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Notes on Steam Jet Refrigeration for Marine Purposes.

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Chairman: J. A. RHYNAS (Chairman of Council).

Synopsis.

There is a likelihood that many engineers will come into contact with steam jet refrigeration plants on board ship, particularly in view of the more general adoption of air conditioning and extension of the refrigeration field in cargo ships. This paper has been written in the hope that it will be of value to marine engineers. The scope of the paper consists of a discussion on the field of application for steam jet refrigeration; notes on the principles and design; notes on nozzle design; operating characteristics; components of typical plants; remarks on efficiency; notes on the use of available low-grade heat for use in refrigeration; applications on board ship; air conditioning; liquid CO_2 cooling; salt-water evaporation, etc.; various combinations; and, finally, possible future trends.

General.

Although the principles of steam jet refrigeration are well known, and cooling by this means is a very old device, it is only in recent years that it has been found to have applications on board ship.

In the industrial field, such as chemical plants, food process plants, the mining industry, breweries, etc., cooling by this means is widely known, and it is this field of application that has been responsible for the constant improvement in technique and design. This paper, however, will be confined solely to the description and application of steam jet refrigeration for marine use.

Naturally few marine engineers are acquainted with steam jet refrigeration apparatus in the same way as they are trained to understand and operate other marine machinery. The paper will, therefore, describe the principles of design, illustrate the various components of steam jet refrigeration plant and show some marine examples, giving at the same time some data on steam consumptions at various pressures, and the effect of vacuum, etc.

The term "refrigeration" covers cooling or freezing, and it should at once be stated that the field for steam jet refrigeration is mainly in the cooling range, for although there have been plants built and operated at temperatures well below the freezing point, using brine as the heat-carrying medium, these plants are designed as series jet machines and are of a very low efficiency.

Confining steam jet refrigeration units to the cooling field means that fresh water can be the heat carrier; this brings in train many advantages.

It will be realized, however, that to cool from atmospheric temperatures down to freezing temperatures there is a big heat load to be handled, and because of the advantages of single-stage jet refrigeration over other forms of refrigeration in its own field, it is becoming more and more recognized.

Principles and Design.

The principles are very simple and while fairly elementary they might be stated shortly as an opening to more detailed description.

If the heat-carrying medium, say water, is introduced into a chamber which is maintained at a low absolute pressure (high vacuum) this water will boil. The latent heat required for evaporation of part of this water comes, of course, from the total mass of water, resulting in a lowering of the sensible heat of the mass with a corresponding drop in temperature of the total mass.

The required vacuum is obtained by means of a thermo-compressor (steam jet) which draws the vapour from the chamber, usually called the flash chamber. The vapour is compressed to a condenser where a vacuum is maintained, corresponding to the temperature of the available sea water, and thus the heat brought in by the water to the flash chamber is thrown overboard in the condenser discharge.

In the ordinary course of their training and work marine engineers seldom have to study the properties of steam at pressures

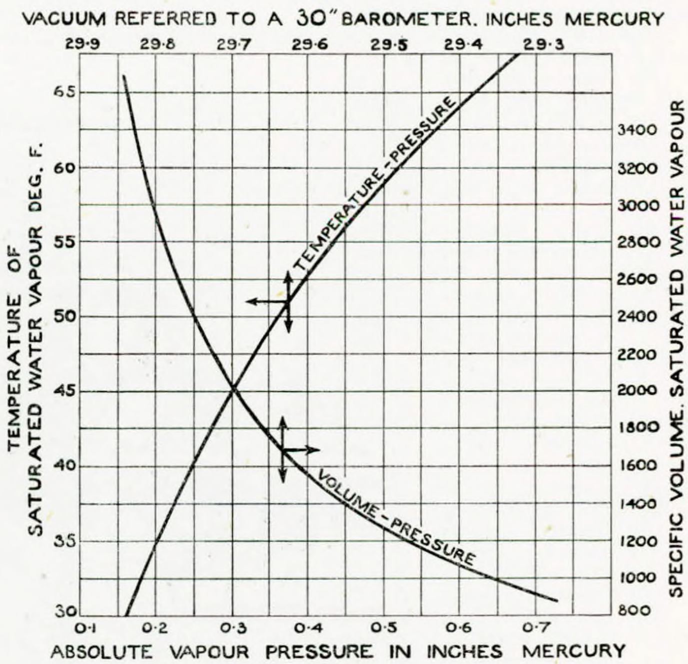

FIG. 1.—*Steam properties at high vacuum.*

lower than say 29in. vacuum, so it will be useful to refer to Fig. 1, which is a graph based on the extension of the steam table for vacua between 29in. and 30in. mercury. This brings out clearly the corresponding evaporation temperatures and the steam volumes over this range of pressure.

It will be seen that if a vacuum of say 29·79in. is maintained in the flash chamber the heat-carrying water entering the chamber can

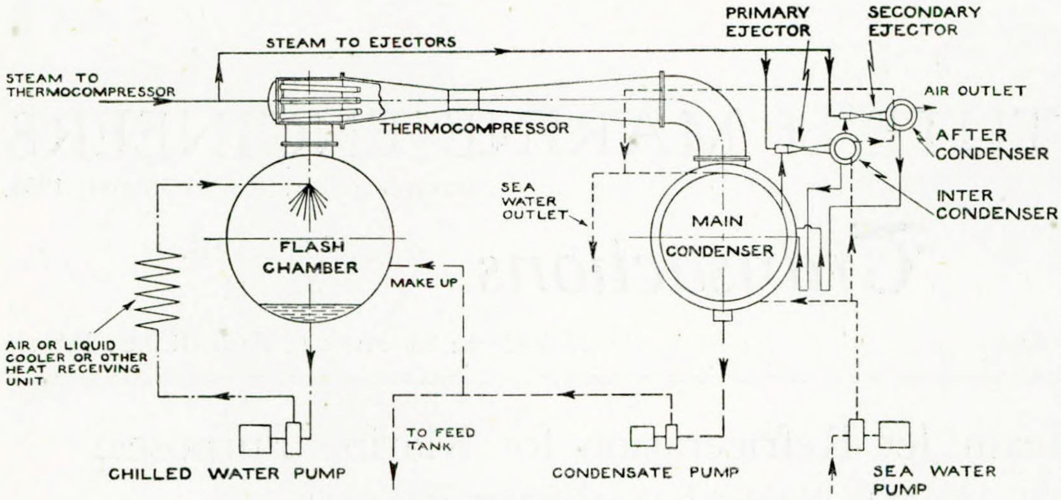

FIG. 2.—*Typical diagram of steam jet refrigeration plant.*

be cooled to 36° F. *i.e.* the temperature of evaporation at that vacuum.

A typical quantitative example is as follows :—

1lb. of water is to be cooled from an inlet temperature of 55° to 45° F., *i.e.* to abstract 10 B.T.U.'s/lb. The required vacuum for vaporization at 45° F. = 29·7in. Hg. Latent heat of vaporization at this pressure is 1,068·4 B.T.U.'s. Heat absorbed in converting fraction of water W to steam

$$= (1{,}068{\cdot}4 - 10)\ W$$

Heat given up by remaining water = $(1 - W) \times (55 - 45)$.

Thus : $(1{,}068{\cdot}4 - 10)W = (1 - W)10$

$$W = 0{\cdot}00938.$$

This shows that rather less than 1 per cent. of the water must be flashed into steam to cool the remainder by 10° F.

Before leaving Fig. 1, note should be taken of the high volume figures for steam at these low pressures, and it is the handling of this rarified vapour that becomes the main factor in the design of steam jet thermo-compressors.

Fig. 2 is a diagram of the main essentials of a steam jet plant, the components of which are :—

(1) Vacuum chamber called the flash chamber.
(2) Thermo-compressor.
(3) Condenser, with air ejectors.
(4) Pumps circulating chilled water to the heat receiving apparatus, where heat is taken up by the chilled water and taken down to the refrigerator. These heat receiving plants may be air coolers, as in air conditioning plants, water coolers, liquid CO_2 coolers, etc.
(5) Condensate pump returning condensed steam to the feed system.

Fig. 3 is an isometric illustration of a typical plant of about one million B.T.U.'s/hr. capacity.

The construction of these components is so standard and simple that only a short description is necessary.

The flash chamber is merely a mild-steel welded vessel into which the warm water is sprayed. Vapour is drawn off the upper half of the chamber by the steam jet thermo-compressors. Where more than one thermo-compressor is used the flash chamber is divided into pressure-tight compartments, one for each thermo-compressor. This enables one thermo-compressor to be shut down, without vapour blowing back from the condenser, by merely shutting the appropriate steam valve. The water level is carried near the bottom of the flash chamber, as most of the evaporation takes place from the surface of the sprays of warm water. This means that, in the case of multiple compressor plants, the chilled water pipes from the compartments should be separate and long enough to allow for depression of the water in the leg from a compartment which is at condenser pressure. Fig. 4 makes this point clear.

The thermo-compressors, Fig. 5, have one or more high-velocity steam jets expanding the actuating steam to flash chamber vacuum. These jets entrain and accelerate the refrigerant vapour from the flash chamber in a convergent tube. The mixture of steam and vapour is projected through a parallel throat section, and then is decelerated in a divergent section where the velocity energy of the mixture is converted into pressure energy.

The vapour head may be of cast or fabricated construction. The combining tube is usually of cast construction in iron or bronze, and the steam chest is of cast-iron, bronze or steel, depending on the steam conditions. The condenser is of the surface type, and is standard marine design. The steam jet air pump and the centrifugal pumps are all standard equipment.

Operating Characteristics.

The characteristics of the plant as regards operation are governed much more by the thermo-compressors than by any other item, and

