Refrigeration Systems

In general, refrigeration systems may be required to create temperatures from:

- about 4°C mainly for air conditioning systems
- down to less than –270°C for very specialised cryogenic research.

Power consumption can vary from:

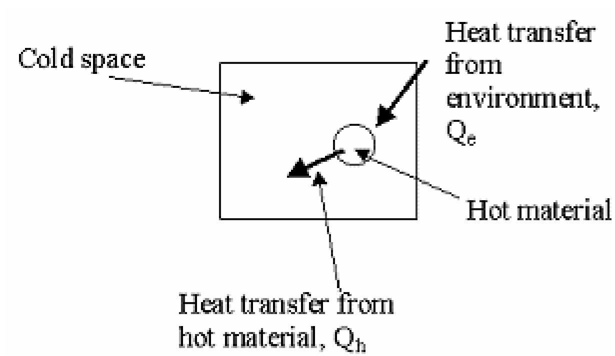
- A few Watts e.g. for some spacecraft applications
- 80 MW+ e.g. large scale gas liquefaction systems

All systems have one thing in common: They must be capable of continuously maintaining a "cold space" at a temperature which is lower than that of the surroundings.

BASIC CONCEPTS (1)

- Heat transfer into the "cold space" from the external environment inevitably occurs because of the temperature difference.
- Heat transfer into the "cold space" may occur because "hot" products are introduced.

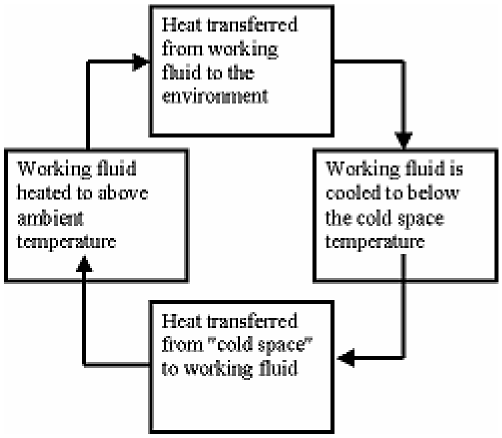
  Total heat transfer into "cold space", $Q_r = Q_e + Q_h$



- For the "cold space" to remain in thermal equilibrium, i.e. at constant temperature, Q_r must be dissipated BUT there cannot be direct heat transfer to the environment because the temperature gradient is wrong. Refrigerators overcome this problem

BASIC CONCEPTS (2)

- Most refrigerators work in a cycle in which a substance, known as the working fluid or refrigerant, is continuously heated and cooled in a closed loop to provide appropriate heat transfer conditions.



- Note that energy must be supplied to raise the fluid temperature – say, W_i.

BASIC CONCEPTS (3)

- Because external energy must be supplied, the efficiency of practical refrigeration systems is important. All other things being equal, the greater the heat transfer from the "cold space", Q_r, for a given energy input, W_i, the better.
- Efficiency, known as the Coefficient of Performance, (COP), is defined as:

  $COP = Q_r / W_i$

- The value of the COP is considerably influenced by the temperature difference between the hot and cold sides of the cycle. The COP falls as the difference increases.
- Theory based on the Carnot cycle shows that the maximum possible COP is given by:

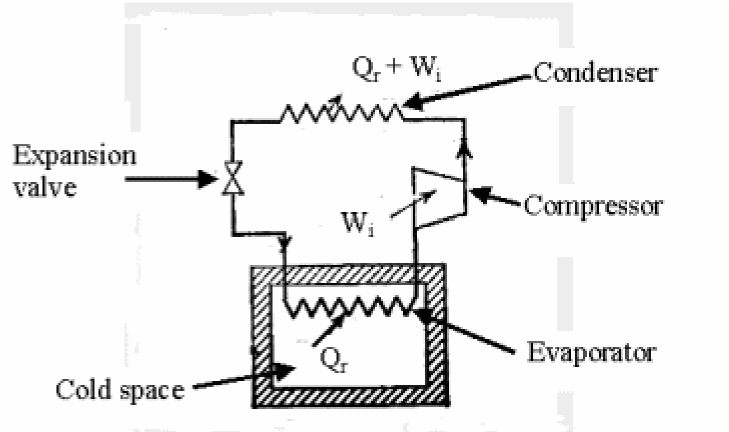
$T_{cold}/(T_{hot} - T_{cold})$ (T in Kelvin)

- For the most common types of refrigeration plant the COP would typically be in the range 3 – 6.
- Note that there are other very important practical concerns which affect capital and operating cost. These include the size and complexity of the plant.

