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FITTING AND RUNNING REFRIGERATING MACHINERY ON SHIPBOARD.

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In the past few years much has been said and written about Refrigerating Machinery. Handbooks are written, periodicals are published, and papers are read before such Societies as ours, and still the subject has much of interest in it. This is perhaps more so in Australia where nearly every passenger vessel has its refrigerating machine and cold rooms, and there are from time to time in our ports splendid specimens of steamships in which a great proportion of the cargo space is taken up by insulated holds. The subject of this paper has been treated historically in several hand books, and the higher thermo dynamics pertaining thereto are available in many text books. In this paper the writer has endeavoured to deal with the subject shortly, and in such a way that it may be read and discussed during one meeting, and therefore only the more salient features are touched upon.

Once it is decided to install refrigerating machinery in a ship, there are several important questions that must first receive consideration. For instance; what is it intended to carry in the chambers? What is the shape and capacity of the chamber or holds, and what type of insulation is to be used therein? What is the temperature of cooling water available? How many hours per day is the machine to run? Now to deal with these questions in the order stated:

If ordinary ship's provisions are to be carried, a temperature slightly under freezing point is all that is necessary in the meat chambers, averaging approximately 20° to 25°; in the vegetable and fruit rooms, however, it must not be allowed to fall to freezing point, 35° to 40° being a suitable figure. Frozen meat cargo must be kept under 20°, and to be safe 15° to 16° should be maintained in the holds. Fruit cargoes carry best at about 33°, and the temperature should never vary more than a degree one way or the other; if it does, then it is safer to let it rise than to let it fall, as a lower temperature will absolutely ruin the fruit, though a few degrees higher for a few hours is not so dangerous.

The shape of the chambers should preferably approximate to a square, as this form exposes the least surface relative to cubic contents. As an illustration—a ship's meat chamber 10ft. x 10ft. x 7ft. would have a capacity of 700 cubic feet and the total surface would be 480 square feet, whereas a chamber 20ft. x 5ft. x 7ft. would also contain 700 cubic feet but would expose a total surface of 550 square feet. This explains why one ship may have trouble in keeping down temperatures, whilst a machine of the same size, and capacity, and with similar piping may on another ship have an easy task, owing entirely to the different shape of the chambers. For instance, in small installations it is a common practice to build cool chambers round a 'tween deck hatch, and, although this is a handy design, still, an engineer who allowed the same refrigeration per cubic foot for this 'tween deck space as for a lower hold would have trouble. Similarly, in many passenger vessels, provision chambers are placed alongside engine and boiler spaces, where high temperatures rule, and although insulation may mitigate this disadvantage, still, designers should make an effort to obtain more suitable positions in which to erect their installations.

"All ships are compromises," is a well worn saying, but it is often the case that refrigerators and chambers are located in some odd corner, bunker spaces, or some such warm spots, and it is only of late years and in new vessels that this old order is changing.

If a chamber can be located below the water line, then so much the better, for the sun beating on a ship's side always adversely affects the economy of an installation.

Then regarding insulation. To get down to bedrock, it must be realised that there are really only two satisfactory forms; one, a perfect vacuum, the other confined air spaces. The perfect vacuum insulation cannot be better illustrated than by referring to the ordinary Thermos flask, but it is not a practicable proposition for insulating ships' chambers; confined air spaces, however are. These spaces can be formed either of layers of boarding so arranged as to provide a set of parallel air cells, comparatively narrow, or spaces can be so provided and filled with substances which are of such a nature that they form air cells in themselves, such as wool, hair, felt, charcoal, pumice and cork.

In designing an insulation for shipboard it must be realised that every inch of insulation reduces the cargo space. At the same time, the cost of some insulators is double that of others, and so, like many other things, a compromise must be arranged. Ship construction, however, helps the refrigerating engineer considerably, for very few deck beams are less than 8in. deep, and if this space be filled with charcoal and about 1½in. of wood linings placed under the beam bulb, the insulation will be good enough for all practical purposes. Similarly with the ship's side, the frames can be utilised to their full depth, but it is even better to make the frames form the required air spaces and then to provide another insulation inside of this again.

