There has also to be considered, in discussing the different agents a point which is of some importance, namely, the effect on the metals employed in the construction of the machines which use them. The sulphurous acid in the Pictet, and the sulphuric ether machines, forms sulphuric acid if by any chance even a small quantity of water is present, and this will rapidly corrode any metal.

Ordinary ether will not attack the ordinary metals, so that copper or brass can be freely used, but the agent itself will readily deteriorate chemically if air or any lubricant enters the machine.

Carbonic acid also does not affect ordinary metals, and copper or brass can be utilized for pipes, &c., but the very high pressure it works under makes the use of steel for the compresser judicious. Ammonia rapidly eats away copper, so that neither copper, brass, or any alloy containing copper can be used in connection with it. Iron and steel, however, are not in the least affected by it, provided the liquid is "anhydrous." This requires the exclusive use of these two metals in an ammonia machine, and may at first sight appear a disadvantage, but in reality is a guarantee that only materials of the best description can be used for its manipulation.

The fact also of the gas being of any extremely pungent nature ensures that the leakage can be quickly discovered and rectified before any loss of efficiency takes place.

Taking everything into account, the moderate pressure at which liquifaction takes place, the constancy of the latent heat for temperatures, the low ratio between its specific and latent heats, the chemical stability of the agent itself, all indicates that ammonia is the best of all the agents now before us, and the most suitable for mechanical refrigerating purposes.

There are two systems of processes employed in the use of ammonia for refrigerating purposes, but so far as the mere principle of the evaporating and refrigerating part of the process is concerned, it is the same in both, the object both aim at being to evaporate the liquid anhydrous ammonia at such pressures and quantity as will produce the required cooling effect; the actual pressure under which the evaporation ought to be effected in any particular case depends entirely on the temperature of the material or room to be cooled, of course the higher this temperature, the higher may be the evaporating pressure, and therefore the higher is the density of the vapour and the greater weight of liquid that can be evaporated in a given time, resulting in a greater amount of heat being extracted, showing that the higher the temperature the greater is the efficiency of ammonia for extracting heat.

It is in the method of again bringing the ammonia into its liquid state, and getting rid of its heat during condensation that the two systems diverge. The systems are called "absorption" and "compression" systems.

1st.—The Absorption Process.

The absorption process was introduced by Carré in the year 1850, and the principle has not been altered since; the process is physical rather than mechanical, and takes advantage of the fact already mentioned that ammonia gas is readily absorbed by water, and that it can be separated from it by the application of heat to the mixture; the boiling or evaporating point of ammonia being so much lower than water for equal pressure, as shown on Diagram 2, allows the ammonia to be drained off in the form of gas before the water will evaporate. But in actual work it has been found practically impossible to prevent aqueous vapour from passing over with the gas, which greatly interferes with the working of the apparatus. In the most modern machines of this class ordinary ammoniaical liquor, containing about 38 per cent. pure ammonia and 62 per cent. of water, is charged into a generator, which is usually heated by means of a steam coil, and a mixed vapour of water and ammonia driven off, into a special form of condenser, where the action of cooling water, owing to the difference between the boiling points of the water and ammonia, causes the former to condense first, it being caught and run back to the generator; the ammonia gas is then condensed nearly anhydrous, and collected in a lower part of the vessel, from where it is drawn off to the refrigerator and allowed to evaporate, usually through coils of iron pipe, which at the other end are in communication with a vessel or absorber containing cold water or weak ammoniaical liquor. The readiness with which the water absorbs the gas, maintains a sufficiently low pressure in the coils of the refrigerator to allow of this evaporation taking place at a sufficiently low temperature to produce the desired cooling effect, the heat required during this evaporation being abstracted either from the brine, or other liquids surrounding the evaporating coils, or the coils themselves are placed in the room to be cooled. The water or weak liquor in the absorber gets strengthened in the process of absorbing the ammonia, and is then passed back into the generator, to be again subjected to heat, the whole process being continuous.

It has been found in practical working that these machines, while being very simple in design, and with very little machinery, allowing their construction to entail only a small first cost, are not sufficiently reliable for general use, and that their efficiency falls considerably below that of the compression system, this being chiefly due to the fact that the heat of vaporisation extracted in the refrigerator is rejected in the absorber, so that the whole heat of vaporisation required to drive off the ammonia gas in the generator has to be supplied by the steam, also that the cooling water has to take up nearly twice as much heat from the condenser and absorber as in the other system.

