

17th Informatory Note on Refrigerating Technologies

How to improve energy efficiency in refrigerating equipment

Introduction

Refrigeration is technology which makes a major contribution to humanity in many ways including food preservation, control of indoor air quality, gas liquefaction, industrial process control, production of food and drink and computer cooling. Without refrigeration, modern life would be impossible. About 15% of the world's electricity is used to drive refrigerating and air-conditioning systems. Inefficient use of energy is a waste of valuable resource and contributes to global warming. Most of the global warming effect of refrigerating systems comes from generating energy to drive them. Only a small proportion comes from the release of certain refrigerants. This informatory note describes how the efficiency of refrigerating systems can be maximized thereby minimizing their global warming impact.

Fundamentals

Refrigeration is the science of making heat flow "uphill" from low to high temperatures. A refrigeration system extracts heat from the substance being refrigerated (cold reservoir) and rejects it to the ambient at a higher temperature (hot reservoir) as indicated in *Figure 1*. This is analogous to the pumping of water to an elevated storage tank. The energy consumption of a refrigerator is roughly proportional to rate of heat extraction (amount of water pumped) and to the temperature lift through which the heat is raised (height water is pumped).

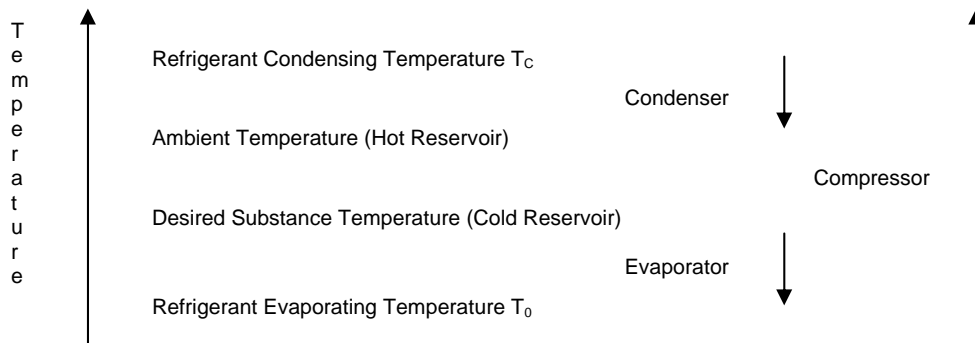


Figure 1. Schematic Diagram of Temperatures and Heat Flows for a Refrigeration System

The energy efficiency of a refrigeration system is usually expressed as a Coefficient of Performance (COP) which is the ratio of the heat extraction rate to the rate of energy use.

Whatever type of refrigerating system is being used, it is fundamental to minimize the required heat extraction and to keep the difference between T_C (condensing temperature) and T_0 (evaporating temperature) as small as possible. Minimizing heat extraction is done by insulating the refrigerated room and low-temperature parts of the refrigeration system, minimizing ambient air infiltration (e.g. door openings and leakage) and reducing energy use in refrigerated applications (e.g. fans and forklifts). Reducing $(T_C - T_0)$ is done by maximizing condenser and evaporator heat transfer performance and minimizing refrigerant pressure drops in suction and discharge pipelines.

Description of a Vapour Compression Refrigeration System

The standard vapour compression refrigeration system consists of a refrigerant in a closed circuit comprising a compressor, a condenser, an expansion device, an evaporator and interconnecting piping (*Figure 2*). In the condenser, compressed refrigerant vapour at high pressure is condensed at high temperature by heat transfer to the surroundings. The high-pressure refrigerant liquid is reduced to a low pressure at the expansion valve. At low pressure, the refrigerant will evaporate at a low temperature enabling it to extract heat from the substance to be cooled. To complete the cycle, the low pressure refrigerant vapour exiting the evaporator is compressed to high pressure by the compressor. The total heat rejected in the condenser is the sum of the heat extracted plus the compressor energy use.