In a vessel with 'tween deck insulated chambers, the conductivity of the iron lower deck is sometimes lost sight of. Such a vessel would have, in the usual style, the top insulation placed under the main deck, the bottom insulation under the lower deck, and in addition thereto a light insulation, either in the form of ribbons or all over the upper surface of the lower deck, should be provided to counteract this conductivity. All masts and trunkways have also to be reckoned with, and their conductivity taken into account and dealt with similarly.

In dealing with chambers insulated with charcoal and pumice care must be taken to provide against the substance settling, especially if not carefully rammed when put in place. No matter how carefully this is done, insulation always will settle somewhat, and should be seen to every now and then. The best way to test is to bore holes close up to the top and probe the insulation.

With the question of insulation is bound up that of doors and hatches. These are necessarily very heavy and should be packed with hair, silicate cotton, or some such resilient material, as the fierce slamming they are subjected to would soon make charcoal or pumice settle down. In many instances, large doors are a mistake in a cool chamber, as a port would often suffice, and at the same time reduce considerably the opening to the ingress of outside air. Cool chamber doors are difficult to fit, and to make them tight they require padding, and engineers should carefully watch and keep this packing soft and well fitted. Of course it is not much use making a tight fitting door if it is to be opened more than necessary, and carelessly left standing open, and most engineers have lively recollections of neglect in this respect.

Now with regard to the Machinery, this is usually worked on one of two systems—Ammonia Compression or Carbonic Anhydryde Compression, shortly known as CO_2, and each of these may be further sub-divided into one of two systems, viz.—brine circulation or direct expansion. Air circulation is also used, but it is only a modification of the direct expansion type. Compressed air machines, the writer does not intend to consider.

A refrigerating machine of the compression type is composed of compressor, condenser, and refrigerator, and a short description of the working cycle will probably be interesting. Ammonia and CO_2 are, of course, liquids only under certain conditions of pressure and temperature. If the refrigerant is in a liquid form in a vessel, and is at a pressure corresponding to surrounding temperature, and the pressure is relieved, the liquid at once begins to evaporate into a gas, and in so doing, is capable of absorbing heat up to its degree of latent heat of evaporation, less its sensible heat. In the same way exactly, benzine or petrol, in evaporating into gas in a carburettor, absorb heat from the surrounding air and precipitate the moisture in the air on the carburettor. The evaporation takes place in the refrigerator coils which are either placed direct in the chamber to be cooled, or immersed in a brine tank. The compressor draws gas from the refrigerator and maintains the requisite low pressure to allow of the refrigerant evaporating. It then delivers the gas into the condenser, where the compressed gas is cooled down to the liquefaction or dew point, the pressure again depending on the temperature of the condensing water. The liquid refrigerant is now in the right state to be again evaporated in the refrigerator, and so the cycle goes on as long as the machine maintains these differences of pressure.

Now dealing with the evaporator or refrigerator side of the plant, in order to get the gas split up into as fine particles as possible, the refrigerator is made up of a series of tubes, generally one inch or one-and-a-quarter inches in bore, and these tubes are so placed as to be surrounded by the medium to be cooled. In a direct expansion plant they are placed on the walls of the cold chambers where they take up the heat that leaks into the room through the walls and ceiling, and they also, of course, refrigerate the contents.

In the other system, viz., the "brine," the evaporating gas tubes are coiled and immersed in a brine tank containing a liquid, made up generally of calcium chloride and water, and which has a lower freezing point than water, to a degree depending upon its density. This brine is pumped through pipe coils placed in the refrigerated chambers, and after refrigerating the contents of the room and absorbing heat leakage it returns again to the brine tank where the ammonia or CO_2 extracts the heat, and so the cycle goes on. Brine thus affords a ready and safe method of collecting heat and conveying it to the refrigerating machine, and many different temperatures can be kept without variation with one temperature of brine, all depending on the amount of brine pumped through particular coils, and the number of nests of coils in operation. A hold can thus be utilised to carry frozen meat at 20° one trip and fruit at 35° the next. Rooms can be arranged to work from the same refrigerator, but being piped differently, they may carry different temperatures to suit their contents. The same result can, of course, be obtained by the direct expansion method, but greater care is needed, the regulation is not so easy, and there is no storage of cold; in fact, the brine is analagous to the fly-wheel of a machine, it "evens up" the work done.

Brine, of course, will freeze if it is allowed to become too weak, and the machine will be doing work which is never indicated by the thermometer, although the machine appears to be loaded. How often it is heard said that the brine "hangs" at 20° or 23° or some other temperature. The fact is that the machine is under these conditions expending its work extracting the latent heat of the brine and converting it into ice.

