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(OF TRANSACTIONS).

REFRIGERATING MACHINERY AND APPLIANCES AS FITTED ON BOARD SHIP.

BY

Mr. R. BALFOUR (Member of Council).

READ AND DISCUSSED AT
58 ROMFORD ROAD, STRATFORD,
On MONDAY, MARCH 16th, 1903.
Chairman: Mr. ROBERT CLARK (Companion).

READ AT 3 PARK PLACE, CARDIFF,
On WEDNESDAY, APRIL 22nd, 1903.
Chairman: Mr. T. W. WAILES (Vice-President).

The Chairman said he would have preferred that his old and esteemed friend Mr. Dunlop had been present, but as he was not able to attend, Mr. Adamson had been good enough to write and ask him to occupy the chair. He had intended coming down to hear Mr. Balfour, so it was a pleasure for him to preside. It would be invidious for him to introduce Mr. Balfour, as that gentleman was well known to them, and he was sure this paper would be most interesting.

Mr. BALFOUR then read his paper as follows: The carriage and storage of refrigerated produce has now become a very important branch of commerce and will extend in the near future. It is of great interest to the public, who so largely depend for their food upon the trade, and it may even be said to be of Imperial interest, as it materially helped the feeding of our soldiers in South Africa during the late war, whilst our sailors now largely depend upon frozen meat for their food during the long spells they are away from port, many of our men-of-war being fitted with a freezing installation. It is, however, of greater importance to marine engineers, many of whom have the responsibility of the valuable installations and the still more valuable cargoes.

The question of the carriage of meat and other commodities from a distance appears at sight to be a simple one, viz., merely how to cool the cargo and how to keep it cold afterwards; but there are many points not at first apparent which have most important bearings upon the subject. Given the most perfect mechanism and the most perfect insulation, it still requires incessant care and continued watchfulness and a knowledge of all the principles involved to ensure the cargo turning out well.

The thermodynamic theory involved is well known to scientists, and was very ably dealt with by Professor Ewing before the Society of Arts in 1897. It will only be necessary in this paper to deal with it in broad outline to show the principles involved.

Cold is merely comparative absence of heat. It is not absolute, except that perhaps the absolute zero of heat may be considered to be perfect cold. Theoretical considerations show that the absolute zero of heat would be −461° F. on the air thermometer. This, however, has never been attained, although a considerable approach has been made to it by Professor Linde and others in their experiments, which have resulted in the liquefaction of air and other gases. In these experiments the Professors have adopted the principle involved in the cold air machine, and have reached the very low temperatures obtained by successive stages. It may also be mentioned that Professor Dewar has attained the very low temperature of −423° F. at atmospheric pressure, in the liquefaction of hydrogen with the assistance of carbonic acid and ethyline. In our actual practice, however, on board ship −100° F., obtained in one stage, is about the coldest with which we have anything to do. There are three systems of refrigerating machinery in general use on board ship, known as the air, ammonia, and carbonic anhydride compression processes. The principle involved in the production of cold in these three processes may be classed under two heads :

1st. The employment of a permanent gas, which, being compressed, rises in temperature. It is then cooled while still under compression, and afterwards expended behind a piston, when a corresponding fall of temperature or refrigeration ensues.

2nd. The use of a volatile liquid, during the evaporation of which a considerable amount of heat becomes latent, its behaviour in this respect being analogous to that of water when changed into steam.

Dealing with the first principle, which applies to the cold air machine. If a volume of air is compressed without friction and without gain or loss of heat from external sources, its temperature becomes raised to an extent measured by the thermal equivalent of the energy exerted in compressing it ; and if the compressed air is afterwards re-expanded to its original pressure, again without gain or loss of heat, it will become cooled down to its original temperature, and will have given back the mechanical energy expended in compressing it. But if, on the other hand, the compressed air is cooled down before it is allowed to re-expand, it will, after expansion, be found to have become colder than it was initially. As mechanical work and heat are mutually convertible, it is obvious that if during expansion the air is caused to do work on a piston, its supply of heat must be drawn on to an extent measured by the thermal equivalent of the work done, and by so doing it will be colder after expansion.

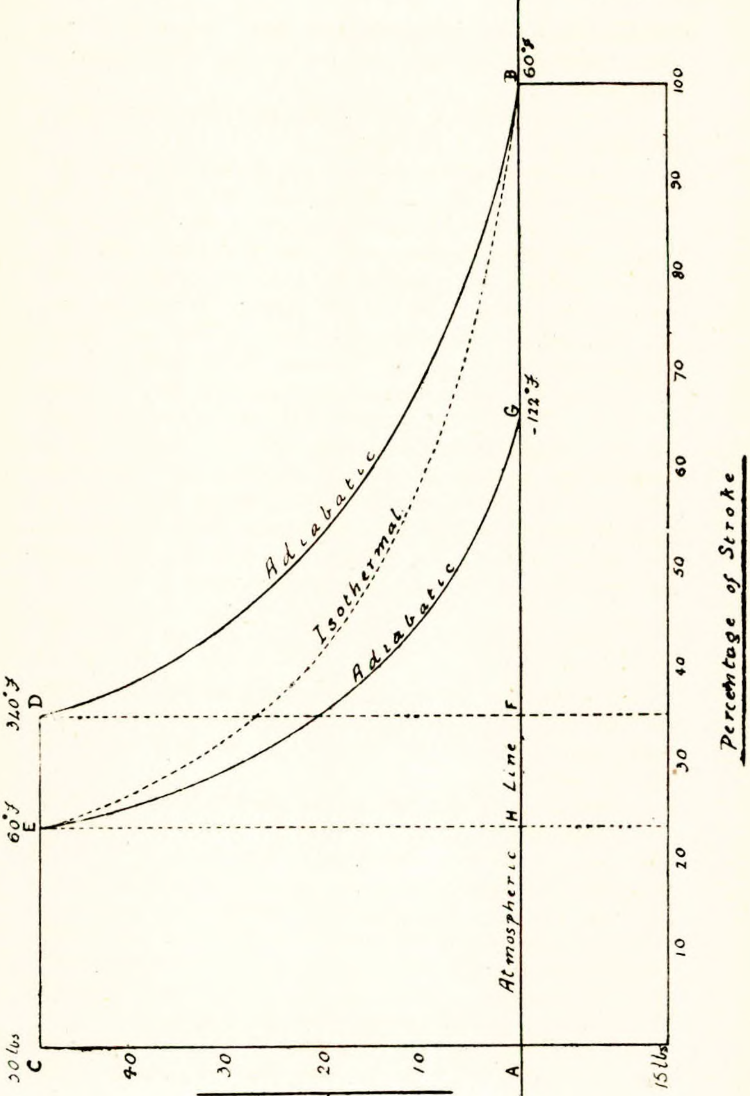

B
60°F
G
-122°F
D
320°F
E
60°F
F
C
A
Adiabatic
Isothermal
Adiabatic
Atmospheric H Line
Percentage of Stroke
lbs per square inch
30 lbs
40
30
20
10
15 lbs
10
20
30
40
50
60
70
80
90
100

DIAGRAM I.

This is shown in the attached ideal diagram of the cycle through which the air is taken in such a machine.

The compression and expansion are assumed to be adiabatic and frictionless.

A B represents a volume of air at atmospheric pressure and at 60° F. The air is compressed to the volume C D, having then a pressure of 65 lb. absolute. Its temperature will rise to about 340° F., and if the air is expanded back to its original pressure, performing work on the piston, it will resume its original temperature, the work given out by its expansion being equal to that done upon it by compression, each being represented by the area B D F. But if the compressed air is cooled down to its original temperature, 60° F., before it is expanded, its volume will be reduced to C E whilst under 65 lb. pressure, and then when expanded to atmospheric pressure its temperature will be reduced to about −122° F., whilst its volume will then be represented by A G, the proportions

$$\frac{C\,E}{C\,D} \text{ being equal to } \frac{A\,G}{A\,B} = \frac{461 + 60}{461 + 340} = \frac{461 - 122}{461 + 60}$$

In this case the work given out during expansion is less than that required for compression, the difference being due to the amount of cooling produced in the air.

Referring to the figure, the area B D F represents the work which would have to be done to compress the air to 65 lb. absolute. The area F D E H represents a further amount of work which has to be done to keep up the pressure during the cooling of the air; otherwise, owing to cold air being less bulky, weight for weight than warm air, the pressure would fall by cooling. The area G E H represents the work given out by the air during expansion.

The difference, viz., the area B D E G, represents the excess of work done over that regained during expansion.

The figures given above are ideal, and are not realised in practice

The great difference between the theoretical and actual results of the final temperatures obtained after expansion is due partly to friction and the action of the cylinder wall, but chiefly to the presence of aqueous vapour in the compressed air, as this vapour not only parts with its sensible heat during the expansion, but also gives up the whole of its latent heat both of evaporation and liquefaction when forming into snow or ice in the expansion cylinder and passages. This is partially overcome in the more modern machines, special appliances being employed for condensing some of the vapour before the air is expanded.

Several types of machines working on the cold air system are in use. In all of them the motive power is an ordinary horizontal steam engine of the compound type, having its own surface condenser, air, circulating, and feed pumps. The air compression and expansion cylinders are set on the bed-plate tandem to the steam cylinders. The air is taken from the cargo chambers into the compression cylinder, which is water-jacketed, so that a certain amount of the heat which is developed during compression is extracted from the air. The more heat that can be so extracted the better for the efficiency of the machine. The air is compressed to a pressure of from 50 to 60 lb. per square inch, and its temperature thereby raised to about from 280° F. to 320° F. The compressed air is then passed through coolers which are situated in the bed of the machine, these coolers being similar in construction to the steam surface condenser, and are kept cool by the circulation of sea water, which at the same time passes through the compression cylinder jacket, and thence through the surface condenser, before being discharged overboard.

The temperature of the compressed air is thus reduced in the coolers to within a few degrees of that of the circulating water, say to about 60° F. The air is further cooled and dried by passing it through a nest of tubes arranged in the return air trunk, around which the cool air from the cargo chambers circulates before it enters the compression cylinder. The temperature of the compressed air is thus reduced to about 40° F. The air which is still under compression is then led to the expansion cylinder, where it drives a piston, thus assisting the working of the machine. In this cylinder it is expanded down to a point very slightly above atmospheric pressure and exhausted into the snow box, the air being at this point at its lowest temperature, which is generally about −80° F. The air is then led through the cargo chambers by wooden trunks of about 2 ft. × 2 ft. section, this space being sufficient to carry the air and also to allow the passage of an attendant to regulate the slides which determine the circulation of the air amongst the cargo.

The trunkways are usually fitted on each side of the cargo chambers and are arranged to fold up out of the way when general cargo is being carried. The vertical inner side is provided with a number of small sliding doors at regular intervals, which can be opened or shut at will according to the temperature required in each chamber, which, when carrying frozen cargoes, ranges between 14° and 16° F. The trunk on one side of the vessel is used as a "delivery," that on the other as a "return," and arrangements are made so that the direction of air circulation can be reversed occasionally.

The following may be considered to be the advantages and disadvantages of the cold air system:

ADVANTAGES.	DISADVANTAGES.
1. The machinery is of simple construction and all parts are easily accessible.	1. The machinery is bulky owing to the enormous quantity of air required to be compressed in a given time.
2. Space occupied by machinery and adjuncts on the round voyage is less than in either of the other systems.	2. Greater steam power required and consequently higher coal consumption.
3. Little or no space taken up by air trunks when carrying general cargo.	3. Accumulation of snow in air trunks.

ADVANTAGES.	DISADVANTAGES.
4. The process is harmless and rapidly produces low temperature.	4. The machine cannot be worked while loading or discharging cargo, as owing to the presence of fog or mist in the air the men refuse duty.
5. The air costs nothing and is always obtainable.	5. The air in most cases being circulated over and over again continually comes in contact with lubricating oil in the air cylinders, which might contaminate the air, and if any mildew be present at any point among the cargo, the air in its course is apt to spread the evil. In some cases the same air circulates through the ship's provision chambers, which is a bad feature, especially where vegetables are carried. It may, however, be mentioned that by the fitting of a special appliance known as a "Water Tower," the air may be purified by a spray of water whilst it is under compression.
6. The insulation throughout the cargo chambers is easily accessible for repairs and cleaning purposes.	6. Difficulty in dealing with cargoes requiring different temperature simultaneously during the voyage.