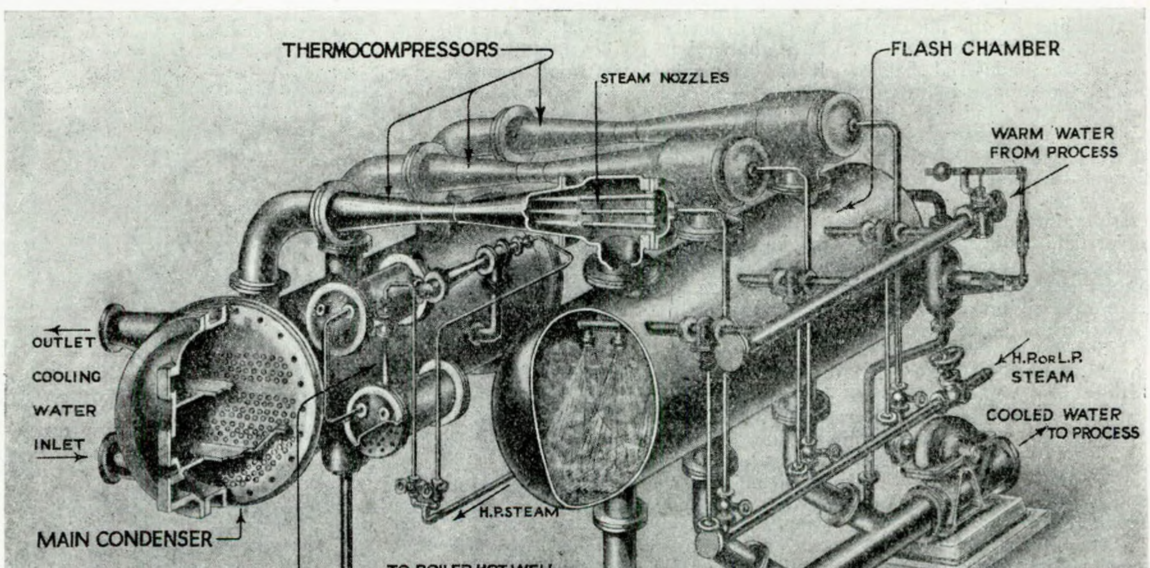

FIG. 3.—*Isometric illustration of steam jet refrigeration plant*

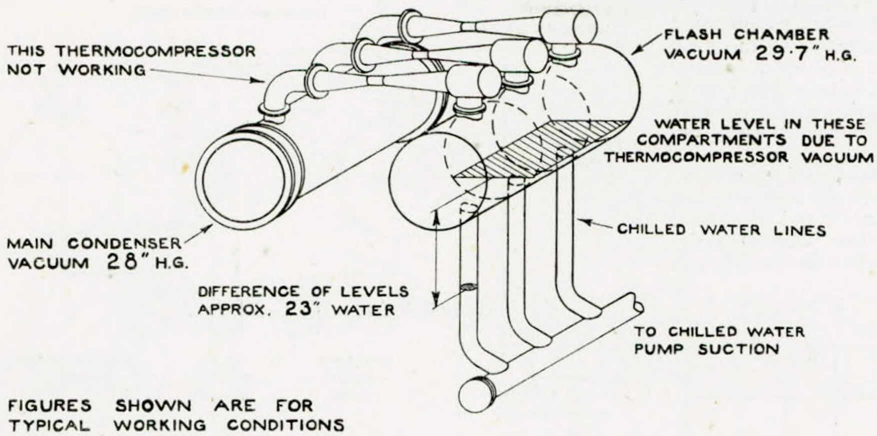

FIG. 4.—*Difference of water levels when one thermo-compressor is shut off.*

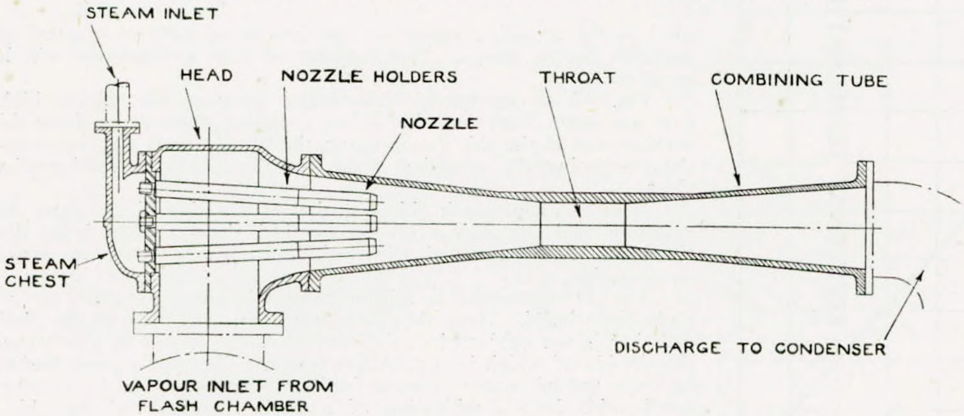

FIG. 5.—*Sectional view of thermo-compressor.*

therefore the performance of the thermo-compressor will be considered.

In a thermo-compressor the size of the parallel throat is the factor that governs the performance more than any other part. This throat acts like a non-return valve preventing flow from the condenser to the flash chamber, but permitting flow in the opposite direction. The non-return effect is only existent if the throat is filled with vapour travelling at the required velocity. Therefore, the volume and speed of mixture flowing through the throat must approximate to the design figure to maintain stability. If this condition is not fulfilled, vapour will flow from the condenser to the flash chamber, and compression will cease.

This criterion leads to several important features in operation. For a given thermo-compressor designed for given conditions :—

(1) The amount of vapour the compressor will handle is approximately independent of steam pressure and condenser pressure, provided that the stability of the jet can be maintained. The best results are obtained when the volume passing through the throat is nearest to the design figure, *i.e.* a low condenser pressure requires a low steam pressure.

(2) The amount of vapour the thermo-compressor will handle is dependent on the suction pressure.

(3) The absolute steam pressure at the nozzles required to maintain stability is proportional to the absolute pressure in the condenser. This is fairly obvious as the volume per lb. of the mixture at the throat is proportional to absolute condenser pressure, and the lbs. of mixture passing are approximately proportional to the absolute steam pressure at the steam nozzles.

The above remarks cover the performance of a thermo-compressor designed for a given set of conditions. To appreciate how the designed steam consumption of a thermo-compressor varies, it is best to consider the thermodynamics of the design. Steam is being expanded through a nozzle, and heat is being converted into velocity. The velocity attained by the steam depends on the available adiabatic heat drop between steam conditions and flash chamber vacuum. This steam

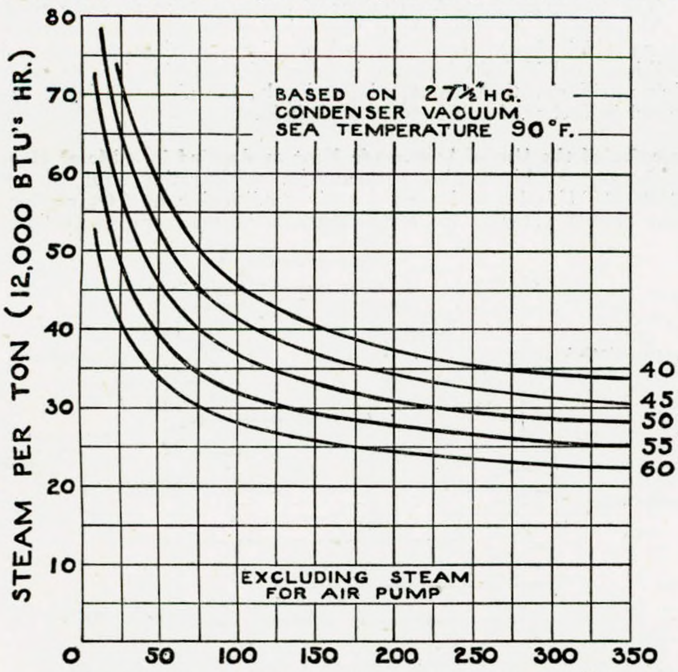

FIG. 6.—*Steam consumption per ton of refrigeration.*

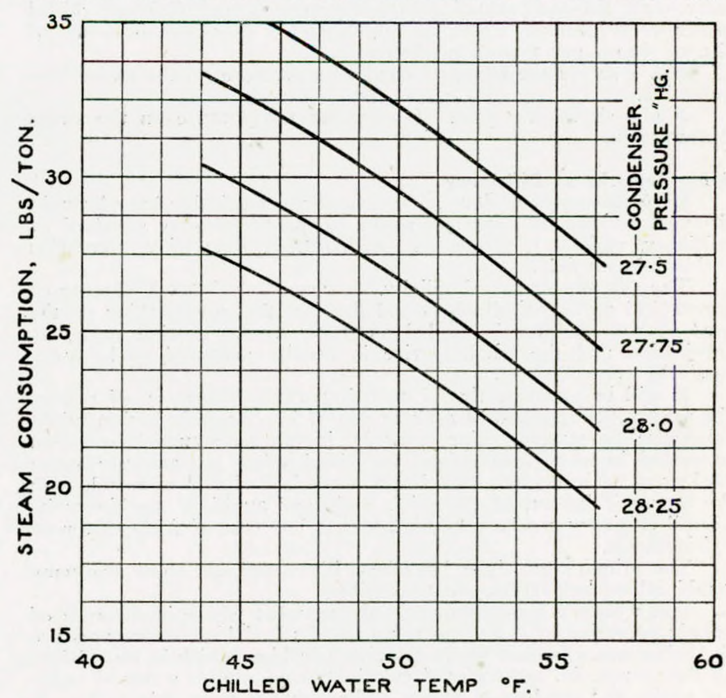

FIG. 7.—*The effect of condenser pressure on the steam consumption*

entrains the vapour, and is compressed to the condenser pressure. The velocity the mixture must attain to give the necessary compression is again dependent on the heat drop from the condenser to the flash chamber. Therefore, the ratio of actuating steam required to vapour compressed depends on the velocity of the steam after expanding to flash chamber vacuum as compared with the velocity of the mixture needed to give the necessary compression ratio. These velocities depend in each case on the adiabatic heat drop.

Thus, it will be seen that the ratio of steam used to vapour compressed decreases with increase in the steam pressure, and with decrease in compression ratio between the flash chamber and condenser.

The following illustrations bring out the salient characteristics of the steam jet plant. Fig. 6 shows how the steam consumption will

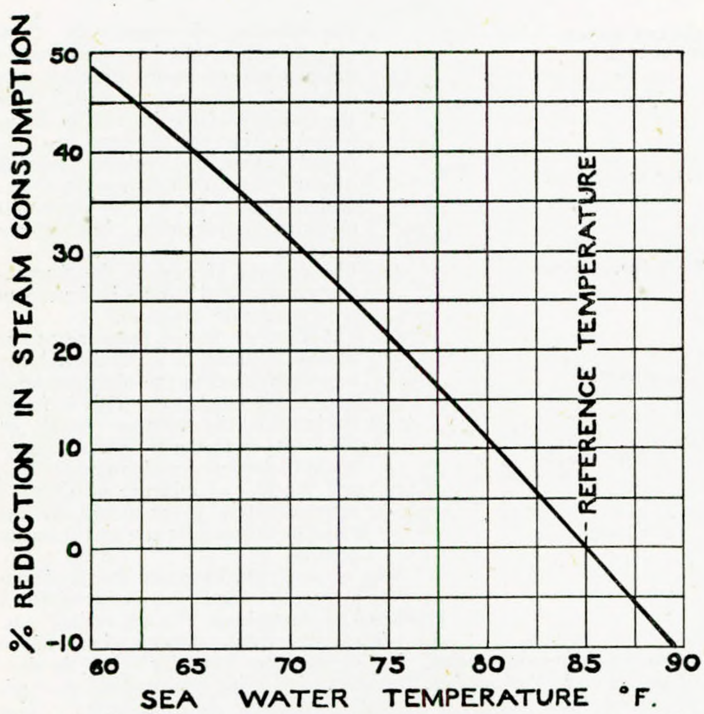

FIG. 8.—*The effect of sea-water temperature on the steam consumption.*

vary with different actuating steam pressures and different chilled water temperatures. These consumptions are expressed in terms of lbs. of steam per ton of refrigeration.

Fig. 7 shows the effect of condenser pressure on the steam consumption.

Fig. 8 shows the effect of sea-water temperature on the steam consumption.

Some Remarks on Efficiency.

Long research and development in steam jet design have brought the performance of steam jet plants to the present-day standard of efficiency, making it competitive with other forms of refrigeration within its own field.

The advantages are simplicity, as steam only is used, absence of mechanical parts, noiselessness and the fact that no attention on the part of the operator is needed as there are no moving parts, no lubrication and the whole device is usually arranged to be automatically controlled.

It will be apparent that a most important feature is, of course, the availability it offers of making use of low grade heat that might otherwise be wasted. For example, it can be actuated by steam generated in waste-heat boilers on Diesel ships, low-pressure steam bled from main engines, and if the plant is designed to match with the economic lay-out of the ship's main and auxiliary machinery its overall efficiency can be very high with a low cost of fuel per ton of refrigeration.

The primary principles have been illustrated, but there are many combinations and arrangements possible.

Fig. 9 shows a diagrammatic arrangement where in the case of vessels operating at the present-day standard of high steam pressure the boiler steam is used firstly to drive a turbine, which in turn drives all the pumps, *i.e.* sea-water circulating pump, chilled-water circulating pump and condensate pump. The exhaust from this turbine is

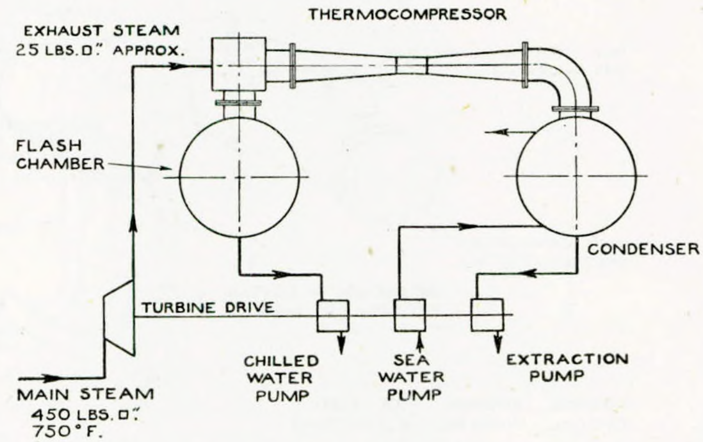

FIG. 9.—*Lay-out with steam turbine exhausting to thermo-compressor.*

used as the actuating steam for the jets at an exhaust pressure of say 25lb./sq. in. gauge. The economy of this arrangement will be apparent.

