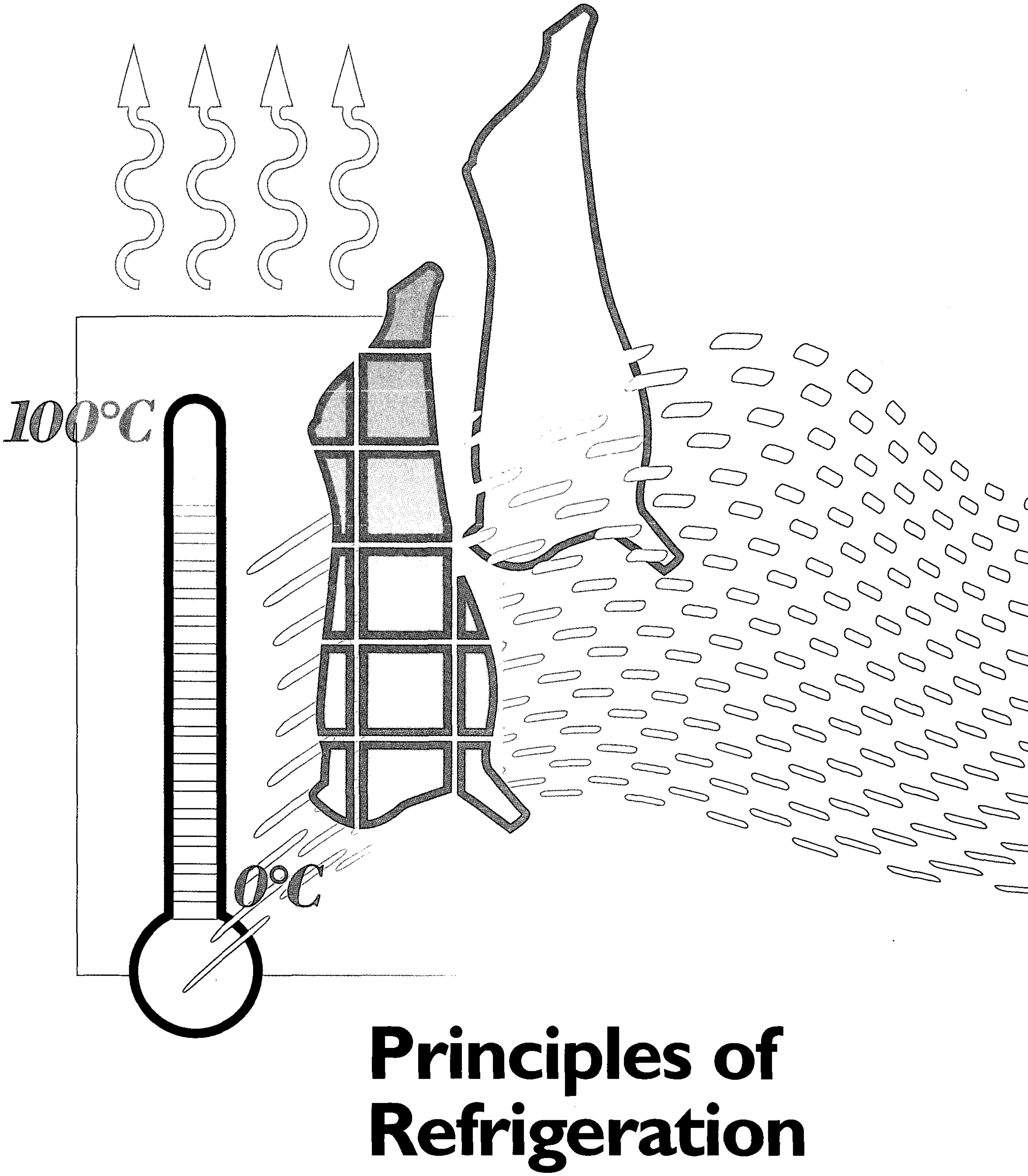

Principles of Refrigeration

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Meat Research Corporation

AMT
AUSTRALIAN MEAT TECHNOLOGY

Refrigeration is the most commonly used method of preserving meat and meat products. For centuries, the only available means of refrigeration was ice which was obtained from mountain tops and frozen lakes and stored for use during summer. In 1824, an essay, "The Motive Power of Heat", was published which established a definition and understanding of heat and the laws by which it operates. The science of thermodynamics developed rapidly, leading to the construction of the first vapour compression cycle refrigeration systems.

