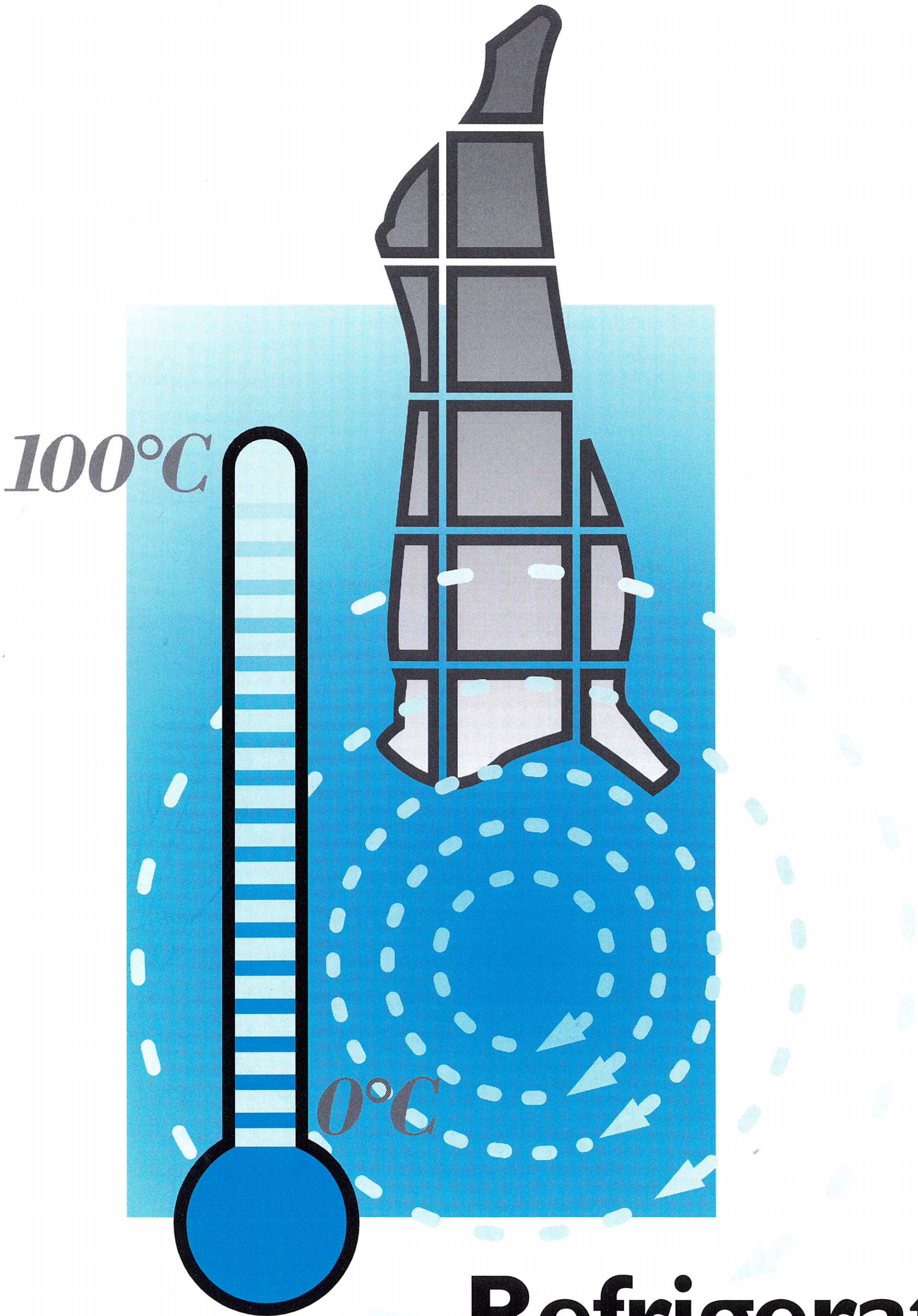

Refrigeration Equipment

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Meat Research Corporation

AMT
AUSTRALIAN MEAT TECHNOLOGY

Refrigeration is the generation of cold by the expansion of a liquid to vapour. In meatworks it is achieved by the mechanical vapour compression process associated with the provision of chilling, freezing or cold storage facilities, either individually or as an integrated process.

In a fully integrated meatworks with chilling, freezing and cold storage operations, the provision of refrigeration services can account for up to 42% of the electrical power consumption. It therefore has the potential to influence the effectiveness and success of energy management programs.

Another brochure addresses the principle of refrigeration operating strategies to minimise energy consumption; however, the potential savings are dependent on the original refrigeration machinery selection and system design.

