

Refrigerating Installations

by *N. K. Dlinnov*

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THE MINISTRY OF THE MEAT AND MILK INDUSTRY
OF THE ESTONIAN S.S.R.

I. PRINCIPLES OF PRODUCTION AND PRESERVATION OF COLD

1. METHODS OF OBTAINING ARTIFICIAL COLD (REFRIGERATION)

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by N.K. DLINNOV

The difference between the engineering and machine-building refrigeration

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REVERSE ENGINEERING INSTALLATION

by N. K. ULLMANN

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I. PRINCIPLES OF PRODUCTION AND TRANSFERENCE OF COLD

1. METHODS OF OBTAINING ARTIFICIAL COLD (REFRIGERATION)

Cooling an object is the removal of heat from it, usually accompanied by a decrease in temperature. The simplest cooling is the direct heat transference between the cooled object and its immediate medium: ambient air, river or sea water, earth. However, with this method, the object cannot be made colder than the ambient temperature. Such cooling is called natural.

Cooling an object below the ambient temperature is called refrigeration (the artificial cooling method).

The difference between the machineless and machine-produced refrigeration

The simplest machineless method is cooling by ice or snow. As the cooled object absorbs the heat, the snow or ice melts, changing to water. As 1 kilogram of ice or snow melts, it removes 80 kcal of heat from its immediate surroundings. At an atmospheric pressure ice and snow melt at 0°C .

If salt is added to the snow or ice, the melting temperature of the admixture decreases. The water formed in the ice and salt mixture is saturated by the salt and during the process of thawing of ice or snow, the mixture cools to a temperature below 0°C , without forming into ice, whereupon the melting temperature of the snow or ice in the brine decreases.

The melting temperature depends on the salt concentration of the mixture. With the increase of the amount of salt in the mixture (however, within definite limits) the melting temperature decreases.

The lowest temperature of a coolant mixture of 23.1% table salt (NaCl) with snow, ice or water is -21.2°C , while with a mixture of 29.9 % calcium chloride (CaCl_2) a temperature of -55°C can be obtained. However, with concentrations of the mixture ex-

ceeding 23.1 % table salt or over 29.9 % calcium chloride, the temperature abruptly increases.

with a 17 % salt concentration the air temperature in the room can decrease to -5°C , while with a 22 % salt concentration it can be from -10 to -12°C .

Refrigeration can also be obtained by mixing ice or snow with diluted acids. For example, the temperature of a mixture containing 7 parts of snow or ice and 4 parts of diluted nitric acid will be -35°C . A lower temperature can also be obtained by dissolving salt in diluted acids. So that, if 5 parts of ammonium nitrate and 6 parts of sodium sulfate are dissolved in 4 parts of diluted nitric acid, the temperature of the mixture will be -40°C .

Machineless methods of refrigeration have notable shortcomings. They are laboursome, low temperatures cannot be obtained and they cannot be automatically controlled.

The best method of artificial refrigeration is using the mechanical production of low temperatures. This method produces lower temperatures and permits automatic control of production processes, yet requiring less labour than the non-mechanical method.

Functioning of modern refrigerators can be based on various principles. At present the most widely used principle is that of boiling of liquids (refrigerant agents). As a result the liquid is vaporized, when a definite amount of heat is abstracted from the ambient medium. The boiling temperature of the fluid depends on its pressure. Pressure is held at a definite value, it is possible to keep a given refrigerant boiling temperature.

The principle of using the expansion of compressed air can also be used for mechanical production of cold. If the compressed air is exposed to expansion, its temperature falls and it becomes a source of cold. In this case, the work of the expansion is a result of the internal energy of gas, which is the basis of the operation principle of air refrigerating machines.

Artificial cold can also be obtained with the aid of dry ice (solidified carbon dioxide). Dry ice, absorbing heat from the cooled room, sublimates, i.e. it changes from the solid to a gaseous state, by-passing the liquid phase.

One kilogram of dry ice, sublimating at atmospheric pressure, absorbs 137 kcal of heat from the ambient environment.

Artificial refrigeration can also be accomplished by the direct thermal-electrical method (Peltier effect). If direct current is passed through a closed circuit of two different conductors, one of the alloys will heat, while the other will get cooler. If the direction of the electric current is changed, the heating of the conductors will also change: where the previously-heated alloy will begin to cool and the cold one will now begin to heat. Until the introduction of semiconductors the Peltier effect had no practical value. In a circuit comprised of semiconductors the "Peltier effect" is extremely effective making it possible to use it for practical purposes, for instance, in house-hold refrigerators.

2. OPERATING PRINCIPLES OF REFRIGERATING MACHINES

The refrigerating machines are comprised of apparatus and devices designed to abstract heat from an object to be cooled, and its transference to the refrigerated ambient environment having a higher temperature than the object being cooled.

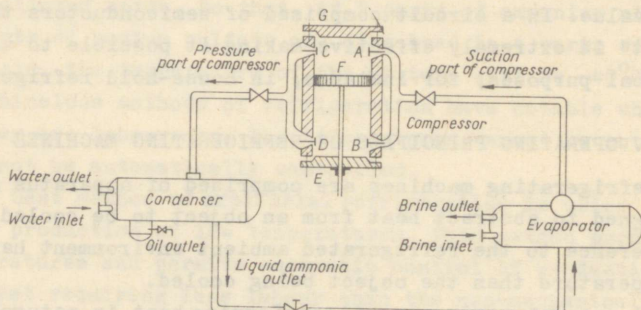
In all natural processes of transferring heat in nature, heat flows from the object having a higher temperature to the body having a lower temperature. The reverse, i.e. the transference of heat from a less heated object to a more heated one by natural means, is impossible without applying energy. Therefore, to transfer heat to a more higher level requires the expenditure of energy obtained from outside.