But there is also another important point to be taken into consideration, namely, that the hot mixture of ammonia and water has a strong corrosive action on iron and steel, and this is sufficiently serious as to entail very heavy yearly expenses in up keep.

2ND.—COMPRESSION PROCESS.

In machines working on this process only "anhydrous" ammonia is, or should be, used, and so far as the evaporation of the liquid in the refrigerator is concerned, is the same as in the absorption process, the essential difference is, that instead of the vapour being absorbed by water it is drawn off by means of a pump, and then compressed and discharged into a condenser, at a pressure sufficient to cause its liquifaction at the temperature of the available cooling water. These temperatures and pressures have before been referred to, and are shown on the curve in Diagram 2, but it would be as well to point out here, that in using these curves for reference it must be remembered that due allowance has to be made in practical working for the rise in temperature of the water passing through or over the condenser, and also for the difference in temperature necessary, in order to permit of the transfer of heat through the metal of the condenser coils.

The ammonia being condensed or liquified in the condenser, flows into the refrigerator and is there evaporated, afterwards being drawn back by the pump and re-compressed. Thus a given quantity of anhydrous ammonia is continually subjected to the same cycle of operations, and unless any escape by leakage from joints or glands no renewals are necessary.

The power expended in driving a compression machine, or in other words, the work applied to the pump, is accounted for as follows :—

a. Friction of machinery.

b. Heat rejected during the compression and discharge.

c. Heat acquired by the gas in passing through the pump.

d. Work expended in discharging the compressed vapour from the pump.

As a set off against these must be reckoned the useful mechanical work performed by the vapour from the refrigerator entering the pump. The higher this, usually termed, suction pressure can be obtained, the less will be the driving power required, and the greater the efficiency of the machine. The heat carried away by the cooling water in the condenser is the heat of vaporisation taken up by the gas in the refrigerator, minus the amount due to the higher pressure at which the liquifaction takes place, plus the heat acquired in the pump itself, and less the amount due to the difference between the temperature at which the vapour is liquified and that at which it entered the pump. Making these allowances, it is thus seen that the heat carried away by the cooling water is the measure of the refrigerating power of any compressor machine, and those machines in which the amount of heat acquired by the gas, in the pump, and otherwise than that taken up in the refrigerator, is small, will necessarily give the highest economy in working and consumption of cooling water.

Having thus briefly described the different refrigerating processes the author will now refer to the Linde system of refrigeration.

This was first introduced in Germany by Professor Linde, about 1875, who was then connected with the Munich University, and since then over 1,750 machines have been set to work in different parts of the world, the manufacture being conducted by three companies, the Linde British Refrigerating Company, Ltd., London; Linde Ice Machine Company, Wisbaden; and the F. W. Wolf Co., Chicago.

The apparatus necessary for the Linde process consists mainly of three parts, the exact arrangement of which has to be designed and arranged for each case to accord with the conditions under which the work has to be done and the space at disposal. These parts are :—

1. The compression pump, which continually draws the ammonia gas from the refrigerator and delivers it into the condenser.

2. The condenser, where, by the continuous circulation of cooling water, the heat which has been abstracted by the

ammonia in the refrigerator is carried off, and the gas condensed and liquified.

3. The refrigerator in which the liquified ammonia is vaporised and caused to extract heat from the substance required to be cooled.

The general arrangement of this type is shown in Plate XVIII., which is a plan of an ice-making plant.

THE COMPRESSOR

is generally constructed on the double acting principle, either horizontal or vertical, and is so arranged that the compression of the gas is accomplished with a close approximation to the isothermal line, this being brought about through cooling the gas during the compression period, by means of a very small quantity of ammonia, introduced into the compressor during each suction stroke. This liquid evaporates during the compression, and the latent heat of this being made available, the heat developed in the cylinder is absorbed or counterbalanced by it.

To explain this further: a gas, as is well known, is either dry or saturated, the former, when it is not in contact with the liquid from which it originated, and when in this state must be of a higher temperature than that of its evaporation point corresponding to its pressure. The latter, when it is in connection with its originating liquid, and then has a temperature exactly corresponding to a certain pressure. Diagram 1 will serve for reference.

If in separate cylinders an equal volume of these gases are compressed behind a frictionless piston, from the same pressure and temperature to the same higher pressure, p_2, it will be found that the dry gas will compress along the adiabatic curve, P.V., giving a temperature of t_2, while the saturated gas will be compressed along the isothermal curve, giving a temperature of t_3, the difference between these representing so much less work required to be exerted for the same compression with the saturated gas than with the dry.