Fig. 10 shows another alternative arrangement where high-pressure steam from the boiler drives a turbine; the exhaust from this turbine goes to the ship's evaporator, the vapour from the evaporator then becoming the actuating steam for the steam jet refrigeration plant.

It will be apparent in this case that evaporation of sea water for make-up feed purposes is very economical, the sea water being distilled into fresh water and doing refrigerating duty in the process of condensation.

Fig. 11 represents a scheme using the flash chamber as an evaporator itself. Here the fresh water carrying heat to the flash chamber is not subjected to the vacuum but is cooled in a coil over the outside of which is sprayed sea water. Thus the vapour flashed off from the salt water becomes fresh-water make-up feed. In other words, this is a combination of a flash chamber and the ship's evaporator in one unit.

It will be seen that a plant put in for steam jet refrigeration can, in this case, be made to do the duty at present done by separate evaporators and condensers. There are many other combinations; for instance the condenser section of the apparatus can, of course, be the ship's auxiliary condenser receiving other steam exhausts and drains, etc. as in usual steam practice.

The foregoing short descriptions of various alternatives are given to show that, by its very nature, steam jet refrigeration is essentially a plant which should always be designed for a particular vessel and conditions, and if full advantage is taken of combining it with other ship's auxiliaries then, as stated previously, the all-in efficiency expressed in fuel used can be very high indeed.

Examples of the Use of Low-grade Heat as Applied in a Motor Ship.

Assume a ship having a steam jet refrigerating load of say 600,000 B.T.U.'s/hr. and used for air conditioning or CO_2 cooling, where chilled water of 40° temperature is the refrigerating medium.

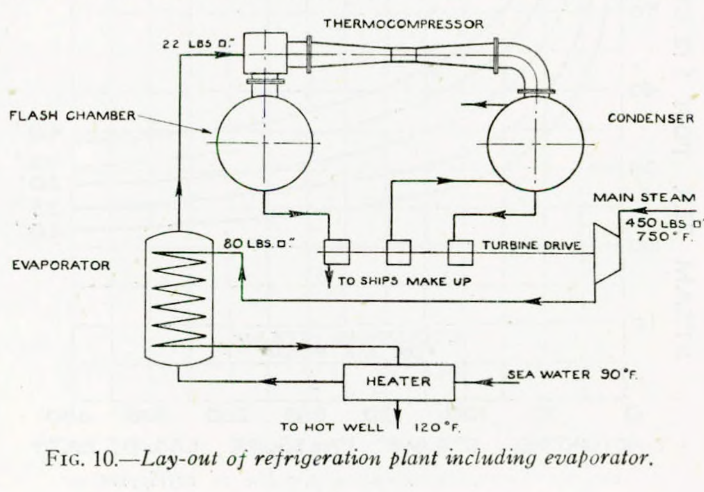

FIG. 10.—*Lay-out of refrigeration plant including evaporator.*

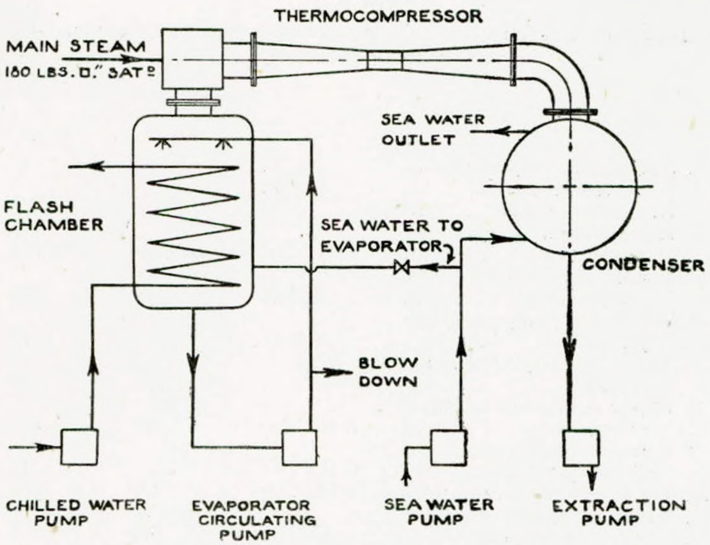

FIG. 11.—*Lay-out using flash chamber as evaporator.*

A steam jet refrigeration plant for this purpose, using low-pressure steam at, say, 60lb. pressure saturated would require :—

$$50 \times 54 \cdot 5 = 2{,}725\text{lb. of steam.}$$

As the saturation temperature of steam at 60lb. $= 307 \cdot 6°$ F., then waste heat gas from the Diesel-engine exhaust, being cooled in a low-pressure waste-heat boiler to 375° F. can be used for the generation of steam.

Heat to be added from water of 80° F. to steam at 60lb. pressure $= 1{,}133 \cdot 9$ B.T.U.'s/lb.

Weight of gas cooled by generation of 2,725lb. of steam

$$= \frac{2{,}725 \times 1{,}133 \cdot 9}{(700\text{-}375) \times 0 \cdot 25} = 38{,}000\text{lb./hr.}$$

This corresponds roughly to the weight of exhaust gas from a 2,500 b.h.p. Diesel engine, so that in such a case there would be no direct fuel cost for the refrigeration duty.

NOTE.—It will be seen that in most motor ships there is ample heat in the exhaust gases for conversion to refrigerating duty.

Application of the Use of Low-grade Heat in a Modern Steamer.

With steam at 450lb. pressure 750° F. for the main engines, and arranged to bleed steam from the turbines at 60lb. pressure for the same refrigerating duty as in the case of the above example for a motor ship, *i.e.* a refrigerating capacity of 50 tons or 600,000 B.T.U.'s/hr.

Actual available heat drop per lb. of steam going through turbine to condenser at 28½in. vacuum = 372 B.T.U.'s/lb.

Actual heat drop per lb. of steam going through turbine to the bled steam point at 60lb. pressure = 147 B.T.U.'s.

Taking the same h.p. as in the motor-ship example, *i.e.* 2,500 h.p., and letting A be steam going through the condenser, then : $372\ A$ plus $147\ (2{,}725) = 2{,}500 \times 2{,}545$.

$$\therefore A = 16{,}000\text{lb.}$$

Total steam to turbine $= 16{,}000 + 2{,}725 = 18{,}725$lb.

If steam was not bled from the turbines the steam consumption would be :—

$$\frac{2{,}500 \times 2{,}545}{372} = 17{,}100\text{lb.}$$

so that only $(18{,}725 - 17{,}100)$ *i.e.* 1,625lb. of steam have to be generated in the boiler to give the same h.p. and this permits of 2,725lb. of steam being bled off for refrigerating duty. Thus, direct fuel cost of refrigeration

$$= \frac{1{,}625 \times 1{,}122}{18{,}500 \times 0 \cdot 88} = 112\text{lb. of fuel per hr., or}$$

$2 \cdot 24$lb. of fuel per ton of refrigeration.

NOTE.—It will be seen that this represents a very high thermal efficiency.

ACTUAL USES AND SOME INSTALLATIONS ON BOARD SHIP.

For Air Conditioning.

As is well known, there is a growing trend towards greater use of air conditioning for passenger and crew accommodation in ships, and in the field of hold ventilation. It is not, however, within the scope of this paper to discuss air conditioning as such, but only to describe the part played by steam jet refrigeration.

This system serves particularly well as the means of refrigeration in air-conditioning schemes by supplying chilled water to air-conditioning units in various parts of the ships. These units may be arrangements of surface air coolers or spray-type washers for dehumidifying and cooling the volumes of air necessary for air conditioning.

The steam jet refrigeration plant can usually be fitted into the machinery space of a ship, the chilled water being pumped through insulated cold water mains to the various air conditioning units, with a return main of heated water coming back to the refrigerating plant.

The optimum system involves large quantities of water cooled through a small range, say from 7° to 10°, and up to the present time the size of plants ranges between a capacity of 250,000 B.T.U.'s per hour to 2,000,000 B.T.U.'s per hour, or expressed in terms of refrigerating units approximately 21 tons to 160 tons of ice per day. But plants of 10,000,000 B.T.U.'s capacity have been built and are postulated for marine use as being practicable units in terms of low first cost, space occupied, etc. In fact, it is in the larger-sized units that the advantages over other forms of refrigeration are most apparent. Among the earlier ships fitted with steam jet refrigeration were the liners *Queen Mary* and *Empress of Britain*, and it has since been applied for air conditioning purposes in H.M. ships.

Wherever fitted it has found favour because of its simplicity and the fact that refrigeration is always possible as long as there is steam available.

In collaboration with the air-conditioning engineers, the whole air-conditioning system and the refrigeration system are made completely automatic and self-regulating. For instance, the temperature of the chilled water is controlled within plus or minus 1·5° F. over widely-varying air-conditioning loads by simple thermostatic governors regulating the steam to the thermo-compressors.

There is at present an installation being installed of 370,000 B.T.U.'s capacity in conjunction with the air conditioning of all living quarters in a tanker. Here advantage has been taken of the features of the steam jet refrigeration plant to use the same equipment for delivering heated water to the air conditioning units by the fitting of a calorifier in the water main, thus using the same units for winter heating. Advantage has also been taken to fit drinking-water coolers at various points, using the chilled water from the refrigerating plant as a coolant. Fig. 12 shows a typical arrangement of a steam jet refrigeration set fitted in conjunction with air conditioning units.

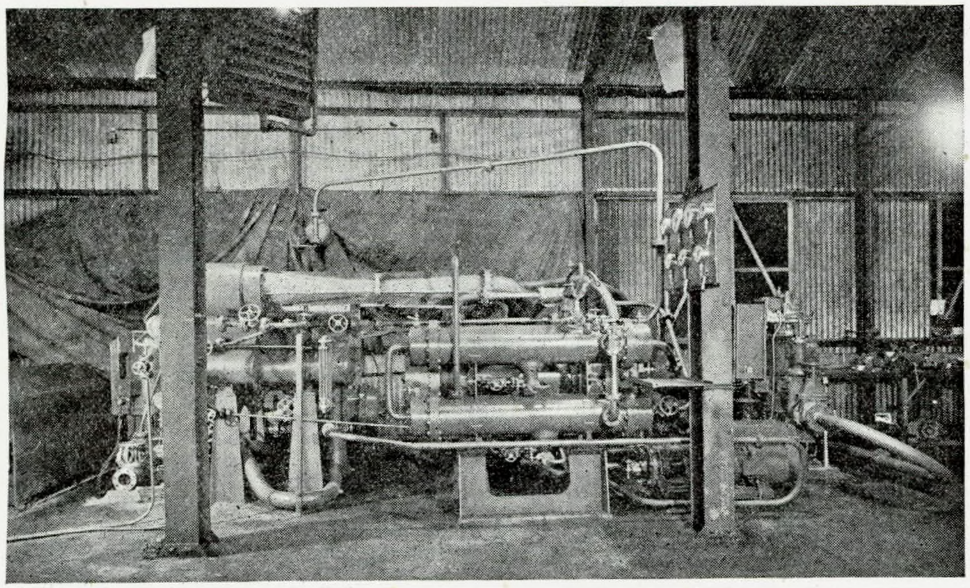

FIG. 12.—*Arrangement of 500,000 B.T.U. set on test.*

Steam Jet Refrigeration in Combination with CO_2 Refrigeration.

A recent development in the use of steam jet refrigeration has been its adoption as a component part of a freezing refrigeration scheme in large refrigerated steamers.

In the system evolved by Mr. John Wheadon, chief superintendent engineer and naval architect of the Royal Mail Lines, two ships, the s.s. *Drina* and *Durango,* were fitted with a combined CO_2 and steam jet refrigeration plant. The principle of this system is the cooling of the liquid CO_2 in the flash chambers of steam jet refrigeration plants. Fig. 13 is a diagram of this combination. In this arrangement the liquid CO_2 circulates through coils in the flash chamber of the steam jet plant where it is cooled to 38° F.