<u>VAPOUR COMPRESSION SYSTEMS</u>

- Vapour compression cycles are the most common form of refrigeration systems.
- These cycles are based on the concepts of:

  i. Latent heat
  ii. Fluid boiling points increase with pressure

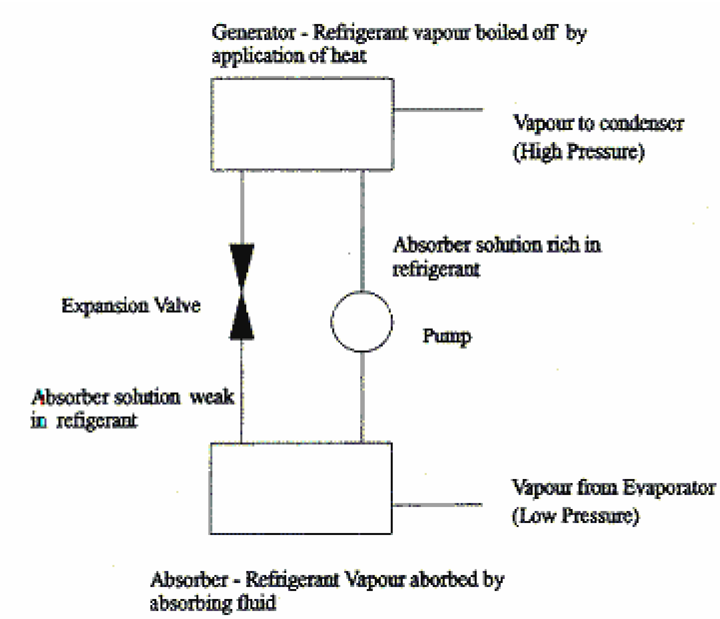


1. Low pressure liquid in evaporator is caused to boil at low temperature by heat transfer from "cold space"
2. Vapour compressed – increases pressure and temperature
3. High temperature vapour transfers heat to environment – vapour condenses
4. Liquid cools and pressure falls as it passes through the expansion valve – back to (1)

WORKING FLUIDS

- The working fluid is a critical "component" of vapour compression schemes. An ideal fluid's properties would include:
    - Good heat transfer properties
    - High latent heat
    - Appropriate pressures for the operating temperature
    - Chemical stability
    - Low toxicity
    - Low fire risk
- A wide range of fluids were developed BUT many were Chlorofluorocarbon compounds, (CFCs). The manufacture of these has been phased out because of environmental concerns.
- A replacement group of fluids, hydrochlorofluorocarbon compounds, HCFCs, are being used as a temporary measure. A refrigerant called R22 is the most common example.
- The long-term replacement for CFCs has been expected to be Hydrofluorocarbon compounds (HFCs). The best known is Refrigerant R134A. However, there is pressure to limit the use of HFCs. The UK Government, for example, does not regard HFCs as a sustainable technology in the long term.

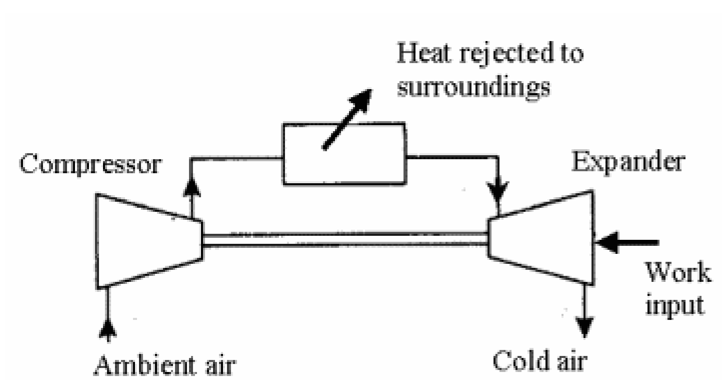
ABSORPTION CYCLES



- The absorption cycle refrigerator is a potential competitor to vapour compression systems in the short term. Very popular in Japan for air conditioning applications and for use in boats and caravans.
- The COP is typically less than 1, i.e. much lower than vapour compression systems, but it uses heat rather than mechanical energy as the high grade energy input. Heat is much cheaper.
- The choice of the fluids is critical. Common pairs are:
    - Water(refrig.)/Aqueous LiBr (absorbent)
    - Ammonia (refrig.)/ Water (absorbent)

GAS CYCLE REFRIGERATION

- Many forms of gas cycle refrigeration are possible but the most common is the reversed Brayton working in open cycle with air as the working fluid.