Referring to brine density tables it will be found, for instance, that brine with a density of 2½ lbs. per gal. freezes at 7° Fah., and at first sight it might be supposed that this was all that had to be guarded against, and that if a machine generally operated at 16° brine everything is in order, but if it is recollected that the pressure of the gas inside the evaporator coils may be as low as 10 lbs., which corresponds to an ammonia temperature of about −10°, then it is apparent that this lower temperature is the one that must be arranged for, and a solution of about 4 lbs. per gallon used instead.

Marine refrigerating machines work under far harder conditions than those ashore, and they should be specially designed for shipboard, as the type of machine designed for land installation usually takes up more room and is of lighter design. A usual arrangement is that of a horizontal box bed on top of which are arranged the steam cylinders and gas compressors, and inside of the bed or tank are placed the condenser coils. In another arrangement the box bed is vertical, the steam cylinders and gas compressors being in front and the gas condenser behind. The parts should all be handily arranged and ample bearing surfaces provided for long running. A very popular design is that in which the steam cylinders are compounded and the compressor duplicated, the H.P. steam cylinder driving one compressor, and the L.P. the other. Such an arrangement has the advantage that when required, only one half the machine need be run, the L.P. side being fitted with a reducing valve to admit of this being done. In a plant arranged in this fashion it will be observed that the terminal point in the steam cylinder stroke, where the pressure is least, is also the terminal point in the ammonia compressor stroke, where the pressure is greatest. This condition necessitates a well balanced fly-wheel and a crank shaft of good proportions to assemble and distribute the power.

Ammonia compressors exhibit many differences in design. Horizontal machines are made double acting, single acting, and sometimes compound; vertical machines generally single acting.

The double acting and single acting compressors need no explanation, their action is the same as that of water pumps, single or double, as the case may be. The compound compressor, however, is of a different type, being made up of two single acting compressors arranged tandem, the low pressure, or gathering compressor, being of large diameter to handle a good volume of the rare low pressure gas which is drawn in and compressed to about one-third the condensing pressure. It is then delivered into the small or high pressure compressor which finally compresses the gas up to the full condenser pressure and delivers it to the condenser. This arrangement has many advantages. The difference in temperature from suction to delivery is divided between the cylinders, each having a more reasonable range. Clearance in the high pressure compressor can be neglected within reason, as all the gas drawn into the L.P. must go into the H.P. side. Another point claimed is that the gland carries less than the full condensing pressure which is carried on the gland end of a double acting compressor, a feature, however, which is not of much importance, as double acting compressors with ordinary good fitting neck rings and rods have no trouble in this respect.

The question of clearance referred to above is an important one, for the clearance in a compressor involves far more loss than the actual measurement suggests. Suppose, for instance, that the clearance in a compressor measures 1/16in., that the suction pressure is 10 lbs., and the delivery 200 lbs., then until the gas at delivery pressure, remaining in the 1/16in. clearance space, is expanded to below 10 lbs., the suction valves cannot open. This would mean that the piston would travel about $\frac{5}{8}$in. before useful work commenced, and the 1/16in. clearance actually represents a loss of $\frac{5}{8}$in. of the stroke of the compressor.

If the cycle of work is looked into, it will be seen that there are two principal transfers of heat, one from the refrigerated room, or brine, to the low pressure cold gas, and the other from the high pressure hot gas to the condensing water pumped from the sea. Both of these are controlled by one valve, known as the regulator valve, which is placed between the condenser and refrigerator.

Now, as has been noted, every degree of gas pressure has a corresponding degree of temperature. Many gauges have dual markings showing both pressure and temperature at one reading, and if engineers in charge of refrigerating machinery would only realise how much better it is to think in "temperatures," act on "temperatures," and log "temperatures" instead of working with pressures of gas and temperatures of rooms, brine and sea water, then better results would be obtained from machines and troubles more easily located. Another important point is that it is the "pounds weight of gas pumped per minute" that enables the work done to be estimated.