Refrigeration by means of liquefiable gases is the second principle with which we now have to deal. The two in general use are ammonia and carbonic acid. Both of these are obtainable in a liquid form. These gases can be changed from the gaseous to the liquid state and *vice versâ* under certain conditions of pressure and temperature. If the pressure which is necessary to maintain these in a liquid state be removed they return to the gaseous state; but to do so a quantity of heat must be absorbed, and this is only obtainable by the reduction of their own temperature, or from surrounding objects.

Their behaviour in this respect, as already stated, is somewhat analogous to that of water when changed into steam, and *vice versâ*. When water is placed over a fire the temperature first rises to 212° F. It then commences to be converted into steam at atmospheric pressure, but remains at the same temperature unless the pressure is raised by confinement, although the fire during the boiling process continues to give out its heat as before. This is in some way absorbed by the steam, but it is not sensible to the thermometer, and is therefore termed "latent" heat. Yet it has been absolutely necessary in order to convert the liquid into gas.

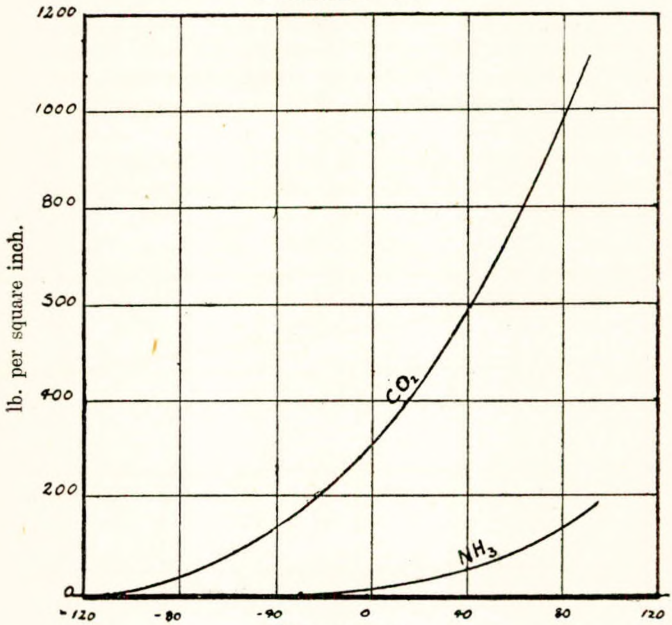
When, however, the steam space is confined so that a pressure is generated, it is found that while the water and steam still retain the same temperature as one another, this temperature is greater according as the pressure becomes increased. The increase of temperature nevertheless is trivial compared with the heat absorbed, and there is still a quantity of latent heat to be applied to raise the water into steam of high pressure.

If now we take a quantity of the hot water (no steam) which has been in contact with steam of say 250 lbs. pressure, its temperature will be about 400° F., but to retain it as water it has still to be kept under the same pressure. If the pressure be reduced to atmospheric pressure its temperature will immediately fall to 212 ° F., but a portion of the water will evaporate into steam. Just so much water will become steam, in fact, as is necessary for the latent heat of the steam to absorb the heat liberated by the fall of temperature from 400° to 212° F. If we assume the latent heat of steam to be 966° F., then the proportion of water turned into steam will be in this case

$$\frac{400 - 212}{966} = \cdot 195$$

In the cases both of liquid ammonia and liquid carbonic acid, this change is brought about without the aid of fire, owing to these liquids having such low boiling points, as shown on the following diagram (No. 2), giving the curves of vapour tension, or corresponding pressures and temperatures of these gases; but in these cases, like that of water and steam, the change from liquid to gas cannot take place without heat becoming latent. The necessary heat to effect the change may be taken from the surroundings, such as brine, air, etc. If much heat is thus available the gas will be warm; but the less heat thus absorbed the colder will be the gas produced.

DIAGRAM II.



The re-conversion of the gas into liquid depends not only on the pressure, but largely also upon the temperature of the available cooling water, which may be as high as 86° F. in tropical climates. This is perhaps the most important point in connection with all mechanical systems of refrigeration.

In selecting a volatile liquid for the purposes of refrigeration the following properties have to be considered:

(1) The latent heat of evaporation when changing into gas;

(2) The temperatures and pressures at which this change takes place;

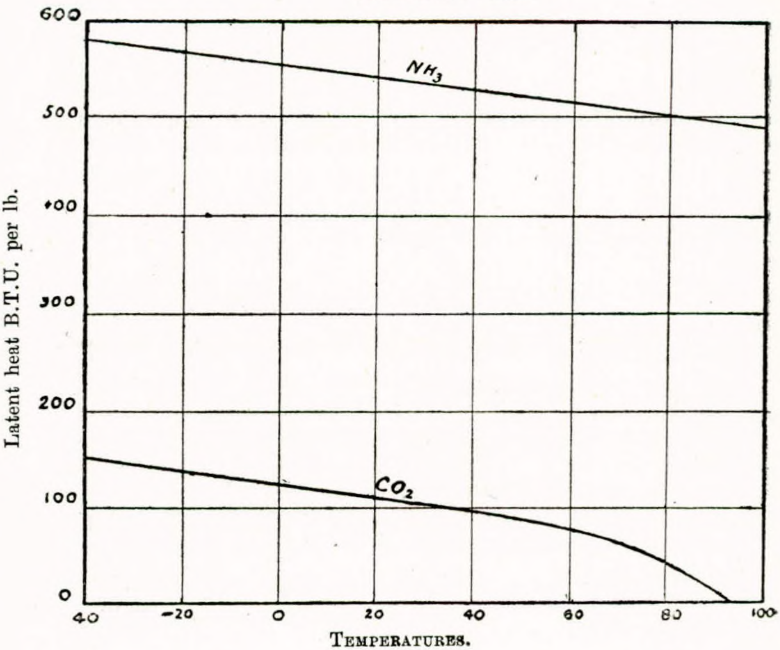
(3) The specific heat of the liquid. This in the case of both ammonia and carbonic acid is unity, and

(4) Density or weight of gas.

Taking ammonia in its anhydrous form, it will be seen from the curve on diagram II that it boils or liquefies at a temperature of about −28° F. at atmospheric pressure, and also at a temperature of about 60° F. at a pressure of 108 lb. per square inch absolute.

Another corresponding pair of temperatures and pressures are −10° F. and 24 lb. per square inch absolute.

DIAGRAM III.



Now let us trace some ammonia in a cycle such as occurs in actual practice. The gas is compressed to a pressure of 108 lb. absolute, and at the same time heat is taken away from it by the cooling apparatus, and it then becomes liquid at a temperature of 60° F. It is then allowed to pass into cooling coils, where it loses its pressure and again becomes gas, but to do so heat becomes latent. From diagram III. it will be seen that at a temperature of —10° F. the latent heat is 562 units, and as the specific heat is unity it follows that the evaporation of 1lb. of ammonia from 60° F. to gas at —10° F. will require heat to be given to it = 562 — (60 + 10) = 492 B.T.U. If less heat is absorbed by it the resulting gas will be correspondingly colder than —10° F.

This measure of heat, viz., 492 units, is the quantity of heat which has to be extracted by the cooler on again compressing the gas.

Carbonic anhydride boils or liquefies at a temperature of about —110° F. at atmospheric pressure, and also at a temperature of, say 60° F., and a corresponding absolute pressure of about 778 lb. per square inch, and at —10° F. and 258 lb. pressure per square inch (see Diagram II) it will absorb during evaporation about 130 units of heat.

As the specific heat of the liquid is unity, the available refrigeration per lb. of liquid evaporated will be

$$130 - (60 + 10) = 60 \text{ B.T.U.}$$

Comparing these mediums of refrigeration, it will be observed that there is a great difference in their latent heat of evaporation; but the density or weight of a cubic foot of ammonia gas at a temperature of say —10° F., is only 0·1107 lb. as against about 2·8 lb. in the case of carbonic acid at the same temperature, and this admits of a much smaller compressor being used with the latter than with ammonia, the relative volume for equal refrigeration being about $\frac{3{\cdot}24^{*}}{23{\cdot}3}$.

* See Professor Siebel's *Compend. of Refrigeration.*

The pressures, however, required to liquefy the carbonic acid are very high, as will be seen on the diagram of vapour tensions or corresponding pressures and temperatures. With condensing water say at 86° F., the pressure is about 1,080 lb. per square inch.

There are several types of machines working on the ammonia compression system. In large installations the Linde and Haslam types are mostly in use, the chief difference between them being in the design of the compressor. The former is of the single-acting compound type, the front end being the low pressure and the other end the high pressure, with volumes of suitable ratio, the space between the compression cylinders having a branch connection to the suction side of the low pressure to prevent accumulation of gas pressure between the two pistons. The Haslam type has two independent single-acting compressors—low pressure and high pressure—the latter of which is water-jacketed.

In both types the covers and valves at the ends of the compressors are arranged so as to make clearance spaces small in order to secure a nearly complete delivery of the contents of the cylinder at each stroke. To prevent leakage of the gas at the piston rod end a specially constructed stuffing box is fitted. The packing is divided into two parts, with a space in the middle containing a lantern bush. This space is connected to the suction side or rectifier, hence any gas which leaks through the inner part of the packing is prevented from passing the outer part of the packing, which is exposed to no more pressure than the difference between the pressure on the suction side and that of the atmosphere. The lubricating oil is led into the space containing the lantern bush or through a hole in the stuffing gland.

The motive power in each case is a horizontal steam engine of the compound type. In the Linde machine the steam cylinders are set tandem and the compressor alongside. In the Haslam machine each steam cylinder has a compressor set tandem to it, the whole being mounted upon a strong wrought steel base which forms the gas condenser. Connected with the compressors there is a separator, a strong cylindrical vessel which intercepts any oil and prevents it getting into the condenser coils. These coils are each made of one length of about 500 ft. of wrought iron pipe, the number of coils used varying according to the size of the machine. The ends of each coil are fitted with separate cocks, and are connected top and bottom to cast iron distributing and collecting pieces from which the pipes for conveying the liquid are led to the expansion or regulating valve, and thence to the evaporators.

The evaporators are usually situated in the 'tween decks, near to and above the chambers to be cooled, and each consists of a number of coils of wrought iron pipes, having a collective length of several miles, stacked in an insulated chamber. At the after end of each chamber a large fan with motor is fitted for circulating the cooled air.

In these types of machines one of two systems of compression is adopted, called the "wet" and "dry" respectively.

In the wet system—employed in the Linde machines—the gas comes back from the evaporators in a saturated condition, or holding small quantities of liquid ammonia in suspension, and the heat of compression is partly taken up by the liquid ammonia held in suspension. By this means the gas is kept down to a moderate temperature, so that there is no necessity for water-jacketing the compressor. The saturation of gas is attained by a special arrangement of valves and ratios of evaporator and condenser.

There is a greater amount of ammonia circulated with wet than with dry compression.

In the dry compression of the Haslam machines, owing to there being less ammonia in circulation, the gas comes back to the compressor superheated and in a dry condition. The heating during compression necessitates the use of a water jacket round the compressor.

Under actual working conditions, however, after low temperatures have been realised, there is very little difference between the two systems, and the water service in the compressor jacket can then be dispensed with. In other respects the cycle of operations is the same in both types.

After the gas is compressed to 100 lbs. or 170 lbs. per square inch, according to the temperature of the condensing water, it is passed into the oil separator and thence to the condenser coils, where it is liquified. It then flows to the expansion valve, and is expanded slowly into the evaporator coils, where, its pressure being reduced to about 10 lbs. per square inch, it again becomes a gas, its temperature during the change of state from liquid to gas falling to about —10° F. The heat necessary to effect this change is taken from the air surrounding the coils. The gas having thus accomplished its cooling work is returned to the compressor, there to again begin afresh the cycle of operations.