The performance of refrigerating machines is determined as the ratio of number of heat units abstracted from the object which is cooled, to those applied as power. The ratio of these two values must be the largest possible: the less the applied power or the higher the value of the abstracted heat, the more perfect the cycle. The ratio of the abstracted heat in respect to the applied power characterizing the efficiency of the cycle, is called refrigerator performance factor (or coefficient) symbolized by the Greek letter

$$\varepsilon = \frac{q^0}{AL^0} .$$

The amount of cold, expressed as kilocalories obtained by applying electrical power equal to 1 kwh , is called the specific refrigerating productivity (coefficient of performance) of the compressor, while the amount of cold created by the suction of 1 m³ of vapour by the compressor is the refrigerating production capacity (volumetric efficiency).

In general, the refrigerating machine with its auxiliary equipment and devices, designed to keep the required temperature in cold chambers, intended for storage of produce, is called a refrigerating installation.



Schematic Diagram of Ammonia Compression Refrigerating Machines

The refrigerating machine consists of the evaporator, compressor, condenser and regulating valve. The liquid refrigerant is passed into the evaporator where it abstracts heat from the brine and begins to boil. The created vapour is sucked in by the compressor and compressed. The hot vapour formed in the compressor is then forced into the condenser, where it gives heat to the water coolant, thus condensed (liquified), it passes through the regulating valve to the evaporator to repeat the cycle. The regulating valve is for throttling the refrigerant agent (from a condensation pressure to the boiling pressure) and to refill the evaporator with the refrigerant.

The liquid refrigerant agent removes heat from the substance being cooled (in this case, from the brine), passing through the evaporator piping. The refrigerant must boil at a lower temperature in order to cool the brine or some other substance to the required temperature.

To accomplish a continuous process of boiling, it is necessary that the refrigerant agent passes the heat abstracted from the brine to some other substance (commonly water) as it is transformed into a liquid state. To transfer heat from the cold vapour of the refrigerant agent created in the evaporator to the water, having considerably higher temperature, it is necessary to apply power to heat the refrigerant agent. Such heating of the vapour is accomplished by the compressor as it compresses the vapour. The compressor has the suction valves A and B and pumping pressure valves C and D. When operated, the compressor piston F never reaches the top wall of the cylinder head tightly. A dead space is formed between the front of the piston F and end walls G or E when the piston is in its extreme end positions, where a certain amount of the refrigerant vapour always remains.

Let us assume, that the piston F moves from the end wall G to the end wall E. The refrigerant vapour remaining in the dead space is displaced and follows the piston occupying the free space in the cylinder. The pressure of the vapour in this part of the cylinder will decrease as the piston moves. When the pressure at the suction end (from the side of the evaporator) will be slightly higher than in that part of the cylinder cavity concerned, the suction valve A opens and begins to suck cold refrigerant vapour from the evaporator into the cylinder of the compressor.

At the other end position of the piston at this time, the remaining vapour becomes compressed; its pressure begins to increase, since the suction valve B will be closed under the pressure of the refrigerant vapour in the cylinder. The pumping end valve D will also be closed under the pressure of condensation. When the pressure at this part of the cylinder becomes higher than that in the condenser, the pumping end valve D opens and the compressed heated refrigerant vapour flows along the piping to reach the condenser.

During the reverse movement of the piston (from the front end to the rear wall), the suction of cold vapour from the evaporator into the cylinder of the compressor will begin through the suction valve B, while the pumping of the compressed vapour from the condenser will pass through valve C. The suction, compression

and pumping of the refrigerant vapour will be subsequently repeated during the entire period of the compressor operation.

The cooled water in the condenser abstracts heat from the superheated refrigerant vapour. When its temperature falls to that of saturation, at a corresponding condensation pressure the vapour temperature decreases. The condensation and pressure depend on the temperature and amount of the water coolant: the more water passes through the condenser, the colder it becomes, the lower the condensation temperature and pressure will decrease and vice versa.

The refrigerant under the condensation pressure passes from the condenser to the evaporator through the regulating valve to be reboiled. The boiling and condensation temperature effects the refrigerating productivity and the power consumption of the refrigerating installation.

3. THE PHYSICO-CHEMICAL AND PHYSIOLOGICAL PROPERTIES OF REFRIGERANTS

The main physical and chemical properties of refrigerants are their reaction in lubricants and water, inertness to metals, explosion dangers and inflammability.

The boiling temperature of refrigerant increases as a result of its high solubility in lubricating oils, causing considerable leakage of oil from the compressor into the system. The boiling temperature of such refrigerants depends on the concentration of oil in the system. The solubility of the refrigerant in oil has its positive significance. It excludes the need for special oil separators. The leakage of oil from the compressor into the system also depends on the consistency of compressors, the dimensions, the wear of cylinders, the speed of the vapour movement, etc.

Refrigerants, which do not dissolve in oil, possess the following merits: the boiling temperature remains constant, the absence of foaming as when using soluble refrigerants, the lubricants readily separate from the refrigerant, which makes it possible to easily remove the oil through the oil drainage outlet. However, such agents also have shortcomings: when used, the oil coats the surfaces of the heat transference devices, which in turn re-

duces the heat transfer factor.

The solubility of the refrigerant agent in water entering the machine is of great importance for normal and continuous operation. The water can freeze since its solubility is low and as a result ice will block the passages, especially the regulating valve, thus hindering the proper functioning of the machine.

Refrigerant agents must be neutral to metals, i.e. they must not cause corrosion and oxydation of the machine elements. They must be explosion proof and must not be inflammable in admixtures with air. They must not be poisonous or cause asphyxia or irritate the mucous membranes of eyes, nose or respiratory tract.

When selecting the refrigerant it will be necessary to consider its cost.

None of the known refrigerant agents at present satisfy all of the requirements stated above.

When selecting the agent, one must consider the operation conditions, application of the refrigerating installation and the design peculiarities of the machine.

Modern refrigerating machines widely use ammonia and freon refrigerants.

Chemical plants prepare refrigerant agents and transport them in steel containers (vessels) pre-tested for durability under corresponding hydraulic test pressures. The vessels are coated with oil or enamel paint, using a definite colour for each agent: for those containing ammonia - yellow, for freon - aluminium.