If these two facts are taken in conjunction it will be apparent that the greater the weight of gas, at the proper temperature, that can be pumped, the greater will be the amount of refrigerating work that can be performed. Let it be assumed, for the sake of explaining this point, that there is an ammonia compressor working under the following conditions:—

Compressor 6in diameter, 10in. stroke, double acting.
Revolutions 120 per minute.
Gauge on evaporator coils 20° Fah. = 33.25 lbs. gauge pressure.
Sea water temperature 70°.

Referring to the tables of properties of ammonia, the following figures are obtained:—At 20° Fah. the heat of vaporization in the thermal units = 543.15, and the volume of vapour per lb. in cubic feet = 5.843. As the ammonia liquid, before it is evaporated, will be about the same temperature as the sea water, in this case 70°, in has to be reduced to 20°, that is, 70°—20° = 50°, before it does any useful work, consequently the net value of the gas is, 543.15—50 = 493.15 B.T.U. Neglecting clearance losses, the calculation now becomes:—

Cubic inches per single stroke = *282.7*

$$\text{Cubic feet per min.} = \frac{282.7 \times 2 \times 120}{1728}$$

$$\text{Weight of gas pumped per min.} = \frac{282.7 \times 2 \times 120}{1728 \times 5.843}$$

Tons refrigeration =

$$\frac{\underset{\text{Hrs.}}{24} \times \underset{\text{B.T.U's.}}{493.15} \times \underset{\text{Volume Swept.}}{282.7} \times \underset{\text{Double Revs.}}{2 \times 120} \times \underset{\text{Min.}}{60}}{\underset{\text{Cub. ft.}}{1728} \times \underset{\text{Vol. per lb.}}{5.843} \times \underset{\text{B.T.U. per ton.}}{318080}} = 15 \text{ tons}$$

But, taking the same compressor at half the above gauge pressure, and all other data as before, the gauge on evaporator coils will show:—

0° Fah. = 15.67 lbs. gauge pressure, the Heat of Vaporization becomes 555.5—70° = 485.5, and the volume of vapor per lb. in cubic feet = 9.028. Tons refrigeration =

$$\frac{24 \times 485.5 \times 282.7 \times 2 \times 120 \times 60}{1728 \times 9.028 \times 318080} = 9.6 \text{ tons}$$

It is not strictly correct to take the full difference between the temperature of the liquid leaving the condenser, and the temperature of the gas in the evaporating coils The actual deduction should be the difference between the temperature of the sea water and the outgoing brine, in a brine circulation plant, and between sea temperature and room temperature in a direct expansion plant. Practically speaking, taking into account clearance, radiation, and other losses, the compressor working under the first conditions would have a capacity of about 12 tons, and under the second, 7 tons of refrigeration.

From these figures it might at first sight be argued that the higher the suction gauge pressure was kept, the more work would be done on the ship's chambers, but as has been said before, the gas must be supplied at the proper temperature.

From what has already been stated, the fact of the temperature and pressure being interdependent is unquestionable, so that the higher the gauge temperature of the gas, the higher the pressure. To work with a high suction temperature as in the first example, viz., 20°, or 33.25 gauge press means that brine or air could, theoretically, be cooled down to this ammonia temperature, that is, the temperature in the evaporator coils. Then all transfer of heat would cease, as the ammonia would be at the same temperature as the surrounding medium, either brine or air as the case might be. As a matter of fact, it would not be possible in practice to get much less than 5° difference between them. Consequently, it follows that the machine would cease to do refrigeration. What has then to be done is this:—The pressure and temperature of the refrigerant must be reduced still further in order to make sufficient difference between the expanding refrigerant and the substance to be cooled, so as to ensure a flow of heat from the one to the other.

Engineers working refrigerating machinery should, therefore, closely attend to the regulation of the plant and observe the fall of temperature until the working limit of the machine is reached, for as the gas becomes rarer, less weight of it is pumped and less refrigeration is done, as has been shown in the above examples. From practical experience it is found that if an ammonia suction pressure of from 12° and 15° lower than the brine temperature in a brine plant is maintained, the best results are obtained.

In a direct expansion plant lower suction temperatures must be maintained, as the air surrounding the coils in the rooms is not so good a conductor of heat as is brine, and the difference between the temperature of the ammonia gas in the room coils and that of the air must be increased to about double so as to ensure proper transfer of heat. All these conditions are brought about by the correct manipulation of the regulating valve. This device, while directly governing the quantity of gas admitted for expansion, governs the pressure also. The refrigerant will be in liquid form at condenser temperature, and pressure, right up to this valve, but from it the liquid expands and becomes a gas at refrigerator pressure and temperature, and is drawn back to the compressor.