For transmitting the cold produced by the ammonia compression machines to the cargo chambers, two methods are employed:

(1) The *direct expansion* system, which is described above. The cooled air in the evaporator chambers is circulated by means of a fan driven by an independent engine round and through the cargo chambers and back again through the evaporator chambers, the same air being continually circulated through the installation. The air trunkways are larger but somewhat similar to those employed for the same purpose where the air compression system is adopted.

(2) The *brine pipe* system. In smaller installations employing ammonia the evaporators adopted are constructed of coils of wrought iron pipes enclosed in an insulated circular steel casing kept full of brine, which is cooled by the evaporation of the gas in the coils. The brine consists of a solution

of chloride of calcium, which is generally kept at a density of about 13 lb. per gallon. The cooled brine is circulated by special duplex pumps through a system of cooling pipes, about 2 in. in diameter, which are fixed to the undersides of the decks and down the sides of the cargo chambers. Special portable grids are also fitted under the hatches.

The system of brine pipes is divided into several sections, each separately controlled by special valves, thereby admitting of any repairs being effected to any one section without interfering with the others. This system, which allows of minute adjustment of the circulating brine, is found to be very suitable for carrying chilled meat, which demands an even temperature. The temperature of the brine can be adjusted to a nicety, either by regulating the back pressure of the gas, or by mixing the brine in a tank.

The following may be considered to be the advantages and disadvantages of the ammonia compression process:

ADVANTAGES.	DISADVANTAGES.
1. The machine is of simple construction, and need not be situated close to the cargo chambers, although the evaporators require to be so.	1. In the direct expansion process the evaporators, each consisting of several miles of piping, take up a considerable amount of space in the 'tween decks.
2. The gas is a powerful refrigerant and is easily liquefied.	2. Ammonia is an exceedingly pungent gas, a very slight leakage being sufficient to prevent any one remaining in its vicinity.
3. It is much less costly in coal consumption than the cold air system.	3. If any leakage occurred in the evaporators, the cargo would be tainted.
4. Leakages are easily discovered where the parts are exposed.	4. At least a full charge of ammonia requires to be carried as spare. This is supplied in steel bottles, which take up a good deal of space, and can only be obtained in certain ports.
5. The ship's provision chambers can be cooled by the direct expansion system, and they are thereby rendered independent of the air circulation through the cargo chamber.	5. Ammonia having great affinity for copper, no such material, nor any of its alloys, can be employed in parts of these machines acted upon by the gas.

ADVANTAGES.	DISADVANTAGES.
6. This process can be used either for the direct expansion or brine cooling system. In the direct expansion system the snow deposited on the evaporator coils can be thawed off at will, thus gaining a high efficiency of cooling surface. No snow accumulates in the air trunks or cargo chambers, and the insulation is easily accessible for the purposes of testing, repairing or cleaning.	6. Where air circulation is employed, the air trunks in the 'tween decks not being collapsible, take up a considerable amount of cargo space.

In the carbonic acid compression process, there is practically only one type of machine employed in the larger installations. This is known as the Hall type. The high pressure of the gas, as before alluded to, requires the machinery to be of strong design, and it is necessary to adopt arrangements of detail considerably different from those in ammonia machines. This particularly applies to the compressors which are bored out of a solid forged ingot of steel. The piston, which is also of special design, is packed by two cup leathers. The piston rod stuffing box is also packed with a pair of cup leathers, a lantern bush forming a space between them, into which lubricating oil is continuously forced by means of an automatic pump fitted with a differential piston, on the smaller side of which is the lubricant, while the larger side is exposed to the full pressure of the gas.

In such machines a pair of compressors is set horizontally, each in tandem with one of the cylinders of a horizontal steam engine. In some cases the engine is triple, the high and intermediate cylinders being on one rod and the low on the other. The whole is fitted upon a cast iron base which contains the steam surface condenser. The air, circulating, and feed pumps are worked by eccentrics fixed on the crank shaft.

Each compressor has its own separator and condenser, the latter, however, being interchangeable. It consists of a number of coils of copper pipes, about 1 in. in diameter, and of heavy gauge. These are mounted in a rectangular cast iron casing. The ends of each coil are connected top and bottom to distributing and collecting boxes. The evaporators and their connections are similar in every respect to those already described as being fitted to ammonia machines worked with the brine pipe system, as also is the method of conveying the cold produced to the cargo chambers. In addition to this, however, in some vessels carrying fruit and dairy produce, special appliances are fitted for dealing with such cargoes requiring only moderate temperatures. These consist of a number of coils of iron pipes stacked in an insulated chamber, similar to that in the ammonia direct expansion system, but the surrounding air which is circulated by a fan is cooled by brine circulated through the coils, instead of by the evaporation of the gas.

In the carbonic anhydride process the cycle of operations is practically the same as in the ammonia process, namely, compression, condensation, and expansion.

The following may be considered to be the advantages and disadvantages of the carbonic acid compression process :

Advantages.	Disadvantages.
1. The machine is comparatively small, very compact, and working parts easily accessible, and, being fitted with a safety valve, the risk of an accident is minimised.	1. Carbonic acid being inodorous leakages are not easily detected ; but on the other hand slight leakages are not dangerous to life.
2. The machine can be placed in the main engine room or at any distance from the cold chambers.	2. High pressures are required for its liquefaction, and the critical temperature of the gas being about 88° F., its efficiency is somewhat affected when used in the tropics.

ADVANTAGES.	DISADVANTAGES.
3. The brine system being chiefly employed in this process, the evaporators, brine deliveries, returns, etc., can be fitted near to the machine, and are, therefore, under the eye of the engineer in charge.	3. There being several miles of brinepipes required in chambers, a certain amount of space is taken up, and the insulation in way of same is not easily accessible for repairing and cleaning purposes.
4. It is much less costly in coal consumption than the cold air system.	4. Brine leakages in the chambers are inaccessible when carrying cargo; but the number of joints in the pipes is greatly reduced, and the pressure is not high.
5. Carbonic acid does not effect ordinary metals. Copper or any of its alloys can be used for any parts of the machinery acted upon by the gas.	5. A considerable amount of snow is deposited on the brine pipes, and when thawed off, after discharging cargo, is apt in careless hands to damage the insulation, and some delay may thus be caused; but this to a large extent may be overcome by passing warm brine through the system.
6. In the brine pipe system any damage sustained to cargo in one chamber does not affect that in the others. The brine in the pipes acts as a storage of cold, and can be circulated while the machine is stopped.	6. A stock of the gas, equal to a full charge at the least, must be carried as spare. This is supplied in steel bottles under a high pressure, necessitating very careful handling and stowage. It must not be exposed to sunshine, and, like similar charges of ammonia, cannot be obtained at all ports. The cost, however, is nominal.
7. Various temperatures can be produced and maintained in different parts of the vessel, by circulating more or less brine as required.	
8. Low temperatures can be produced in any part of the vessel from the engine room without regard to distance.	
9. The meat chambers or holds can be cooled while men are working therein.	

Reverting to the mechanism, it may be observed that in machines of either type it is requisite not only that the whole of the details should be sound, but that the critical parts should be thoroughly tight.

In the air compression system the important parts of the machine, as regards tightness, are the valves and pistons of the air compression and expansion cylinders, and also the tubes of the air coolers and driers, as any leakage from these parts very materially affects the efficiency of the machine.

Before starting the machine, the condenser and hot well should be thoroughly drained by means of a pipe led to a tank below their level or to the main engine hot well. A considerable saving of fresh water is thereby effected, as in most cases the feed pump of the machine is not of sufficient capacity to deal with the abnormal quantity of condensed water which accumulates, particularly in the condenser, as a result of warming up the engine.

While cooling down the cargo chambers, before loading a refrigerated cargo, as cold air occupies less space than warm air, an additional quantity of air has to be admitted to the space, and for this the supplementary air valve or slide, which is fitted to the return air trunk, should be kept open, otherwise a partial vacuum in the chambers would be created.

When starting the machine from time to time during the voyage, after it has been standing for some time, the air should not be drawn from the chambers until the machine is properly working in good order, as, during this time, all air relief cocks are kept fully open. This precaution will save a considerable amount of cold air.

Temperatures of the air should be taken before and after compression, and before and after expansion, and that of the cooling water should also be noted. These records will show whether everything is working satisfactorily. Further, special attention should be paid to the temperature of the return air before entering the compression cylinder, as this is often lower than it ought to be, generally due to oversight on the part of the attendant, who may leave the return air trunk shutter on the delivery side partially open when reversing the air circulation, thus allowing the fresh cold air to short circuit.

The drain cocks on the air coolers and driers require to be frequently opened to draw off any water condensed in cooling the compressed air, so as to obviate as much as possible the formation of snow or ice in the exhaust passages of the expansion cylinder and snow box.

Before the ammonia compression machines leave the makers' works special tests are applied by hydraulic pressure to all the parts which are subject to the pressure of the gas, viz., the compression cylinders and cast iron connections to 700 lb. per square inch, and the condenser and evaporator coils and their connections to 2,000 lb. per square inch.

After the machinery and appliances are fitted on board, and before the plant is charged with ammonia, the whole system, which is subject to the pressure of the gas, is tested by air to 300 lb. pressure per square inch. A thick soap lather is spread over the various joints, and leakages are exposed by the formation of bubbles, under the above pressure.

The most important parts requiring attention during working are the compression cylinder valves, with their springs and buffers; the tightness of piston; the piston rod and its stuffing box; the adjustment of the piston at the end of the stroke for clearance, which must be kept as small as possible in order to obtain a high efficiency; the separator, which should be frequently drained; the condenser coils, which should be drawn, examined, and tested, say every two years.

Before the carbonic acid machines leave the makers' works every part which is subject to the pressure of the gas is first tested by hydraulic pressure to 3,000 lb. per square inch, and then again tested when submerged in a tank of water under compressed air at 1,500 lb. per square inch, when any porosity is indicated by bubbles.

The parts afterwards requiring most attention are practically the same as those of the ammonia plant, with the addition of the brine pipe system, which should be tested every voyage before loading a refrigerated cargo. Special attention has also to be given to the density of the brine.

Portable covers should be fitted to the gas condensers and evaporators to enable a test to be applied to the coils at any time without having to remove same from their place.

With regard to the refrigerating power required, the chief points to be considered are:

1. The cubical capacity of chambers to be cooled and their external superficial area.
2. The nature of the cargo to be carried.
3. The thickness and quality of the insulation.

The object, of course, is to prevent, as far as possible, heat from entering the chambers to be cooled. The more perfect the insulation is, the less will be the demand upon the refrigerating machinery. On the other hand, if the insulation is defective or of insufficient thickness, more refrigerating power is needed to maintain a low temperature of chamber.

A powerful plant with poor insulation may, therefore, be as efficient as a smaller one combined with a better insulation.

When first the chambers are closed and the machine started, the heat has to be abstracted from the insulation as well as that which tends to pass from the atmosphere into the chamber. The machinery has to be sufficiently powerful to do this, and if it does it in a reasonable time, say in twenty-four hours, there should be no doubt of its capacity to keep the chambers cool, even when the vessel is passing through the tropics, where the air temperature is considerably higher.

In all the systems the makers design their machines to be sufficiently powerful to enable the requisite low temperature of about 15° F. to be maintained in the tropics when working only twelve hours per day. In the larger installations either duplex machines or two single machines are fitted. In some cases it is preferred to keep one machine, or half the total power, continuously at work, supplemented occasionally in the tropics by a few hours' work of the other machine. In others, both machines are worked together for the requisite number of hours per day.

Refrigerating machines are rated in terms of their ice melting capacity in tons per 24 hours, the unit of capacity being equal to the amount of the heat absorbed in the melting of one ton of ice at 32° F. to water at 32° F. The latent heat of ice being 142 units, the equivalent amount of one ton of ice will, therefore, be 318,080 B.T.U'S.

It is not within the scope of this paper to go fully into the question of insulation. A few of the important points which come under observation in actual experience, and which require attention in order to keep the insulation in good condition may, however, be mentioned in conclusion.

As it is absolutely necessary to have portable portions of insulation in cargo chambers, such as hatch covers, limber hatches, tank manhole door plugs, etc., which have to be frequently removed and replaced, special attention should be paid to them so as to ensure an air-tight fit before loading a refrigerated cargo.