Ammonia (NH_3) - is a colourless gas having a suffocatingly strong characteristic odour, obtained usually by uniting hydrogen with nitrogen, using a catalyst. Ammonia ensures a high refrigerating production capacity. Overpressure reaches the limits of 16 - 17 atm. (usually 9 - 11 atm.) in the condenser even at a high temperature of about 35°C when using a water coolant, while in the evaporator system operated in refrigeration machines it is slightly above the atmospheric pressure, as a result, air is excluded from entering the system. At atmospheric pressure ammonia boils at a temperature of -33.4°C , the congealing temperature of -77.7°C .

By using modern perfected hermetically sealed agregates, ammonia installations can successfully work at boiling temperatures of -40 to -50°C , i.e. with a pressure below the atmospheric. The heat transfer coefficient of apparatus using ammonia are sufficiently high, ensuring intensive operation of the heat transference apparatus of the refrigerating machines.

Ammonia has a harmful affect on the human organism if the air contains even as little as 0.03 %. Exposed to air, ammonia does not burn so well (having a yellow flame), but in oxygen it burns well (giving a greenish flame). Ammonia is explosive in air concentration of 16 to 25 %. Its cost if compared to other agents is not high.

Ammonia is chiefly used in piston-type refrigerating machines having varying productivity for operation with a condensation temperature not exceeding 40°C .

Till the present time ammonia is commonly used in many of the refrigerating installations of the food industry (meat, dairy, fisheries, etc) and household refrigerators.

Freon is a derivative of methane CH_4 and ethane C_2H_6 . If atoms of fluorine or chlorine are replaced in methane or ethane, we obtain a substance of the freon group. The larger the union of the chlorine atoms, the lower the boiling temperature of the refrigerant. Freons are practically harmless and in most cases non-explosive. The most widespread refrigerant of the freon group, freon-12 (CF_2Cl_2 difluoro-dichloromethane). At atmospheric pressure freon-12 boils at -29.8°C , solidification temperature is -155°C . Freon-12 has been used widely in piston compressors to provide varying refrigeration productivity with condensation temperatures to 60°C . This agent is of high fluidity. It passes through the smallest openings and pores of metals, dissolving non-metallic inclusions. Freon-12 dissolves rubber, therefore, a special type of rubber, resistant to freon is used in freon-refrigerating installations. Freon-12 is readily dissolved by lubricating oils, but it does not dissolve in water, therefore, when water is applied into the system it can cause corrosion to clog the regulating valve. water is removed from the system by silica gel cartridges (alumi-

nium oxide), also by adding various liquids into the system, which decrease the freezing temperature of water. For example, monoethyl ether of ethylene glycol which does not effect the boiling point, does not react the agent or oil, does not crystallize at low temperatures and has a low viscosity.

If it is not near an open fire, freon-12 is absolutely harmless for personnel servicing refrigeration plants. It causes asphyxia only with large concentrations in the air (about 40 % of volume), by displacement of oxygen because of its high specific weight. An open flame decomposes freon-12 into its component parts poisonous hydrogen fluoride and hydrogen chloride, with the forming of a poisonous gas-phosgene. It is for this reason that smoking is forbidden in premises where refrigerating machines are installed.

Freon-22 (CHF_2Cl) Difluoromonochlormethane. At atmospheric pressure freon-22 boils at a temperature of 40.8°C and solidifies at -160°C . It is widely used in piston compressor-refrigerating machines providing various output capacities for operation at condensation temperatures up to 40°C . Freon-22 is a refrigerant with a future, it is already beginning to replace Freon-12, due to its considerably lower specific volume of the compressor suction vapour.

II. REFRIGERATING MACHINE DESIGN

1. CLASSIFICATION OF COMPRESSORS

The compressor is the main part of the refrigerating machine. It sucks the refrigerant from the evaporator system, compresses it and pumps it into the condenser.

The compressor must satisfy the following requirements. It must be of a simple design, maintain equilibrium, provide economical operation and must be simple and reliable in operation. The compressor must be made of a maximum of unified sub-assemblies and components (made to fit a number of single-type compressors) and, if possible, of inexpensive materials. It must be light in weight and have small dimensions. The compressor must be simple to dismantle and provide comfort in maintenance of its various parts during operation of the installation. In addition, the compressor

must work reliably over a long period without unnecessary interruptions. It must be resistant to short-term wet compression and permit possible over-loading during operation.

The different types of compressors are the piston, rotary with rotating pistons and centrifugal (turbine) compressors. The piston compressor is practically universally used.

The piston compressors are distinguished by the following features.

According to the refrigerant used: freon, ammonia, carbon-dioxide, etc.

According to the disposition of the cylinder axis: vertical (cylinder axis vertically disposed to the axis of the casing and crankshaft) the Y-shaped (angular disposition of cylinder blocks), horizontal (cylinder axis are horizontally disposed), W-shaped and VV-shaped.

According to the number of cylinders: single-cylinder, multicylinder.

According to the number of working cavities - single-acting (compression of refrigerant vapour is done by a single ended piston) and double-acting (vapour is compressed at both ends of the piston).

According to the motion of the vapour in the cylinder uniflow (motion of the refrigerant vapours flow in one direction during the cycle of the entire operation process from suction and ending in pumping) and the non-uniflow (motion of the refrigerant vapour changes its direction of flow during the compressor operation).

According to the number of compressor stages: single-stage compression (vapour is compressed by the pressure of suction until reaching the pumping pressure by one cylinder) and multi-stage (compression of the vapour takes place consecutively in various cylinders; for example, in a low-pressure cylinder - to intermediate pressure, then in a high-pressure cylinder-to the condensation pressure).

According to the speed of the crankshaft - low speed (horizontal having up to 200 r.p.m., vertical and Y-shaped with up to 500

r.p.m.) and high-speed (horizontal with 200 r.p.m., vertical and Y-shaped with no less than 720 r.p.m.).

