MOISTURE IN REFRIGERATING MACHINERY CIRCUITS AND COMPONENTS

BY

LIEUTENANT-COMMANDER (E) M. B. F. RANKEN, M.I.Mar.E., A.M.Inst.R., R.N.

PART I

The Author wishes it to be understood that he claims little originality for the technical information contained in this article, which is simply an attempt to collect all the information available on this important and controversial subject under one heading. No attempt has been made to indicate the sources of individual items of information, but a list of references and acknowledgements will be given at the end of Part III.

It is hoped that those more intimate with the everyday practical problems involved will contribute more detailed information for publication in future numbers.

Introduction

It is safe to say that at least 90% of the troubles experienced with modern Dichlorodifluoromethane, Arcton 6 or Freon 12, and methyl chloride refrigerating machinery are due directly or indirectly to the entry of moisture to the refrigerant circuit.

These troubles are greatly magnified in their effect because maintenance personnel, who have been taught about, or have only had experience with carbon dioxide machinery, do not realize how far-reaching are the effects of moisture in Arcton 6 or methyl chloride refrigerant circuits. An example of this lack of appreciation may be found in the statement of one leading manufacturer that up to 60% of the expansion valves returned to them as defective were only affected by moisture, which could easily have been dealt with on the job.

The majority of moisture troubles are caused by insufficient attention to detail on the part of operating and maintenance personnel at all levels. It is the purpose of this article to explain (*a*) what are the effects of moisture once it has entered the plant, (*b*) how moisture may be prevented from entering the refrigerant circuit, and finally (*c*) how the moisture may be removed after it has entered.

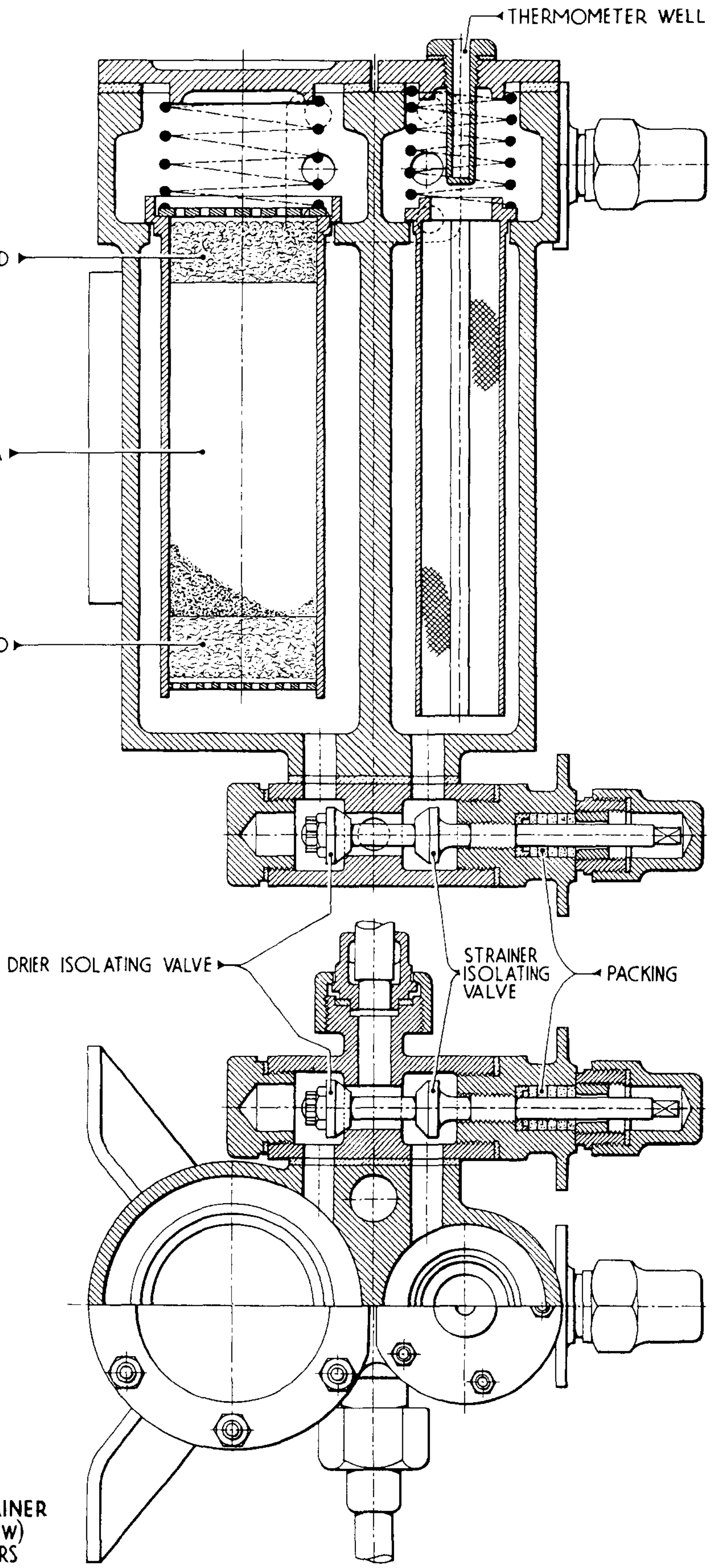
Moisture has many undesirable effects on the plant, other than inside the refrigerant circuit itself, e.g. the rotting of pipe and room insulation, and the reduction of heat transfer rates by the formation of frost and ice, but these effects and how they may be minimised will not be discussed in this article. An attempt has, however, been made to include all available relevant information on moisture effects in refrigerant circuits and the best methods of prevention and cure.

Effects of Moisture

The principal effects of moisture in refrigerant circuits are as follows :—

(*a*) Freeze-ups at the expansion valve or in the low side of the plant.

(*b*) Corrosion of the materials of which the plant is made and the formation of sludges.