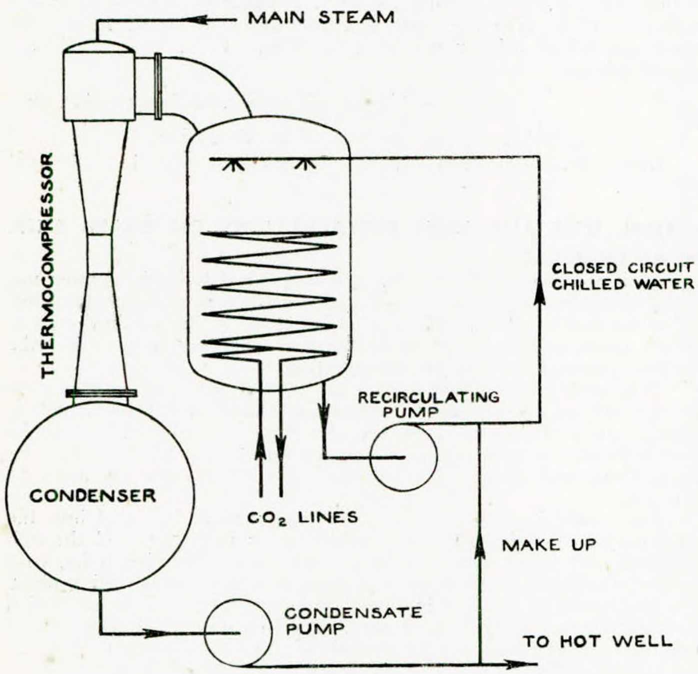

FIG. 13.—*Lay-out of plant for CO_2 cooling.*

Table I shows the characteristics of a straight CO_2 installation compared with a combined CO_2 and steam jet refrigerating plant.

It will be seen from Fig. 14, which shows the cycle on the Mollier diagram for CO_2, that the additional cooling is represented by the extension of line *A, B* to *E* and the additional refrigeration done by the brine as shown to be from *F* to *C* on the line *C, D.*

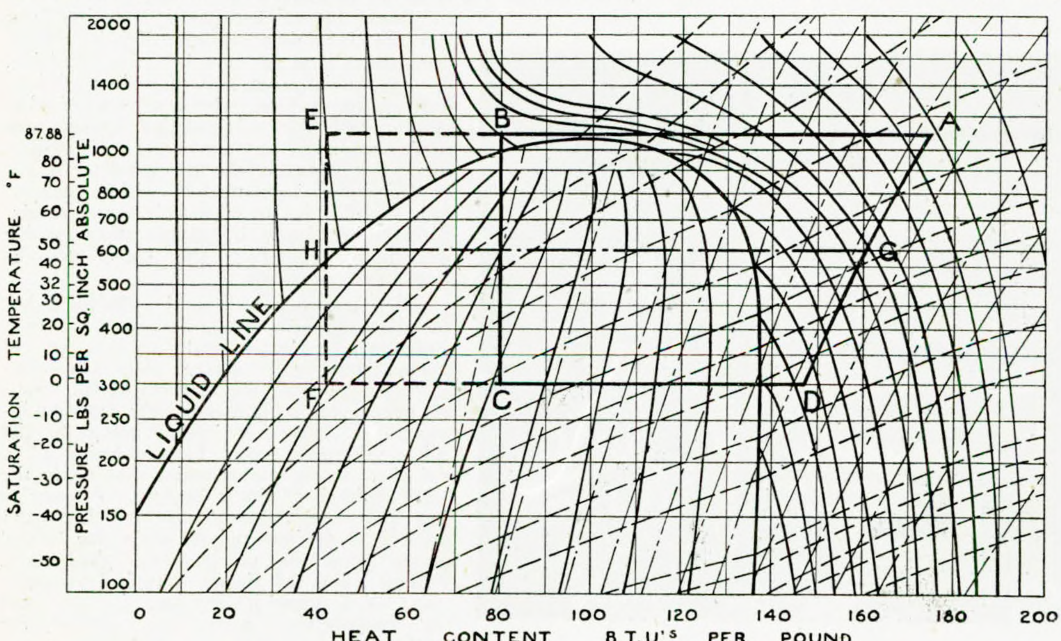

FIG. 14.—*Mollier diagram for carbon dioxide.*

TABLE I.

COMPARISON OF A STRAIGHT CO_2 INSTALLATION WITH A COMBINED CO_2 AND STEAM JET PLANT.

		Straight CO_2 Plant.	CO_2 with Steam Jet Plant.
1. Sea water temperature ...	°F.	85	85
2. Brine temperature	°F.	5	5
3. Evaporator gauge	°F.	0	0
4. Refrigeration output per compressor	B.T.U. hr.	610,000	700,000
5. Motors installed for three compressors	B.H.P.	555	390
6 Motors for pumps in steam jet plant	B.H.P.	—	24
7. Total motor B.H.P. installed		555	414
8. Power consumption three compressors	B.H.P. hr.	435	315
9. Power consumption of steam jet pumps ...	B.H.P. hr.	—	12
10. Total power consumption	B.H.P. hr.	435	327
11. Average motor efficiency	%	88	88
12. Power consumption ...	Kw. hr.	370	278
13. Saving in motor power installed	B.H.P.	—	141
14. Saving in power consumption	Kw. hr.	—	92
15. Refrigeration output per B.H.P. installed ...	B.T.U. hr.	3,297	5,385
16. Increase in output per B.H.P. installed due to steam jet cooling ...	%	—	63·3

In these first two ships no attempt was made to change the normal pressure and temperature cycle and the CO_2 condensation was effected in the ordinary CO_2 condensers; only the further cooling took place in the steam jet refrigerating plant.

It will be apparent that if both condensation and cooling are done at the lower temperatures of the steam jet refrigerating plant instead of condensation at sea temperatures and cooling only at the low temperature, then compression need not exceed 600lb. per sq. inch (line *G, H*) as compared with 1,100lb. per sq. inch, and the power required for the CO_2 refrigeration apparatus would be approximately one-third of the normal CO_2 installation with sea-water condensation and cooling.

Against this, of course, there would be the increased steam consumption of the steam jet refrigeration plant because of the extra work it has to do, *i.e.* condensation as well as cooling, but if, as shown previously, this refrigeration can be done by the use of low-grade waste heat then the whole combination would be very efficient indeed.

One of the most important features of this new combination arrangement is that the refrigerating capacity of the machines is independent of sea-water temperature, for under all sea temperature conditions a constant CO_2 temperature is maintained at 38°.

Both the above applications bring out the possibility of adding to the capacity of the refrigerating units in existing ships without having to budget for additional electric power and additional CO_2 machinery, and it is an ideal method of boosting up or adding to a ship's refrigerating capacity.

Fig. 15 shows the general arrangement of the steam jet refrigeration plant on the Royal Mail *Loch* ships, following the satisfactory installation in the s.s. *Drina* and *Durango.*

Evaporation of Sea Water for Ship's Purposes.

It will be apparent that another use that can be made of steam jet refrigeration is the evaporation of sea water at low temperatures well below the scaling point.

It has been shown previously that salt water can be introduced into the flash chamber and serve as the refrigerant, and the vapour from such would, of course, be make-up feed. This principle can be extended and the plant designed to handle large quantities of evaporated sea water for ship's general purposes, and various combinations are possible. A typical one may now be described.

Combination Plants.

Assuming a modern ship had an air-conditioning load, a liquid CO_2 cooling load and an evaporator load, then a very simple and economical combination can be made on the lines of the arrangement shown in Fig. 16.

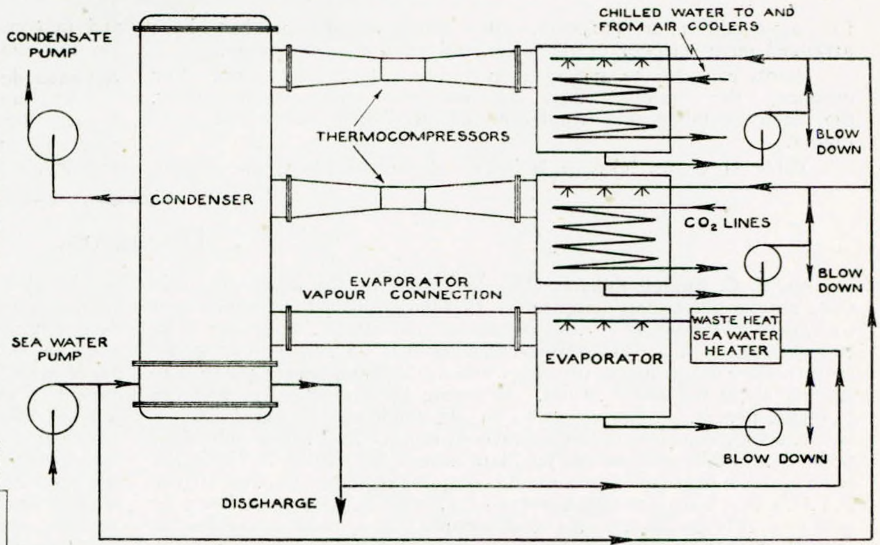

FIG. 16.—*Diagram of combination plant for air conditioning, CO_2 cooling and evaporating.*

Here it will be seen that there is a flash chamber divided into three parts. In one section salt water has been cooled and partially vaporized, which in turn cools fresh water which is the refrigerant for the air-conditioning load. In another chamber salt water has been cooled and vaporized and in turn cools liquid CO_2 as previously described. Each of these two chambers would, of course, have their independent thermo-compressor. These would compress to the condenser in which there would be carried a vacuum corresponding to the sea temperature, which with a sea temperature of say 85° F. would be 28·0in. The third section of the flash chamber would be made common with the condenser through a pipe duct. Therefore the vacuum in the third section of the flash chamber would be also 28in., *i.e.* approximately 100° F. Into this chamber the necessary salt water to be evaporated would flow through sprays at an entering temperature of, say, 150° F., the quantities and the amount evaporated being such as to satisfy the fresh-water requirements of the vessel.

This system offers a means of using to advantage any hot salt water available for running into this evaporator section of the flash chamber, in which case the fuel cost of evaporating the salt water would be nil.

Space Occupied.

It has been mentioned previously in this paper that steam jet refrigeration plant is essentially a plant designed for specific conditions if full advantage is to be taken of it, and this applies very particularly in regard to the question of space occupied, weight, etc. As this equipment is a combination of independent components it can be arranged in very many forms. In one large ship, the *Empress of Britain,* the whole plant, which was one million B.T.U.'s in capacity, was housed in the tunnel space packed between the spare tail shafts in a low deck height, and each component part was so arranged that it could be passed through a standard water-tight door. In other ships, particularly H.M. ships, the plants have been of extremely light weight, and so made that each part could be passed through armoured hatches. All have been arranged with the condensers, flash chambers, etc., in various relative positions, sometimes well spread, sometimes at different angles according to the floor space available and the deck heights.