According to the refrigeration capacity - small compressors (refrigerating capacities, in standard kcal up to 5,000 m. kcal/hour); second size ($Q_0 = 5000$ to 50,000 m. kcal/hour); medium ($Q_0 = 50,000$ to 400,000 m kcal/hour) and larger sizes (having refrigeration capacities exceeding 400,000 m kcal/hour).

Refrigeration capacity of the machine in standard kilocalories is considered to be specified at a boiling temperature of -15°C , condensation temperature of 30°C , and a temperature before regulating valve of 25°C .

Compressors may be classified into the following types:

BE "VU" - vertical uniflow, BH "VN" vertical, non-uniflow, YH-Y "YU-Y"-shaped uniflow, YH-Y "YN-Y" shaped non-uniflow, ГД "HD" horizontal double-action.

The basic units and parts of the piston compressor are: the crankcase, cylinder head shell, piston and its rings, rod, crankshaft with its counter weights, stuffing box of the shaft, the suction and delivery valves, screw lubrication, pump, rough and fine purifying filters.

2. REFRIGERATOR INSTALLATION EQUIPMENT

The basic heat transference apparatus are the evaporators and the condensers.

The evaporator is the heat transference apparatus in which the refrigerant boils because of the heat abstracted from the cooled medium: the brine, air or water. The effectiveness of the heat transference in the evaporator depends on the intensity of heat abstraction during boiling of the refrigerant, the speed of the flowing intermediate heat transference substance (brine, air or water) and on the cleanness of the heat irradiation surfaces. The heat transference will decrease, due to the presence of snow, corrosion or if other deposits coat the heat irradiation surfaces.

The vertical pipe evaporators

The vertical pipe evaporator is made as a rectangular welded tank of sheet iron having a thickness of not less than 6 mm, which

enholds the respective evaporator sections. Each section has two horizontal collectors made of seamless pipes, to which short vertical pipes are welded, slightly bent at the ends. There are also several vertical pipes of a larger diameter in the section.

The short pipes for evaporators with a cooling surface up to 160 sq.m., are made of seamless piping having a diameter of 38 x 3 mm, while for the evaporators $F_{cool} = 200 \text{ m}^2$ and more - are made of piping having a diameter of 57 x 3.5 mm.

To avoid liquid ammonia particles from entering the suction end, each section has a liquid separator, welded to its upper collector. The liquid separators are connected to the lower collectors of the sections to pass the separated liquid particles. The normal level of liquid ammonia in the evaporator must be at the height, which is lower than the generatrix of the upper collector. A tube gauge is fitted for observing the level of the liquid ammonia.

The sections are connected together by the collector and oil collector. The latter is connected to an oil-catcher with a drain cock for draining the oil from the evaporator. The oil-catcher is coupled to the suction collector through a compensating pipe having a thickened section.

Each evaporator has a screw agitator to circulate the brine. The evaporator tank is divided by longitudinal partitions into sections to form brine passages.

To exclude the brine from overflowing the tank edges, it is equipped with an overflow pipe, along which the excess brine flows into the tank for mixing the brine. The brine is also poured from the evaporator into this tank through the drainage pipe before repairs or during maintenance inspection.

To reduce external heat convection, the tank of the evaporator is coated with heat insulation having a thickness of 200 mm.

The evaporator is mounted on a base to avoid moisture from entering the insulation coating.

The top of the tank is closed with a wooden cover to keep the brine free of dirt and also that it will not warm up. The chamber cooling batteries or heat transference apparatus receive the brine

through the pump action, which collects it through a coupler at the end wall of the tank (at the agitator).

The evaporator works in the following way: the liquid ammonia reaches the evaporator from above, through the liquid collector, from where it spreads along the pipes to the sections. The created ammonia vapour moves upwards along the short pipes carrying with it particles of liquid ammonia. Part of it, taken from the upper collector, flows back downward, while a part of it together with the vapour enters the liquid separator from where it also flows down to the lower collector. The ammonia vapour is sucked by the compressor along the suction piping line. The lubricating oil, accumulated in the lower collectors, flows along the oil drainage piping to the oil catcher, from where it is periodically emptied through the drain cock into any container for further use after it has been filtered.

A vertical pipe evaporator can produce about 2500 kcal/hour per sq.m. of its evaporating surface, when the evaporator is filled with ammonia as rated, while the difference of the boiling temperature of the refrigerant and delivered brine is $5 - 7^{\circ}\text{C}$, and the brine flow is 0.3 - 0.4 metres per second.

The vertical pipe evaporator and tank are simple in design, convenient for inspection and cleaning.

The drawback of such evaporators are: liability to accelerated corrosion, especially when using brine of sodium chloride.

The panel (radiator piping) evaporator

This type of evaporator was designed by engineers A.B. Harchenko and A.I. Shuvalov at the Moscow "Compressor Plant". As for the principles of its operation, it has much in common with the vertical pipe type compressor. The basic difference between the panel evaporator and vertical pipe type lies in the constructional features of the evaporator sections.

The sections are comprised of panel radiators, connected between the top and bottom collectors: at the top they are connected to the vapour collector, and at the bottom to the liquid (condensate) collector. Each panel is made of two steel plates, pressed

to form an especially-designed radiator configuration with projections and cavities. The projections have a semicircular shape, while the cavities are flat, rounded to pass-over to the projection all together forming a multitude of channel passages.

The use of heat irradiation surfaces of shaped steel panels considerably increase the economical effect. Beside the effect of a lower over-all weight by 25 - 30 %, the cost of installing seamless piping is 5 - 6 times less, as compared to conventional apparatus using pipes. A feature of this type of evaporator is its low ammonia filling capacity, which is twice less than the vertical pipe evaporator, while its heat transference is an average of 15 % higher. This is explained by the more intensive circulation of the vapour-liquid ammonia mixture in the panel channels, which have a smaller cross-section area, than that of the vertical pipes of the evaporator, and likewise it has a higher heat transfer rater.