Initially used to produce ice, these refrigeration systems were also used in breweries and meat plants. The meat industry was at the forefront of the application of refrigeration, and its use enabled the development of large central processing plants, and the distribution of wholesome meat to urban areas and transport by sea to Europe.

Although times have changed, meat processors today should have a basic understanding of the operation of refrigeration systems and their components.

The Vapour Compression Cycle

The essential elements of the basic vapour compression system are the refrigerant, compressor, condenser and receiver, refrigerant expansion device and the evaporator. (Figure 1).

The basic refrigeration cycle can be depicted on a pressure-enthalpy chart. (Figure 2) (Enthalpy is the heat content of a substance and is expressed in terms of kJ/kg.) Commencing at 1, vapour at low pressure and temperature is drawn into the compressor where the compressor, in doing work, increases the pressure and temperature of the vapour.

FIGURE 1 **Elements of a simple vapour compression cycle**

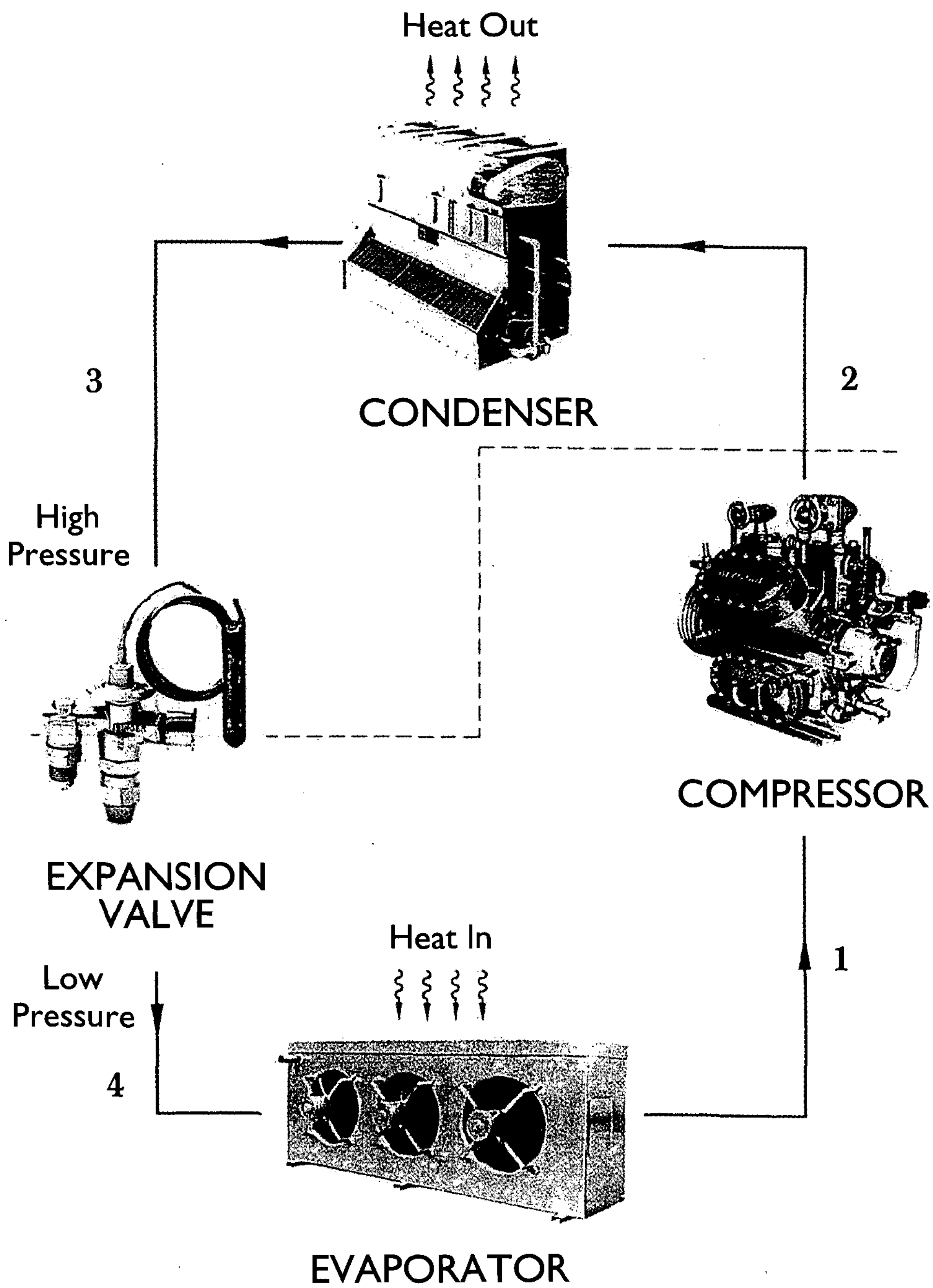
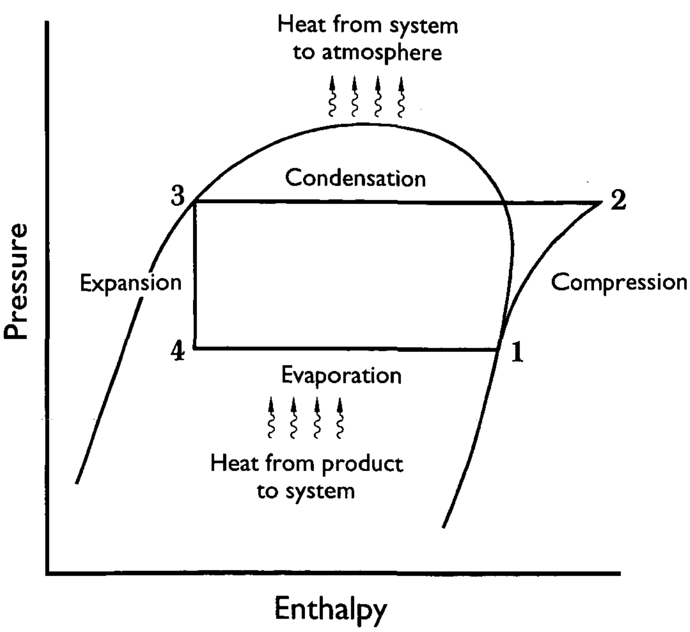