COMBINED DRIER & STRAINER
(G. & J. WEIR LTD GLASGOW)
AS FITTED IN DESTROYERS

(*c*) Corrosion fatigue of spring flap valves in Arcton 6 plants.

(*d*) Copper plating in Arcton 6, methyl chloride and other plants using halogenated refrigerants.

(*e*) Chemical damage to the motor insulation of sealed-unit domestic refrigerators.

These effects will each be considered in turn.

Freeze-Ups

If the amount of moisture in the refrigerant circuit exceeds a certain low limit, which depends on the refrigerant in use, a freeze-up will occur either in the expansion valve, in which case it will normally result in a complete blockage, or at some point in the low side of the plant as soon as the temperature drops below 32°F., the freezing point of water.

Such a freeze-up will often result in a complete stoppage of refrigeration and it will certainly take a lot of care and patience to remove the moisture completely from the plant. As previously stated, the expansion valve is often blamed quite wrongly for this failure.

The amount of moisture which can be accommodated without causing a freeze-up varies greatly according to the refrigerant in use, as follows :—

Ammonia NH_3. Large quantities of moisture can be accommodated as the water is absorbed by the ammonia to form a solution of very low freezing point. However, excessive moisture upsets the operation of the plant and this sets the limit which is acceptable. It should be noted that driers are of no use for removing moisture from ammonia plants and it is generally necessary to blow out the whole charge and recharge with dry refrigerant. In some cases, however, pumping down the evaporator and blowing out what remains is sufficient.

Carbon Dioxide CO_2. The solubility of water in carbon dioxide is relatively high and this, coupled with the high pressure differences maintained across the expansion valve, usually prevents freeze-ups in carbon dioxide machines. If necessary, a small quantity of alcohol may be put into the circuit with the refrigerant to melt any ice formed and this may be removed from the scale trap or oil separator. Carbon dioxide cylinders are always liable to contain moisture and it is normal practice to stand the cylinders vertically with the valve down for several hours before use, and then to blow out any moisture before charging the plant. When possible it is desirable to use a drier in the charging line, as with other refrigerants, but driers are not normally supplied with carbon dioxide machines.

Sulphur Dioxide SO_2. The solubility of water in sulphur dioxide is also quite high, but the limit is again set by corrosion.

Arcton 6 CCl_2F_2, *Methyl Chloride* CH_3Cl (*Halogenated Refrigerants*). The solubility of moisture in the halogenated refrigerants is extremely low, e.g. the limits for Arcton 6 liquid are :—

Evaporating Temperature °F.	125	100	30	20	10	0	—10	—20	—30
Dissolved Moisture p.p.m. (parts per million)	280	160	16	12	8	6	3	1	0

The limits are somewhat higher for a mixture of Arcton 6 liquid and vapour, e.g. at 10°F. it is found that the vapour absorbs 13.3 times as much moisture as the liquid ; if 20% of the Arcton 6 liquid evaporates as ' flash gas ' in passing the expansion valve, which is quite a normal figure, the solubility of the mixture rises to 27.7 p.p.m. ; similarly at 20°F., for a 25% evaporation of the liquid, the overall solubility becomes 61.5 p.p.m.

The acceptable limits of moisture in the refrigerant circuit are therefore extremely small and the following are practical figures :—

Arcton 6	10 p.p.m. (0.001 %)
Methyl Chloride	50 p.p.m. (0.005 %)

Assuming that an average drop of water weighs 1/10,000 lb, or 100 p.p.m. when mixed with 1 lb of refrigerant these limits are equivalent to 1/10th of a drop per lb of refrigerant for Arcton 6 and 1/2 a drop per lb for methyl chloride.

In large plants which are usually fitted with high pressure float-controlled expansion valves, a somewhat larger quantity of moisture can be accommodated, but small plants, which use constant pressure or thermostatic expansion valves, or a capillary tube, are particularly susceptible to freeze-ups and the above limits must not be exceeded. In sealed units even lower limits are frequently set during manufacture to ensure long and trouble-free life.

Corrosion

Moisture will start or accelerate corrosion in refrigerant circuits, both by itself and in combination with the refrigerant and lubricating oil. The rate and extent of corrosion depends on the quantity of moisture present, on the temperature, and on the refrigerant in use. Corrosion is rapid with sulphur dioxide but slow with all other common refrigerants. It is worst at the highest temperature points in the plant, i.e. at the compressor discharge, and this in turn is worse in the tropics than in temperate climates ; the higher the temperature, the less moisture can be accommodated without causing corrosion. The presence of air also accelerates corrosion except in the case of sulphur dioxide, and air must therefore be excluded as well as moisture.

Ammonia NH_3. Ammonia circuits can accommodate large quantities of moisture without corrosion being set up, but it is best to keep the moisture content as low as possible for thermodynamic reasons. Corrosion does not occur in these plants because ammonia, NH_3, mixed with water, H_2O, forms ammonium hydroxide, NH_4OH, which is a strong alkali. Ammonium hydroxide is highly corrosive to copper and high copper alloys, and it is for this reason that these materials cannot be used for ammonia plants.

Carbon Dioxide CO_2. Carbon dioxide is soluble in water, one volume of water dissolving an equal volume of the gas at 60°F. and the solution so formed contains a little carbonic acid, H_2CO_3, which is very weakly acid. The solution is so weak that it will hardly react with most acid indicators, and for practical purposes in refrigerant circuits it may be neglected. However, moisture must be kept low to prevent direct corrosion of ferrous materials, especially if any air is present.

Sulphur Dioxide SO_2. Moisture combines with sulphur dioxide to form sulphurous acid, H_2SO_3, which is highly corrosive. With 300 p.p.m. of moisture, mild corrosion will occur, while with 1,500 p.p.m. very severe corrosion takes place. 1,000 p.p.m. of moisture will cause a breakdown.