Shell-pipe evaporator

The shell-pipe ammonia evaporators are designed as a horizontally disposed welded cylinders (shells), fitted to grated steel bottom bases of two inch seamless pipes. At both ends of the cylinder there are spheric covers with built-in inner ribs, for creating a passage, so that the brine flows through the respective pipes and also to increase its cooling properties.

The upper part of the shell has couplings for mounting a manometer and for a three-way closing cock with two safety valves. A pot-like oil-catcher fitted with a glass-globe cock is welded to the bottom of the cylinder for routine removal of possible deposits and lubricating oil from the evaporator.

The liquid ammonia enters the inner space of the evaporator shell through the coupling at the bottom of the apparatus. At the same time the ammonia vapour is drawn by the compressor from the upper areas of the evaporator through the vapour dome with compartments for drying the vapour. Evaporators having surfaces exceeding 110 m^2 are supplied with separate liquid separators.

The amount of ammonia in the evaporator is considered to be

correct if the level of the liquid ammonia in the shell is at a height, which is between the second and third pipe row as counted from the top. The level of the liquid ammonia in the separator can be approximated by the hoar frost line of the uninsulated piping, connecting the vapour and liquid spaces of the evaporator. With a normally filled evaporator, the ammonia boils intensively in the inter-piping area, and the evaporator functions to providing the required brine temperature.

The brine fed by the pump enters the evaporator through the bottom fitting of one of its covers, continuously passing along the piping making several complete turns (depending on number of passages) before it flows out of the apparatus through the upper fitting on the cover mentioned earlier. To reduce the outside heat convection, the evaporator is covered with a 200 mm thick heat-insulation coating.

In a normally filled ammonia evaporator, having a difference of the boiling temperature of NH_3 and that of the brine equal to 5°C and with a speed of the brine flow being 1.5 m/sec., one square metre of the evaporator surface can remove 2,000 - 2,250 kcal/hour.

The evaporator-air cooler (air conditioner)

Air coolers (conditioners) are designed to cool the air in premises, where the air circulation is actuated by fans (ventilators).

The fans (there may be several of them) draw the air from the chamber to be cooled and pass it through a cooling coil, the cooled air is then forced at a high velocity into the cooled chamber through a nozzle or mouth piece. The air jet, ejected at a high speed, causes displacement of the ambient air, creating a considerable air circulation in the entire chamber.

The simplest in design and therefore the most widely-used are the dry refrigerating installations provided with vertical batteries and a system of cross-sectional air displacement. The vertical air cooler is made as a battery of horizontal ribbed pipes. Centrifugal or axial fans are mounted over the batteries. The lower part of the air cooler framework is open and is used as the air intake. An open tray is placed under the battery to catch the thawed water.

Evaporator-cooling apparatus

The most commonly used cooler is the one where the cooling is done in the immediate vicinity of a battery of radiators (in which the refrigerant boils within) or where brine is circulated after it is refrigerated in the evaporator.

The batteries are made of seamless pipes having diameters of 57 x 3.5 mm spaced usually at a distance of 220 mm between the pipe center lines of the cooling batteries, while the spacing of the brine circulation batteries is 130 mm.

In installations, where the battery is mounted on the wall, the pump feeds the cold brine from below, while the heated brine moves upwards along the same side of the battery. These ammonia and brine radiator batteries are made of horizontal pipes shaped as flat coils.

At present, cooling batteries using short piping have found wide use. They are made of pipe -lengths of about 2 - 3 metres placed vertically between two horizontal collectors, providing rapid vapour removal and an easy way of removing lubricating oils, which increases the battery efficiency.

N.P. Tkachev introduced the usage of a battery of ribbed radiators, made of smooth seamless steel pipes fitted with ribs made of 1 - 2 mm galvanized or iron sheets. A part of the ribs can be made of production scraps. The use of the ribbed batteries have the following merits: the costs of seamless pipes are out. The installation area of the cooling apparatus is reduced. The refrigerant filler capacity of the system is considerably decreased.

The cascade battery system designed by E.S. Scherbakov functions as follows. The liquid refrigerant agent enters the battery through the upper fittings from where the agent flows downward successively along a series (cascade) of horizontal pipes, kept partially filled with the refrigerant (15-30% of the cross-sectional area). When the refrigerant reaches the level of the drainage piping, it flows into the receiver piping. The vapour flows along the vapour piping to the collector, from where it passes through the fitting into the suction pipe line. All of the unvapourized liquid refrigerant flows along the pipe line into the receiver tank

for re-circulation.

The merits of the E.S. Scherbakov battery system are as follows.

Because of the excellent separation of the refrigerant vapour from the liquid within the battery itself, there is no need to install liquid separators in refrigeration systems using the "cascade" type batteries; the refrigerant filler volume is small (not more than 12% of the battery volume).

Absence of the hydrostatic liquid column as a result the temperature rating in the battery remains unchanged regardless of the height of the piping.

Condensers

The condensers are heat transference apparatus in which the refrigerant vapour is reduced as a result of the transference of heat to the cooled water or air. The irradiation factor is decreased because of foreign deposits, such as silica scale, dirt or lubricants settling on the surface of the heat transference condenser. Therefore, it is necessary to keep the surface constantly clean of foreign deposits.

At present, the following types of condensers are manufactured: the shell type, the evaporator type, the sprinkler type with an intermediate tap for draining the liquid refrigerant agent and with air cooling.

The earlier manufactured counter-flow double-pipe and element condensers have been removed from production, because of excessive waste of metal (the manufacturing of the said types requires twice as much metal, as compared to the shell type). Ejected at a high speed, causes disturbance of the air, creating a considerable

The horizontal shell condenser

This type of condenser is made as a horizontal cylinder (shell) welded to a grate of steel pipes, which in turn are fastened to seamless pipes having a diameter of 38 x 3.5 and 25 x 3 mm.

The hot ammonia vapour enters the shell from above, while the liquid ammonia flows out from below. The cooled water flows along the pipes, making several turns (depending on the number of passages) in accordance to number of sections available in the welded

cast-iron or steel end covers of the apparatus. By using successive water passage, a notable increase of the heat transfer rating is obtained, while yet providing a better condensation of the refrigerant vapour.

