burned to generate thermal energy in anything from households to industrial kilns. Now that greenhouse gas levels in the atmosphere have surpassed critical levels, society has realised the importance of harnessing alternative technologies to fight climate change.

The Paris Agreement of 2015 aims to keep global temperature rise to within 1.5°C of pre-industrial levels. It calls for decarbonisation of global economic activity and a technological transformation. The switch from conventional fuel-fired heating boilers to heat pumps is an element of this transition.

According to Stefano Fedeli, Business Development and Marketing Manager at General Gas in Italy, "the heat pump trend is gaining traction in many EU countries because it is clear that they will help to mitigate greenhouse gas emissions and decrease energy expenditure." This statement is substantiated by the fact that in the year 2020 alone, roughly 14 million heat pumps were installed across the EU.

Heat pumps are increasingly recognised as being a tool for not only making established unit operations 'greener' but also for reducing energy consumption and greenhouse gas emissions. When renewable power from wind, solar, or hydroelectric sources is used to run the refrigerant gas cycle in a heat pump, it is a sustainable, zero-emission process.

Heat pump technology

A heat pump is a device that can provide heating or cooling and can be used for numerous residential, commercial, or industrial applications. The system is referred to as a heat pump, an air conditioner, or chiller depending on the service it provides. Each heat pump has five key components, namely: an evaporator, a compressor, a condenser, an expansion valve, and a heat transfer fluid, which is a refrigerant gas.

Heat pumps utilise electricity and ambient thermal heat to transfer energy from a lower to a higher potential. The efficiency of a heat pump is expressed by its coefficient of performance (COP). This is the ratio between the output energy drawn out of the heat pump and the input power supplied. According to Fedeli, "A heat pump usually has a COP of three to five, which means it can deliver up to five kW of thermal energy for every kW of electrical power supplied to the compressor." The actual COP varies from season to season and from refrigerant to refrigerant.

Heat pumps can be classified as air source, water source, or geothermal depending on the heat source. Air-to-air reversible heat pumps are gaining popularity in domestic applications. This is because the same unit can be used for heating and cooling. In heating mode, the indoor heating unit serves as the condenser and the outdoor heating unit serves as the evaporator. When the machine is switched to cooling mode, the mechanism reverses. Waste heat from cooling one part of the house can be circulated to other areas of the building that need heating, or it can be used to heat domestic hot water.

On a larger scale, district heating and cooling can also be

achieved. This is the plan for the Danish town of Esbjerg in western Denmark, where a powerful compressor supplied by MAN Energy Solutions will compress carbon dioxide (CO_2) as a refrigerant gas within a very large-scale heat pump. The North Sea close to the town will be used as the heat source.

Advantages and limitations

Heat pumps that run on green energy provide heating and cooling that is clean and emission-free. This will assist in the transition to a zero-emission, carbon-neutral economy.

Additionally, heat pumps have additional advantages such as a long-life span, low running costs, low maintenance costs, and better safety compared to combustion systems. The energy needed to heat one house with a gas boiler if converted into electricity is sufficient to heat two to three houses with heat pump technology.

One of the limitations of a heat pump is that it has a seasonal performance. When the outdoor air temperature plummets to between -10°C and -20°C in the depths of winter, the performance of the heat pump suffers. This is because during winter the outdoor heating unit acts as an evaporator and the air temperature is insufficient to boil the refrigerant liquid. When the ambient air temperature rises to a peak in the summer, the performance of the heat pump again decreases. The COP decreases with an increasing temperature difference between a heat source and heat sink, according to the second law of thermodynamics.

When climate conditions become tough, it is especially important to select the most versatile refrigerant to avoid excessive power consumptions. Fedeli adds, "This situation can be easily tackled by using a refrigerant such as R1234ze or R454B which both have versatile efficiency characteristics. The former has a very wide application range, especially for larger heat pumps, the second has works at similar pressures to R410A with a high cooling and heating capacity, preserving the overall dimensions and weight."

Refrigerant gases for heat pumps

The heat pumps offered today employ synthetic refrigerants such as R410A, R407C and R134a. As a specific example, R410A has a critical temperature of 72.8°C and critical pressure of 49 bar. This refrigerant gas can heat up the water up to 60°C.

Refrigerants such as butane, ammonia, and carbon dioxide have comparatively higher critical temperatures which are suitable for industrial applications. The global warming contribution of these, so called 'natural refrigerants' is also less than those of most F-Gases.

However, butane is highly flammable and thus can only be used in applications where this fire hazard is acceptable. Similarly, the toxicity of ammonia has prevented its widespread use in sensitive public buildings such as schools or shopping centres.

The following aspects must be considered when selecting a refrigerant: critical temperature, critical pressure, stability, flammability, toxicity, global warming potential (GWP), the cost of the refrigerant and, most importantly the total system lifetime cost and environmental impact. The higher the GWP value, the more the refrigerant gas warms the Earth compared to CO_2, if it is released into the atmosphere.

Fedeli reminds us that, "Choosing the lowest GWP refrigerant, which will often be R744, CO_2, might not be the best choice for the long-term greenhouse effect. If the energy consumption of the system increases during severe climate conditions, the GWP benefit would be erased by the additional kW of power that would be required." One kWh of electrical power equates to about 400g of CO_2 emissions in the EU.

The project engineer for a large plant or architect for an off-the-shelf heat pump installation will generally make the decision on refrigerant gas selection. "Solstice® ze, which is R-1234ze was developed by Honeywell and is ideal for larger heat pumps," adds Fedeli. "Refrigerants such as R454B or R32 tend to be favoured for residential applications and my belief is that R454B will play a leading role due to its low GWP value and mild-flammability as a class A2L refrigerant. R454B can also be used in systems that were designed for R410A, whereas R32 requires a complete system redesign."

He continues to say that, "At General Gas, we supply refrigerant gases for heat pumps in cylinders containing 10kg or 12kg of product for smaller domestic jobs. These heat pumps typically require about 5kg of refrigerant gas to charge the circuit or very small quantities for top-ups after the initial installation. We also offer 900kg roll tanks for larger jobs that may require thousands of kilograms of refrigerant gas to charge a new system."

Scaling up and electrification of industrial processes

The working fluid inside the heat pump determines its operating conditions. For industrial applications, the goal is to combine a heat pump with waste recovery units so that waste heat will be converted to useful energy.

To reach temperatures of 70°C and higher in such industrial applications, the refrigerant must have a very high critical temperature and low critical pressure. This is because high-pressure refrigerants require the use of sophisticated materials. CFCs and HCFCs were ideal for such industrial applications, but they were banned after the Montreal Protocol.

Existing heat pumps can supply heat up to 80°C. In the future, refrigerant gas innovation and technology developments may lead to heat pumps capable of providing heat at temperatures up to 500°C. This will extend the field of application to many industrial processes such as steam generation and drying. Electrification of industrial processes using this type of technology with renewable power will make a significant reduction of fossil fuel consumption and greenhouse gas emissions to contribute to net-zero targets and decarbonisation. gw


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