Arcton 6 CCl_2F_2, *Methyl Chloride* CH_3Cl (*Halogenated Refrigerants*). The acceptable limits of moisture to prevent corrosion in plants charged with the halogenated refrigerants are much lower than for the other refrigerants. Mild corrosion occurs with 200 p.p.m. of moisture in Arcton 6 or methyl chloride, becoming severe at about 500 p.p.m. In the presence of moisture, methyl chloride forms hydrochloric acid, HCl, which attacks most metals ; methyl chloride also attacks aluminium and its alloys, but this is a direct reaction not associated with moisture. Arcton 6 on the other hand forms hydrofluoric acid, HF, which attacks metals by hydrolysis but is mild in its action. There is, however, a cumulative effect due to the catalytic effect of the salts produced by oxidation.

Thus corrosion starts in Arcton 6 and methyl chloride plants with 0.02% moisture by weight, equivalent to two drops of water per lb of refrigerant, but much lower limits are required to prevent freeze-ups, etc.

Of the sludges found in refrigerant circuits, 90% are due initially to the reaction of moisture with the refrigerant, lubricating oil and materials of which the plant is made. These sludges are formed from the products of corrosion and cause chokes in liquid and suction strainers and in pipe lines. Sludges must therefore be prevented by every possible means.

The other 10% of sludges are found to be due to the oil and other minor causes, e.g. wax may separate out of the oil at low temperatures and cause choked expansion valves ; hence the need for lubricating oils with low wax content.

Corrosion Fatigue

It has been found that corrosion fatigue of spring flap suction or discharge valves occurs in Arcton 6 refrigerant circuits in the presence of a considerable quantity of moisture.

' Copper Plating ' with Halogenated Refrigerants

A phenomenon known as ' Copper Plating ' occurs in refrigerating plants charged with Arcton 6, methyl chloride or any other halogenated refrigerant. The effect is to transfer copper from the insides of copper, bronze or brass parts, such as pipes, or the motor windings of sealed compressor units, and deposit it on other metal surfaces, especially steel ; this deposition occurs more readily on bright, clean, polished and relatively warmer surfaces, such as journals, bearings, pistons and cylinder walls. If tolerances are really close, there is a danger of binding or actual seizure occurring due to copper plating.

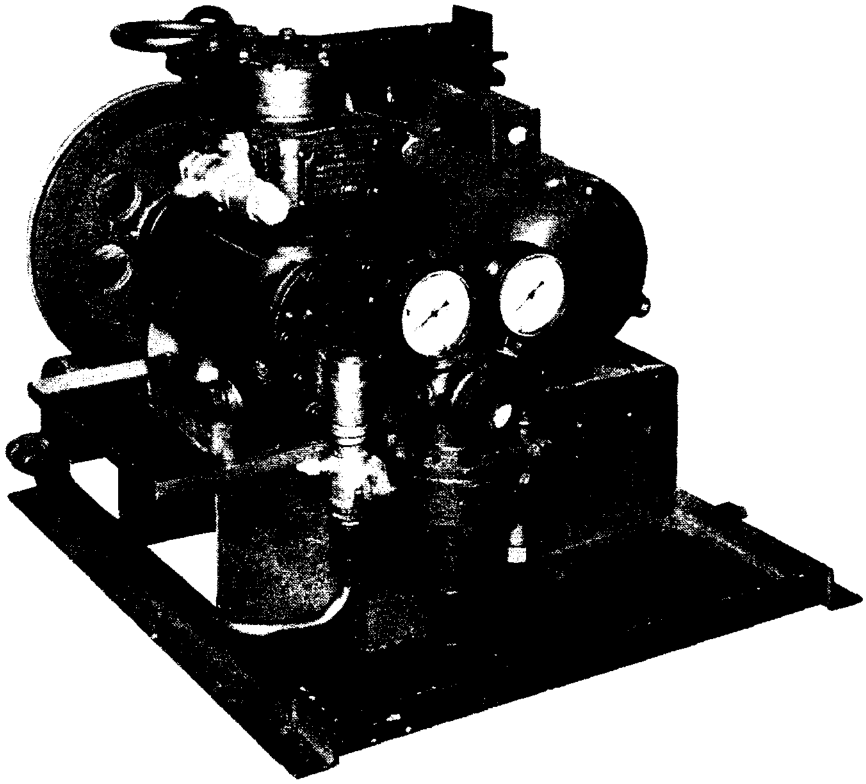
Copper plating is a complex chemical reaction, the actual mechanism of which is obscure and not fully understood. Copper is dissolved in the mixture of oil and refrigerant, and it has been established that the type of oil used, particularly its resin content, has an effect on the rate of copper plating. Methyl chloride assists the solution of copper in the oil and refrigerant mixture and hence plating is worse with methyl chloride than with Arcton 6. The presence of moisture or air in the refrigerant circuit, though not essential to copper plating, invariably aggravates and may start the reaction. With a highly stable lubricating oil and no water or air present, the system is usually immune from plating, and this shows the need for excluding moisture and air from the circuit.

Copper plating is more prevalent in machines working at high temperatures and is almost non-existent at low temperatures. That it chiefly occurs on working surfaces heated by friction is significant. It has been observed in the low (cold) side of the refrigerant circuit, but this is an infrequent occurrence.

The latest theory is that copper plating may be due only to the refrigerant and minute quantities of moisture setting up hydrolysis with the copper. Hence there appears to be a need for even more stable halogenated refrigerants than those already available.

Chemical Damage to Sealed-Unit Motor Windings

The insulation of sealed-unit compressor motors may be damaged by moisture in the refrigerant, both by chemical reaction and due to the hygroscopic properties of some materials. These effects are aggravated by the high tem-



D.R. Compressor Condenser and Gas Control Unit

peratures at which these sealed compressor motors have to run. The allowable moisture content for these units is therefore even lower than for open-type nachines.