The insulation efficiency is likely to be depreciated by

1. Moisture affecting insulation, and
2. Settling of non-conducting material, etc.

The parts most likely to be affected by dampness are, the bottom in way of the hatchways ; under the evaporators, machine rooms, air drying pipes, snow boxes, meat ports and provision chambers ; in the ribbands along the sides of 'tween decks ; in way of water tight doors, and in way of the brine pipes where they pass through bulkheads.

Slackness is likely to be found at the top of the sides of the chambers, bulkheads and pump casings, under stringers, brackets and bulkhead horizontal stiffeners. Portable plugs or linings should be fitted for replenishing these parts.

In addition to the foregoing, the insulation and casing over the ammonia pipes, and brine pipes where they pass through the bunker spaces, should be examined from time to time.

There are other points which might be touched upon and which demand some consideration, as, for instance, indicating the machinery and lubrication of same; the question of the auxiliary engines, thermometers, spare gear, etc.

Time, however, will not admit of these matters being dealt with in this Paper; but it is hoped prominence may be given to them in the discussion which is to follow.

From what has preceded, it will, I think, be admitted that the importance of mechanical refrigeration cannot be over estimated by the Marine Engineer. He must be in a position, before he can hope to obtain appointment as Chief Engineer of a vessel, to take charge of any refrigerating plant which may be installed on board, and in order to enable him to perform his duties in connection therewith satisfactorily, it is imperative that he should have a knowledge of the principles involved.

If this Paper will in any way help to throw light upon doubtful points in connection with mechanical refrigeration on shipboard, and will prove of assistance to our younger generation of marine engineers, the object I had in bringing this subject before this Institution will have been attained.

The CHAIRMAN said they had all listened to the interesting paper Mr. Balfour had read. It had been suggested by Mr. Adamson, in order to give them a little time to think over what had been read, that the Denny Medal awarded to Mr. J. H. Silley should now be presented to him. That would allow them an opportunity of considering what they were going to say in the discussion. He felt highly honoured in being asked to be there that evening in the absence of his old friend and their esteemed president, David Dunlop, whom he would have liked to have seen presenting the medal. At the same time, when he received Mr. Adamson's communication that morning asking him to accept the honourable position that he filled that night, he could not forget that he was about one of the oldest living friends of the worthy gentleman who had presented the fund for that medal to the Institute. He had known the late Peter Denny for over sixty years. When he first met him Dr. Peter Denny was in Paisley. He was connected with the firm of Barr & McNabb, and his brother, Alexander Denny, was the designer of the noted steamers that were known as "the clippers of the Clyde." He was the first to bring in the straight stem. Peter Denny was in Paisley for eighteen months; he went from there to Dumbarton, and with his brothers started the great industry that now flourishes on that side of the Clyde. He could only count four living individuals who were at the launch of the steamer *Lady Brisbane*, which, he thought, took place in 1844. Barr & McNab, the two partners, had both joined the majority; three others and himself were, he thought, the only living persons of his acquaintance who were present at that launch, so they would realise how he felt when asked to preside that evening when he had those memories.

The CHAIRMAN then presented to Mr. J. H. Silley the Denny Gold Medal, which had been awarded him for his paper on "The Treatment of Boilers under Forced and Induced Draft." In making the presentation,

The CHAIRMAN said: It is my pleasing duty to present to you this medal for the able paper which you read in this Institute, and I can only say that I hope you will long be spared to look upon it, and also upon the figure of that good old man, because if there ever was a nobleman by birth, it was Dr. Peter Denny. You will be able, I hope, to hand this down to your children as an incentive to them to say, "Father merited this; let us go and do likewise." I have much pleasure in presenting this medal to you.

Mr. J. H. SILLEY, in reply, said: I sincerely thank the Council for the honour they have conferred upon me in awarding me this medal, and my thanks also turn to the donor whose handsome gift created it. I must also thank you, Mr. Chairman, for your kind remarks. When I received the Council's first intimation of this it came as a very agreeable surprise; I did not think it within the range of possibility. I can only say that I did my best to state my experiences and opinion, as a sea-going engineer, such experiences having often been asked for in this Institute, and I feel gratified that the Council have considered my paper worthy of notice, although I feel that it had many shortcomings.

The Chairman then intimated that Mr. Balfour's paper was open for discussion by the members.

Mr. PETER SMITH, who opened the discussion, said: The subject of the paper we have met here to-night to discuss is, as the author terms it, a very important branch of commerce, and of Imperial interest. I would like to emphasise that by stating that it is of national importance, inasmuch as the life of the nation depends on the system of refrigeration being carried out in the most efficient and most economical manner possible. When we come to consider the increasing population of the United Kingdom and the limited area under cultivation for the production of the necessaries of life, we are entirely dependent on the importation of fresh meat for our existence. I must confess myself disappointed in the perusal of the paper, because I consider that a subject of such vital importance could not be in better hands than in those of a practical man like Mr. Balfour. I have no hesitation in saying that Mr. Balfour could have given us much more valuable information as to the best type of refrigerating machinery, also the best medium in the shape of insulating material, the most approved method of fixing same, etc., but perhaps we will be able to draw that from him during the discussion. I understand that Lloyd's surveyors have linked on to their other duties the responsibility of certifying that the refrigerating plant and the insulation of the meat holds are both up to the requirements in every vessel intended for frozen meat carrying. I am not sure but they have even to go farther in foreign ports, viz., to see that the meat is put on board in a fit state for carrying. I would like to ask Mr. Balfour what he considers the best process of the three he has mentioned in his paper to meet the particular requirements in a vessel passing through the tropics. Also the best insulating material, the amount of same, and the best method of fixing the wood-work, etc. It used to be the practice to fit an air space at the skin of the vessel, equal to the depth of the frames, but that has several disadvantages, one being the amount of space it takes up, as well as leaving the skin of the vessel and frames liable to corrosion. The general practice now is to fill in the space between the frames to a depth of at least nine inches of fine charcoal plus at least three inches of several thicknesses of wood. I would like to know if there is any better insulating material in the market than fine charcoal. I presume Mr. Balfour intended his paper to apply more particularly to the conveyance of frozen meat to this country and not to its subsequent cold storage, because he mentions in one paragraph that in either of the three systems mentioned, the motive power is always a horizontal steam engine. Now we know that in shore installation the motive power is often obtained from gas engines, and in many cases the electric motor is coming into use. For cold storage requirements the dry air system has become almost practically obsolete, being too expensive in coal consumption, space occupied, and upkeep. I question, however, if there is any other system more suited for the special conditions applicable to a vessel under way. I believe the CO_2 system is doing good work in many vessels; there is, however, always the risk of a leak occurring in some of the brine pipes in the meat hold, and then comes the difficulty of getting at it for repairs.

The CHAIRMAN thought it would be invidious to ask Mr. Balfour for special names; it would look a little bit biassed, not but that in his mind he knew which he considered the best system. He thought they ought to take the generalities.

Mr. W. E. FARENDEN (Associate Member) said the cold air system was used for preserving the ship's and passengers' provisions, in addition to making ice, as well as for carrying frozen cargoes, such as meat or butter, and keeping fruit cargoes cool. The temperature of the atmosphere surrounding these machines did not affect their efficiency to any appreciable extent, but as the temperature increased the machine was run more hours per day. The machine was very reliable, and the weight and space occupied was less than in either of the other systems. The accumulation of snow in the air trunks was not a serious disadvantage, as it could be easily removed as soon as the machine was stopped. With regard to the disadvantage that the machine could not be worked while loading or discharging cargo, he held that the machine could be worked, but the general practice was to cool down the holds before receiving the cargo. The advantages of the cold air system mentioned by the author in paragraphs 4 and 5 (especially No. 5) were great points in favour of it, and therefore no special precautions against dangers were necessary, beyond carrying the usual spare gear ready to fit when required. The amount of repairs and up-keep of that type of machine was small, and the glycerine and freezer oil for the expansion and compression cylinders respectively (which were the chief stores required) were also comparatively small. With regard to a disadvantage mentioned in paragraph 5, that the air in most cases was circulated over and over again, continually coming in contact with lubricating oil in the air cylinders which might contaminate the air, he believed that most machines had a change valve fitted, so that when found necessary the foul air from the hold could be discharged direct into the atmosphere, and fresh air taken into the compressor; or the air could be purified by a washing tower. With regard to the difficulty of carrying, say, a cargo of meat and fruit, requiring different temperatures owing to the liability of the gases given off the fruit, tainting the meat, he considered this could be overcome by arranging a separate circulation, or taking the return air from the meat hold to the fruit room, or by drawing the air from the latter place direct with a fan and discharging it into the atmosphere or through the washing tower. Although the carbonic anhydride machine was comparatively small and compact, it must not be forgotten that space had to be found for the evaporators, CO_2 condensers, brine pumps, return tank, delivery and return leads, and a considerable quantity of chemicals that have to be carried, consisting of steel cylinders containing the CO_2 gas under pressure, and tanks containing the chloride of calcium for the brine. In addition to that, there was space lost in the holds by reason of the several miles of brine pipes that were required, besides a considerable space for fan engines and air cooler for use when carrying a fruit cargo. The latter was a permanent loss of space from the holds in a vessel that might only be required for fruit carrying one voyage a year. With the CO_2 system the insulation in way of brine pipes was not so easily accessible for repairs as it was with the cold air system. He would be glad to know whether the author had heard of any complaints due to the brine pipes being electrically welded and the process damaging the material. Also, would the author advocate using straight pipes of iron screwed with nuts and galvanised? The brine pipes in the hold occupied more space and weight, as compared with wood air trunks for the cold air system. Another disadvantage was that the brine pipes had always to be carried in place on the outward and homeward voyage, thus taking up valuable cargo space, whereas the wood trunks could be made portable. With regard to the coal consumption being less with the CO_2 than with the cold air machine, that was the case, but the consumption increased in tropical climates, and, added to the cost of chemicals used and repairs, it would not be much under the cold air, taking all the other losses into consideration. Whilst the CO_2 system was suitable for meat, it was not suitable for fruit or cheese, and the brine pipes under the roof and down the sides of the holds had to be shut off when carrying the latter, and additional space had to be taken out of the holds for air cooler, brine pipes, ventilators with fans and engines, to the extent of some tons of space, depending on the capacity of the holds. Air trunks had also to be fitted in the holds with that system for fruit, the same as in the cold air system. The meat cargo brine pipes also took up space in the holds, although these were not in use when carrying fruit. With regard to the disadvantage of having to carry a stock of gas for the CO_2 system, he knew of an instance where a vessel fitted with the CO_2 machinery stopped another vessel at sea to get a supply. There was no such disadvantage with the cold air system. There was a big risk in carrying CO_2, and if the supply should at any time escape the machinery would be useless. There was little or no risk with cold air, and that system was less likely to get out of order than the CO_2 machinery. As the CO_2 could not be obtained at all ports, as had been mentioned by the author, it was necessary for the vessel to have a large stock on board in reserve, for in the event of their running short of the gas, it would probably mean the spoiling of a valuable cargo. In vessels insulated both forward and aft, and where only one CO_2 machine was placed in the main engine room there was considerable risk; also, space was taken up by the brine pipes from the machinery to the cargo holds forward, which, with bends, meant a few hundred feet of piping. The pipes would have to be made accessible to get at the joints, and insulated and protected when passing through the bunkers, which meant loss of space. Anything going wrong with these pipes cut off the supply of cold brine to the forward holds; therefore, an engine forward, and another aft, was preferable. He would like the author to state the thickness, and kind of insulation he would recommend for meat carrying. The insulation for one width of planking all round the top of insulation should be left portable for repairs when required. Indicator diagrams should be taken frequently from each of the air and steam cylinders to see how the machine was working, as the economy of the system depended so much on efficiency. The snow box temperatures should also be carefully noted at regular times each day.