Refrigerants

Ammonia (R717) or Hydrocarbons?

In the past the availability of refrigerants was not of major concern in deciding which to use. As a general rule ammonia was selected for large installations, with fluorocarbons (eg. freons) preferred for smaller industrial or commercial applications. The development of large, variable capacity, screw compressors saw an increase in the use of chlorofluorocarbons (CFCs) for larger installations. However, this is no longer the case due to environmental considerations with the phasing out of CFCs and the limited life of some interim replacements.

Transitional refrigerants, the hydrochlorofluorocarbons (HCFCs), are due to be phased out in developing countries by the year 2020, although a small amount will be available until 2030 for servicing 'long-life' equipment. There have been moves to bring forward the phase-out date prior to 2020 but this was rejected by the Parties to the 1995 Montreal Protocol at their most recent meeting held in Montreal in September 1997. HCFC 123 has a very low Ozone Depleting Property (ODP) of 0.02 and will most likely be the last of the HCFCs to be phased out.

Australia does not have an approved list of replacement refrigerants but, according to AFCAM (Association of Fluorocarbon Consumers and Manufacturers), will accept those approved under the USA EPA SNAP (Significant New Alternatives Policy) Program, although it is not legally binding here.

There is a growing proliferation of replacement refrigerants for CFCs and it is beyond the scope of this brochure to detail them; however, Table 1 lists some of the more common alternatives for industrial process refrigeration.

TABLE 1 CFC replacements for industrial process refrigeration

ODS†	Replacements							
11	HCFC123*							
12	HCFC22*	R401A*	R401B*	R134A	R717			
502	HCFC22*	HCFC123*	R402A*	R402B*	R404A	R407A	R407B	R717

† ozone depleting substance (refrigerants)
* transitional refrigerants

Ammonia (R717) is still the most environmentally friendly of the refrigerants with an ozone depletion potential of zero and minimal greenhouse effect.

The operational energy costs and capital cost of a refrigeration plant differ little between the most commonly used refrigerants, i.e. ammonia, R22, R134a, R401A, R401B, R402A or R402B. The thermodynamic difference is limited to about 5%; however, ammonia is cheaper to purchase per kg than any of the other refrigerants and requires a smaller quantity of refrigerant in circulation and pumping energy per unit of 'cold' generated. Each of the refrigerants has an optimal operating range and the equipment availability will often be the deciding factor on the refrigerant selected.

R717 in Process Areas

To date ammonia has been accepted for use as a direct refrigerant in boning rooms and other process areas within Australia, although it has been banned in other countries including New Zealand. Legislation has recently been drafted in NSW for the elimination of ammonia in boning rooms for new installations. Ongoing acceptance in other

States is probably dependent on the continued absence of any major leak or disaster resulting in serious injury or loss of life. Although ammonia is toxic and can be fatal in heavy concentrations, it is readily detectable as it is an irritant at very low concentrations, and in the event of a small leak it enables process areas to be quickly evacuated. Water has an affinity with ammonia and can absorb up to one hundred times its own weight; therefore, water sprays can quickly and effectively control small to medium leaks in confined areas. The installation of ammonia detectors is mandatory within process areas and plant machinery rooms in some States, and as provided in Australian Standard AS1677-1986 'Refrigerating Systems'.

In new installations the use of secondary refrigerant, brine or glycol, to circulate the air coolers is desirable. In using secondary refrigerants, the primary refrigerant (ammonia) is isolated from the process area, the initial heat transfer between the ammonia and the secondary refrigerant is accomplished in a remote heat exchanger, the secondary refrigerant is then pumped through the air coolers located within the process area. The secondary refrigerants are the glycols or brine solutions; both are water soluble but, while the glycols are non-corrosive, brines are very corrosive. Propylene glycol is the most common of the glycols used for refrigeration installations.

Equipment Design

For low temperature applications, the first consideration is deciding on a single or two-stage (multiple) system. Multi-staging saves energy by improving compressor efficiency and by flashing off some of the vapour to an intermediate pressure rather than the lowest system operating pressure. Generally speaking, a two-stage system will be more efficient than a single-stage operation but the capital cost will be higher. In an ammonia plant operating at +35 C° condensing temperature it is unlikely that multi-stage compression can be justified above -25 C° evaporating temperature.

Compressors, the Decision – Screw or Reciprocating Compressors?

Reciprocating piston compressors (Fig. 1) are the stalwarts of the refrigeration and meat industries; however, in the early 1970s screw compressors (Fig. 2) became extremely popular. They were promoted on the basis of their high turn-down ratio from 100 to 10% capacity and high compression ratio, which expand their operating range. Screw compressors can be used either as high-stage or low-stage (booster) machines and operate over a higher temperature range.