Methods of Entry of Moisture

Moisture may enter the refrigerant circuit by one of the following means :—

(*a*) Insufficient attention to detail or carelessness during manufacture, maintenance or repair, e.g. water used for hydraulic testing during manufacture not properly removed afterwards. If water is used for hydraulic testing of a plant after it has been in service, even greater care and patience are required o remove it.

(*b*) Entry of moisture, chiefly in atmospheric air, during erection or servicing. Under normal atmospheric conditions, 5 cu. in. of air contain enough moisture o cause a freeze-up at the expansion valve and also eventually deterioration of the refrigerant, etc.

(*c*) Leaks during normal operation due to drawing in moist air under vacuum n the low side.

(*d*) Charging the plant with wet refrigerant or lubricating oil. Refrigerant usually leaves the makers' works in large transport drums, which are far too heavy and inconvenient for servicing purposes. It is, therefore, common practice to decant the refrigerant from these large containers into the service cylinders to be used on the job. Stringent precautions are taken to ensure that only dry and uncontaminated refrigerant leaves the makers' works ; similarly, strict precautions are required in the operation of the decanting plants and, particularly, in the cleaning and drying of the service cylinders prior to refilling.

Refrigerator oil is at present supplied to the Service in inconvenient 5-gallon drums, which cannot readily be kept properly sealed against moisture. It is hoped soon to adopt a new British Standard, which is at present being prepared. Oil manufactured to this Standard will be of the highest quality and will be supplied in small sealed expendable containers of small capacity (see also p. 319 (*h*)).

(*e*) Leakage of water or brine into the circuit from one of the heat exchangers.

(*f*) Entry of moisture in the form of steam from welding gases. In some cases a flow of dry nitrogen or other gas is maintained through the pipe during welding to carry this steam away.

(*g*) Oxidation of certain hydrocarbons in the lubricating oil to produce moisture.

(*h*) Decomposition of the motor insulation of sealed unit compressor motors.

The moisture may be present either (a) as liquid or ' free ' moisture, or (b) as hygroscopic or ' bound ' moisture. Free moisture enters by the methods described above. Bound moisture, on the other hand, is a loose term for water held by adsorption or absorption, as follows :—

(i) Water absorbed in sealed unit compressor motor windings.

(ii) Water adsorbed in desiccants such as silica gel or activated alumina.

(iii) Water absorbed in desiccants such as calcium sulphate.

(iv) Water adsorbed on metal surfaces. (Very little is adsorbed in this way.)

(v) Water trapped on metal surfaces by lubricating oil. (Only a small quantity is held in this way.)

It is particularly difficult to remove bound water, requiring, as it does, temperatures of the order 200-400°F. and considerable time and care.

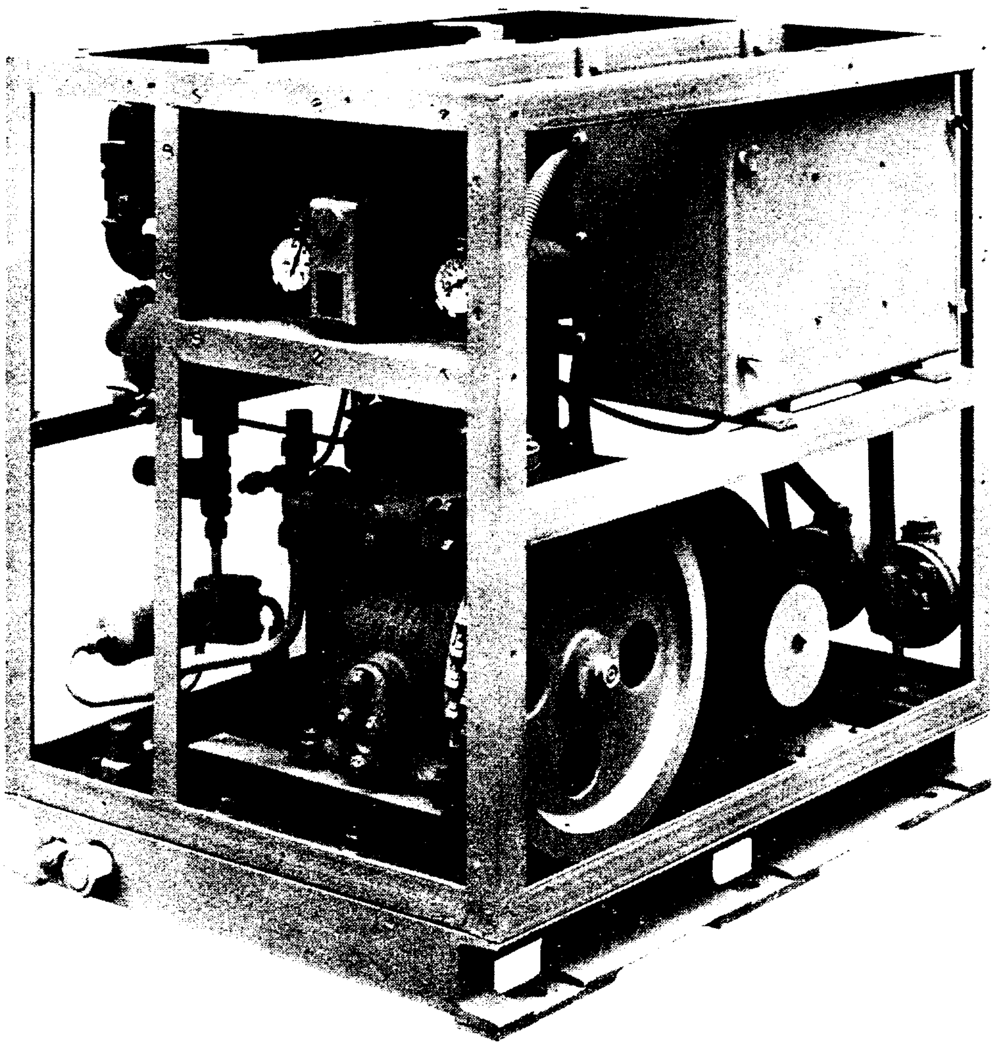
Symptoms of Moisture in the Refrigerant Circuit

Moisture above a very small percentage will freeze in the circuit and the ice so formed will cause a partial or complete blockage, usually in the expansion valve but occasionally at some point in the low side, e.g. at a restriction, bend or joint in a pipe, or where the low pressure liquid pipe discharges into a flooded evaporator from a float-controlled expansion valve.