Mr. SHANKS said he thought it was the duty of them all to thank Mr. Balfour for the admirable paper he had put before them that evening. He entirely disagreed with the first speaker, as he was not disappointed. Mr. Smith apparently wanted Mr. Balfour to draw out a specification of all the different systems. That was a thing the author could not do. He advised all the members to study the paper that had been read to them that evening. Mr. Balfour had been at great pains to go into the theory of the three different systems, which were all interesting. The principal advantages and disadvantages of the different systems were points they were all specially interested in, and of which he himself had a little knowledge. Mr. Balfour first of all spoke of the advantages of the cold-air system, and had said that the machinery was simple in construction, and easily accessible. That was so, but it was machinery that required a great deal of attention. Then the author said that the space occupied by the machinery and adjuncts on the round voyage were less than with any other system. Well, he would like that some experienced members would take that question up in the discussion, as he somewhat doubted it. There was one other disadvantage in connection with the dry-air system, and that was that the machinery had got to be at its work; they could not put their refrigerating plant in the engine-room. With the CO_2 system, they could put the machine wherever they liked, and cool any part of the ship. He knew there were shipowners and superintendent engineers who said they would have nothing but the ammonia system, and nowhere but in the engine-room. He differed from those gentlemen. With regard to the differences of temperature that required to be carried in the different holds, they were told by some that it could not be done with the dry air system, but they knew that some people were doing it, and Mr. Farenden had described how the different range could be maintained by a washing tower and by regulating slides in the different holds. He believed that with a washing tower they could maintain a different temperature in four or five holds when using the dry-air system. With the ammonia system and the CO_2 system they had to introduce other things. They could not carry fruit with the CO_2 system without a battery—at least he did not think it was possible. He understood that the temperature of the hold was kept down by gravitation, and not by circulation of the air, and it seemed to him to be almost impossible to keep a uniform temperature through a hold without a circulation of the air. There were other products besides fruit to be carried, as, for instance, cheese. These were a few ideas passing through his mind in connection with the different temperatures that had to be maintained in dealing with the carrying of frozen produce. He did not think Mr. Balfour had ever attempted to deal with insulation in connection with his paper. Insulation was such an important thing that it required a separate paper altogether. Insulation, in his opinion, was more important than what they had had that night, and he hoped Mr. Balfour would carry the question of refrigeration further, and tell them something about insulation, and its defects in connection with refrigeration.

Mr. J. THOM (Member) said the author at the beginning of his paper referred to the fact that Professor Dewar had attained the very low temperature of −423° F. If it were of any interest he would like to inform them than on Feb. 25 Professor W. G. Adams, of King's College, London, solidified hydrogen and afterwards broke the vessel it was in, revealing a solid piece of material very similar in appearance to glass. So that must be quite twenty degrees under the temperature obtained by Professor Dewar, probably more. The temperature was registered by a gas thermometer containing helium. It was just as well to know the most recent low temperature that had been obtained. With regard to the different kinds of refrigerating machinery, he did not think there was any radical difference between the three types so far as the space they took up collectively for the whole series of arrangements, as by being placed in parts of the ship that were not so useful or did not affect the carrying capacity of the holds there was a good deal gained. If they came to compare the coal consumption of the volatile gas machine with the coal consumption of the air machine they dropped down to about one-fifth of the coal consumption for gas machines. Mr. Balfour had said that only certain metals would stand ammonia. There was one metal not generally known that did very good duty; he referred to phosphor-bronze. That metal would not wear or deteriorate in a year or two; it might afterwards. In speaking of the cold air machine not being suitable for different temperatures, he was of opinion that different temperatures could be maintained with that system, but it required a good deal of manipulation. It would not do to say, "We will put so-and-so in here and there," because there might be certain articles that would contaminate the air. They must not drive the bad air back into the machine, but only deliver sufficient dry air to keep the cargo cool, with an exit for contaminated air to the atmosphere. The contaminated air might be forced out by means of a fan, or it might just be forced out from the machine. It was possible to carry butter and cheese close to each other without contaminating either. Regarding ammonia or CO_2 machines for carrying fruit, he considered it was quite possible to carry fruit with ammonia pipes, either direct expansion or brine pipes, in the roof or sides of the fruit rooms, but they must circulate fresh dry air. The pipes would cool the air where they were put. If they wanted to drive any air into a compartment in order to get the contaminated air out they must supply air to make up for what they drove out. This air had to be dried before they could put it alongside fruit, or it would destroy it. If the air which they put into the fruit chamber to make up for what they had pumped out were dry he considered it would be possible to carry the fruit safely.

Mr. W. McLaren (Member) said that many like himself had had very little experience of refrigeration. One was always pleased to learn, and there was no doubt that many would take the advantage of studying Mr. Balfour's paper at home. He would like to ask Mr. Balfour if he would continue the subject, as there were some of their members in later life who desired knowledge quite as much as the younger members. He would like to ask the author whether he would recommend the ammonia system or the CO_2 system being installed in the engine-room. He knew of a case of which he was told that it was sometimes difficult to work the main engines owing to a leakage; such, he thought, would be rather dangerous, and a point rather in favour of the dry air machine, although it had to be placed close to its work. It was possible that a system of fans could be fitted in connection with the ammonia and CO_2 machines to blow the cold air through the chambers. He would like to know whether the fitting of such fans would materially increase the cost of supplying always fresh air instead of chilled air being continually circulated.

Mr. GEO. ADAMS (Member) said that one speaker had raised the question whether the air from the dry air machine became contaminated with oil or not. Some little time ago the same query arose in regard to a provision chamber, the contents of which were kept refrigerated by means of a cold air machine. A test was decided upon, and some blankets were hung up in the chamber, when it was found that small particles of oil were deposited on them. It proved that a contaminating effect could go on with the cold air machine, if not carefully watched. The question had also been raised as to whether the space occupied by a dry air machine was greater or less than that occupied by the CO_2 machine. When they came to consider the space occupied by the CO_2 machine and all its adjuncts, and took into consideration the miles of piping used in connection with it, together with the tanks and return tanks, and the receptacle for holding the brine, he thought they would be right in saying that the space would be greater than that required for a cold air machine of the same capacity. When they came to consider that in an engine-room carrying the dry air system they had the machinery on the one bed-plate, with the addition of a small space occupied by the air-drier, they would see that the space occupied by the CO_2 plant was larger and the weight greater. In addition, there was the weight of the circulating brine. The paper opened up so many points for discussion that one query cropped up after another. He thought they would have to reserve many evenings before the questions could be thoroughly thrashed out. The question of refrigerating and the amount of frozen meat carried to this country was of vital importance to engineers, shipowners, and the general public. They knew that they could not obtain the whole of their food supply from this country, and they were obliged to be dependent on other countries. When they considered the enormous quantities of meat, fruit, and dairy produce that was imported not only from our own colonies, but also from other countries, particularly from South America, they would agree that the carriage of refrigerated produce was only in its infancy. He thought they would see increases in that trade, and, as Mr. Balfour had remarked, it was a necessity that the marine engineer who desired to become a chief engineer should be in a position to take in hand the supervision of any system of refrigeration that might be placed in the vessel to which he was appointed. It was obvious that he must know what was embodied in the present paper, i.e., the principle of refrigeration. If these were not known there could not be the satisfactory results obtainable.

Mr. PETER SMITH said he knew Mr. Balfour was in possession of valuable knowledge, and he did not think he would be guilty of giving away any of the secrets of his profession in giving them some benefit of his large and varied experience by stating the general outlines and causes of damaged cargo that had come under his knowledge. He would like again to say that he believed the dry-air system was the best system for ships' use. Every engineer present probably had experience in carrying refrigerated produce from the Colonies, as he himself had, in the shape of mutton, rabbits, butter and fruit, all on the same voyage, but in different compartments, each to have their required temperature. In carrying fruit he failed to see how the CO_2 could be made efficient. An apple was like an animal in that it lived and breathed; it absorbed oxygen and gave off carbonic acid. If they used the CO_2 system they could keep the hold cool, but could they perform the other necessary operation, viz., to supply sufficient oxygen and extract carbonic acid? They were often asked to carry butter, a most sensitive produce for absorbing flavour, in the lower hold, and on the deck immediately above a quantity of apples, of keenly searching smell, pears, and other fruits. What were they to do in such a case in order to preserve both kinds of cargo and prevent contamination. The method he employed was to make the butter safe by freezing it first and then utilise one of the ventilating fans to exhaust the air from the fruit chamber up the ventilator, so that no air whatever returned to the machine. The decks and hatches were, of course, all caulked and made tight. By this arrangement they were taking away from the machine all the cold air, and they had to make good that air from the atmosphere, and take warm air into the machine, and what was worse, when they got into the tropics they got an enormous amount of moisture, and the snow that collected in the trunks was excessive.

Mr. W. C. ROBERTS (Chairman of Council) said he thought Mr. Balfour had supplied them with every information. They had had an excellent paper that evening, and the author had gone out of his way to supply the information, and he considered him deserving of great credit. The paper was for the benefit of shipowners, and all concerned in the question of refrigeration.

Mr. J. PRICE, A.M.Inst.C.E. (Visitor), said he had been invited by Mr. Thom to attend, and the paper had been of very great interest to him. He could not claim to be acquainted with recent marine refrigeration, but he had had some experience with two systems of land refrigeration some years ago. The Institute was to be congratulated on having such a paper, and the author was also to be congratulated for his really masterly production. He (the speaker) knew a good deal of the literature on mechanical refrigeration, but he knew of nothing that put the matter so concisely and clearly as the paper that had been read. He had in consequence learnt a good deal that evening, and he had now a better appreciation of the theory of refrigeration. He had also now a better grasp of the intimate co-relation that there was between heat and work. Mr. Thom had informed them that hydrogen had been frozen. Hitherto, $-461°$ F. had been accepted as absolute cold, and now, wonderful to state, the figures quoted by Mr. Thom show that scientists had almost reached that point. The paper teemed with interest. Some of the speakers had wanted more information, but so far as they had got, he had had quite enough for one night, and only hoped to be able to remember it. If the author would give them further information at some future time, he hoped to be granted the privilege of hearing him. The opposition in parallel columns of the advantages and disadvantages of the different systems enabled them to form a comparison. He could quite appreciate that Mr. Balfour was in such a position that it would be invidious and beyond his province to select out any one particular type. Some ten or twelve years ago the speaker had some experience with the Linde plant for land installations. The point had been raised about air trunks, and what one might call differential refrigeration. If his memory served him right, several of the marine plants put in in the early days of the Linde machine were very similar to what were put in now in the land installations, where the evaporating coils were contained in a chamber through which the air was circulated; thus they could get their air circulated at different temperatures and applied just where required. A point had been raised that evening which interested him, that was the contamination of the air passing through the coolers. One system of Linde's was to cool the air by means of discs rotating in brine at low temperature; or by another plan (Le Mesurier's), in which the brine was raised by a sort of Persian wheel, the troughs of which being perforated allowed the brine to fall through the air like rain. With these there was found one thing that he would like to mention. In starting a plant for one of the abattoirs at Birkenhead, they found that with the cold brine they actually washed out of the air an average of $4\frac{1}{2}$ lb. of water per head chilled. He once got the idea that bacteria, or something of that nature, might be carried by that particular air through the chambers. In fact, a reference to the point had been made that evening, as to the carrying of mildew with the cold air circulation. To test this, in one of the trunks leading from the refrigerating coils he placed two saucers, one filled with a weak solution of nitrate of silver, and the other filled with a weak solution of permanganate of potash. He left them there for a time, and when he took them out there was no alteration in the colour of the permanganate of potash, which showed there had been nothing passed through the trunk of a deleterious character, and the silver solution also showed no evidence of the presence of brine. He was especially interested in the question of separating out the oil carried over in suspension along with the compressed gas, this being a problem he had to deal with in the working of his new type of Air Lift Pumping Plant, as the oil so carried over is that used for lubricating the compressor and its piston rod, and being generally more or less blackened is objectionable when in evidence on water intended for domestic or brewing purposes. Being very finely comminuted it will require some special treatment, as none of the separators used for exhaust steam seem to completely meet the case. However, he trusted that the problem would be satisfactorily solved by the time the further paper from Mr. Balfour came before the Institute.