In two ships now building the vacuum refrigeration plants will be spaced adjacent to the boilers and arranged vertically between the boilers and the ship's side, occupying very little width and length, but greater height. In an installation now being fitted in a tanker

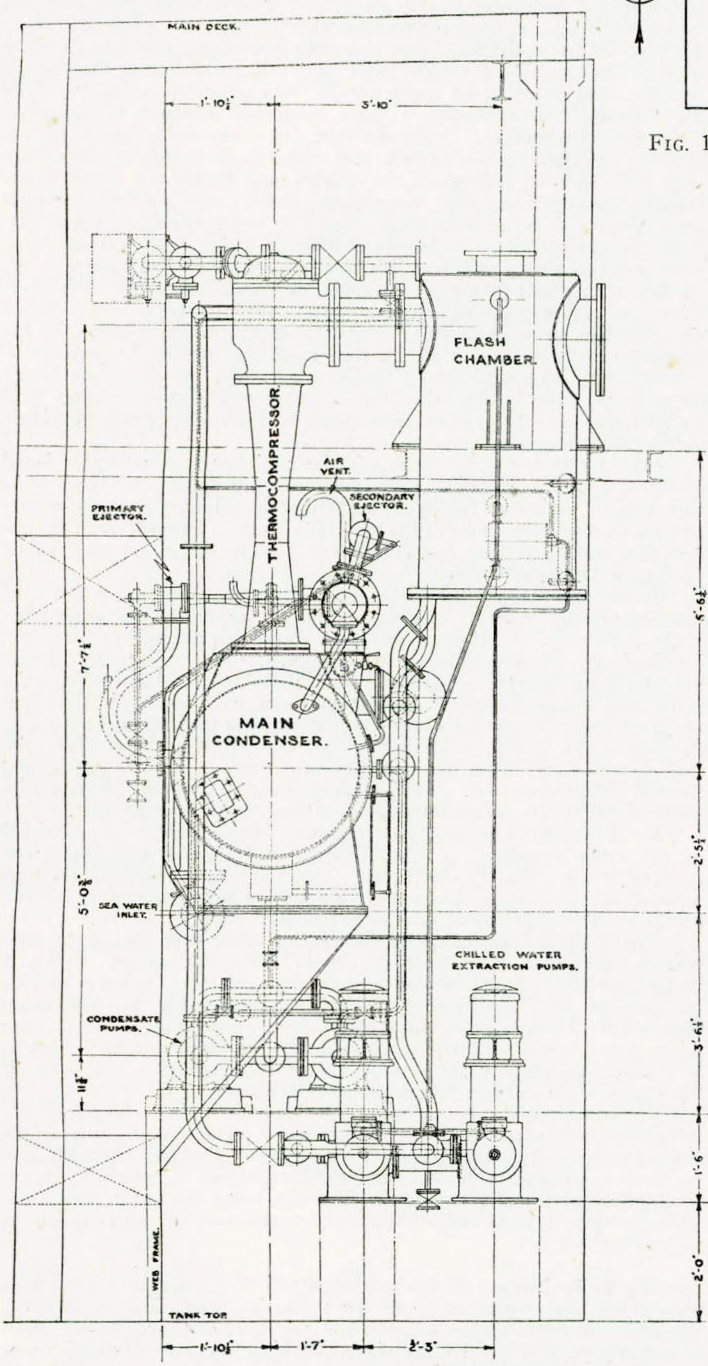

FIG. 15.—*Arrangement of steam jet plant for CO_2 cooling.*

TABLE II.

WEIGHTS OF STEAM JET REFRIGERATION PLANTS.

Output of Plant. Tons refrigeration.	Weight of Plant. Tons.	Weight/Output Ratio. Tons/Ton refrig.
40	8	0·2
80	11½	0·144
240	25½	0·106

for air-conditioning purposes, the whole equipment has been arranged on a stringer at the after end of the engine room.

Plants can also be arranged on different decks and levels. For instance, the pumps may be on the engine-room floor, the flash chamber and condenser on the deck above, or even higher.

Table II shows how, with increased size of plant, the weight, and in consequence space occupied and cost, is lower in terms of per ton of refrigeration as the size increases.

Acknowledgments.

The author wishes to acknowledge the permission given by Messrs. Foster Wheeler, Limited for the publication of various diagrams and data, and the assistance given by his colleague, Mr. Hayden, in the preparation of the text and diagrams.

Discussion.

Mr. E. C. Russell-Roberts (Member), opening the discussion, said that, taking the author's figure of 1,100lb. condensation, which was equivalent to about 95° F. condensation and 80° F. sea-water with evaporation 0° F., a CO_2 machine of 620,000 B.T.U.'s per hour would require 125·3 b.h.p. net at the shaft and a condenser water pump consuming about 6·7 B.T.U.'s net. Reducing the condensation pressure to 600lb. per sq. in. equivalent to 50° F. condensation and 38-40° F. liquid, a CO_2 machine of this size would require 52·3 b.h.p. The duty to be performed with steam jet plant would be 620,000 B.T.U.'s per hour plus the heat equivalent of the compressor motor i.h.p. of 110,000 B.T.U.'s per hour, making a total of 730,000 B.T.U.'s per hour, or 60·8 tons refrigeration. This would require at a mean figure (in the author's table) of 40lb. of steam per hour per ton, 2,430lb. of steam per hour. Converting this to power for purposes of comparison: taking a turbo-generator consuming 20lb. per kW. hour and a motor efficiency of 85 per cent., it would be equivalent to a motor b.h.p. of 138. In proportion to the figures in Table 1, the pumps would require 41·6 B.T.U.'s. This gave comparison between the straight CO_2 plant and the combination plant as follows:

Straight plant, CO_2 compressor 125·3 b.h.p., condenser water pump 6·7 b.h.p., total 132 b.h.p.

Combination plant, CO_2 compressor 52·3 b.h.p., water pump nil, b.h.p. equivalent of steam jet plant 138, steam jet plant pumps 41·6 b.h.p., total 231·9 b.h.p.

This showed a deficit in the combination plant as compared with the straight plant of about 100 b.h.p. Hence, to obtain a balance between the two plants with no gain for the combination set, 72·5 per cent. of the steam would have to be obtained for nothing—*i.e.* 1,760lb. out of the total of 2,430lb. The size of the plant would also be large. In a three-machine set, the CO_2 plant would be of 1,860,000 B.T.U.'s/hr. plus a steam jet plant of 2,190,000 B.T.U.'s/hr. for a usable output of 1,860,000 B.T.U.'s/hr.

It must be pointed out that the above figures, together with all figures throughout the paper, were taken under the most favourable conditions for the steam jet plant, that was to say, with the CO_2 plant working at high water temperature and low evaporation temperature.

It should be borne in mind that the CO_2 plant was the only type of equipment in which much gain could be obtained by sub-cooling the CO_2 liquid owing to its high specific heat and, under the conditions given in Table 1, the increased output by liquid sub-cooling was between 40 and 50 per cent.

With an ammonia plant under the same conditions the gain was only 10·7 per cent., resulting in a steam jet liquid sub-cooling plant for equipment of the same size of only about 200,000 B.T.U.'s per hour.

In the case of Freon 12 the gain would be 20·6 per cent., which would approximately double the size of the steam jet plant as compared with an ammonia installation, but would still give a very small steam jet plant in comparison with the size of the main installation.

It should also be borne in mind, in the case of CO_2 plants, that liquid sub-cooling could be equally as well carried out by another compression refrigerating machine as with steam jet plant and, in fact, this was done some years ago prior to the suggestion of using steam jet plant for this purpose. This modification was carried out in the Houlder vessels *Dunster Grange* and *El Argentino* which originally had two CO_2 machines each.

A third steam-driven CO_2 machine was added to each ship of about half the size of the original machines, and arranged to work at high evaporation temperature and sub-cool the liquid through approximately the same range as in Table 1. The effect of this was to give an output the same as would have been obtained with three machines of the same size as originally fitted.

Mr. J. K. W. MacVicar (Associate) welcomed the paper from many points of view, but perhaps principally because it gave a clear and simple explanation of the apparent fallacy associated with the term "cooling by use of steam". In the course of his ordinary business he had found it advisable, on many occasions and for various considerations, to recommend the installation of this type of plant in conjunction with air conditioning or comfort cooling. If the prospective customer had not been familiar with the principles of vacuum refrigeration, or alternatively had not appreciated what cooling could be accomplished by using equipment of a type already fitted on board ship, and with which he was quite familiar, he (the speaker) had been faced with the task of explaining those principles without having the benefit of the author's wide experience. By making the paper available to marine engineers, the author had performed a very useful function and had considerably eased the speaker's personal problem.

To the air-conditioning engineer the method by which the cooling medium was obtained was not very important, for the function of that plant could be equally well achieved by orthodox mechanical refrigeration methods or by steam jet refrigeration, as indicated by the author. Nevertheless, on some occasions vacuum refrigeration had many advantages. For example, on a vessel designed to use ordinary mechanical ventilation and heating, it might be necessary at a later stage to introduce air conditioning to one or more public spaces; the superintendent engineer was then faced with the decision as to what type of refrigerating plant was most suitable for his particular requirements. If the vessel already had a large refrigerating load and a stand-by machine, his problem was relatively simple. If, on the other hand, his main refrigerating plant consisted merely of what was required for ordinary domestic cold chambers, he was faced with the problem of fitting additional refrigerating plant. If his generator capacity was fully taxed, it might be impossible for him to consider applying mechanical refrigeration. If, however, his boiler capacity permitted, he could obtain the necessary refrigerating load by utilizing vacuum refrigeration plant without adding any considerable load to his generators.

On an existing ship, moreover, the engineer was naturally faced with the problem of housing the refrigerating plant. As the author had pointed out, the flexibility of vacuum refrigerating equipment frequently overcame this difficulty. The author had referred to one case in which such plant had been housed in the tunnel spaces between the spare tail shafts.

It was generally appreciated that air-conditioning plant must be thermostatically controlled to take care of the fluctuating conditions in the public spaces. As any variation in the requirements of the air-conditioning unit immediately reflected on the duty of the refrigerating plant, the extension of thermostatic control to the refrigerating plant itself was always an advantage. On a vacuum refrigerating plant with two or more thermo-compressors, control of the refrigerating duty was readily achieved by introducing thermostats into the chilled water, to determine whether one, two or more compressors should be in operation. This control was, of course, obtained by shutting off steam automatically from the thermo-compressor.

In air conditioning the correct air conditions might be obtained by (*a*) surface coolers, or (*b*) air washers, in which the water was sprayed into the air. Probably the vacuum refrigerating plant was not quite so satisfactory in the second case, as the water tended to become aerated, and an additional load was thus put on the air pump.

The methods suggested by the author of linking up the vacuum refrigeration with other duties on the ship were interesting. In Fig. 9 he had indicated a system whereby the exhaust steam from a turbine was fed to the thermo-compressor, the work done by the steam through the turbine being utilized to drive the pumps. What were the author's views concerning the effect on the turbine and the pumps in a three-compressor plant when thermostatic control had shut off the steam from two of the thermo-compressors?

In the case where steam was bled from the main turbine to serve the thermo-compressors, the turbine would no doubt be designed to deal with this duty. Bearing in mind, however, that the air-conditioning load must always be fluctuating, the author's views on the probable effect of this fluctuation, with steam being opened up and shut off from time to time under the action of thermostatic control, would be interesting.

Mr. S. B. Jackson (Member) observed that as evaporation had been particularly referred to in the paper he would like to describe a method of evaporation without the use of steam jets based upon heat pump principles. He had been working for a number of years on heat pumps and believed that this type of evaporator showed very considerable promise in the future in special reference to marine practice.

He had known this type of evaporator for at least 12 years and objected to it being described as the Kleinschmidt process.[1,2] The only originality of Kleinschmidt was the employment of a Roots blower. The reasons compression, evaporation or condensation had not been supported were that fuel had been too cheap, and a certain amount of inertia.

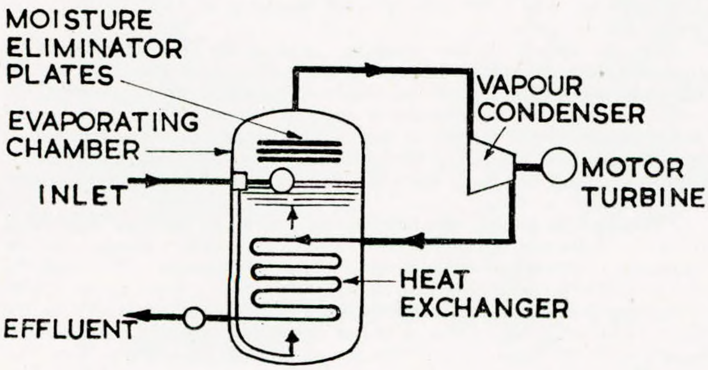

FIG. 17.

Fig. 17 showed a compression evaporator. Steam vapour at any pressure and temperature was compressed by the vapour compressor, the compressed steam being returned to the vessel via the heat exchanger where it released its latent heat to the boiling water and was condensed. Contraflow principles were employed.

The energy expenditure and the cost of evaporation were only a percentage of that of even quadruple-effect steam jet compression evaporation. The amount of driving power depended upon the temperature difference between the heating and boiling temperatures. By adequate dimensioning of the heat transfer surface this could be kept so small as to be within 10° F., thereby giving very high evaporation factors. The economy as compared with the quadruple-effect steam jet evaporators was 20 to 25 per cent., against triple-effect evaporators 40 per cent., and compared with single-effect 70 per cent.