Moisture in the circuit is indicated by a high vacuum in the evaporator and in some cases also by a high condenser gauge reading. If the plant is left running, the ice will melt after a few minutes and the evaporator gauge reading will rise quickly for a few seconds until the ice forms again. Hot rags wrapped round the expansion valve or other suspected part will indicate that it is moisture by melting the ice more quickly. This method may also be used to clear minor freeze-ups at the expansion valve and enable the moisture to pass round the circuit until it reaches the drier. It must be noted, however, that the drier only collects a very small amount of moisture on each passage of the refrigerant through it ; the drier must therefore be left in circuit for many hours or even days to clear the circuit completely.

With small quantities of moisture in some plants, large variations in the evaporator gauge reading only will be experienced ; this is caused by the expansion valve spring and bellows being strong enough to break away the ice as it is formed and free the valve.

The high vacua caused by moisture freezing into ice and blocking the circuit



Lightfoot Refrigeration Co. Ltd., Wembley

WATER-COOLED CONDENSING UNIT FOR ONE TON AIR CONDITIONING PLANT, SHOWING ARRANGEMENT OF DRIER BETWEEN CONDENSER AND LIQUID OUTLET TO EVAPORATOR

ɘnd to transfer oil from the crankcase and into the high side of the plant ; unning of the compressor bearings may result in bad cases. Moisture also ɔrms sludge with the oil which tends to harden diaphragms and bellows, hus reducing their elasticity and causing them to become brittle.

Sight glasses containing anhydrous copper sulphate crystals have been used ı some cases for indicating the presence of moisture in the plant, but are xtremely unreliable and are not recommended.

Partial or complete cessation of refrigeration is likely with moisture in the lant, and uneven frosting of evaporator coils may indicate the position of hokes in the low side, or in the high pressure liquid line, where chokes can ccur due to choking or over-saturation of driers.

Water is sometimes trapped in the low side of the plant where it forms ice. 'his eventually sublimes and passes over to the condenser, where it becomes 'ater again. It will then pass into the liquid receiver, where it will remain n top of the refrigerant until the level drops enough, due to leaks, to enable it to pass on round the circuit again and cause more trouble. It is about this time that recharging will become necessary and this may result in the new refrigerant being wrongly taken for being wet.

Prevention of Entry of Moisture

Elaborate processes are employed during the manufacture and erection of a plant to remove all traces of moisture and air from the component parts and pipes making up the refrigerant circuit ; it is vitally important to take similarly elaborate precautions to ensure that no moisture gets in again during normal operation, maintenance or repair, as follows :—

(*a*) The most important precaution of all is to prevent all leakage of refrigerant from the circuit and maintain the plant properly charged at all times. Nearly all the ways by which moisture enters are due initially to leaks of one kind or another.

(*b*) Pipe connections and joints in the refrigerant circuit should never be broken, unless it is absolutely necessary ; they must never be broken while the machine is running, and their temperature should be equal to or above the surrounding ambient temperature, or moisture will condense on them and may later enter the open connections.

(*c*) Never break more than one joint at a time and fit blanks on the open connections before breaking another.

(*d*) Always seal the ends of pipes or units which are disconnected and purge out any air or dirt by blowing through with refrigerant gas before finally reconnecting them in the circuit. This includes charging pipes, gauges, driers, refrigerant cylinders, etc., which are not necessarily connected permanently in the circuit. Always replace tightly all valve spindle caps and blanking plugs, etc.

(*e*) Always remove as much valuable refrigerant as possible from that part of the circuit which is to be opened up, by pumping down with the compressor or draining, but never pump down below 1-2 lb/sq. in. (gauge), i.e. never create a vacuum which would draw in air, except under properly controlled conditions, such as during evacuation and dehydration.

(*f*) Refrigerant cylinders are not always completely free of moisture. This particularly applies to carbon dioxide, but has also been experienced with Arcton 6 and methyl chloride. It is therefore preferable to charge with the valve uppermost, i.e. as gas, not as liquid. In the case of carbon dioxide, which is lighter than water, the cylinder should be stood with the valve downwards for some hours before charging ; the valve should then be cracked and the water blown out, before inverting the cylinder for charging. (See also p. 316 (*d*).)

(*g*) Always charge through a drier and have a second drier in the circuit during charging and for a few hours afterwards. Replace the drying agent (desiccant) and felt filters in the driers frequently, or reactivate. The drier in the charging circuit must be fully reactivated, or filled with perfectly fresh desiccant ; otherwise the refrigerant may pick up moisture in the drier. Strainers should be cleaned frequently in a new plant or after maintenance, and not less than six-monthly thereafter.

(*h*) Always keep all refrigerator oil, which is specially dehydrated by the manufacturers, in properly sealed airtight containers ; small conical-necked cans are best—ideally these are also sealed with an adsorbent such as silica gel. It is preferable always to use a new container of oil ; the oil left in half-used containers should not be used in refrigerating machinery. The oil should be added to the machine without pouring it in air, i.e. it is possible in many machines to add the oil through the charging pipe. Make sure that the correct grade of dehydrated oil is used ; never mix different grades. (See also p. 316 (*d*).) A simple test, which it is claimed will indicate the presence of as little as 10 p.p.m. of moisture in the oil, is as follows:

Heat a thin piece of metal or a knife blade in a flame to a temperature well above 212°F., the boiling point of water, but not sufficiently high to ignite the oil. Pour a few drops of the suspect oil on the hot metal. If any moisture is present, it will be indicated by a 'crackling' sound and by the production of steam.