Mr. W. C. Roberts proposed a very hearty vote of thanks to the Chairman for presiding. He was pleased to see such a large gathering as they had that night.

Mr. J. H. Silley, in seconding, said: It gives me great pleasure to second this vote of thanks, and I feel sure you all join in giving expression to the pleasure we feel in having with us to-night one who is so closely associated with shipping. I think it very appropriate that Mr. Clark should be Chairman over a meeting gathered to listen to a paper on refrigeration, in view of his own close connection with frozen cargo carrying steamers.

The CHAIRMAN, in responding to the vote of thanks, said Mr. Balfour's paper would undoubtedly be of great use to them. He felt sure he was expressing the sentiments of all the members when he said they were all very much indebted to the author for his able and exhaustive paper. He hoped he would give them another paper, when he would wish to have the pleasure of hearing his remarks.

The vote of thanks to the Chairman was cordially agreed to.

Mr. J. R. RUTHVEN moved that a vote of thanks be accorded to Mr. Balfour for his paper, which had been most interesting. He thought Mr. Balfour had gone into the matter very carefully, without committing himself to any one system. There was no bias in the paper. He had given them a fair view of the advantages and disadvantages of the various systems.

Mr. ANGUS MORRISON seconded the motion, which was unanimously agreed to.

Mr. BALFOUR thanked them for their patient hearing of his paper. He would probably be able to give them another paper on "Insulation" at a later date. He thought the people of this country ought to be ashamed of themselves. The Americans had gone more thoroughly into the matter of refrigeration than they had. Our insular position and the experience of the South African War ought to stir them up in the matter, or the German would be ousting them out of it.

Mr. JAMES ADAMSON (Hon. Secretary) said the matter rested with the members present whether they should continue, at Mr. Balfour's convenience, the discussion of his paper before the close of their present half session, or wait until they resumed their meetings in the autumn. The earliest date available during the current part of the session was April 27th.

It was ultimately decided by the meeting that the further discussion of the paper should be deferred until the autumn.

The HON. SECRETARY: Arrangements are being made to continue the discussion, in accordance with the resolution of the meeting, on Monday, October 12th, at 7.30 p.m.; and in order to meet the wishes of several members that a hall should be engaged in the City for occasional meetings the discussion that evening will be held, by the courtesy of the Committee, in the London Institution, Finsbury Circus, E.C.

It is desired that members should do what they can to further the discussion on this subject, and, in order to assist those who may not be able to attend the meeting, the paper and discussion already held will be issued to the membership to give an opportunity to as many as possible of sending in contributions and questions before October, to be read at the meeting.

It may also be intimated that the subject of pump arrangements in connection with marine engines will be further introduced for discussion on Monday, September 14th, and the adjourned discussion on Water-Tube Boilers will be resumed on Monday, September 28th, at 58 Romford Road, at 8 p.m.

Contributions on these subjects are also invited.

INSTITUTE OF MARINE ENGINEERS

INCORPORATED.

SESSION 1903-1904.

President—SIR JOHN GUNN.

Local President (B.C. Centre)—LORD TREDEGAR.

VOLUME XV.

ONE HUNDRED AND ELEVENTH PAPER
(OF TRANSACTIONS).

REFRIGERATING MACHINERY AND APPLIANCES AS FITTED ON BOARD SHIP.

BY

MR. R. BALFOUR (MEMBER OF COUNCIL).

DISCUSSION CONTINUED

AT

58 ROMFORD ROAD, STRATFORD,

ON

MONDAY, NOVEMBER 9th, 1903.

CHAIRMAN: MR. J. E. ELMSLIE (MEMBER OF COUNCIL).

The CHAIRMAN: We have met to-night to continue the discussion on Mr. Balfour's paper on "Refrigerating Appliances as Fitted on Board Ship." We will ask him to open by replying to some of the remarks made on the last occasion.

Mr. BALFOUR said it was unfortunate that very few members were present at the last meeting, which was held at the London Institution. That fact was very much to be regretted, and he thought the members ought to take more interest in important subjects submitted to them for discussion. On that occasion he had left off without referring to the remarks of the Hon. Secretary, Mr. Adamson, who had asked if he had had any experience of corrosion taking place in ammonia condensers. In the submerged condensers on board ship they had the nest of pipes surrounded by sea water. By some it was considered better to have the piping externally galvanised to overcome the corrosive action of the sea water. In some cases, however, a coating of anti-corrosive solution was merely given to the pipes. His experience had been that any difficulties arising with the submerged condensers in the ammonia system were chiefly due to the fastenings of the pipes, and also to the presence of wood (containing acid), pieces of which in some cases were inserted between the coils to keep them apart in order to allow free water circulation. In the more modern machines, however, that trouble had been overcome. In large machines the ammonia condensers were about 20 ft. long and the pipes were secured at the ends by round staple fastenings. The question of these fastenings was a point for the refrigerating machinery manufacturers to improve upon, so as to minimise the trouble due to vibration and jarring by increasing the surface of the attachment, thus reducing the friction and the wear and tear that might take place locally. (At this stage Mr. Balfour demonstrated his meaning by means of sketches on the blackboard.) Mr. Adamson, in referring to the question of insulation, mentioned rice husks as being employed for insulating purposes. The use of rice husks was probably a question of £ s. d., and he would not advocate its use, as it was an enticement to rats.

Mr. J. Thom (Member): I was not present at the previous meeting, and therefore do not know much of what was dealt with on that occasion, but as Mr. Balfour has mentioned the condenser, I am able to give you some slight information thereon. Referring to the question of explosions in the valve casings with the cold air machine, you will find that the higher the pressure the higher the temperature will be, and with the low pressures there is no fear of explosion. The lubricating oils that are suitable for the lower are not suitable for the higher pressures and temperatures. I do not think there would be any trouble as far as temperature is concerned with the high pressures if the style of valves used to admit and exhaust the air from those cylinders are of the balanced class, so as to give little friction, as long as the cylinders and casings are well water jacketed. But many of those valves are made with very large surfaces, thus causing a lot of friction, and if those faces by any means got a little dry at any time I am quite sure an explosion would take place. I have seen instances of the oil being fired, and instead of cooling down the chambers we were trying to set them on fire. It was true no flame went through, but there was certainly a lot of smoke. That was simply caused by the high temperature resulting from the friction of the valves on the faces, under those conditions. As a rule, the machines did not give any trouble after you had once got some of the holds cooled down and some cargo on board, as you would get a fairly low temperature return air coming back from the chambers, very much lower than you would have when cooling down at first. If you should have to cool down all the holds at once, the machine would be running continuously for a matter of a day before the return air would come down to 32°, and at first would be, say, 75°. That condition was often the cause of the valves giving trouble. As soon as the valve began to fire the temperature rose like powder going off. There are many ways of finding that out, or of knowing what is happening, but it is possible that a valve might scratch away a little without letting you know. I think it would be advisable in such circumstances to fit a thermometer to show the temperature of the air immediately surrounding the valve. Such thermometers, I have found, are fitted with a range of about 300 to 500 degrees, and as soon as that valve begins to give trouble the thermometer breaks owing to the temperature rising sufficiently high to burst the tube, and being connected to the air space, allows air to escape. That plan lets one know exactly what is happening at the expense of the thermometer. The oils for those high temperatures must be of the very best quality; they must have a high flash point, and when ordering oils for refrigerating machinery care should be taken that the contractors understand what kind of oils you require, for unless they are told exactly what is wanted, how are they to know whether it is high or low flash oil which is required? And with the dry air machine you require oils of both classes. You require an oil for the compression cylinder with a high flash point, and for the expansion cylinder you require a very good lubricant for a low temperature. There are instances where you might use glycerine. Glycerine, however, would not always answer, as it is a very poor lubricant, and will not take the weight of a valve of any size. But you could get a good mineral oil that would give much better results and not freeze until it got to a pretty low temperature. Mr. Balfour has spoken of the ammonia condenser tubes deteriorating. Of course, the condensers that are used on board ship are of the submerged class. No corrosion takes place on the ammonia side (usually the inside) of those tubes, and I may say I have never seen ammonia attack good wrought iron, steel, or cast-iron. So far as the outsides of the tubes are concerned, you will have the same actions going on that you have with sea water and variable temperature, and the means you would employ to give protection against these effects would be either galvanising or painting—the former when the plant is new, and the latter when overhauling at any time. These tubes ought not to corrode very much, except at the places where they are hung or supported, and these supports, I would say, ought to have good large surfaces. The material of which the supports are made should be the same material as the tubes, and galvanised, or in some other way protected. Those tubes, as shown on the blackboard, instead of being stapled at the ends, should be hung, if possible, and not supported at the ends, as shown. They should be supported lengthways, so that if they wanted to contract or expand they could do so. If they are held at the ends there is a certain amount of pull or jamming of the supports into the tubes, and there is always vibration about a machine. The throb of the water from the pumps would cause a certain amount of vibration. If those supports were made the shape of the tube, to grip all round (not necessarily too tight) there would be very little chance of corrosion taking place. There is no trouble with corrosion in the evaporative condensers, unless you are using a very corrosive kind of water; and then my experience is that bitumastic solution should be applied oftener than when you have non-corrosive kinds of water. The evaporative condenser you can see oftener, and treat according to its wants as you go along. Painting once a year is sufficient with some, with others twice. With fresh river water a certain amount of slime is deposited on the pipes, which has to be cleaned off. In other instances a hard scale is formed on the tubes, which has to be cleaned off, or you will not get the full result of the water going over the tubes, and the forward pressure will rise because of the difficulty of the heat getting through the scale, as with a boiler tube. The tubes of immersed condensers on board ship get coated with scale, especially if the ship has to pass frequently through the tropics or is trading in tropical climates. In a few months there would be a good amount of scale on the pipes. Vessels running to the West Indies are practically in the tropics the greater part of the voyage, and those vessels get a lot of scale on the tubes of their condensers in a very short time. The tubes have to be drawn and cleaned every now and again. With reference to fires breaking out in refrigerating chambers on board ships, although it is possible, I do not think it very likely, that the air going from the dry air machine into the holds is ever the cause of fire; as after the machines have been running a short time there is always some snow in the trunks, and that snow would be likely to catch all the sparks that might be passing along. The fires that have taken place on board ship in the refrigerated spaces are always supposed to have been caused by spontaneous combustion arising from some unknown cause. I have known of a case of spontaneous combustion with charcoal insulation, which had evidently started amongst the charcoal, not from the outside but right in the heart of it. The refrigerating machine had not been running more than four days before the fire occurred. Seventy thousand sheep had been put on board twelve hours previously. The fire took place in the highest part of the chamber, very near the machine and next to an empty coal bunker. There was no likelihood of high temperature arising from parts of the ship exposed to the sun, and the heat from the engine room was not more than 90°, which, I think, would not have been the cause of the fire. Altogether it was rather a difficult matter to say how it started; the Insurance Company put it down to the cloths on the sheep, saying that when the sheep came on board the cloths must have been very dry and some spark must have fallen on them, which remained there and caused the fire. I do not think they would carry a live spark for several hours. In addition to this the sheep were stowed quite twenty feet away from where the fire broke out.