FIGURE 2 **Pressure/enthalpy diagram for simple vapour compression cycle**



The vapour at high pressure and temperature then passes to the condenser (2) where it is cooled, giving up its latent heat, and condenses to its liquid form where it is stored in a receiver.

The high-pressure liquid is then expanded through an expansion device (3). At this point, the refrigerant is at a low pressure and is mostly liquid. It has a low boiling point due to the low pressure.

When it enters the evaporator (4), the liquid refrigerant boils, absorbing the necessary latent heat for evaporation from the surroundings of the evaporator. The vapour at low pressure and temperature then passes to the suction side of the compressor (1), completing the cycle.

The diagram shows the behaviour of an ideal system. Real systems behave slightly differently as shown in Figure 3. In particular, when the liquid evaporates, the gas becomes superheated (i.e. heated above its evaporating temperature) before leaving the evaporator and the liquid subcools in the condenser. Although small losses occur through the system due to friction through pipes and valves, these losses can be kept to a minimum by careful pipe sizing.

The Refrigerant

The refrigerant is the working fluid of the cycle. It absorbs heat as it vaporises at a low temperature and gives up heat by condensing at a high temperature and pressure. To be suitable for use as a refrigerant in a vapour compression cycle, a fluid must possess certain chemical, physical and thermodynamic properties that make it both safe and economical to use.