Screw compressors are more efficient than reciprocating compressors at 100%-load capacity but much less efficient than unloaded reciprocating compressors at relatively high part-load. Despite the high turn-down ratio capability of the screw compressors they, and the electric drive motors, become increasingly inefficient when operated below about 60% load capacity.

Capacity regulation of each type of compressor is achieved in the following manner:

In a multiple cylinder reciprocating compressor, banks of cylinders are progressively decompressed (unloaded), i.e. an eight cylinder machine would operate in steps of 100, 75, 50 and 25% capacity. In the conventional screw compressor, a sliding unloader valve progressively uncovers the discharge port to reduce the length of screw under compression, causing an increasing proportion of the gas to recirculate back to the suction port without doing any effective cooling. This comparison between reciprocating and screw compressors is illustrated in Table 2 which shows typical data for compressors operating at part-load.

There is a claim by the manufacturers of microprocessor-controlled, variable volumetric ratio, screw compressors that the design and control strategy has overcome the inherent problem of low efficiency at part-load.

Variable-speed drive motors can increase the efficiencies of screw compressors at part-load. However, at least one manufacturer has determined that the minimum practicable speed of its screw compressors is 2000 rpm (about 60% of design speed), below which gas by-pass or rotor slippage becomes unacceptably high. Another factor to be taken into consideration with variable-speed drives is the minimum speed for effective lubrication with direct-drive lubrication pumps. This applies to both screw compressors and reciprocating compressors. A separately driven lubrication pump may be required to ensure adequate lubrication when operating at low speed.

TABLE 2 Typical compressor part-load operation data (Cleland, A. C., Cleland, D. J., "Cost-effective Refrigeration" in IIR Workshop Proceedings, 1992).

Eight-cylinder reciprocating compressor				
% of capacity	100	75	50	25
% of full-load power	100	78	55	33
Part load efficiency	1.0	0.97	0.91	0.76
% Increase in energy per unit of refrig.	0	4	10	32

Screw compressor at mid-range pressure ratio					
% of capacity	100	80	60	40	20
% of full-load power	100	87	79	72	66
Part-load efficiency	1.0	0.92	0.76	0.56	0.30
% Increase in energy per unit of refrig.	0	9	32	80	230

The decision – screw or reciprocating compressors? – will depend on the type of installation, heat-load pattern and size. In many instances the solution is a combination of both types. A single, large screw compressor should be considered only where the load is steady and the compressor can be operated above 60% capacity consistently. This is a most unlikely scenario in a meatworks. Multiple compressors provide the advantage that one unit can be operated at low load and additional machines brought on-line as the load increases. However, for screw compressors the load should be shared. When an additional machine starts up, the previously fully-loaded machine should be off-loaded to 60% capacity, the additional machine allowed to ramp up to this capacity, and the two then cycled together. A smaller-capacity compressor for use during periods of extended low load, such as at weekends, can provide substantial energy savings.