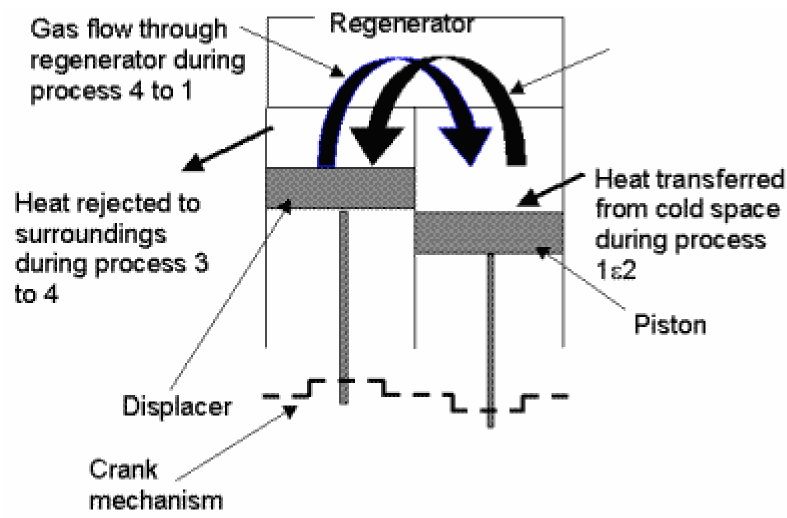


- Less efficient than vapour compression systems but the difference

reduces as the output temperature falls. Similar performance at less than about −70°C
- No refrigerants and simple construction
- Mature technology – often used for aircraft air conditioning – but no large scale systems appear to be available commercially

STIRLING CYCLE (1)

- The Stirling cycle has the same efficiency as the Carnot cycle under equivalent conditions but it provides a better basis for a practical design. However, practical devices operate only approximately as Stirling cycles and their implementation has been disappointing.



- The working fluid is usually helium – no problems with refrigerants

STIRLING CYCLE (2)

- Basic operation of a Stirling cycle refrigerator as follows:

Process 1→ 2 The displacer remains stationary and the piston descends. The gas expands and its pressure falls. The gas temperature is cold but it remains constant because of heat transfer from the cold space.

Process 2→ 3 The displacer descends and the piston rises. The gas is maintained at constant volume and it passes through the regenerator which is hotter than the gas. The gas heats up due to heat transfer from the regenerator and its pressure rises; the regenerator cools.

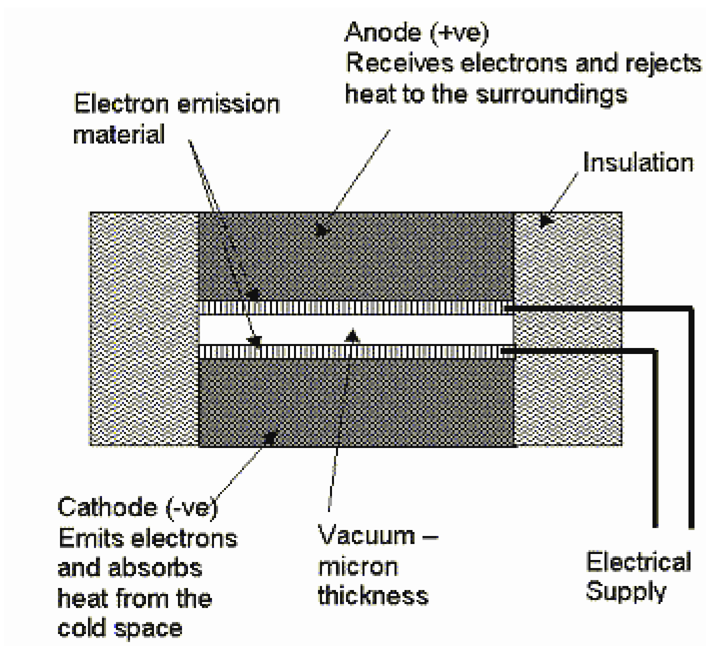
Process 3→ 4 The displacer remains stationary and the piston rises. The gas is compressed and its pressure rises. The gas is hot and remains at constant temperature because of heat transfer to a heat sink.

Process 4→ 1 The displacer rises and the piston descends. The gas is maintained at constant volume and it passes through the regenerator which is colder than the gas. The gas cools due to heat transfer to the regenerator and its pressure falls; the regenerator heats up.