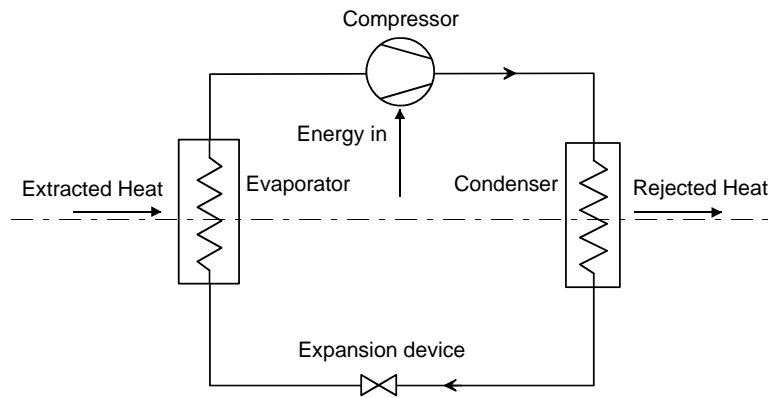


Figure 2. Schematic of a Simple Vapour Compression Refrigeration System

Loss of refrigerant from the circuit would have a very detrimental effect on the reliability of the system, so great care is taken to make refrigerating systems as leak-tight as possible. Individual domestic refrigerators, of which there are more than one billion, each contains a very small amount of refrigerant. Such systems are expected to run for more than 20 years without addition of refrigerant. The global warming effect of such refrigerators is significant but nearly all of it is caused by carbon dioxide produced when the electricity to run the refrigerator is generated.

Effect of System Components on Efficiency

Refrigerant

Very few substances have properties appropriate for a refrigerant and, of these, few have stood the test of time and continue to be used as refrigerants. *Figure 3* shows some of the substances that have been used as refrigerants and how their use has varied over time.

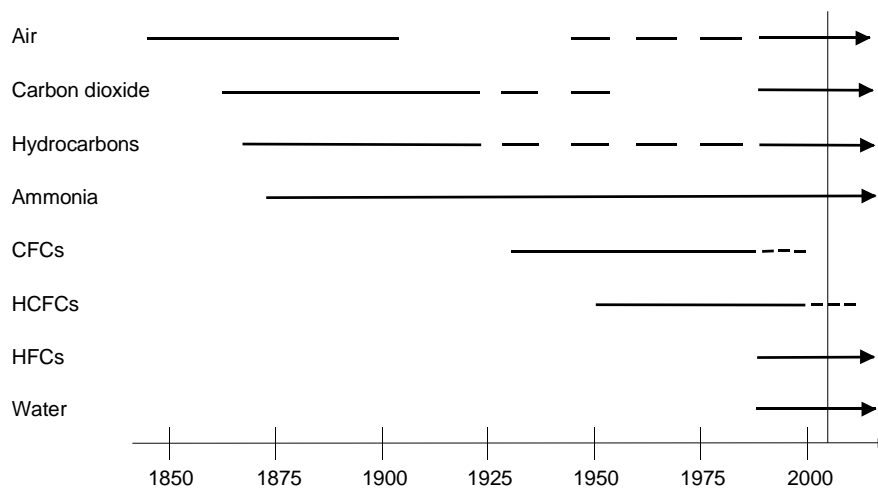


Figure 3. Typical Refrigerants and Their Historical Use

There is no ideal refrigerant. Selection of a refrigerant is a compromise between many factors including ease of manufacture, cost, toxicity, flammability, environmental impact, corrosiveness and thermodynamic properties as well as energy efficiency. A key characteristic is the pressure/temperature relationship. In general, for energy efficiency it is desirable for the refrigerant critical point (temperature above which the refrigerant cannot condense) to be high compared with the heat extraction and rejection temperatures.

Good transport and heat transfer properties are also important for energy efficiency as they reduce running costs and allow smaller temperature differences to be employed in evaporators and condensers and hence smaller overall temperature lifts. In general, refrigerants of low molecular weight and low viscosity will have the best properties.

Compressor

Compressors will lose efficiency if the temperature lift is higher than necessary and they will also lose efficiency if droplets of refrigerant liquid are present in the suction vapour or if the suction vapour becomes too hot. Compressor maintenance, where possible, and the preservation of lubricant quality are important to retain energy efficiency. For some compressor types (particularly screw and centrifugal), their part-load energy efficiency performance is poor compared with at full load, so sustained part-loaded operation should be avoided. Variable speed drive technology and improved control systems can minimize the energy penalty but increase capital costs.