There is thus a very great economy of power gained by using the saturated gas, and also the temperature being kept down to nearly the liquifying point due to the condensing pressure; there is no necessity for any appliance for keeping the cylinder cool when at work

This is exactly the converse of what takes place in a steam engine; there, it does not need to be explained that the perfect engine would expand the steam on the isothermal line, but on account of the difficulties of getting and using superheated steam, the expansion is invariably on the adiabatic line, but the steam engine expands the gas, the ammonia machine compresses it. In other words, we want to take as much power as we can out of the steam while we want to put as little as possible into the ammonia.

In the cylinders using dry gas the temperature due to the compression is so much in excess of that due to the condensing pressure, that it is necessary to surround the cylinder with a water jacket, or else the cylinder would get excessively heated and not be properly lubricated In the Linde compressor, on account of the gases being kept down to ordinary temperatures, there is no necessity for any water jacket round the cylinder, and, in fact, the compressors when at work will always be found to be covered with hoar frost. and there is no occasion to introduce any oil into the cylinder, as the moist gas is found to be an excellent lubricator.

This result of using saturated gas is obtained by a special arrangement of valves and ratios of refrigerator and condenser capacities.

As it is of the utmost importance to completely evacuate the compressor on each discharge, the clearance allowed at the end of the cylinder is made as small as $\frac{1}{32}$ to $\frac{1}{16}$ of an inch, and the piston rod end bearing is arranged with adjusting screws, so that at any time this can be regulated, if required, by the wear of the brasses causing the clearance to be unequal.

Combined with the compressor is a vessel for intercepting any oil which may be carried in from the gland of the stuffing-box, which, if allowed to pass into the coils of the condenser, would, by coating the inside, reduce its efficiency; this collector is fitted with an arrangement for automatically passing the oil so caught into a vessel called a rectifier, from which it can be drawn periodically and filtered to be used over again. Owing to the compressor being double-acting, and the strains thus equalised, they can be run at a high number of revolutions per minute; the larger sizes, say a 50-ton ice machine, usually making 65 revolutions, and the small sizes up to 140 revolutions. This allows of the steam engines being of small dimensions; the I.H.P. for a 50-ton machine would be only 60.

CONDENSER.

This is made in several different forms to meet the requirements and exigencies of the work intended and position where erected, the principle being always the same. The ammonia gas, after leaving the compressor, passes through specially designed valves, these being for the purpose of stopping communication and enabling repairs to be carried out when required without loss of ammonia. The condenser coils are made in one length, varying according to the size of machine, from 20ft. to 500ft., without a joint, and, before leaving, the manufacturers are always tested to 2,000lb. pressure per square inch, the number of coils varying according to size of machine, the ends being connected together by cast iron collecting pieces, to which the ends of the coils are jointed with spigot and faucet joints, having an india-rubber ring between, all flanges throughout being made in this manner. The top collecting piece distributes the gas to the several coils, and the lower collects the liquified ammonia, from whence it is taken to the refrigerator.

The three forms of condenser made are the "submerged," "open air," and "evaporative." The first is generally used when the circulating water is not restricted, but in this case economy is obtained by using the water after leaving the condenser for condensing the steam of the driving engines. The submerged condenser is cylindrical in form, the casing being made of wrought iron and the coils bent to suit; the cooling water enters at bottom and overflows on top into a tank, from whence it is again drawn through engine condenser.

Open Air Condenser.

This form is best suited for warm climates; the coils rest on suitable frames outside of the building, usually overhead, the circulating water being pumped up, and allowed to flow through perforated holes in circulating pipes, and trickles over the condenser coils.

Evaporative Condenser.

This form is designed specially when the amount of circulating water is restricted, and according to quantity available; the system is the same as the open air condenser, but the coils are cased in with timber, and a fan drives a strong current of air from the bottom upwards, causing a rapid evaporation which increases the efficiency.

In this way the same water is used over and over again, it only being necessary to make up the quantity lost by evaporation, this being about 500 gallons only per hour for a 50-ton ice machine; for a submerged condenser the quantity of cooling water required to do the same work would be about 6,400 gallons per hour.

The Refrigerator

In which the cooling process is performed of extracting the heat from the surrounding bodies, which are generally brine, water, or air, the process being the reverse of the condenser, the ammonia gas being allowed to expand as before explained. This is accomplished in strong wrought iron pipes of long lengths, suitably placed, either in a tank containing brine or in a room.