The covers which close the shells at both ends are provided with an air relief cock mounted at the top, to release the air from the water space. At the bottom, there is a water outlet cock, used to drain water from the condenser during repairs or maintenance. Likewise, water is emptied during operation intermissions in the winter season, when there is a danger of the water freezing in the condenser piping. Fittings are mounted on the upper cover for holding a three-way closing-cock with two safety valves, the manometer, and outlet fitting for delivery of the uncondensed gases and air to the air exhaust, lastly, for coupling the compensation piping connected to the receiver tank. A gauge is mounted on the shell for checking the level of the liquid ammonia in the condenser and finally, the shell is fitted with an oil release cock for removing oil.

A horizontal ammonia shell-pipe condenser, with a water flow speed of 1 m/sec. and difference of temperatures of the refrigerant and that of cooling water of $5 - 6^{\circ}$, can remove 4000 - 5000 kcal/hour, per sq. m. of surface.

The vertical shell-pipe condenser is designed as a vertical steel cylinder (shell). The end facing is fitted with a grate of pipe fastened to seamless steel pipes having a diameter of 57×3.5 mm.

The hot ammonia vapour, pumped by the compressor, after passing the oil separator, enters the shell inter-pipe space of the condenser through a fitting located at the top of the shell, from where the condensed ammonia flows out at the bottom of the condenser into the receiver tank through a fitting, located at a height of 140 mm from the bottom of the tubular grating. An angle oil cock is mounted at the bottom of the shell. A glass gauge indicating the liquid ammonia level is mounted at the lower side wall of the shell. The condenser pressure is shown by the manometer, mounted at a height of 1560 - 1650 mm from the bottom grating. On the top side of the condenser is a three-way closing cock with two sa-

fety valves, and an air relief cock. The fitting for coupling the compensation pipe to the receiver is located at a height of 1800 mm from the air separator. The latter is mounted at a height of 550 mm from the bottom tubular grating.

Cooling water enters from above into the circular spacing between the water receiver tank and ferrule, from where it passes through the slots to the upper tubular grating. A cap with a slit is placed over each tube, through which the water flows into the tube, washing the inner surface of the pipes with a thin stream of water. The caps are fitted with an over-flow tubing placed above the normal water level. In case of over-flowing of the water distributing device, the excess water flows into the condenser through the above tubes. The worked water is poured into the reservoir under the condenser, so that it can be re-used after it has cooled. To improve the removal of the heat from the condenser, the upper part of the shell sometimes has a welded pipe with holes in it, through which water is passed continuously, thus evenly washing the outer surface of the shell.

The effectiveness of the condenser performance is provided by a free release of the condensate from the heat transmission surface of the apparatus and the high speed of the water flow. One sq. metre of surface area of the vertical shell-type condenser can remove 3500 - 4500 kcal/hour.

The sprinkler condenser with the intermediate drainage of liquid ammonia is comprised of a number of sections made of seamless horizontally disposed pipes having a diameter of 57 x 3.5 mm. Each section having a surface area of 15 m² consists of 14 pipes with four liquid ammonia intermediate tap outlets. The cooling water is pumped into a distributing tank, from where it flows through a distributing device to the sprinkler pipes. The hot ammonia vapour enters each section from below. The water trickles along the outer surface of the pipes, removing heat from the ammonia vapour, as a result of which the vapour is liquified (condensed). A part of the heat is transferred from the water by convection, while the larger amount is transferred during evaporation. Intermediate con-

condensate pipes are coupled to separate sectors of each section, from where the ammonia condensate flows along the individual pipes into the receiver tank, thus improving the usage of the condenser heat transference surface.

Applying ammonia vapour into the condenser from below is convenient, because the lubrication oil entering the condenser with the hot ammonia vapour settles on the walls of the tubes at the bottom of the apparatus, hardly ever reaching the upper area.

The worked water is re-used in the condenser, where the water from the tray below is pumped to the distributing tank at the top of the condenser, into which the cold water is also fed.

Sprinkler condensers are indispensable in cases, when little cooling water is available and if it is dirty.

When using the sprinkler condenser it is possible to abstract 3500 - 4500 kcal/hour per sq. metre of its surface area.

3. AUXILIARY EQUIPMENT OF COMPRESSION MACHINES

The auxiliary equipment used with compression machinery is necessary to ensure normal operation conditions to improve the performance ratings and operation safety.

Liquid ammonia supercoolers are designed to decrease the temperature below the condensation temperature under the same pressure and to increase refrigeration productivity, consisting of counter-flow, double-piping or element-type apparatus, cooled by cold water. The apparatus is installed before the regulating station.

Receivers or collectors of liquid ammonia are made as horizontally-placed welded vessels. Linear receivers are to collect the liquid ammonia condensate thus creating a reserve, for smoothly feeding the regulating station. The drainage receiver tanks are used to remove the liquid ammonia from the evaporator, during the thawing of the batteries with heated vapour. Circulating receivers are used in systems using pumps.

Oil separators collect the oil released from the compressor with the ammonia vapour. The separation of the oil globules from the vapour is caused by the changes of the vapour movement, when

they enter the oil separator, where its speed is considerably retarded to 0.7 m/sec. The oil globules, which are heavier, settle at the bottom of the oil separator, while the heated ammonia vapour rise upward, passing to the condenser.

The compressor plant (Moscow) manufactures oil separators, in which the vapour is washed with liquid ammonia. From the compressor the heated ammonia vapour enters the oil-separator along a pipe, the end of which is submerged 150 - 200 mm below the liquid ammonia level. The ammonia vapour, freed of lubricating oil, enters the condenser through the grated conical retainers at the top of the apparatus.

|| Oil-collectors are designed to repress the oil from the oil-separators, to extract the ammonia vapour from the oil and pass it onward under a lower pressure. Thus improving operation safety during maintenance and decreasing the loss of ammonia when the oil is drained from the system.