Condenser

To keep refrigerant heat rejection temperatures as low as possible, condenser heat transfer rates should be maximized and the cooling medium temperature minimized. Evaporative condensers are often the most efficient because they reject heat to the

wet-bulb temperature of the ambient air. For instance, humid air at 25°C and 60% relative humidity has a wet-bulb temperature of 16°C. However, they require careful maintenance to avoid *Legionella* contamination. Water-cooled condensers combined with cooling towers also approach ambient wet-bulb temperature but there is an additional temperature difference to drive heat from the refrigerant into the water, so refrigerant heat rejection temperature is generally higher. Water use can be excessive if a cooling tower is not used. Air-cooled condensers are usually the least efficient method as they reject heat to the air dry-bulb temperature, which is generally significantly higher than wet-bulb or water temperature. However, for small systems they are commonly used because they are cheap, simple and require little maintenance.

It is important to keep all types of condenser clean and free from fouling. Condensers rejecting heat to atmosphere must be allowed plenty of fresh air and protected against any tendency for the air to re-circulate back to the condenser inlet. Systems that operate with refrigerant suction pressures less than atmospheric (e.g. low temperature ammonia or air-conditioning with HCFC-123) should use purgers to remove non-condensables from the refrigerant.

Expansion devices

Many expansion devices require significant pressure difference to allow proper operation. Therefore condensing pressure is often maintained at artificially high levels, even at low ambient temperatures. The biggest culprit in this respect is the conventional thermostatic expansion valve which is often selected because of its very low cost. One solution is to use electronically controlled expansion valves.

Evaporators

As for condensers, evaporators should be designed to operate at minimum economic temperature difference so that the refrigerant heat extraction temperature can be as high as possible for a given substance temperature. Increasing heat extraction temperature also reduces the size of the compressor required.

As well as evaporator size, aspects such as refrigerant distribution, circuiting and velocity, use of enhanced surfaces, air speeds (for air coolers) can all significantly affect energy efficiency. Air coolers that operate at temperatures below freezing must be defrosted regularly to restore performance. Electric defrost is simple but is least efficient and therefore only suitable for small systems. Electric defrost has to be paid for at least twice, to put the electric heat into the cooler and to take it out again. Water defrost, hot gas defrost, and defrost by the circulation of warm fluid through the cooler, are all potentially more efficient. However, whatever the system, it is important to optimize the frequency and duration of defrost to avoid unnecessary defrosting.

Interconnecting piping

Efficiency can be reduced if interconnecting piping is of the wrong size or is arranged in ways that cause unnecessary pressure drop or inhibit oil return (e.g. excessive bends and fitting).

Importance of controls

A refrigeration system with well-designed components will not operate efficiently unless the components are correctly matched and controlled. Energy efficiency has not always been the prime consideration when selecting effective controls. If possible, the following control options should be avoided to maximize energy efficiency:

- slide valve unloading of over-sized screw compressors;
- hot gas bypass of compressors;
- throttling valves between evaporators and compressors;
- evaporator control by starving refrigerant supply;
- too frequent defrosts;
- condenser head pressure controls except when necessary.

Conclusion

Improving the energy efficiency of refrigeration systems is not difficult and should be encouraged because of the environmental benefits. It often involves a trade-off between initial costs and on-going operating costs. There are many situations where economics motivate the equipment supplier to provide the cheapest solution, especially if the supplier does not have to pay for the running costs of the system. Standards should be set for energy efficiency for all types of refrigerating system. Governments should legislate to ensure that suppliers are penalized for supplying systems that do not reach acceptable standards of efficiency and to ensure that users of efficient systems benefit by more than the resulting reduction in running costs. If this were done, it is reasonable to suppose that the energy consumption of refrigerating systems could be reduced by at least 20% in the short term. An objective of 30-50% reduction — depending on applications — by 2020 is a goal which could be achieved.

This Informatory Note was prepared by S. Forbes Pearson, winner of the IIR Gustav Lorentzen Medal awarded at the 21st IIR International Congress of Refrigeration in Washington DC in August 2003. It was reviewed by 24 experts worldwide.

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