Mr. W. E. FARENDEN (Associate Member). Mr. Balfour stated in reply to questions at our last meeting that "it was now the plan to lodge such pipes (the brine pipes with the CO_2 system) between the beams, so that little or no cargo space was lost." I would like to ask Mr. Balfour what would be done in a vessel fitted with channel beams, say 8 in. by 3½ in. on each frame—instead of the large deep bulb T beams—where they were fitted on every other frame of the ship. The bulb T beams were, say, 12 in. deep, but with the channel beams, fitted on every frame, they were able to reduce their depth. The insulation should be 10 or 11 in. thick at the deck, according to Mr. Balfour's remarks as to the most efficient thickness of cold storage insulation. Mr. Balfour also spoke of objection raised against the CO_2 system on the ground that it was not suitable for carrying fruit or cheese. I do not think that he made himself clearly understood at the previous meeting. He should have stated that to carry fruit or cheese with the CO_2 system it would be necessary to have an addition to the brine pipes that are required for meat cargoes. Mr. Balfour mentioned that the up-to-date plan with that system was for the air to be passed over a battery of pipes containing brine. The air was then forced through the chamber by a fan and through air trunks, as with the cold air machine, so as to keep the temperature required for fruit or cheese. I believe that the brine pipes under the ceiling and down the sides of the hold are shut off and not used when carrying cheese or fruit cargoes. The additional space required for the battery of pipes and fan beyond that already taken up by the brine pipes in a hold of about 600 tons would mean a permanent loss of from twelve to fifteen tons of valuable cargo space, and that on a ship running between London and Australia or Tasmania, where the vessel would only carry fruit cargo one voyage during the year, was a point worth considering. In replying to another question, Mr. Balfour said that when cooling down the holds they ought to keep open the supplementary valve to the atmosphere. Did he mean that the return air from the hold should be taken direct to the atmosphere instead of into the machine? Mr. Balfour also said that with the carbonic anhydride engine it was quite possible to carry fruit along with frozen meat. I do not think that Mr. Balfour meant to say that fruit and meat were carried in the same hold with the carbonic system, but they could be carried in different holds, as with the cold air machine. In another part of his reply Mr. Balfour said he would advise them to be careful and keep their water-jacketing thoroughly well cleaned, so as to preclude the possibility of an explosion. I quite agree with that advice, although with machines working with 50 lb. air pressure there was no need to fear trouble of that kind, but think the casing of the cylinders should be fitted with hand-holes, so that the doors could be taken off to facilitate the cleaning of the jackets.

Mr. D. S. LEE (Member) said he would like to ask Mr. Balfour about the various insulations that were used on board ship, especially as to the thickness he would recommend and the medium used. Mr. Balfour had mentioned the air space. That was almost universal some little time ago, though now in many cases the insulation was put against the sides of the ship or against the bulkheads without any air space intervening. The latter method gave as good results so long as the insulation was kept dry.

Mr. W. H. FLOOD (Member) said there was one little point that occurred to him regarding the fastenings of the pipes in the condenser. He noticed that Mr. Farenden had made a remark about the electric welding of condenser pipes, and also of the brine pipes. He knew for a fact that Messrs. Hall, of Dartford, and others, had electrically welded the whole of their tubes for years, and he thought he was right when he said that they had had under consideration for some time past the idea of electrically welding the lugs for fastenings in various positions on sections of tubes to get over the difficulty that Mr. Balfour had referred to, namely, the local defects arising through the fastenings being attached in the ordinary way with wood blocks.

From his experience of electrical matters generally, he would say that it would not be a very difficult thing to do, and he thought it would be a very fine thing, especially with closed systems of piping.

Mr. G. SHEARER (Member): Mr. Flood had spoken of having the coil fastenings electrically welded to the tubes. That, he thought, was a great mistake. Where they had variations of temperature, the throbbing of pumps, and vibration on board a ship, he would say that it was a mistake to make a thing solid there—at least a coil pipe. It must be a case of give and take with all those variations of temperature. Mr. Balfour had mentioned the wood between the tubes. He was of opinion that if they had pieces of good pitch pine or American elm there would be very little chance of any acid action taking place between those coils of piping. He would suggest, however, that instead of using wood they should employ india-rubber. They all knew that india-rubber of a certain kind would stand the effect of any sea water, although it lost its elasticity at low temperatures. If there were much vibration on any pipe at the lower temperatures it would be a very simple matter to put in an india-rubber pad much the same as was used in the brake of a bicycle, so that the india-rubber could not get out of place. That would be a very simple fixture, and, he thought, a very effective one. Regarding explosions, he had had a good deal of experience with the dry air machine. He thought he was amongst the first to use that machine, and he must say that there was a wide change from that time to the present. He well remembered that when they commenced refrigeration they really had no idea of it, comparatively. The discharge shoot was laid along the deck level of the room. The machine of which he was speaking was for provisions—one of the old Bell-Coleman machines—and that happened some considerable time ago. The ship on which that machine was fitted was a high-class mail steamer, and it was her first voyage with the machine. The meat was thrown down on the deck instead of being hung up. It was simply packed on the deck in its hot condition as it came from the slaughter-house. They had hot weather at the time, and when they got down to Plymouth they found that a great deal of the meat was decomposed through lying on the deck, where it settled down, preventing the cold air affecting it. That portion of the meat was jettisoned and they got in a fresh supply, and that fresh supply was hung up. That was the first refrigerating machine that he had to deal with, and so far as he could remember he did not get any instructions, as no one appeared to know much about it. He found, however, as they all knew now, that the cold air simply lay in a strata along the deck like fog. It struck him that that must be the wrong place for the discharge pipe. To get over the difficulty he got the ship's carpenter to construct a shoot to carry the discharge to the roof, fixing it to the overhead deck, much the same as in the modern systems, and had openings here and there to distribute the air. On looking into the chamber he then found that the cold air was falling from the roof just like fog. Previous to the alteration, and without using the thermometer, but simply by feeling, he discovered a great variation in the temperature. The chamber was not a very large one, and as the meat was used up and had more space he found that it took many more revolutions to keep the temperature down. He put up a staff between the floor and the next deck, on which he fixed five or six thermometers, so as to register the temperature in the different strata. He found something like a difference of from 20 to 25 degrees from the floor to the roof. It was after he took those temperatures that he put in the shoot to lead the discharge to the roof, and afterwards he had no further trouble. With a view to curtailing the space he had a canvas bulkhead put up. They were then reduced to about a quarter of the space, and after he had fixed that canvas bulkhead he found a great change took place. The space being so reduced he found that he could run with about nearly half the revolutions that had been necessary before that bulkhead was erected. He would like to ask Mr. Balfour, as an expert, whether he considered the ammonia or the CO_2 machine the better? Which did he consider the safest in the hands of engineers? He had never been with the ammonia machine, and possibly he might be a little biased against that system because of the trouble arising through the ammonia escaping. That was why he asked the question, although he could scarcely expect him to answer. That, however, he would leave to him. At the same time, he would like to know. With the CO_2 system he had always thought that there was a great danger through the leakage of the brine pipes and joints. He had heard of the electric welding of pipes, but had never had any experience of them in refrigerating machinery. Compared with the couplings that were used with the CO_2 system he thought the electric welding of the pipes was a splendid idea. If they had a large cargo, how was it possible to get at the joints? If a leak took place they could not get near. In the first place it would be a most difficult matter to locate that leak when the hold was full of cargo. They could ascertain that a leak existed, but he did not see how it was possible in ordinary circumstances to get near the defective joint. At a previous meeting Mr. Farenden had mentioned something about pipes being disconnected from their place in the holds when on the outward voyage with general cargo, and stowed away in some other place. If in that instance the pipes were taken down and stowed away, and then had to be replaced, he thought the engineers must have had a sorrowful job on the foreign station. He considered that the jointing of those pipes was the principal thing in connection with the whole affair—outside the machine room—and not taking into account the insulation. Insulation was the most important feature, and, as Mr. Balfour had said, it would occupy a paper itself. He had no doubt that in a short time their experimental department would be able to enlighten them on that subject by having practical tests made in their laboratory. If insulating material were sent in—and that it would be sent in he had no doubt—many of them would be only too pleased to take part in the experiments, and he felt certain they would be able to cope with the point. He did not see any difficulty so far as going into the theoretical points in the temperature of the insulation was concerned, but they would go into the question in a thorough practical way, for they all knew that their practice was much more important from a commercial point of view than what their theory was.

Mr. J. PRICE, A.M. Inst. C.E. (Visitor) said he would confine his remarks to points that had been raised that evening. Mr. Balfour had commenced with the question of explosions. Those explosions he thought would be found to be chiefly due to the gasification of the oil used for lubrication of the compressor. He could scarcely conceive that any small quantity of charcoal dust that might be drawn in could be contributory to an explosion. The temperature of compression, of course, was high, so high indeed that one speaker had referred to it passing off in smoke. He had recently had occasion to use air compressors, compressing up to 150 pounds per square inch, and even at lower pressures than that he had found that in opening the drain cock on the receiver a distinct smoke cloud very often showed itself. The air compressors used were very well water-jacketed. In one particular case he had no doubt that the smoke cloud was due to the oil that was used. The compressor was in use to supply air to an air lift pump in connection with the water supply of a southern town, and they had some trouble with the oil passing through the machine and showing itself on the surface of the water in the settling reservoirs.

When mineral oil was used they found an oil taint; the water tasting slightly of petroleum. So they commenced to use lard oil, and they told him by using that oil they had nearly smashed up the compressor, as the valves were found coated with a thick deposit of charcoal which prevented them from opening sufficiently to relieve the pressure of compression in the cylinder, this being due to the carbonisation of the animal oil. As compression on shipboard was not to such pressure and by consequence to such temperature as to cause gasification of the oil—the excess temperature which produces the effect mentioned would, he thought, be found due to leaky delivery valves—allowing the cylinder on the return stroke to be partially filled with air under compression and consequently highly heated, so that the next compression started from a higher temperature than would have been the case had the cylinder been filled with air of the atmospheric temperature. Mention had been made of local action in regard to the condenser coils. He was not familiar with the way condenser tubes were fitted on board ship, but if they considered that iron and steel tubes were fairly sensitive to heat and its resulting expansion and contraction, he would ask if any one could conceive a worse way of supporting them in position than that shown on the upper portion of the blackboard, which was stretching them by a sort of hook bolt. At one time it would be slack and at another time very tight indeed, and he did not see why those tubes could not be suspended by vertical suspenders. He believed those vertical suspenders were used in shore condensers. With regard to wood packing between the coils—as mentioned by Mr. Balfour—and its effect, it would be rather interesting if one could trace the cause. The idea had suggested itself to him that possibly one cause might be the fact that by those pieces of wood the current of the water was somewhat impeded. It would be interesting to know which side of the packing, the upper or the lower, seemed to have the most corrosive effect. They almost invariably found that there was a great deal of what they might call occluded air in water, particularly in water that had been pumped. The result of pumping that water into the condenser tank, or even letting it flow through and drawing it off afterwards, would be that the water would be heated. One of the first results of heating water was to drive off the occluded air, and that air in ascending might, he fancied, collect under the wood packing and at once provide the means for corrosion by oxidation of the tube. That oxidation once commenced went on accumulatively, and the motion of the tubes under the action of the compression and the motion of the ship would very readily provide fresh surface to be oxidised in turn. He was particularly interested by the reference made to rice husks as an insulation media. A quondam partner of his had hoped to make his fortune out of rice husks, and patented its application for insulating purposes under the title Vegetable Silica, but he found, unfortunately, that rice husks could not be bought in sufficient quantity in this country, so he supposed that project had not gone very far. In regard to insulation, one gentleman had spoken of the air spaces. He thought it would be found that the value of an insulator was very much in proportion to its faculty for locking up, or sealing, or occluding air, which it could keep in a still condition. Of all the insulations that they knew of, he did not know that there was any one superior to air if they could only keep it quite still, and avoid its faculty for establishing convective currents. He happened to be looking over a list of insulations that were now in use, and he remembered that one of the American companies tried to apply the idea of still air by putting in cardboard boxes sealed at each end. Even those boxes were sufficiently large to allow of circulation of the air and thereby convection of heat. Charcoal, wool, felts, and cow-hair, when used as insulation, were all dependent principally on the air that could be occluded amongst their particles. The last speaker had referred to electric welding. Well, had it not been for electric welding most of the coils that were used both for submerged and air condensers, and, he presumed, also for use on board ship, would have been practically impossible. They would certainly have been unreliable, and he believed they might take it that all the large coils in use nowadays were electrically welded and had proved very successful. He thought the gentlemen who had spoken of detecting leakage from CO_2 pipes in the holds of vessels must have overlooked the fact that they were not usually put in the insulated chambers themselves. They were either used for cooling brine, or, in shore insulations, used for cooling air, which was subsequently circulated by a fan. At a previous meeting he had referred to the problem of separating out the oil carried over in suspension along with the compressed gases. He was sorry to say that problem had not yet been quite solved. He had tried a good many means of checking that oil, and although he could check a portion, he could not check the whole of it. Every maker of oil separators used for steam had fought shy of that particular treatment of the oil in compressed air. He might say, before sitting down, that he had listened with intense interest to the experience of gentlemen who were really better qualified from that very experience to speak on that subject than himself. He thanked them for the opportunity of listening to that experience.