In ice-making, the tanks containing the brine are rectangular in form, the expansion coils being placed either in the bottom or at the sides, and completely immersed in the brine, the heat being extracted from the brine by the passage of the ammonia gas through the coils. Into this cold brine any number of pans containing water are immersed, called the can system, or the brine is circulated through cells, intermediate cells holding the water to be frozen. The brine extracts the heat from the water contained in the moulds, until it is frozen into a solid block. In the larger plants these moulds are set in frames, and these are kept constantly travelling from the back end of the brine tank towards the front, each row of moulds when frozen is mechanically lifted out of the brine, immersed in a bath of slightly warm water to loosen the ice from the sides of the cans, again lifted up and canted, when the blocks of ice fall out on a table. So complete are the mechanical arrangements for this operation that only one man is required to manipulate the whole, and ordinary ice can thus be made at 3s. 6d. per ton. When pure crystal ice is required, the water has either first to be evaporated and condensed, or filtered and kept in constant agitation either by paddles kept moving back and forwards in the water, or by the Barmister process, by which the water is intermittently sucked up and dropped again by the action of a pump, the air in the water being liberated and carried off by the suction pump performing the operation. For transmitting the cold produced to refrigerating chambers, four methods are employed and used according to conditions.

(*a*) The brine pipe system, in which the brine after being cooled in the refrigerator is constantly circulated through pipes placed in the rooms to be cooled, and returned to the refrigerator to be re-cooled.

(*b*) The direct expansion system. Instead of using brine as a bearer of cold, the refrigerator is placed directly in the room to be cooled, in the form of nests of pipes placed either in the ceilings or at the sides, and the ammonia flashed through these direct from the liquid receiver, being drawn back to the compressor direct.

Both of these systems have their advantages and disadvantages. In the brine pipe system the dangers from leakages are small, as at the most only a little inconvenience from dropping of brine would result, and the brine in the pipes acts at a storage of cold represented in B.T.U., multiplied by the weight of brine contained in the pipes, multiplied by the specific heat, multiplied by the difference in temperature of the brine and the room to be cooled. On the other hand, the direct expansion system has the advantages that it dispenses with the intermediate brine, thus reducing the mechanism necessary; there is a slightly higher efficiency gained by the higher suction pressure which can be worked with, but there is no store of cold in the pipes in case of a stoppage, and should a leak occur in the numerous pipes and joints in the rooms, the result is disastrous from many points.

Both these methods also labour under the disadvantages of the moisture in the rooms collecting on the pipes in the form of snow, or hoar frost, and this acting as a non-conductor, interferes with their refrigerating power.

The circulation of air is also very moderate, depending entirely on the natural tendency of cold air falling and warm air rising on the pipes.

This is not, in the case of storage rooms or rooms where a temperature above freezing is wanted, of so much importance, but where dealing with provisions, fresh meat, or perishable articles, is not satisfactory. To overcome this, the Linde Company have brought out an improved method on each of these.

(*c*) The brine is cooled in a shallow rectangular open tank containing the evaporator coils. On the tank is mounted a number of slowly-revolving transverse shafts, and on each shaft is fixed a number of parallel discs, partly immersed in the brine, the entire apparatus being placed in an insulated passage through which an air current is continually passed by a fan, in a direction parallel to the revolving discs. It will be seen that as the discs revolve and are kept covered by a film of the refrigerated brine, the air passing between the disc-spaces becomes cooled, and produces a low temperature in any chamber or room into which it may be conducted through properly arranged air-trunks. As a rule the air is always taken back from the cold rooms, passed over the discs and returned to the cold rooms, and any required amount of fresh air is introduced by means of adjustable openings in the air trunks communicating with the outer atmosphere. In this instance, also, moisture may be removed from the refrigerated rooms and deposited in the brine contained in the trough. No accumulation of frost can take place, and the refrigerating surfaces are always perfectly active. The circumstance of all moisture being deposited in the brine necessitates either a periodical loss of the same or its re-concentration. The fan produces a very effective air circulation within the rooms to be cooled. This, in most cases, is extremely desirable, and, as will be readily understood, produces the most beneficial results.