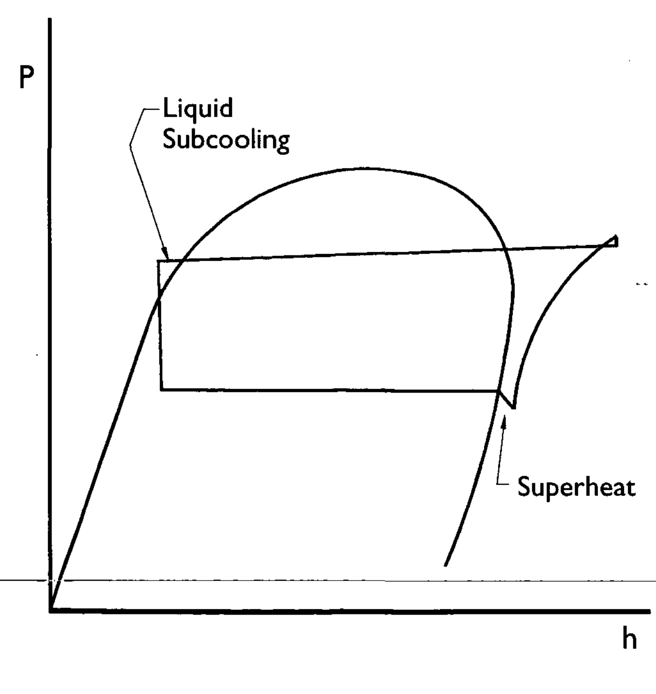
The main requirements for a refrigerant:

- ☐ Suitable boiling and condensing pressures
- ☐ Low volume flow for refrigerating effect
- ☐ Low compressor power requirement
- ☐ Safe to use (Should not be toxic or explosive)
- ☐ Does not react with construction materials
- ☐ Has a low tendency to leak and any leaks can be easily detected
- ☐ Low cost

There is no ideal refrigerant, but different refrigerants are more suited to specific applications.

Ammonia (R717) is environmentally friendly and meets many of the listed requirements – but it is toxic. Its pungent odour at low concentrations ensures that personnel are repulsed long before exposure becomes dangerous. There is little risk

FIGURE 3 **Diagrammatic representation of the real refrigeration system**



Fans blow air over the tubes in the case of the forced draught cooler (FDC) or draw air through the evaporator in the case of the induced draught cooler (IDC). The fans are selected to provide adequate air circulation at the required velocity over the product to be cooled.

The cooling capacity of the evaporator depends primarily on the surface area of the coils and the temperature difference between the refrigerant and the air being cooled. Finned coil evaporator design is a complex subject, with performance influenced by factors such as tube diameter, tube configuration, fin spacing, number of rows of coils, face area and coil depth. In the case of carcase cooling applications, best results are generally achieved by having a large face area, shallow depth and a small temperature difference between refrigerant and air.

Application to Meat Plants

An effective and efficient refrigeration system is essential to the proper function of a meat plant. The system must have adequate refrigeration capacity to maintain the temperatures required in both product cooling and holding areas and in processing areas when subject to varying ambient and processing conditions.

A refrigeration system is most efficient – uses the least power – when the smallest temperature differential exists in the refrigerant between the evaporator and condenser. This can only be achieved when the surface area of the evaporator maintains the smallest possible temperature differential between the refrigerant and the cooling air and when the cooling capacity of the condensers can dissipate all heat input to the system under the most extreme ambient conditions.

Additional information

More detailed information on this subject is provided in the following:

"CFC Phase-out Debate Warms Up", AIRAH Journal, October 1995

ASHRAE Handbook Fundamentals

Additional information

Additional help and advice are available from Food Science Australia, Meat Industry Services Section:

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Ian Eustace	(07) 3214 2117	(07) 3214 2103
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in its use where proper precautions in design and installation are observed. Ammonia is predominantly used in large industrial installations where trained operators are available.