FIGURE 1 Reciprocating Compressor

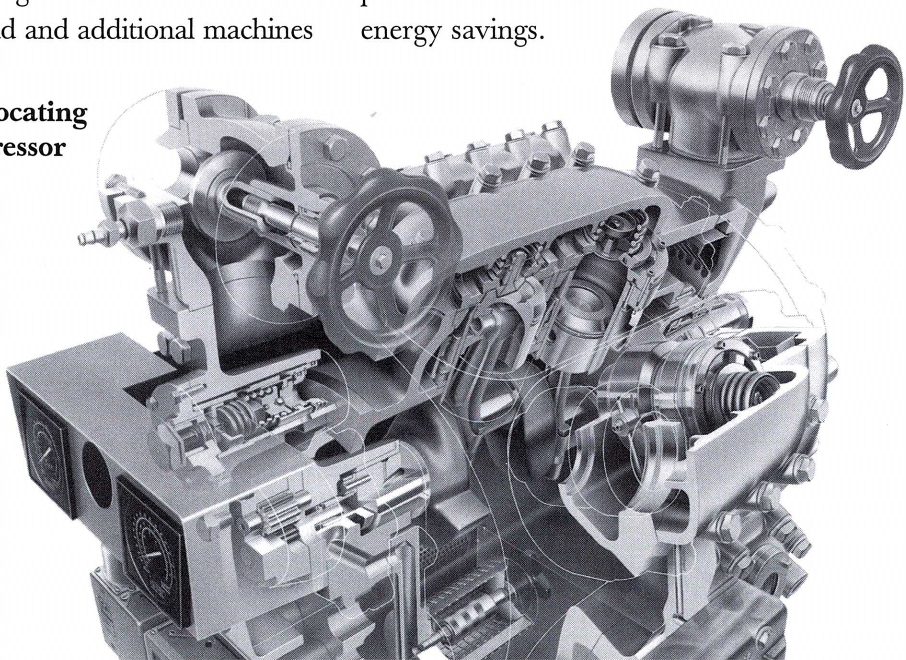
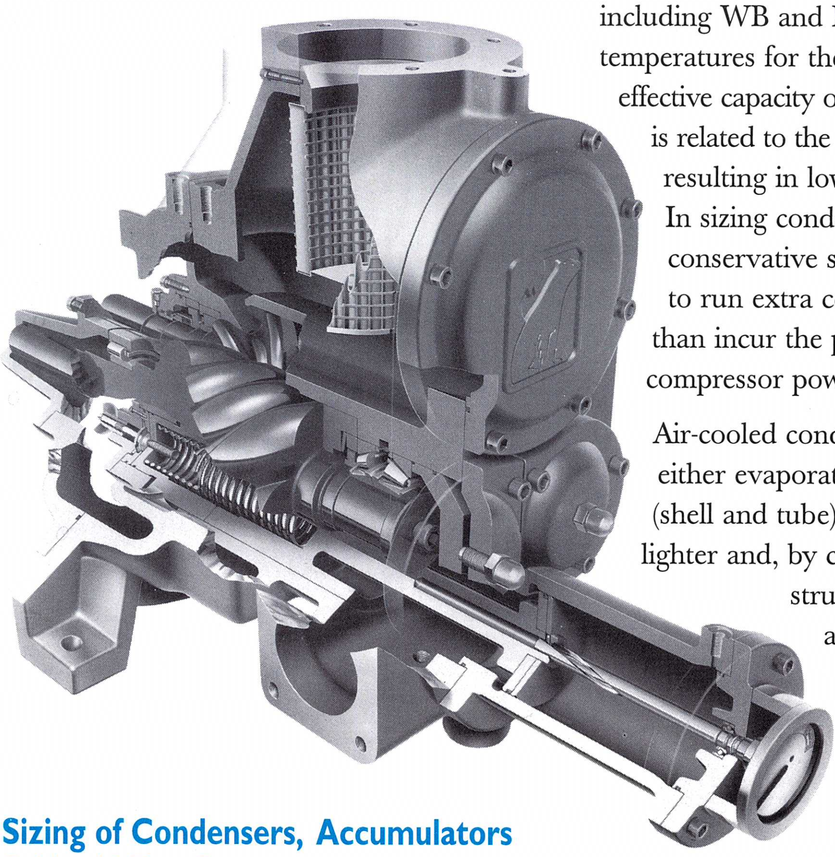


FIGURE 2 Screw Compressor



Sizing of Condensers, Accumulators & Liquid Receivers

The operating and energy efficiency of a refrigeration plant is a summation of the contribution and impact of the individual components. It is essential that the equipment is selected and installed with proper regard to likely operating scenarios and climatic conditions.

Condensers

Insufficient condensing capacity will result in higher compressor discharge pressures and temperatures, and lower overall refrigeration plant capacity. The effective capacity of compressors will be reduced, with lower COP (co-efficient of performance, i.e. ratio of refrigeration produced per unit of energy input), with resulting increased absorbed motor power (Figures 3 and 4).

Selection of adequate condensing capacity must take into consideration the range of climatic conditions including WB and DB (wet & dry bulb) temperatures for the site location. The effective capacity of evaporative condensers is related to the WB, with high humidity resulting in lower condensing capacity. In sizing condensers, it is better to be conservative since it is much cheaper to run extra condensing capacity than incur the penalty of increased compressor power.

Air-cooled condensers are cheaper than either evaporative or water-cooled (shell and tube) units. They are also lighter and, by comparison, the support structure and installation are simplified. However they are not as efficient and they are normally used in smaller installations only.

Accumulators

Accumulator vessels or liquid separators may be either vertical or horizontal in configuration. Generally, the vertical design is adequate for smaller plants, with horizontal vessels being appropriate for larger instal-lations; however, the physical layout of the engine-room may be the deciding factor. Irrespective of the configuration, it is important that the liquid operating level provide sufficient suction head for the liquid pumps.