Liquid separators are designed to separate particles of liquid ammonia from wet vapour, which are drawn from the evaporator system. The presence of liquid ammonia can cause hydraulic bursts and damage of the compressor. The particles are separated from the vapour due to the change of direction of the vapour movement when decreasing its speed to 0.5 m/sec.

Air separators are designed to remove the air and uncondensed (inert) gas from the system. When the system contains these gases, its heat transfer rating is lower resulting in the increase of the condensation pressure and consequently power consumption. As the condensation temperature increases only 1° , the compressor power consumption increases by 3 - 4%. When removing the air and ammonia admixture it is advisable to cool it first, since the loss of ammonia is lower when the admixture is chilled.

Intermediate vessels are used in double-pressure stage ammonia refrigerating machines to cool the superheated ammonia vapour, discharged by the low pressure compressor. Liquid ammonia is cooled to a temperature, corresponding to the intermediate vessel pressure and simultaneously due to barbotage, the superheated vapour

is cooled on leaving the low pressure compressor. The intermediate vessels are placed between the low pressure pumping cylinder line and the line of the suction cylinder of the following stage.

Filters placed in the line of the suction end of the compressor or dirt catchers, are destined to protect the cylinder surface from damage, because of the possible entrance of particles of rust, scale, sand or other deposits. Filters placed in lines before the regulating valve are needed to protect the automatic control apparatus from obstruction, while filters in the lubricant pump line are to filter the oil.

III. OPERATION OF REFRIGERATING INSTALLATIONS

During operation of compressors (starting, maintenance, stopping), adhere to the special instructions compiled by manufacturers or approved by enterprises operating said refrigerating installations. There are conventional regulations, which should be adhered during operation. Several of them are given below.

1. PRELIMINARY PREPARATIONS AND STARTING COMPRESSORS

The registered data in the daily log of the machine department usually provides information concerning the reasons why the operation was halted. After studying the log information continue inspecting the machine, remove all obstacles interfering the starting.

Inspect to see if all manometer valves are open; check that oil is available in the crankcase and also in the bearing extension if included in the construction. Next, check that the water coolant passes into the condenser, the safety valve and cylinder water jacket. Likewise, check that water enters into the coil which cools the crankcase oil, if available. Finally, check that the brine pump switches on (used with closed type evaporators).

Check that the sealing valves can be opened in the pumping mains (line), from the compressor to the condenser, and in the liquid mains, from the condenser to the regulating station. Check

the operation of the cooling apparatus, likewise, test the functioning of the suction mains from the cooling batteries or evaporator to the compressor (the sealing valves in the pumping and suction ends of the compressor and regulating valve which should be kept closed.).

Then to ease the starting, open the by-passage completely (open the valve between the pumping /delivery/ and suction ends of the compressor), by turning the fly-wheel handle at least by one turn and switching on the electric motor of the compressor. As soon as the electric motor gains its normal rotation speed, close the by-pass and simultaneously rapidly open the compressor pumping (delivery) valve, carefully observing the manometer to check the pressure in the oil mains, from the oil pump, which must be 0.5 to 1 atm. higher, than the pressure in the crankcase.

After this, slowly open the sealing valve in the suction mains from the compressor, doing this, slowly and carefully to avoid the possibility of sucking liquid ammonia or refrigerant into the cylinder. If signs of wet compression are noticeable, slightly close the suction valve, and if knocking will occur, quickly close the valve completely. After the knocking ceases slowly re-open the valve. All the while, observe the readings of the manometer and ammeter. If the pressure and electric current are above normal, stop the operation and find the fault, taking measures for elimination and repair. After the suction valve of the compressor is open, continue by opening the regulating valve and adjust for a normal operation of the refrigerating installation.

2. COMPRESSOR MAINTENANCE

The effectiveness and economy of the installation performance depends first of all on how correctly the boiling temperature, suction, superheating and condensation are held within the rated values.

The boiling temperature during direct cooling must be $8 - 10^{\circ}$ lower than the temperature of the cold chamber, while with brine cooling it is to be 5° lower than the working brine temperature, which in turn must be $8 - 10^{\circ}$ lower than that of the given chambers

temperature.

The condensation temperature depends on the cooling water temperature. The higher the water temperature, the higher the condensation temperature and vice versa. The temperature is considered normal if it exceeds that of the delivered water from the condenser by 4 to 6°.

To provide dry compression, the temperature of the ammonia vapour intake must be 5 - 10° higher than the boiling temperature, while the superheating (pumping) temperature depends on the boiling and condensation temperatures. An approximation of the superheating temperature can be made by using the following experimental formula

$$t_n = (t_o - t_k) \times 2.4$$

where t_o and t_k - boiling and condensation temperatures.

Vertical and Y-shaped compressors cannot be operated during the pumping temperature exceeding 135°C, while using the horizontal type - it should not be above 125°C, because the high superheating temperature can cause disturbance in the lubrication of the moving parts of the machine, causing the formation of scale in the valves and even combustion of oil. The boiling temperature of the refrigerant agent depends on the filler volume in the evaporator system and on the working surface of the operated cooling apparatus of the compressor. If the number of operated batteries is insufficient or if their surface area is small, or if the system is filled with too little refrigerant, the boiling temperature in the evaporator system will be lower than rated.

3. STOPPING THE COMPRESSOR

The compressor operation is stopped by following the procedure opposite that of starting it, i.e. at first close the regulating valve, then, after a certain quantity of the refrigerant vapour has been sucked from the equipment coupled during operation, close the suction valve. The electric motor is switched off only after the over-pressure in the crankcase has fallen to 0 atm.

4. POSSIBLE FAILURES IN THE OPERATION OF REFRIGERATING INSTALLATIONS AND MEASURES FOR THEIR ELIMINATION

Low pressure in the evaporator system

A decrease in the evaporator system pressure may be caused by the following reasons.

If manually adjusting the regulating valve, it is insufficiently opened; check and when needed, open it wider.