(*d*) The refrigerator coils in which the vaporisation of the liquid anhydrous ammonia takes place are sometimes constructed with extra large surfaces, and placed in a separate chamber. In the latter case, a fan constantly circulates the air between this chamber and the refrigerated rooms. This is the system generally adopted on board ships, and it has been found to be, in all respects, most satisfactory. In cases where the air temperature is not sufficiently high to cause a complete removal of the snow deposited on the ammonia-coils, the snow is thawed by the ammonia vapour, the evaporator coils being, for the time being, used as a condenser. Occasionally the snow is thawed by a current of hot air taken from the outside.

Though all the foregoing systems and apparatus have been applied on an extensive scale in actual practice for the refrigeration of storage and freezing rooms, the system most strongly recommended, in cases where the application is possible, is the combination of revolving discs immersed in brine. It is a very simple and compact arrangement, involving no expensive repairs.

The rapid circulation of the fan is easily managed, and has been found, where applied, to give perfectly dry and pure air in the rooms, no frost or snow accumulating in the air ducts or passages. This is similar to that erected at North Sydney.

The great importance of dry freezing rooms in the freezing of meat cannot be too well understood, as it is of paramount importance to the producer, who has to rely on the realized prices in foreign markets for his profits. It also reduces the risk of the tainted meat by gradually, although rapidly, extracting the heat from the carcass and allowing the freezing operation to be carried on by a continued changing of the air in the chamber, carrying with it the moisture and heat extracted from the meat. By this means, in place of the meat being frozen on the outside, or, in other words, covered with a film of ice, the surface is kept dry and the heat from the interior allowed to escape. Again, this system has the advantage that meat, after it is killed, can be at once run into the chamber, and the amount of air regulated to allow of any required degree of temperature for gradually chilling the carcass before freezing.

For the preservation of fruit, a strong circulation of air is necessary, and to this want may be attributed the non-success of much of our fruit that has perished during transit.

Remarkably good results have been obtained in carrying the cold air to long distances. In the case of the installation of the new Melbourne Markets, the air being delivered into the cool chambers in Flinders Street, a distance of 450ft from the coolers, leaving the cooler at 2° F., has a temperature of 10° F., or a rise only from 8° to 9° F. from delivery at cooler end into chamber, and this is due to the friction of the air round the many angles which it has to pass in its course. In the straight length from cooler, a distance of 140 ft. the loss is nil. It might be mentioned that under the contract it was only required to keep these chambers at a temperature of 40° F. and like the chambers on the other side was never intended to do freezing work, but the success has been so great that the whole are now utilized for freezing operations.

As showing the great advance mechanical refrigeration has recently made in economy, it may be mentioned that the two machines at Melbourne, having a capacity of 60 tons of ice made, or 120 tons melted, per day, do the equivalent of this work in freezing on a consumption of only 4¾ tons of gas-coke, including the driving of the electric lighting plant.

An installation of Linde machines is now being erected in Manchester, England, where 400,000 cubic feet of freezing storage space will be cooled by four compressors with a power equal to the production of 150 tons of ice per 24 hours, driven by triple expansion steam engine, on a consumption of five tons of ordinary steam coal per day. To do this with compressed air machines would require a consumption of about 35 tons of coal per day.

The author regrets that time will not allow of going more minutely into this most interesting subject, and has to apologise for the rather elementary nature of the paper, but press of business prevented preparation of extended data as to efficiency and results that would have been of perhaps more value to the institution, and he would have liked also to prepare more enlarged diagrams for this meeting, but trusts that the drawings submitted, being actual working plans, will be satisfactory.

DESCRIPTION OF PLATES.

Diagram I—Showing the curves of temperatures and pressures during compression and expansion of a permanent gas.

Diagram II.—Showing the curves of pressures corresponding to the temperatures of different gases.

Diagram III.—Curves, showing the variations in latent heat of different liquids.

Plate XVI.—Is a plan of a compressed air refrigerating machine—Lightfoot's system.

Plate XVII.—Plan of a compressed air refrigerating machine--Haslam's system.

Plate XVIII.—Plan of small size, Linde system, ammonia machine combined with steam engine and ammonia condenser, as usually fitted for small land installations.

Plate XIX.—Plan of refrigerating installation at Municipal Markets, Woolloomooloo, Sydney, showing arrangement of Linde machine, with coolers and rooms for fish and meat.

Plate XX.—Plan of refrigerating installation at Municipal Markets, Melbourne, showing general arrangement of Linde machinery, coolers, and rooms

Plate XXI.—Plan of refrigerating installation of the Wellington Bacon Curing Co., showing Linde machinery with brine pipe installation for cooling the rooms.