The halocarbon refrigerants R12 and R22 are widely used in domestic refrigerators, display cabinets, butchers' shops and small abattoirs where unattended operation is essential. Because R12 is a chlorofluorocarbon (CFC) and is implicated in the greenhouse effect, its use is being phased out. Manufacture of R12 ceased at the beginning of 1996 and is being progressively replaced in existing installations. R22 is an HCFC (hyrdo-chlorofluorocarbon) and is not due for phase-out until 2020.

The Compressor

The energy input in the refrigeration cycle is provided by the compressor. The amount of energy required depends on the volume of refrigerant being circulated and the increase in pressure required to condense the refrigeration vapour. Lowering the temperature in the evaporator or increasing the temperature in the condenser results in greater pressure differences between evaporator and condenser. This increases the power requirement of the compressor and hence the running costs of the refrigeration system.

In a large plant using an ammonia system, the compressors and ancillary equipment are normally located in a central engine room. In small plants, butcher shops and the like, the compressor/ condenser unit is often located adjacent to the refrigerated space.

Chilling applications require only single-stage compression. When suction temperatures below -30°C are required for freezing applications, two-stage compression can be justified. Refrigeration compressors operate most efficiently at moderate pressure ratios. By utilising two stages, high overall pressure ratios can be achieved economically.

The Condenser

Compressing the vapour causes its pressure and temperature to increase. The hot, high-pressure vapour is then transferred to the condenser. Its latent heat is then removed by cooling, causing the vapour to return to a liquid still at high pressure.

In ammonia systems, the evaporative condenser (Figure 4) is the most common type used. Air-cooled condensers and receiver (Figure 5) are used for small packaged plants with halocarbon refrigerants.

FIGURE 4 Diagrammatic sketch showing arrangement of an evaporative condenser

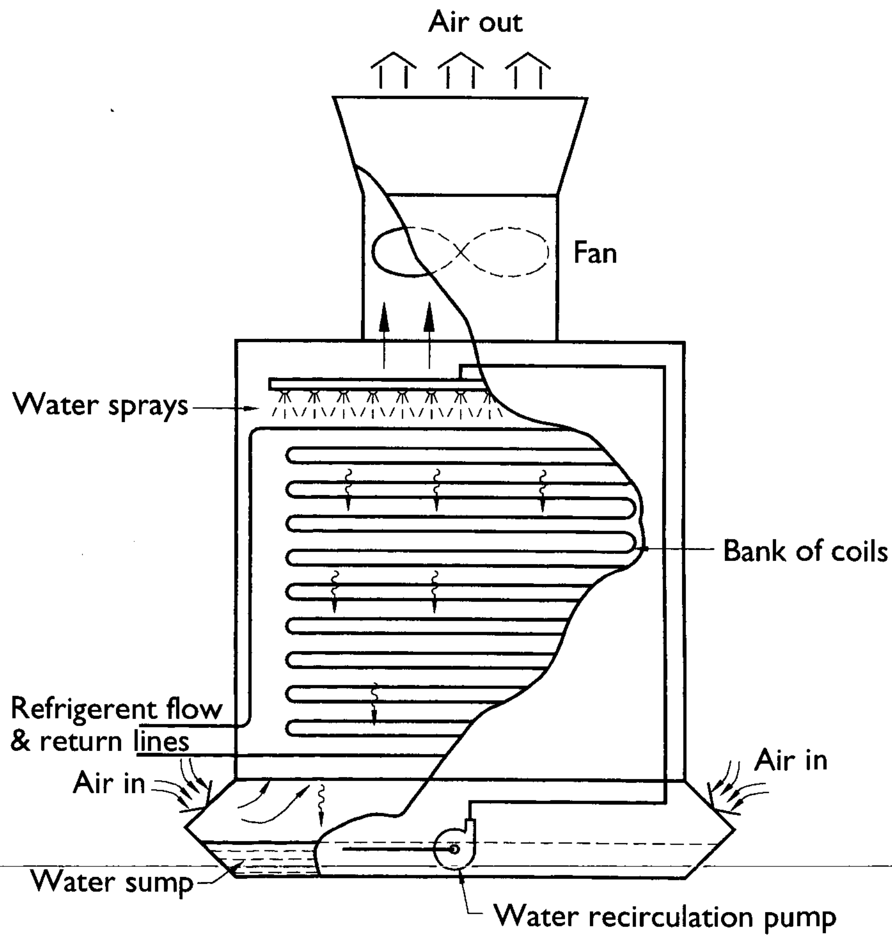
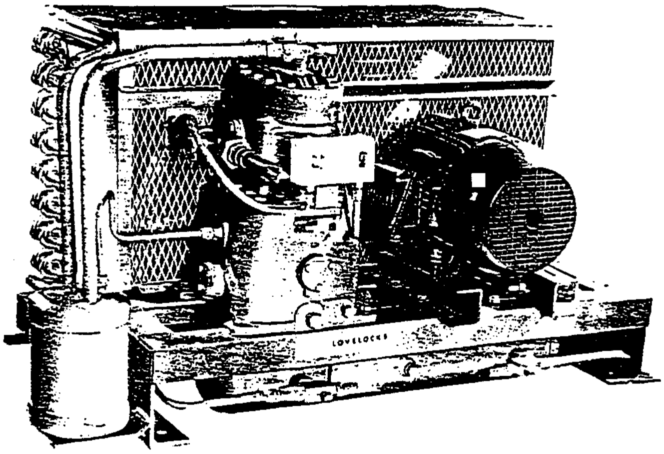