The system has too little refrigerant agent:

Symptom - the linear receiver tank has no liquid ammonia (observe the receiver glass-gauge) - the cooling battery is slightly covered with snowy coating; it is not possible to increase the pressure by opening the regulating valve to its extreme open position.

In such cases it is necessary to add ammonia into the systems from the ammonia container or from the reservoir. Dirty heat transference surfaces of the evaporator must be cleaned of oil and dirt.

If the snowy coating covering the cooling apparatus is more than permissible remove the excess snow.

Blocking of the evaporator piping (closed by ice plugs) because of too weak brine concentration. Salt deposits have been formed, due to an abnormally high concentration of brine; clean and keep the brine concentration within the rates as specified in the operation instructions.

Surface area of the evaporator system in use is insufficient; connect additional surfaces to the system.

Excess pressure in the evaporator system

An excess pressure in the evaporator system may be caused by the following reasons.

The regulating valve is too open; it should be slightly closed.

The system is over-filled with ammonia. Symptoms - wet compression is observed, which may cause hydraulic knocking of the

cylinder; the suction end line is coated with hoar frost; The suction temperature is nearly equal to the boiling temperature; the actual pumping (delivery) temperature (superheating) is considerably less than rated; it will be necessary to remove a certain amount of the refrigerant agent from the system into tested ammonia containers, or into the reserve receiver tank.

Possible defects in compressor operation may be leakage in the valves, piston rings or by-pass; make an inspection and repair the compressor.

High superheating of vapour (high compressor pumping temperature)

The reasons for high superheating are numerous.

Incorrect regulation in feeding the refrigerant into the evaporating system; re-adjust the regulating valve.

Insufficient quantity of the refrigerant agent in the system; add refrigerant into the system;

The presence of too much air and uncondensed gases in the system. Symptom - the manometer pointer deflection fluctuates. It will be necessary to switch on the air separator.

The correct amount of water does not enter the compressor water jacket; symptom - the temperature of water delivered from the jacket exceeds 40°C . It is necessary to increase the feeding of cold water into the compressor jacket.

Unsatisfactory insulation of the suction mains, complete absence or partially damaged insulation also causes high superheating in the machine. The insulation must be repaired. Leakage of the vapour from the pumping cavity into the suction cavity. It will be necessary to inspect the compressor and repair the defects in the valve seats of the machine or by-pass.

The surface area of the cooling apparatus, coupled to the compressor is insufficient. It will be necessary to couple an additional cooling apparatus.

Excessive condensation pressure

Excessive condensation pressure may be caused by the following reasons.

The presence of excess air and uncondensed gas in the system. Uneven sprinkling of the cooling water on the piping of the condenser or inadequate supplying of the cooling water. It will be necessary to adjust the feeding of the cold water to the condenser.

Dirty condenser heat transference surface because of lubricating oil deposits or scale. It will be necessary to drain the oil and clean the surface of scale.

Excess refrigerant agent in the system.

Clogging of the regulating valve. Symptom - the temperature cannot be increased in the equipment connected for operation even though the regulating valves are completely open.

In this case the equipment of the evaporator system must be sucked empty of the refrigerant agent (until obtaining a vacuum), then several times open and close the regulating valve, so that the applied pressure forces the valve open; if, however, this does not open the valve, dismantle and repair.

Inadequate condenser surface area coupled to operate; it will be necessary to add additional condenser surface.

5. REFRIGERATING INSTALLATION USED IN DAIRY ENTERPRISES

Refrigerating installations for use in dairy enterprises are mostly designed to cool milk and milk products in refrigerating apparatus, likewise, for cooling and cold storage of the dairy produce in chambers.

The cooling (chilling) of milk to be sent from the farms and dairy-receiving points to creameries is a necessary requirement to ensure high quality. Milk must be cooled immediately after it is milked and cold stored at $5 - 7^{\circ}\text{C}$, until it is processed. At the farms and dairy-receiving points, milk usually is cooled in cans, placed in especially designed refrigerating machines, which are continuously operating and in cold tanks.

Technological specifications of the dairy in cities require that milk is cooled immediately after delivery by passing the flowing milk and cream through refrigerating apparatus at a temperature of $4 - 5^{\circ}\text{C}$; likewise, after pasteurization. Mostly all of

the dairies use water and brine as refrigerant agents.

The use of a brine refrigerant in sections of the pasteurization apparatus and coolers is not advisable because of its intensive corrosive activity to metals and for other reasons. The transferring from the brine cooling to cooling by "icy water" at 1°C , considerably reduces the corrosive activity in the equipment and chilling mains, thus lengthening their working life.

The heat transfer rate with the use of water is on average of 20% higher than that when working with brine. That is explained by the increased heat transference of the heat carriers, caused by the use of less viscous media, as water.

The refrigeration load in many dairies varies considerably. To equalize the cold expenditure (consumption), it is preferable to use cold accumulators.

If the cooling temperature of 0°C is sufficient for given production process, the cold accumulators can be used effectively.

During hours when the need of cooling and power consumption at the creameries is at its minimum (night hours, etc.), ice is made on the batteries of panel evaporators. In this case the distance between the sections of the tank is increased to 125 mm. From 1 sq. metre of surface area it is possible to accumulate up to 3600 kcal of cold, obtaining ice having a thickness of 40 mm.

During the hours of maximum cold consumption, the compressor can be cut-off and the apparatus can be supplied by centrifugal pumps with "icy water" at a temperature of $0.5 - 1^{\circ}\text{C}$. Used water having a temperature of $4 - 5^{\circ}\text{C}$ is fed back into the evaporator. It is cooled by using the latent thawing heat of ice (80 kcal/kg).

By using accumulated cooling, the performance of cold production in the installations decreases more than twice.

To ensure reliable operation of refrigeration installations, to maintain a definite temperature in the cold chamber it will be necessary to introduce automatic control operation of refrigeration installations.

The duty of the operating personnel is the general maintenance of the installation operation, servicing of the automatic apparatus and carrying out of miscellaneous tasks.

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J. H. COOPER

REFRIGERATING MACHINES

AND REFRIGERATION

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