FIGURE 3 Compressor power consumption per unit of refrigeration for various suction temperatures

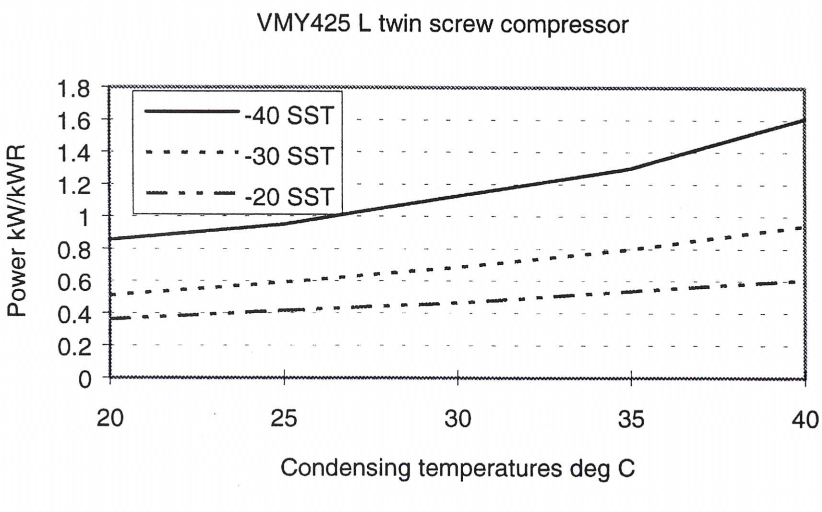
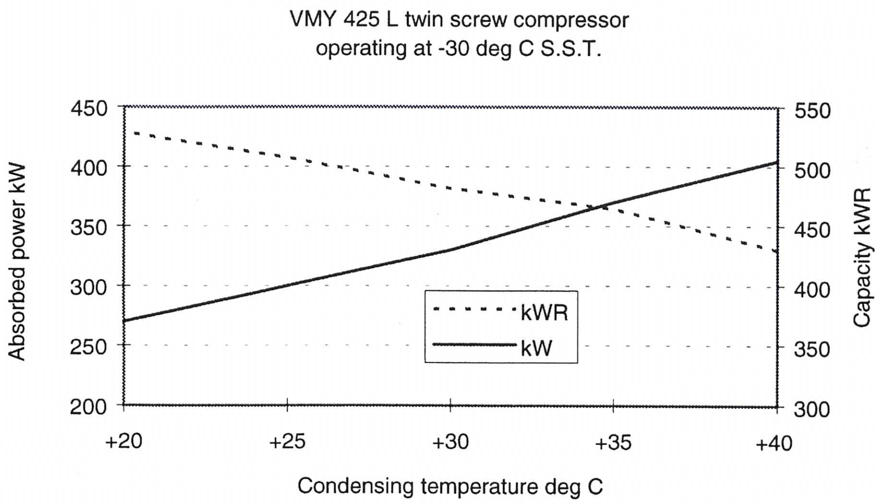


FIGURE 4 **Power consumption and refrigeration capacity at various condensing temperatures**



In selecting an accumulator, it is important to ensure that there is adequate capacity to handle the varying volume of liquid and vapour likely to be returned to the engine-room under all operating conditions. Sufficient liquid storage must be provided to cope with the fluctuating volume returning from the evaporator circuits under varying load and operating conditions. Also, there must be sufficient gas volume to promote moderate gas velocity over the surface of the boiling liquid refrigerant, and to prevent entrainment of liquid droplets and carry over into the compressor suction.

Liquid Receivers

The refrigerant operating level in the receiver and interconnecting pipework must provide free drainage from the condenser to prevent liquid lock-up which would effectively reduce condensing capacity.

To provide for servicing and refrigeration plant modifications, there must be sufficient capacity in the receivers to store the maximum liquid volume to be evacuated from any individual circuit during pump-out. The actual volume in each circuit is determined by the number and location of the isolating valves provided in the system.

Additional Information

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

"Cost-effective Refrigeration", Cleland, A. C., Cleland, D. J., Pham, T. Q., in *IIR Workshop Proceedings, Sydney,* 1992

"Pitfalls in Industrial Refrigeration Plant Design", Lundmark, N., *Vikool Trade Presentation, Brisbane,* July 1991

"Ammonia, the Forgotten CFC Alternative", Jensen, S., *Vikool Trade Presentation, Brisbane,* July 1991

"Sabroe Screw Compressor Units", *Technical Data*

"Alternative Refrigerants – The Quest for Perfection". pp. 16 - 18, Joyner, B.;
"Keeping Cool about Global Warming". pp. 19 - 20, Harris, M. R.;
"How Should Fluorocarbon Refrigerants Be Evaluated Opposite the Global Climate Change Issue?" pp. 28 - 33, Vogelsberg, F. A. Jr in *AIRAH Journal,* October 1995

Additional information

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