By evaporating at atmospheric conditions no special sealing devices were required for the compressor, but the economy when

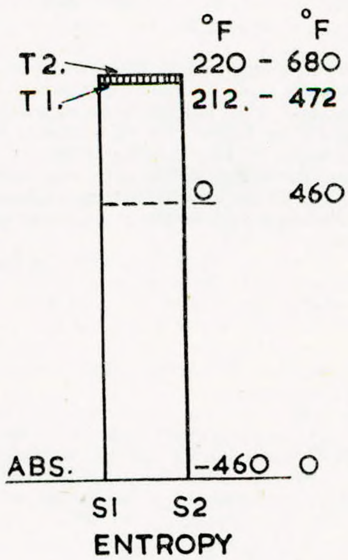

FIG. 18.

[1] Ensign J. E. Pottharst, "Motorship", Vol. XXX, No. 11, November, 1945, pp. 1108, 1109 and 1120.
"The Nautical Gazette", Vol. 137, No. 12, December, 1945, p. 91. (Abstracted Trans. Inst. Mar. E., Vol. LVIII, No. 3, April, 1946, pp. 25-26).

[2] J. J. Roche, "Motorship", Vol. XXXI, No. 3, March, 1946, pp. 242-243. (Abstracted Trans. Inst. Mar. E., Vol. LVIII, No. 4, May, 1946, pp. 36-37).

evaporating at moderate pressures was tempting. Only a very small pump for evacuating the effluent was required, depending upon the head to which it had to be pumped. The inlet water could be heated from any waste-heat sources by a suitable pre-heater, reducing the total energy consumption.

To compare the performance of the vapour compressor evaporator, Fig. 18 showed the fundamental Carnot diagram where T_2-T_1 gave ΔT, the temperature difference between the vapour and the heat pump output. Supposing water was evaporated at 212° F. and raised 5° F., allowing a loss of 3° F. between the vessel and the compressor and letting $\eta_m=0{\cdot}87$, $\eta_g=0{\cdot}97$, $\eta_c=0{\cdot}60$ refer to the efficiencies of the driving motor, gearing and compressor respectively, giving an overall efficiency η_o of 0·505 (0·55 was a more practical value), then

$$\frac{T_2}{T_2-T_1}\cdot\eta_{mgc}=\frac{680}{8}\times0{\cdot}87\times0{\cdot}97\times0{\cdot}60=43{\cdot}0 \text{ Coefficient of Performance.}$$

Now the latent heat at 217° F. was 965 B.T.U.'s per lb. Putting $\eta_i=0{\cdot}925$ as the efficiency of the heat exchanger and the insulation of the chamber

then $\frac{965\times1{\cdot}0}{0{\cdot}925}=1{,}042$ B.T.U.'s

and $\frac{1{,}042}{43}=24{\cdot}3$ B.T.U.'s input to evaporate 1lb. water corresponding to 7·2 Watts per lb. evaporated.

Distillation of say 2,500lb. water required $\frac{24{\cdot}3\times2{,}500}{3{,}412}=17{\cdot}8$ kW., corresponding to 24 h.p., necessitating a standard 25 h.p. motor, and $\frac{2{,}500}{17{\cdot}8}=140$lb. per kW.-hr. As a matter of interest, direct electric heating would require 11 to 13 times as much energy to produce the same result.

In the paper the adiabatic heat drop for 450lb. per sq. in. 750° F. and 28·5ins. Hg vacuum was used. Applying this to the turbo-generator supplying the energy to the evaporator compressor motor and putting $H_r=372$, η_t 0·70 and η_{gen} as 0·91 for the adiabatic heat drop, turbine efficiency and generator efficiency respectively, a steam consumption of 14·4lb. per kW.-hr. was obtained. But the actual increase of demand was dependent upon the machine increment rate which was assessed as 12·5lb. per kW.-hr.

So 17·8×12·5=222lb. *additional* steam required and $\frac{2{,}500}{222}=11{\cdot}25$lb. evaporated/lb. steam required.

The best triple-effect evaporator operating at 600lb. per sq. in. 850° F. gave 7·18lb. distillate/lb. steam, and the best quadruple-effect produced about 9·0 distillate/lb. steam. If a turbine drove the compressor, the performance would be even more favourable and it was quite easy to select the appropriate efficiencies to deduce this information. However, the flexibility of the electrical system had much to be said in its favour.

Considering the evaporator variables; η_m was virtually constant for a wide range of motor load, η_g was constant for all practical purposes, and η_c was constant for constant volume and speed, the evaporation temperature being constant for all general conditions. The main factor which changed was ΔT, which was controlled by the rate of scaling. If a zeolite exchange plant preceded the evaporator (and which could be supplied at negligible cost) automatically regenerated by sea water, the efficiency over very long periods was extremely high. The only other variable, but this was effected by design, was T_2, for as the vaporizing temperature increased the latent heat per lb. decreased and hence the economy was proportionately improved as might be expected. The design of the plant was essentially of highly specialized type. Distillate of the highest purity was produced with improvement of boiler and turbine operation.

Analysing the results above for a ship using oil fuel of 18,500 B.T.U.'s per lb. calorific value and a boiler efficiency of 85 per cent., nearly 150lb. water was evaporated per lb. of fuel. This was by no means the best performance, but it was given to indicate the possibilities of a heat pump machine which would be in production in the near future and for which there was much scope in marine service. The economy was such that the equipment paid for itself in a relatively short period and its claims could not very well be neglected.

Fig. 19 showed the logical extension of this principle to vapour compression for the production of chilled water. Operation of the compressor lowered the absolute pressure in the vessel, causing boiling of the liquid in the manner described in the paper. The vapour was compressed by a high-speed centrifugal machine, increased in temperature, and condensed, the air being extracted in the conventional manner.

As no steam was employed for vapour compression, the temperatures of the immediately associated pipes and the vessel itself were substantially lower than those attaching to steam jet compression,

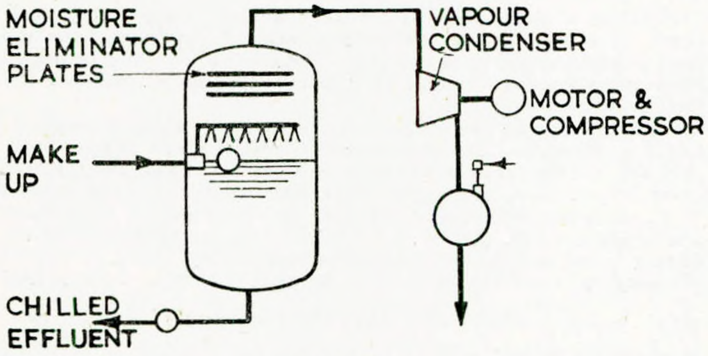

FIG. 19.

the radiation and conduction losses being substantially reduced. Further, the elimination of steam permitted a much smaller condenser and a reduction in air ejector capacity. The whole plant formed a very compact unit operating under appreciably less arduous conditions than those for steam jet compression. A supply of electrical energy or a steam turbine drive was all that was necessary, and this was easy to arrange.

Regarding economy, he had no experience of the design of steam jet compressors and was therefore not qualified to interpret the curves given in Figs. 6 and 7, but it was obvious that steam jet compression was of relatively low efficiency. For example, it could be shown that the maximum *adiabatic* efficiency of a steam jet compressor used as an air pump was only about 5·8 per cent., although the specific volumes of the gas handled were very much more favourable than the attenuated volumes of water vapour in the region of 40° F. and below. It would appear that by careful design the rotary compressor would permit compression of steam volumes more closely approximating the freezing point than by steam jet compression. Probably the author could give the actual value of the adiabatic efficiency of a steam jet compressor.

Finally, the efficiency of a centrifugal compressor depended upon (*a*) the suction pressure, (*b*) the delivery pressure, and (*c*) the speed. With a machine operating at 7,500-9,000 r.p.m., employing 6 to 8 stages, it would be to the order of 60 per cent. Therefore it might be expected that when dealing with rarified steam vapour the centrifugal compressor would prove more satisfactory. There were, of course, a number of self-suggestive additional applications.

Mr. A. C. Vivian (Visitor) said that Fig. 3 reminded him of an old friend, for his company had installed a similar plant with three thermo-compressors but of 50 tons (600,000 B.T.U.'s per hour) capacity in Abadan eleven years earlier. The plant supplied chilled water at 50° F. to air cooling coils in a closed circuit, the water returning to the flash chamber at 60° F., with steam supply at 160lb. per sq. in. and 570° F., and condensing water at a maximum temperature of 95° F. Recent tests showed that the plant was still operating at its designed capacity, and the spares used had been only steam nozzles and minor parts for condensate extraction and chilled water pumps.

During the past eleven years the company had installed sixteen plants by various makers, of 750 tons (9,000,000 B.T.U.'s per hour) total capacity, working on steam mostly at 90lb. per sq. in. saturated, but some at higher pressures. The individual thermo-compressors ranged from 17 to 50 tons. Some of these plants had been running for many years and maintenance charges had been low. The plants ran continuously twenty-four hours a day through an eight months' cooling season, apart from an occasional shut down for condenser cleaning. These plants were installed for air conditioning, but the surplus condensate was becoming a valuable by-product for boiler feed-water make-up.

The author had mentioned some of the advantages of steam jet plant, among which the speaker and his colleagues reckoned the most important to be safety and low maintenance, and particularly a non-toxic refrigerant, *i.e.* pure chilled water. For land use the main disadvantage was the large amount of cooling water required for the condenser compared with mechanical refrigeration—in the order of three times as much. That disadvantage did not exist in marine use, as the ocean was alongside. For land use a great advantage could sometimes be obtained if the functions of a water cooling tower and a tubular condenser could be combined in the form of an evaporative condenser which would require only a very small percentage of the cooling water or better still in the form of an air-cooled condenser requiring no water. He asked for the author's opinion on the question.

There was no doubt of the economy, which the author had stressed, obtained by employing steam jet plants for using low-pressure steam or engine heat which might otherwise be wasted. In some cases, however, high-pressure superheated steam was available but not low-pressure steam or waste heat. He asked whether the author would recommend de-superheating the steam so as to supply it saturated to the thermo-compressor; alternatively, if condenser size were also considered, could a thermo-compressor be designed to work as economically on superheated steam as on saturated steam? The plant to which he had referred working at 570° F. used just under 30lb. of steam per hour per ton.

On the subject of heat transfer, suppose in Fig. 3 the temperature of the steam chests of the thermo-compressors was 320° F., for example, and of the bottom of the flash chambers 50° F.; except for a thin joint there was metallic connection between the two. Would the economy of the system be appreciably improved by introducing a considerable heat-insulating joint between the steam chest, the thermo-compressor and the flash chamber, particularly if superheated steam was used?

Among the several applications of steam jet cooling illustrated in Figs. 9-16, the possibility of using the flash chamber as an evaporator for sea-water was particularly interesting. This entailed throwing away coolth, because it was necessary to blow down chilled water continuously to prevent an undesirable rise in salinity in the flash chamber. He asked whether the blow down would be, for example, 20 per cent. of the circulating chilled sea-water. This loss of coolth would be avoided if the sea-water were used in Lancashire boilers to supply steam to the thermo-compressor at the expense of a greater boiler blow down and more frequent boiler shut downs for scaling.

He hoped to hear some discussion about corrosion and scaling in steam jet equipment when using sea-water and fresh water. He had not so far used sea-water in connection with steam jet plants. He also hoped that the author would say something about throttling control on steam jets. This might possibly be difficult to achieve. The plants which the speaker's company had installed all worked on the "on-off" principle.

Mr. Bernard C. Oldham (Visitor) said that for the sake of historical accuracy he would like to point out an error in the opening paragraph of the paper.

While it might be correct so far as the author's Company was concerned that applications on board ship had only occurred in recent years, it was by no means the case with steam jet refrigeration in general. For the first ten years that he heard of steam jet refrigeration it was usually referred to as the system used in the French Navy where they had plenty of steam, and that sufficient steam was seldom found elsewhere.

He believed it was introduced by the French firm of Prache and Bouillon near Bordeaux and later Leblanc who became connected with Westinghouse, and The British Westinghouse Company were dealing with Westinghouse-Leblanc in this country between 1910 and 1912, after which steam jet refrigeration appeared to have been in the background until the early 1930's. He remembered having first seen Fig. 1 of the paper in an article contributed by the author's firm in 1932, as he remembered misreading it in connection with a paper for another institution in 1933.