If the machine is on the CO_2 principle it is always worked with saturated gas, that is, gas possessing some degree of latent heat. This heat is used for the purpose of keeping down the temperature of the gas during the compression process, when work is being done on it, and its temperature would be raised. $C.O_2$ machines are packed with cup leathers in the pistons and hat leathers in the glands, and they require cool, moist gas for good running results. Ammonia machines are worked on both the saturated and dry gas methods, and the marine engineer may be called upon to handle either type. The pressures and temperatures given by the writer, for regulating to the best advantage, are for saturated gas ammonia compressors. Dry gas compressors must be run with a greater difference between refrigerator temperatures and expansion coil temperatures.

It is a well-known fact that when a set of marine propelling machinery has all its different valves, the expansion links, the quantity of steam to the heater. the make up feed valve, the different feed checks on the boiler, etc., all carefully set, things go smoothly and easily, and every engineer knows that if one valve is altered, probably all the rest have also to be adjusted, owing to the balance being upset. It is the same with the refrigerating machine; get everything properly set, and no trouble ensues; begin altering, and all is out of gear. It is consequently better to run the machine for long spells rather than for short ones.

The writer has already mentioned the proper point to keep the suction pressure at, and this is a most important matter, but a further important item is with regard to the charge of gas in the machine. Speaking generally, there are very few machines that are overcharged, and a greater number are run only partially charged. It is possible to charge a plant with $C.O_2$ or ammonia until the condenser and other parts up to the regulating valve are full up with liquid refrigerant, but with ordinary care this should never occur, for as the condenser coils get filled with liquid the condensing surface is becoming less and less, and the condenser gauge shows this immediately by the pressure increasing. The writer once saw an ammonia plant in which the condenser gauge pointer had traversed right round the dial and was indicating 40 lbs. on the second revolution, when the engine pulled up, and it was only by the gauge pointer receding far beyond the zero mark that the true cause of the stoppage was found. Hitherto the fault had been attributed to the steam engine. Referring again to the question of charging, and the point at which to stop, there is the regulating valve, on one side of which is gas being condensed to a liquid, and on the other liquid being evaporated into gas, and there should be, between these two, a liquid seal, otherwise partially condensed gas from the high pressure side will find its way to the low pressure side of the plant. The engineer in charge should maintain a seal of sufficient amplitude, and to this end most plants have a liquid receiver, which acts as a balance reservoir, and permits of a generous charge being put in without affecting the condenser area by filling up the lower tier of tubes. All plants leak, some more than others, and this leakage must be made up, otherwise the efficiency of the plant drops. $C.O_2$ plants are the worst offenders in the matter of leaks, as leaks can be silent and odorless, and so attention is not drawn to them. Ammonia, on the other hand, by its smell, proclaims the slightest leak. Other than the above suggestions, no rule can be given as to charging. Each plant must be treated with judgment in this respect, and the rule with regard to increased condenser pressure must be observed with caution, as air or foreign gases may also cause a rise in pressure. The writer, on one occasion, met with a peculiarity in a $C.O_2$ machine, in the following manner:—A ship that had been using a gas which gave certain pressures was supplied with another make of gas, of which the condensing pressure was found to be much lower for corresponding degrees of cooling water. The engineers had been in the habit of really overcharging the plant in order to obtain the old pressures, when it was discovered that the machine was doing better work when apparently short of gas.

It is not possible to go fully into the question of probable mechanical faults in a refrigerating plant in this paper. In every compressor the object is to provide a gas pump pure and simple, designed to pump gas with minimum clearance spaces, and to be easily accessible. The valves are automatic and cannot usually get out of their setting, and so long as they are mechanically in order should maintain a high efficiency. Generally speaking, greater care must be taken with the gland rods, pistons and rings, than with those in steam cylinders. Rods must be as smooth as glass, especially with $C.O_2$ machines. Piston rings must be carefully turned. All compressor barrels must be true and have good surfaces. Cleanliness is essential; the best oil only should be used, and not a drop more than is absolutely necessary, and it is to be remembered that an oil which retains its qualities at low temperature is not necessarily satisfactory, it should also stand a fairly high temperature, especially in dry gas machines, for if carbonization occurs, scoring will result.