- Stirling cycle refrigerators can produce cryogenic temperatures and are commercially available with capacities up to about 25kW. The concept has produced many variants and it is the subject of much R&D

THERMIONIC REFRIGERATION

- Thermionic emission is the passage of electrons through a vacuum under the action of an an electric charge. Electrons flow from a negatively charged pate, the cathode, to a positively charged plate, the anode.
- During thermionic emission, the anode heats and the cathode cools. The process can occur at low temperatures and this forms the basis of a refrigerator.

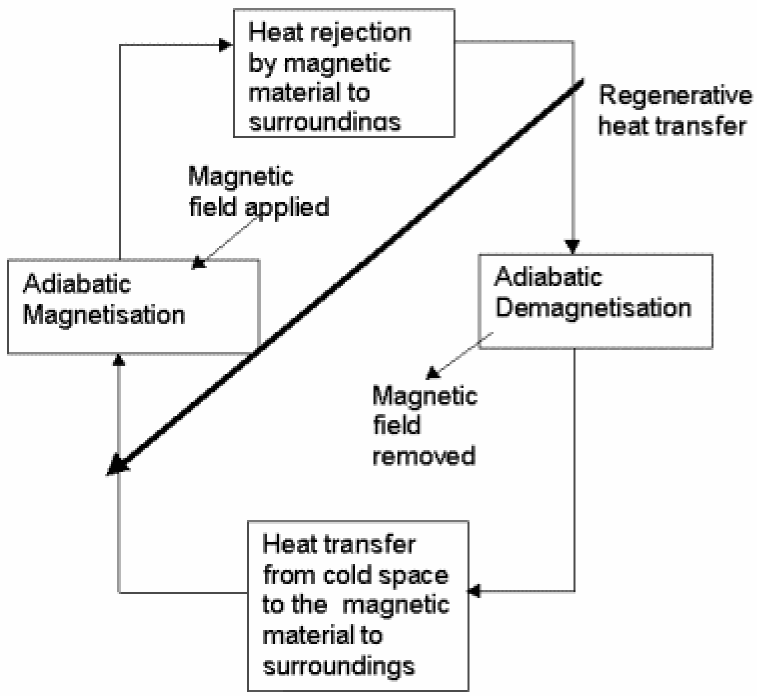


THERMIONIC REFRIGERATION (2)

- The concept has been developed by a company called Borealis – sometimes referred to as the Borealis refrigerator.
- The system is refrigerant free, with no moving parts and suitable for modular construction. Temperatures as low as –80°C are technically possible but developments are based on domestic refrigerator temperatures.
- There are problems with the chemical stability of electrode materials and with the production of the chip because of the small gap.
- Publicity has suggested that mass production would be possible by 2000.

MAGNETIC REFRIGERATION

- Based on the magneto-calorific effect – some materials heat up when they are magnetised and cool down when demagnetised.
- Used for many years to produce cryogenic temperatures but recent developments may allow effective devices to operate at domestic refrigerator levels.



NOTE: Work must be supplied to "drive" the magnetic material through the cycle.

MAGNETIC REFRIGERATION (2)

- Devices are expected to have high efficiency but also high capital cost.
- No refrigerants
- Capacities up to 50kW are being considered
- Best suited to "large" plant with high utilisation

OTHER REFRIGERATION SYSTEMS

- *Gifford-McMahon* – similar concept to the Stirling cycle, successful as a low capacity cryogenic device
- *Pulse Tube* – various forms with different names. Thermodynamically similar to a Stirling cycle but compression and expansion created by pressure waves in a tube.
- *Optical cooling* - based on the promotion of electromagnetic radiation with incident radiation such the energy of the emitted photons is greater than that of those received. This causes cooling to occur.

- *Vortex Tubes* - Converts a stream of compressed air into two outlet streams, one hotter and the other colder than the inlet stream. A simple, well established technology but low capacity, typically less than 1kW.
- *Vuilleumier Refrigeration* A Stirling cycle type device but simpler mechanically. However, it requires an input of high grade heat as well as mechanical energy. Reasonably efficient, safe working fluid, quiet but it has been developed only to the experimental stage.
- *Malone Refrigeration* A Stirling cycle device but using liquid near its critical point rather than a vapour as the working fluid. Primitive prototypes only but is intended as a efficient, compact design with a safe working fluid.

CONCLUSIONS

- Vapour compression systems are well established but there are niche markets for absorption cycles, air cycles and Stirling cycle devices.
- Difficulties over the long term availability of working fluids for vapour compression systems might stimulate interest in other systems.
- There is wide ranging research into refrigeration systems. The available evidence suggests that the Borealis refrigerator should be attractive in the near future.