He noted that all the technical data and test figures referred to 30″ H.G. It would appear to be difficult to make corrections every time when the barometer was not at 30″, and it would be interesting to learn whether there was a ready means of converting actual readings to that basis. Probably there was some method of dual calibration of gauges for pressure and temperature similar to gauges used in compression refrigerating plant.

He noticed in the paper the qualifications "provided that the stability of the jet can be maintained" and in another place that "the steam jet is essentially designed for specific conditions". This made him wonder what happened when the specified conditions were not available. He had never operated a steam jet refrigeration plant, but it did occur to him that there might be serious problems in dealing with the variations in load or with variations in supply steam pressure, and he, and no doubt others in the audience, would like to know how these contingencies were provided against.

On the proposal of **Mr. A. F. C. Timpson, M.B.E.** (Member of Council) a vote of thanks was accorded to the author by acclamation.

BY CORRESPONDENCE.

Mr. R. W. Cromarty (Member): Whilst the author and those taking part in the discussion gave a wealth of technical detail, with the exception of Mr. Vivian, who gave some details regarding a land installation, no information was given regarding the practical operation and maintenance of units as fitted on shipboard. Having during a brief visit sighted the unit mentioned by the author fitted to the refrigerating machinery in the m.v. *Drina*, the writer had anticipated that the author would have been in a position to give some comments and service results about this interesting marine application. Perhaps in his reply the author would make good this omission.

The writer had not had the opportunity to read the paper, but it would appear that the steam jet refrigerator as fitted in the m.v. *Drina* was most advantageous when the sea-water temperature was high. That was when it was hardest to maintain the almost perfect vacuum required for efficient operation. The writer understood that this type of unit would not function if the vacuum in the flash chamber was not over 28in. when the unit was started, even though the condenser gauge showed over 28in. vacuum. What were the author's views on this?

Whilst claiming several advantages, one of which was "no moving parts" and another "automatic operation", the author did not go on to claim "hence no maintenance".

The writer's experience was that units of this type tended to be neglected, *e.g.* the well-known steam jet vacuum augmentor in which if the jets were not properly maintained, there was a great loss of efficiency. The condenser was the heart of the unit, but the perfect non-leak marine condenser had yet to be made. Hence the author's statement that the unit could be used as an evaporator was most interesting. What special precautions were taken to prevent priming, to deal with contaminated condensate, or the increasing density of the liquid in the flash chamber when used as an evaporator, and for cleaning? Would the author agree that a unit such as fitted in the m.v. *Drina* could maintain its initial efficiency after say 20 years' service without major renewals?

Mr. H. F. Faultless: Were the figures incorporated in the graphs showing steam consumptions for various conditions intended to represent the latest practice or merely to indicate general trends?

Throughout the paper, when making comparisons between performance at different sets of conditions, the writer thought it should be made clear beyond all doubt whether this comparison was between a plant built for one condition and then operated at another or whether the comparison was between plants built specially for the different conditions under review.

On page 213 mention was made of the regulation of plants used for air-conditioning, and it was stated that control within plus or minus 1·5° F. could be arranged. It might have been interesting to those not familiar with steam jet plants to have been given more information as to how this was accomplished.

Under the heading "Combination Plants" reference was made to salt-water entering the evaporator at 150° F., and the writer wondered from where this would come. He took it that this salt-water would have first been used elsewhere for other purposes where it had picked up heat.

A. J. Sims, O.B.E., R.C.N.C., M.I.N.A.: The author referred to the use made of steam jet refrigeration in meeting air-conditioning applications in H.M. ships.

This method was one of several which were given very full consideration for this purpose during the war, when the air-conditioning of certain selected compartments became indispensable. In the discussions on the best ways of achieving this, the advice of the author and of other experts in air-conditioning technique assisted in ensuring that all the possibilities were fully examined.

Steam jet refrigeration for warship air-conditioning purposes was of particular interest when compared with the Freon plant. The latter was undoubtedly the better to use for air-conditioning loads of the order of 150,000 to 200,000 B.T.U.'s per hour or less. Above this zone, the steam jet plant had some attractive features; for example, no special refrigerant was required. Again, Freon was a difficult refrigerant to confine in a system involving extensive pipe-work and for a centralized plant—inferred from the magnitude of the air-conditioning load concerned—brine circulation became desirable to serve the compartments being treated; in the steam jet plant the cooled water was circulated direct. All the advantages were not with the steam jet plant, however, and the merits of the two systems needed to be considered for each application.

There was generally an advantage in keeping the chilled water temperature at a lower value in marine applications than was essential from purely air-conditioning considerations. This resulted in an increase in the power—and therefore in the weight—of the steam jet plant and its ancillaries, but the plant could usually be placed low down in the ship. On the other hand, the air treatment units for the compartments served—usually higher up in the ship—were thereby reduced in size and weight and some easement occurred in the problem of accommodating the gear. Also the size of the chilled water circulation pipes could be slightly reduced.

The paper was valuable in giving the latest information available on the possibilities of this interesting method of marine refrigeration.

The Author's Reply to the Discussion.

The author, in reply, promised a full written answer, which the questions undoubtedly deserved. To Mr. Russell-Roberts, however, he rejoined that where the paper mentioned the extension of the work of steam-jet plants into the cooling field as well as the compression field, it designedly stated that this was done by the use of low steam heat in order to gain efficiency. Obviously more efficiency might be obtained from electric power, but designers tried to use steam first for its normal purpose as a prime mover, and took it for refrigeration after it had been greatly debased. A very strong case could be made out in favour of the combination of plants; they had always proved very efficient and there were great possibilities in their extension.

Regarding Mr. MacVicar's points, when water was used in the spray type washer it carried down into the system all the dirt of the atmosphere, and probably acids also. Surface-cooler type air-conditioning plants certainly avoided these troubles completely.

Some of the combinations in the paper were forecasts of what could be done; most of them had been worked out in great detail. He assured Mr. MacVicar that in carrying these various combinations forward it would be possible to take care satisfactorily of the controlling side of the apparatus.

Mr. Jackson's figure of 2,500lb. had been the one used in the paper for steam consumption. This, however, was debased steam, not steam generated in the boiler for the purpose. It had been used at 60lb. pressure after it had done work from 450lb. downwards. There was no reason why steam should not be used at a pressure as low as 2lb. Mechanical compression was well known to be very efficient, but if plants were to be worked at these very low actuating pressures, which could be done with steam-jet plant, a good case could be made out for the steam jet against a mechanical compressor. Their relative performance was not, however, comparable unless all other factors were taken into consideration.

The steam consumptions given in the tables had been measured on tests and not calculated. The curves were based on measured figures.

Regarding Mr. Vivian's remarks, he undertook to study Mr. Vivian's interesting suggestion about cooling towers. He thought it would always pay to introduce a de-superheater if the supply steam was highly superheated, for although because of greater heat value the steam consumption would be lower, the efficiency fell off, and the fitting of a de-superheater was an optimum choice.

Amplifying the foregoing verbal reply, the author in written reply stated that Mr. Russell-Roberts in giving his figures for a comparison between a straight CO_2 installation and a combined CO_2 and steam jet installation could surely have made a more direct comparison in terms of the fuel burned per ton of refrigeration, rather than laboriously converting the work done by the steam-jet plant to electrical horse power.

Throughout the paper stress had been laid on the fact that the advantages of steam jet plant included the use of low-grade debased heat, such as that in enclosed gases from Diesel engines or steam bled from low pressure stages of steam prime movers.

As Mr. Russell-Roberts knew, the combination plants in the *Drina* and *Durango* used waste heat from Diesel engines; he knew also that the electrical load in these installations was 92 kW./hr. less with the steam jet plant combination, and that there was a saving in fuel of a small order, not an increase, and that the all-in cost of the combination was very favourable.

However, taking Mr. Russell-Roberts's figures, surely the following comparison held good:—

STRAIGHT CO_2 SET.

H.p. to be provided by turbo-generators.

CO_2 compressor	125·3
Sea-water pumps	6·7
Turbo-generator condenser circulating pump h.p. for condensing 2,320lb. steam	6·5
Total	138·5

Fuel chargeable taking 20lb. of steam per kW./hr. using usual efficiency figures for motor and turbo-generator, and assuming 14lb. of steam per lb. of oil	185lb./hr.

COMBINATION SET.

Again using Mr. Russell-Robert's figures we had:—

H.p. to be provided by turbo-generator for CO_2 compressor	52·3 h.p.
V.R. pumps	19·5 „
Total	71·8 „

So firstly there would be nearly 50 per cent. less electrical power to be provided in the form of turbo-generator equipment.

The fuel for this lower h.p. would, of course, by direct comparison, be:—

$$185 \times \frac{71{\cdot}8}{138{\cdot}5} = 96\text{lb./hr.}$$

The paper gave 2·24lb. of fuel per ton refrigeration for a plant using steam at 60lb. pressure.

So that using Mr. Russell-Roberts's figures for the steam jet plant load:—

$$\frac{730{,}000 \times 2{\cdot}24}{12{,}000} = 136\text{lb. of fuel.}$$

A total of 232lb. of fuel.

So that at the most, using Mr. Russell-Roberts's figures, there was a difference of 47lb. fuel/hr. and this only applied where there was a direct charge of fuel for the steam-jet plant's total steam.

Obviously at lower bled steam pressures, or with steam generated from waste gases, the comparisons would be in favour of the steam-jet combination.

However, obviously the fuel used, or the difference in fuel used was of no real account, but one big advantage of the combination sets lay in the fact that the CO_2 sets installed need not be installed as they were at present, capable of their full duty at the highest and critical sea temperature, but could be much smaller and designed to take full advantage of the liquid CO_2 temperatures from the steam jet plant, whose characteristics were that it cooled to a constant temperature up to the highest sea temperature.

There was also the gain of smaller electrical load and many other features.

This lengthy reply had been given because the author felt that the figures presented by Mr. Russell-Roberts gave a rather false impression, particularly as Mr. Russell-Roberts had full knowledge of the many advantages and satisfactory working of the first two combination CO_2 and steam jet plants built.

Mr. MacVicar's remarks were very helpful, particularly on the part that steam-jet refrigeration played in air-conditioning schemes, and for his explanation of the very fine control of the temperature of the chilled water achieved by thermostats.

The author would confirm that although the consumption of the necessary air pump on the steam-jet refrigeration condenser was only a small proportion of the total steam used, its duty would be greater in an air-conditioning system using air washers in which the water was sprayed in the air, as there would be more air to be handled by the air pump.

Also with a spray-type washer air-conditioning system, it was quite possible that there might be contamination of the water returned to the steam-jet refrigeration plant by acids taken from the air, particularly if the air should in any way be contaminated by smoke from the funnels, and it was quite possible to have an acid condition which would in time show its effect in the steam-jet plant.

From many points of view the author thought that the surface-type cooler in air-conditioning systems was nearly always the better choice.

Mr. MacVicar asked what would be the effect on the turbo-pumps in a combination system shown in Fig. 9, where in the three-compressor plant thermostatically controlled steam might be cut off from one or two of the thermo-compressors. In a system using exhaust steam from the turbine as the actuating steam there would be, to take care of fluctuating load conditions on the thermo-compressors, both relief of excess steam from the turbo-feed pump exhaust to the condenser, and also a connection bringing in additional steam to the exhaust steam, all arranged to maintain a constant pressure at the actuating steam nozzles under any variation of load.

Mr. Jackson, having observed that evaporation by use of steam-jet apparatus had been referred to in the paper, had described in great detail the principles of economics of vapour-compression evaporators.

It was well known, of course, that mechanical compression of vapour by means of the centrifugal compressors had been used before, but the advantages of simplicity and absence of moving parts were less, and it should be borne in mind that the steam-jet refrigeration plant described in the paper was essentially very economical when full advantage was taken of the use of debased heat, *i.e.* bled from turbines or generated at low pressures from Diesel exhaust gases.