Refrigerator oil should be clear and bright when held up to a strong light in a glass jar. If it appears dull and cloudy, it should be rejected as unsuitable for use in refrigerating machinery.

(*i*) See that the felt filters and the activated alumina, silica gel or other desiccant to be used in the driers are kept dry and clean in properly sealed containers. Keep gauze strainer inserts similarly protected against moisture and dirt.

(*j*) Make sure that the crankcase gland seals of all machines are properly supplied with oil, either under pressure or by splash ; it is on the maintenance of an oil film or seal that these glands depend for their gas-tightness.

(*k*) Keep all parts dry externally as well as internally. Working parts should be smeared with oil, while disconnected from the plant, to prevent rust. This oil should be dried off and renewed before replacing the parts in the plant.

Constant, vigilant and intelligent attention to detail on the lines described above will prevent an untold amount of trouble and leave personnel free for adequate routine maintenance and inspection. The prevention of entry of moisture is far simpler than its removal afterwards and requires much less time, skill and patience.

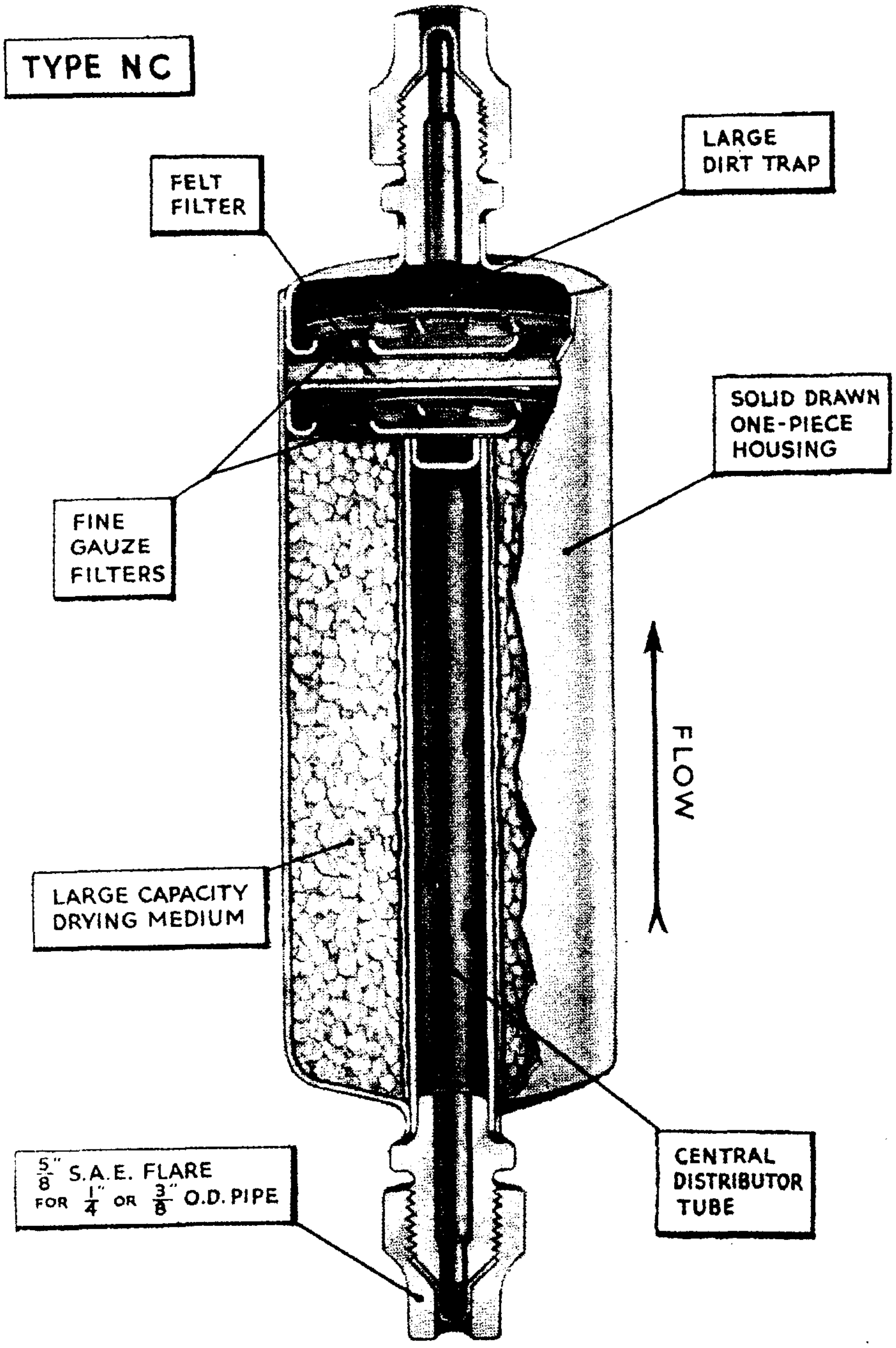
(*l*) The use of methyl alcohol in refrigerant circuits to prevent moisture from freezing is undesirable, except occasionally in emergency in carbon dioxide machines. If it is used, the drier must be removed from the circuit, as the methyl alcohol would be adsorbed therein.

Dehydration Methods Available

Once moisture has entered a plant it is essential to remove it again as soon as possible. The process of removal is known as 'Dehydration' and is probably the most important process in all refrigerator maintenance and repair.