FIGURE 5 **Air cooled Condenser**



Because water sprays are used to aid cooling, the capacity of the evaporative condenser is influenced by the ambient wet-bulb temperature. In most parts of Australia, particularly when ambient temperatures are high, the wet-bulb temperature is significantly lower than the dry-bulb temperature. This gives the evaporative condenser its greatest advantage over the air-cooled condenser.

Both types of condenser require free circulation of air over the coils for effective cooling.

Ideally, condensers should be located well clear of buildings and structures that could restrict air flow. For efficient operation, air-cooled condensers should not be located in areas such as boiler houses where the ambient temperature could be high. Evaporative condensers have been implicated in outbreaks of Legionnaire's disease and should not be sited adjacent to ventilation system intakes.

The evaporative condenser requires a supply of good quality water for its operation. Because water is continuously being evaporated from the cooling coil surfaces, scale will be formed by precipitation of salts. If this scale is allowed to build up, heat transfer rates will be reduced, causing an increase in refrigerant temperature. Effective cooling can then only be maintained if the compressor operates at higher pressures. This, in turn, will result in greater power usage and higher operating cost.

The condenser must have sufficient cooling capacity to dissipate both the heat extracted by the evaporator and the heat added by the compressor.

The Expansion Device

The expansion device maintains the pressure differential between evaporators and condensers necessary for the correct operation of the refrigeration system. It allows the refrigerant to expand from the high-pressure level to the low-pressure side of the system.

The thermostatic expansion valve is the most common type of expansion valve and is used almost exclusively in small and medium-sized systems. This valve measures the difference between the inlet and exit temperatures of the refrigerant to the evaporator and tries to control the refrigerant flow so the liquid completely changes to a gas before exiting the evaporator. By allowing a small amount of superheat (3°-10°C) in the exiting vapour, liquid does not exist and cannot flow on to the compressor.

Central ammonia systems normally use pumped liquid recirculation systems with flooded evaporators. The liquid/gas mixture in the "wet suction" line is returned to a surge tank where separation of the two phases occurs.

The compressor draws the dry refrigerant gas from the top of the vessel, and liquid is pumped from the bottom of the vessel to the evaporators. Accurate temperature control and minimum product weight loss can be achieved by using a modulating back-pressure regulator to control the flow of refrigerant so the evaporator temperature is the highest possible as the heat load in the room reduces.

The Evaporator

After passing through the expansion device, the refrigerant is now at a low pressure and is fed through the evaporator. The evaporator consists of banks of coiled tube with the surface area increased by the addition of fins. The refrigerant is contained within the tubes, and the air which extracts the heat from the product passes over the finned tubes.