Mr. PETER SMITH (Member) said he had not intended taking part in the discussion that evening for two reasons, the first of which was that he was unfortunately not present at the last meeting at the London Institution, and the second was that he had said a good deal at the introduction of Mr. Balfour's paper—perhaps a little too much. However, he might explain that by saying that he always, if possible, disagreed with the author of a paper. He did that on principle—to induce discussion. Mr.

Balfour's paper was an excellent one theoretically; it was a most able paper, but at the same time they all knew that Mr. Balfour could give them a great amount of practical experience, the result of his own observation. That evening he had given them some practical information regarding the Hall and Haslam systems of cold air machines. Referring to the high temperatures, he thought over 60 lb. air pressure was far too high. He thought that about 50 lb. per square inch was the most effective pressure to carry in the dry air machines. Mr. Balfour had pointed out the causes of corrosion with the condenser coils, which he thought were the brackets for steadying the coils. Unless they increased the surface there was a good deal of vibration in those coils, especially on board ship, which would very soon tend to wear and corrosion. He agreed with Mr. Thom as to the position of the cleats for steadying the coils; these ought to be suspended in such a way that they could expand or contract, so reducing the friction or working in the coils. He did not know much about the CO_2 system of refrigeration. Mr. Farenden had brought forward a point about the pipes being prevented from taking up space by being placed between the beams. With the ordinary depth of beam there was not much space left, when they had from 10 to 12 inches of insulation; the pipes would be still left exposed. With regard to air space at the ship's side, Mr. Price had said that still air was a splendid non-conductor, and an excellent thing to have at the ship's side—that was as an air space behind the insulation. He thought that was practically done away with now, and that as a general rule the insulation material was placed directly in contact with the side of the vessel.

Mr. PRICE: My point was that the air was not still under those conditions; it was circulating.

Mr. SMITH, continuing, said if the air were circulating it was, of course, no advantage—in fact, it was a disadvantage, for it allowed corrosion to take place at the ship's side, especially when there were, as there often were, ventilators going down the side of the vessel. If air could be kept still it was an excellent non-conductor, and would prove an advantage in a tropical climate. On a vessel trading to Australia, and having to stop at Colombo, which was a very hot place, and the vessel not moving for several days, it was often very difficult to keep the temperature down, and necessitated the extra running of the machine. In such an instance, if they had still air between the insulation and the sides of the ship, say 3 in., it would be very beneficial. Mr. Shearer had touched upon the question of the steadying of the condenser coils, and had suggested the introduction of some india-rubber pads. That would be a very good thing, and not very difficult to put in. Mr. Shearer had also spoken of discharging the cold air high up in the hold, and had said that he found a difference of temperature of about 20° in the depth of the hold. He did not say, however, how deep that hold was. In the room in which they were then assembled, he had no doubt they would find a difference in the temperature of 20° between the top and the floor. Refrigerating machines ought always to be placed above the level of the compartments that were insulated, because with the cold air machine the air ought always to be discharged high up. Now, sometimes the machine was placed right under a compartment that was insulated. If they had to make the cold air ascend and the hot air descend, they had extra work, and that reduced the efficiency of the machine to a very great extent. If shipowners and those who constructed refrigerating machinery would take that into consideration, there would be a little saving. He was not prepared to say more that evening, but if Mr. Balfour would just go on the same tack as he had started on that night, and give them a few more practical hints, they would be very useful. Mr. Adamson at last night's discussion mentioned something about the best temperature to carry butter. When they first commenced to export butter from Australia, there was considerable divergence of opinion on that point. I had charge of one of the first trial shipments to this country, and my instructions were that the temperature of the hold was to be from 30° to 34°. I was given to understand that it would spoil butter to freeze it hard. It has, however, been found from experience that such is not the case, and the exporters now ask for it to be kept as low as 20°. It is very convenient on a long voyage to be able to carry frozen milk, but it is never the same quality after it is thawed. During the process of freezing the watery portion is solidified first, which disintegrates the component parts, and when being thawed those parts never assimilate again, the result being simply skimmed milk. It is also a great boon to be able to carry ice cream hard frozen from this country for use in a passenger steamer in the tropics, but it must be kept as cold as possible, otherwise it will lose its flavour.

The CHAIRMAN: I understand we have a visitor from New Zealand. Perhaps he would favour us with some remarks on the discussion.

Mr. JAMES BASIRE (New Zealand) said he did not feel prepared to take part in the discussion, or criticise what he had heard that night, for the simple reason that he had not had sufficient experience in meat carrying. He had certainly been with the dry air machine, and with Hall's, and also with the Linde machine, but only in a small way. He did not, therefore, feel prepared to make any remarks on the subject. He felt very much gratified that he had had an opportunity of visiting the Institute premises with the note of introduction to the Hon. Secretary.

Mr. W. MCLAREN said he thought his experience had gone the length of the remarks that he had made previously. Referring to the experiments that they suggested making with the insulating materials —they could no doubt deal with the atmospheric temperature, but to go below that was their difficulty. So far as he could hear, the trouble with all the different insulations used was the question of moisture. That was the difficulty that would present itself to them. Mr. Shearer was quite correct when he said that they would have a fair trial, but that trial would be on the rise of the atmosphere, and not below it. He might mention that what they had in view was to deal with a body of heated metal enclosed in an air-tight tube. If they could get the ice, then they would be able to go further ahead with those insulations required for refrigeration. He would take that opportunity of remarking that if any member would but lead them into the way of making a start, they would only be too pleased to accept his assistance. As a simple example, he might say that if they were railway travelling and found they had left their rug behind, they could use a newspaper in its place, and they would have the finest insulator that he knew of.

Mr. SHEARER, replying to Mr. McLaren's remarks regarding the insulation experiments, said it was simply a matter of £ s. d. If they could get a small hand refrigerating machine, which was not a very expensive affair, he thought they would manage to carry the whole thing out.

The CHAIRMAN: Before calling upon Mr. Balfour for his reply, has any other gentleman any further remarks to make?

Mr. SHEARER: We have had so many variations of air spacing in insulation. Sometimes the air space was on the ship's side, and at other times half way through the insulation. I have known of a case where the insulation was 14 in. thick.

Mr. BALFOUR: They were experimenting about that time.

Mr. SHEARER: We got good results out of it.

Mr. BALFOUR: I notice that we get more alive to the laws of nature.

Mr. SHEARER: That just shows the resource of the marine engineer. My first experience was that the cold air was delivered too low down. We had to make the reform. We were not indebted to the refrigerating engineer for the advantages made on board ship. It was all due to the marine engineer. They are beginning to think so now, although for some years they have not recognised us. There was an instance. They put in a machine that blew the blast at a low level, which is contrary to nature. They must put the machinery above the work, and allow nature to do the rest. It is the law of gravitation.

The CHAIRMAN: The paper that we have had from Mr. Balfour is one of the most valuable and practical ones that has come before this Institute. When this paper comes to be printed in the "Transactions," and is in the hands of some of our sea-going members, they will feel there is some substantial advantage in sea-going engineers belong-to this Institute.

Mr. A. O. WALKER (Member), referring to Mr. Shearer's suggestion that indiarubber pads might be inserted between the pipes, said that when Mr. Newall read his paper on the uses of indiarubber, he told them that indiarubber lost its elasticity at a temperature of 40°. How would that effect the use of indiarubber? Again, with regard to electrically-welded supports for the pipes, such supports did not involve making the pipes hard-and-fast fixtures.

Mr. BALFOUR: What temperature did you mention?

Mr. WALKER: 40°. Continuing, he thought that, provided no damage was done to the pipes by the electric welding of the supports, it was a very good way.

Mr. BALFOUR then replied to the various questions that had been raised. Mr. Thom, he said, had referred to explosions in the air compression cylinders and had supported his theory in regard to them, viz., that such explosions were due to the ignition of the gases in the air compression cylinder valve casings. He agreed with Mr. Thom that the most trying conditions for refrigerating machines were when they were cooling down holds, starting with a temperature of, say, 90° F. A question was raised regarding the cause of fires which have occurred in vessels fitted with insulation, and it was thought that these might have been caused by charcoal through spontaneous combustion. It appears, however, that it is only in the case of freshly made charcoal which has not been properly cooled that there is any possibility of spontaneous combustion. In all cases, if ignition or heating does not occur within eight or ten days of making the charcoal, there will be no further risk of this nature. In the case of flake charcoal, which is mostly employed on board ship, a less time for cooling is sufficient, owing to the small size of the flakes. In his experience he had never yet found any direct evidence to show that fires had occurred on board ship through spontaneous combustion in the charcoal insulation. Where fires have occurred they have been found to have been due to extraneous circumstances, such as short circuiting of electric cables, naked lights left in too close proximity to the match-board linings, compressed jute or wool put on board in such a condition that renders them liable to spontaneous combustion, and for other reasons which have been brought to light by investigation. Mr. Farenden had referred to the lodging of the brine pipes between the deck beams, where the latter were only 8 in. deep. He would not say that that was the every-day practice, but in large vessels where the beams were about 12 in. deep it had certainly saved a considerable amount of cargo space. Mr. Farenden had also said that 11 in. of charcoal was necessary. He would like to know who was the expert who first introduced that quantity. He was inclined to think that it was merely the exigencies of the construction of the ship which demanded that amount of insulating material to be fitted. The innermost edges of the frames and beams were the most important points requiring insulation. These, he thought, did not get sufficient attention. The subject of insulation was one that would involve a paper of great proportions, and they could not do justice to it by only nibbling at it. In fruit carrying by either system there was undoubtedly a great deal of space taken up. Mr. Flood had referred to electric welding of piping. That system of welding had enabled the engineer to overcome the trouble of innumerable joints that were only approachable by tongs. These screwed joints had been the cause of much anxiety when the ship was full of cargo. If anything went wrong in any of the brine circuits the engineer was only guided in locating the trouble by the return volume of brine. Mr. Shearer had asked whether he (Mr. Balfour) would recommend the ammonia or the CO_2 system. He would only say that the ammonia compression system was probably the most efficient, whilst the CO_2 was the safer. The next speaker was Mr. Price, and Mr. Balfour thought that their thanks were due to him for the research he had made in connection with this subject. Mr. Balfour agreed with Mr. Price that air was the cause of a good deal of the corrosion which takes place in condensers, etc. Mr. Smith had spoken of still air as being a good insulator. That is so, but the air space at the ship's side could not be considered to be still air. The best insulator is a material which holds air in minute cells within itself. With such an insulator, circulation of air by connection currents is prevented. Mr. Shearer gave an account of his experiences during the early stages of refrigeration on board ship. During this period he evidently was a victim of experiments, yet with his resource he was able to surmount the difficulties without the aid of the expert manufacturer. Mr. Balfour said that Mr. Maclaren had referred to a most important question in his remarks about the suggested testing of insulating material. They had done a good deal in the way of fuel testing, and he would advise that they now take up the testing of insulating material, but this would require financial support. In conclusion, he wished to thank them for the interest they had taken in the discussion.

Mr. J. R. RUTHVEN proposed that a very hearty vote of thanks be accorded to Mr. Balfour for his excellent paper and for the still more valuable additions that he had made to it at the three meetings they had had. They were greatly indebted to him for his kindness in coming down to Stratford and continuing the discussion so ably. He did not know how they would have done without him in carrying on the discussion. The subject was of vital importance to the people of this little island, who must depend a great deal on their food supplies from abroad. If the marine engineer did nothing else than bring them their food supplies from the other side of the world, he thought he was entitled to all our thanks.

Mr. SHEARER seconded the proposition, which was carried unanimously.

Mr. BALFOUR having acknowledged the vote,

The CHAIRMAN announced that on Monday, November 23, the President would deliver his presidential address at the London Institute, Finsbury Circus, E.C. On that evening Mr. K. C. Bales would also read a paper on "Grinding Machinery and Abrasive Wheels."

A vote of thanks to the Chairman for presiding brought the meeting to a close.