Where only a small quantity of moisture has entered a plant during normal operation, and it is not desirable or necessary to jettison the whole charge of refrigerant, the moisture may be removed by means of chemical driers or desiccants placed in the circuit. These chemicals remove the moisture either by adsorption or absorption, the former being preferable and the most common. It is also possible to purge moisture out of small units by blowing through with refrigerant gas.

However, for the complete removal of moisture and air after maintenance or repair, it is necessary to discharge any of the refrigerant charge which still remains in the plant and then carry out a proper evacuation and dehydration process. These processes all rely on a vacuum to evacuate the air and moisture, the latter in the form of vapour. However, there are many methods of applying this vacuum to suit individual requirements and the best of these will each be described in turn.



TEDDINGTON TYPE NC FILTER-DRIER

The Use of Chemical Driers

As previously stated, chemical driers may be used for dealing with small quantities of moisture. They consist of cylindrical containers completely filled with the desiccant, which is held between felt and gauze filters at either end, that at the outlet being essential to prevent any of the desiccant being carried round the circuit ; this is important, as desiccants are inclined to powder slightly in service, due to vibration and other causes. The drier must be of adequate cross-section to prevent excessive pressure drop, and of sufficient length to give good contact between the refrigerant and the desiccant. A minimum of 12 cu. in. of desiccant per compressor horse-power is required for satisfactory drying. Make sure that the drier is fitted in the circuit so that flow is in the direction marked on it, to prevent the possibility of clogging.

Driers are usually installed in the high pressure liquid line as close as possible to the expansion valve, to protect it against freezing up ; the drier also acts as a filter and prevents the passage of dirt or other solids into it.

Driers are more effective at low temperatures than at high, e.g. in an Arcton 6 plant they are six times more effective in the low pressure liquid line and three times more effective in the compressor suction line, than in the high pressure liquid line, assuming a high pressure liquid temperature of 130°F. However, except for sulphur dioxide, where a suction line drier is necessary because moisture is absorbed by sulphur dioxide in the liquid phase, low side driers are not fitted because (*a*) a pressure drop in the suction line is likely to affect the compressor and hence refrigerating capacity, and (*b*) a pressure drop must be avoided in the low pressure liquid line when thermostatic expansion valves are in use, as this will result in loss of sensitive control by the feeler bulb, excessive superheating of the suction gas and hence lack of refrigeration in the latter part of the evaporator coils. A freeze-up may occur in a drier if it becomes over-saturated or partially choked and the resultant pressure drop causes temperatures below freezing ; this is more likely to happen with driers fitted in the low side than in the high side.

When a drier is fitted in a liquid line, the liquid should enter at the bottom and leave at the top, to improve the contact between the refrigerant liquid and the desiccant ; in the suction line, flow should be in the reverse direction, to ensure that the lubricating oil is carried on back to the compressor with the refrigerant gas.

A drier in the high pressure liquid line is more effective the higher the evaporating temperature and the lower the high pressure liquid temperature.

It is most important to remember that driers require a considerable time to remove even the smallest amounts of moisture, e.g. to reduce the moisture content of a methyl chloride circuit from 0.02% to 0.01% (i.e. by one drop of moisture per lb of refrigerant), requires well over six hours—1/6th of the moisture might be adsorbed in the first hour, but progressively less would come out as the refrigerant became drier. Also, water may be dissolved or entrained in the compressor lubricating oil and will take a long time to come out of the oil and pass round the circuit to the drier where it can be removed. Driers should therefore be left in circuit for at least 12 hours and preferably for 24 hours or more.

Another important requirement is to recharge or reactivate the drier at frequent intervals. For a very wet plant the drier should be changed every five hours, for a wet plant every 24 hours and in other cases at least every three or four days. The inside of a drier should be cleaned and dried out with methylated spirits on each occasion of stripping and recharging.

The agents to be used in the driers, being highly hygroscopic, must be kept in sealed containers and the driers themselves must also be sealed when not in use. Factory packed units or refills are best, if available ; unfortunately these are not made in the United Kingdom at present due to manufacturing difficulties.

In emergency it is better to fit a drier which is actually too small than not to fit one at all, but it must be emphasized again that driers are intended to deal only with small quantities of moisture and are totally inadequate as an alternative to proper dehydration in bad cases, or when putting a plant into service after repair or first erection.

Properties of Drying Materials

Compounds are used in driers which are capable of adsorbing or reacting chemically with the moisture contained in liquid or gaseous refrigerant-oil mixtures. These desiccants must not have any undesirable effects on any of the materials used in the system—refrigerant, lubricating oil or metal. They must be capable of reducing the moisture level to well below the limits set by the refrigerant in use and must show no tendency to disintegrate or liquefy and pass round the circuit.

The most suitable desiccants for use in refrigerant driers are those which will adsorb moisture, since these are chemically inert and can be reactivated, i.e. made active again, over and over again after use. An adsorbent is defined as ' a material which has the ability to cause molecules of gases, liquids or solids to adhere to its internal surfaces without changing the adsorbent physically or chemically '.

Commonly used adsorbent materials are activated alumina and silica gel, the internal pore surface area of the latter, on which moisture can be adsorbed, being estimated to be about 50,000 sq. ft. per cu. in. of desiccant. The amount of moisture adsorbed depends on the water vapour pressure and on the temperature—the lower the temperature the better. Vapours adsorbed are condensed in the pores of the material and retained by capillary attraction ; there is a consequent release of heat which is slightly greater than the latent heat of the vapour adsorbed. In some applications, but not that under discussion, auxiliary cooling has to be provided, to prevent excessive temperatures being generated. This is done by direct cooling of the adsorbent or by pre-cooling of the entering fluid.

Arcton 6 in equilibrium with a bone-dry adsorbent will also contain no moisture.

Activated Alumina is a white, opaque, granular form of aluminium oxide ; it is highly porous and chemically inert. From relatively dry gases having low relative humidities, activated alumina appears to be more adsorbent than silica gel, but there is little to choose on this score in practice (FIG. 1). Activated alumina does not disintegrate or pulverise so readily as silica gel. Activated alumina can reduce the moisture content of a fluid to an amount equivalent to a dew point of —105°F. ; the dew point for silica gel is —85°F.

Silica Gel is a hard, glassy, granular form of silicon dioxide, similar to quartz ; as with activated alumina, it is highly porous and chemically inert. The internal volume of both materials consists of myriads of thin-walled capillaries or pores having an average diameter of about 4×10^{-7} cm. The internal pore volume forms between 50% and 70% of the total volume of the material.

Some comparative properties of activated alumina and silica gel are given in Table I (see Part II). Both materials will adsorb acids as well as moisture. They both have the advantage that they can be reactivated by heating, as described under the following cross-heading, and can thus be used over and over again.

Other desiccants which absorb moisture by chemical reaction are calcium sulphate, calcium oxide, calcium chloride, barium oxide, barium perchlorate, magnesium perchlorate and soda lime. None of these chemicals are recommended for normal use ; they should only be used in emergency and with extreme care. Some liquefy and may pass round the circuit and none can be used more than once. Table II (see Part II) gives the relative efficiency of these and some other materials as drying agents.

As an example, calcium chloride, which is a most efficient drying agent,

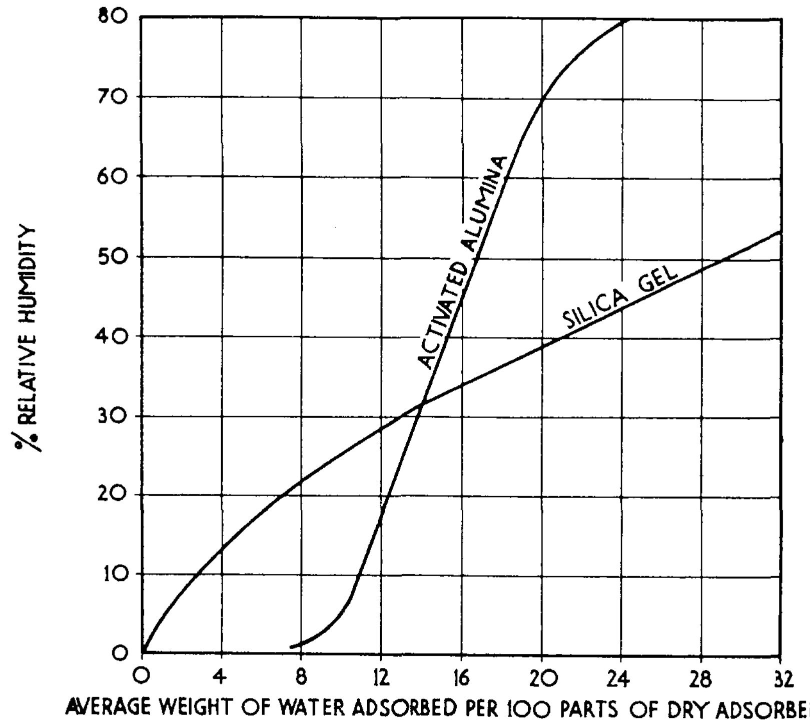


FIG. 1 — STATIC ADSORPTION OF WATER VAPOUR BY ACTIVATED ALUMINA AND SILICA GEL AT 68°F

liquefies into brine, as it absorbs moisture, and so it must not be left in circuit for more than about 12 hours. It can dry sufficiently for methyl chloride, but not for Arcton 6.

One of the most efficient absorbents is phosphorus pentoxide, P_2O_5, which is used extensively as a moisture trap, under carefully controlled conditions, in many dehydration processes and will be described in full detail later.

Reactivation of Adsorbent Desiccants

Driers charged with adsorbent desiccants can be reactivated, when saturated with moisture, by subjecting them to a temperature between 300°F. and 450°F. for at least three hours. For complete reactivation a temperature of at least 350°F. is required ; temperatures above 600°F. will permanently impair their adsorptive properties. Also temperatures higher than 450°F. will char the felt filters.

However, to maintain a moisture content as low as, say, 5 p.p.m., which is quite a reasonable level at which to aim, would mean that a useful moisture concentration in silica gel of only 1% could be tolerated before reactivation became necessary. A very high degree of dryness must therefore be achieved. It is not found possible to achieve this entirely satisfactorily by means of heat alone and ideally a temperature of over 350°F. applied with the desiccant under a vacuum of at least 50 microns (0.05 mm) Hg absolute pressure is required. How this may be achieved will be described later, though it is not often possible, on account of the specialized equipment required.

Reactivation is usually carried out in a dehydrating oven and it is important not to place any other substances in the oven, which are likely to give off moisture. Care must also be taken, since inflammable gases or vapours may be driven off, owing to lubricating oil having been adsorbed.

It is most important, if good results are to be obtained, for reactivation to be as complete as possible and ample time should be given at high temperature.

Vacuum Dehydration Methods Available

As previously stated, all dehydration processes, other than the use of chemical driers, rely on the complete evacuation of the system by means of a vacuum. The methods used, however, vary greatly according to the application, and the vacuum used also varies considerably, though, in all types, the higher the vacuum the better. The various processes of vacuum dehydration may be broadly classified as follows :—

(*a*) High vacuum with or without additional heating and with a moisture trap on the pump suction.

(*b*) High vacuum and inert gas sweeping, various methods being used to produce dry gas. Additional heating is also used.

(*c*) High vacuum and displacement by atmospheric air, artificially dried if possible.

On the whole the best method is (*a*) above, but it requires constant care and attention. Where only semi-skilled labour is available, (*b*) is probably the simpler method. (*c*) is not so satisfactory for most purposes as (*a*) or (*b*), but has advantages for some applications. All the methods will be described in Part III of this article.