The principles of vapour compression were the same whether done mechanically or by steam jet, and while the efficiencies of the two schemes when compared in any particular installation might show a gain in favour of mechanical compression, the only thing that really mattered was the cost of the fuel generating the necessary steam, the first cost of the plants, the simplicity, space, weight, etc.

Mechanical vapour compression evaporators undoubtedly showed a very good performance, but it would seem that to keep the proportions and the h.p. reasonable, the evaporator would have to work at atmospheric pressures, and then scaling would be a serious problem.

Mr. Vivian had made a valuable contribution to the discussion and, taking the points he raised in order, it was particularly interesting to hear that a steam-jet refrigerating plant installed in Abadan 11 years ago was still operating at its designed capacity, and that the spares used were only some nozzles and minor spare parts for the pumps.

Mr. Vivian stated that he considered among the more important advantages safety and low maintenance and the use of a non-toxic refrigerant, *i.e.* pure chilled water. He pointed out that the main disadvantage was the large amount of cooling water required, a disadvantage which did not apply to marine plants.

In this respect the author thought that combination condensers and cooling towers could be designed which would reduce the amount of cooling water required, but considered that the air-cooling condenser would not be a satisfactory proposition as the condenser vacuum would be limited by the dry bulb temperature. In other words it would depend so much on the climatic conditions, which could not be expected to be favourable in hot climates.

Regarding the heat loss possible by conduction from the hot steam chest to the metal of the flash chamber, it had been found that even a thin joint between the two bodies of metal at different temperatures prevented a heat flow of any considerable magnitude, and the slight additional work that had to be done because of any heat flow on this account was considered to be very small indeed.

Regarding the question of whether the author would recommend de-superheating in cases where high-pressure superheated steam was available, the answer was that de-superheating was to be recommended, for although the availability for doing work in high-pressure steam was higher, the efficiency of the thermo-compressor was found not to be as high when using superheated steam as saturated steam, so that while the steam consumption was somewhat less when using superheated steam it was not less by the amount one would estimate from the available heat drop.

The superheated steam of high temperature brought in the complication of the heat flow by conduction which Mr. Vivian mentioned, but to a more serious extent, as there was with highly-superheated steam quite a heat flow from the compressor to the condenser, which in turn affected the top of the condenser and the vacuum obtainable. The author thought, therefore, that the optimum choice in the case of having highly-superheated steam available was the use of a de-superheater making available an increased weight of saturated or slightly superheated steam.

Regarding the point Mr. Vivian raised on the throttling control on steam jets, multi-nozzle thermo-compressors were not suitable for throttling as there was very little reduction in capacity with reduction of steam pressure until the collapsing point of the jets was reached.

On the question regarding using the plant for an evaporator, it was asked whether the blowdown would be for example 20 per cent. of the circulating chilled sea-water. The amount of blowdown to maintain constant density would be a direct function of the amount of vapour flashed, which was governed by the temperature to which the salt-water was raised before entering the flash chamber, and the absolute pressure and temperature at which the evaporation was carried.

It would be clear that if the sea-water used had already received heat from a source of heat that would be otherwise thrown away, such as waste heat from Diesel engines, salt-water from any available source such as oil burners, condenser, overboard discharges, etc., then the blowdown losses would be extremely small or negligible.

Replying to Mr. Oldham, the author stated in the opening of the paper that the steam-jet refrigeration was a very old device, and that although the French Navy and some of the French Naval Marine had some very early examples of steam-jet refrigeration it was used in this country in industrial plants at an equally early date.

Mr. Oldham, noting that the technical data and test figures referred to 30″ h.g. asked whether there was a ready means of converting actual readings to that basis. Instruments of the nature of the kenotometer were always used, which was, of course, an absolute vacuum gauge.

When recording extremely low pressures approaching 30" of mercury, the ordinary mercury readings were always checked by the direct temperature method, which was more likely to be accurate.

Mr. Oldham considered that there might be serious problems in dealing with variations in load or variations in steam pressure, noting mention in the paper of the stability of the jet and the fact that the steam jet was always designed for specific conditions. It was intended to convey in the paper that a steam jet was, of course, operating at maximum efficiency when designed for a steady set of conditions in respect of steam pressure and available vacuum required for any given chilled water temperature. Of course, a plant would not be satisfactory if a steam jet could not maintain stability over fairly wide variations from the designed conditions, and in the design of the thermo-compressor this point was always considered and it was designed to be stable over any possible variation in steam pressure, or possible variation in vacuum due to change in sea temperatures.

Very often the optimum design arrived at accepted a slight compromise in terms of efficiency to secure stability conditions over a wide range.

Mr. Cromarty found the paper lacking in information regarding the practical operation and maintenance of steam-jet plants as actually fitted on board ship.

The author would make good this omission and state that in all the vessels so far fitted the practical operation of the units had been amazingly simple and utterly reliable, and as regards maintenance there had been in practice almost a complete absence of maintenance charges. The author would, however, refer Mr. Cromarty to Mr. Vivian's contribution which bore on this subject..

By the very nature of the plant it was an assembly of a welded tank into which pure distilled water entered and left, a small standard auxiliary condenser and some standard motor-driven centrifugal pumps. In other words, the plant was just as reliable and low in maintenance as this same type of equipment was when used in other parts of a ship for other purposes.

It was true in the life-time of a ship there would be the usual cleaning of condenser and occasional testing for tightness; the only parts that might require renewal over a period of years would be the small stainless steel nozzles of the steam jets. It was a plant extremely simple to operate, it required the minimum of personal attention, as it was mostly automatically controlled, and the maintenance costs were extremely low.

Mr. Cromarty was interested in the use of the combination arrangement wherein the unit could be used as an evaporator, and he would agree that as evaporation would be taking place at very low temperatures (which meant that a very high percentage of blowdown could be accepted without undue heat loss) the control of density in the apparatus when used as an evaporator was easily achieved.

As regards priming, the features mentioned above would reduce the possibilities of priming, and of course priming would be avoided in the design by due attention to water surface evaporation ratios, height of steam space and the introduction of mechanical drying devices if they were found necessary in any particular installation.

Mr. Cromarty asked the direct question whether such a unit as fitted in the *Drina* could maintain its initial efficiency after say 20 years' service without major renewals. The author certainly expected the plants in these ships to do so given the ordinary inspection and testing that other parts of the ship's machinery installation received.

Having referred to the use of steam-jet refrigeration in H.M. ships it was very useful to have Mr. Sims' valuable contribution, particularly his informative comments on the reasons why a particular choice of low chilled water temperature was often made with a view to keeping down the weight of the air cooler units which were placed much higher in the ships.

This was an example of the policy mentioned in the paper that steam-jet refrigeration plants should always be designed for the conditions applying to any particular installation, and Mr. Sims indicated that an increased steam consumption which must accompany the choice of a lower chilled water temperature was in the interests of low top weights of the air-conditioning installation

The author agreed with Mr. Sims that the really attractive features of the steam-jet refrigeration schemes became more apparent as the size of the plant went up. This was understandable from the very nature of the plant.

In reply to Mr. Faultless, the figures for steam consumption given in the graphs were actual steam consumption, and, of course, were not those theoretically possible, but rather practical figures for assessing estimates. They were also figures based on sets designed to take full account of fluctuations of steam pressure, stability conditions and other practical points. They, therefore, could be taken to be conservative figures for reliable estimating.

As requested by Mr. Faultless, the author would make it clear that the comparisons between performances at different conditions meant comparison between plants built specially for the different conditions under review and not for a plant built for one condition and operated at another.

Regarding the regulation of plants to within 1½ deg. temperature, this was accomplished by having controlling steam valves on the thermo-compressors operated by thermostatic solenoids inserted in the chilled water discharge which cut the valves in or out within the margin of 1½ deg. as given.

Regarding the reference made to salt-water entering the evaporator section of a combination plant at 150° F., the author would make it clear that there were many sources on board ship where salt water was heated, for instance overboard discharge from condensers, overboard discharge from lubricating oil coolers, etc., and this available heat would, of course, be taken into account and only sufficient direct heating given to salt-water beyond this existing temperature to raise it to 150° F.

Mr. Faultless was correct in assuming that the salt-water would have been used elsewhere for other purposes where it had picked up heat.

JUNIOR LECTURE.

Woolwich Polytechnic.

A lecture on "The Launching of Ships" was delivered at Woolwich Polytechnic on Monday, 18th November, 1946, at 7 p.m., by Mr. R. S. Hogg, Hons. C.G.L.I., to an audience of 150, of whom many were apprentices from local works. A number of naval officers were also present.

The Chair was occupied by Dr. E. Mallett, the Principal of the College, who first called upon Mr. T. A. Bennett, B.Sc., who was representing the Council at the meeting, to speak on the work of the Institute.

Mr. Bennett described the series of lectures which the Council of the Institute have arranged to be given for the benefit of students at technical colleges throughout the country, and expressed the view that the audience would shortly endorse his opinion that Woolwich Polytechnic had secured one of the best lecturers and one of the most interesting subjects of the series.

Mr. Hogg then proceeded to give his lecture, dealing first with the difficulties and dangers which might arise and then, by the aid of some very illuminating slides showing curves of net buoyancy moment as the ship slid down the ways, with the calculations which must be made to ensure a perfect launch. He went on to describe with the help of blackboard sketches and slides, how the slipways and fore poppet were built up, and finally how the ship was released and brought to rest after becoming water borne.

The audience showed the interest and attention given to the lecture by asking many penetrating questions, to which the lecturer gave full and instructive answers before the proceedings were brought to a close.

A hearty vote of thanks to Mr. Hogg, proposed by Mr. M. H. Ashworth, who said that the lecture had been enjoyable, interesting and educational, was carried with acclamation.

Mr. Bennett, on behalf of the Council, thanked the Chairman for his co-operation in the arrangements for this very successful meeting, and the Chairman, in reply, expressed the pleasure it gave him to be of assistance in the good work of the Institute in providing these excellent lectures.

JUNIOR SECTION.

Film Display—"Steam."

On Thursday evening, 21st November, at 7 p.m., Messrs. Babcock & Wilcox's film entitled "Steam" was displayed at a Junior Section meeting in the Lecture Hall of the Institute.

In the clarity of its presentation and the excellence of the photography the film was a model which all producers of documentaries should emulate. The first sequence dealt with the development of design from the original B. & W. water-tube boiler of 1856 to present-day boilers. The models and animated diagrams by means of which this development was traced, also showed how increase in pressure and temperature has effected great reductions in fuel consumption.

The large part which scientific and technical research plays in steam engineering was impressively shown by a tour of the Company's well-equipped research laboratories. The general construction and operation of a modern power station boiler was then described in detail by a series of close-ups of the well-known high head boiler.

The second sequence gave a comprehensive survey of the many and varied products manufactured at the Company's works at Renfrew and Dumbarton, special attention being paid to the interesting process of drum construction by fusion welding. The forging of sinuous headers, drum ends and other pressure parts was shown, while the views of the tube mills illustrated the production of solid-drawn tubes from the billet. These tubes were subsequently seen being made into boiler sections, water walls, superheater and economiser elements, etc. Views were also shown of the pipework shop where all sizes and designs for a wide range of pressure are fabricated, full use being made of the latest technique in hand and machine welding.

The film concluded with the erection of the steam plant for a modern power station, and gave a very good impression of the prodigious size and complexity of such a unit.

At the conclusion of the display a very hearty vote of thanks was accorded to Messrs. Babcock & Wilcox, Ltd., on the proposal of Mr. E. W. Cranston, Wh.Sc. (Chairman of the Junior Section Committee).

ADDITIONS TO THE LIBRARY.

Presented by the Publishers.

B.S. 1328: 1946—Methods of Sampling Water Used in Steam Generation. 25pp., 6 figs., price 3s. 6d. net, post free from British Standards Institution, 28, Victoria Street, London, S.W.1.

Transactions of the North-East Coast Institution of Engineers and Shipbuilders. Bound Volume 62—1945-1946.

On the Bridge. By Vice-Admiral Sir James A. G. Troup, K.B.E., C.B. Hutchinson & Co. (Publishers) Ltd. London, 1945. 76pp., with 21 unique maps, 5s. net.

Transactions of the Scottish Engineering Students' Association—Vol. 1. Session 1945-1946.

Red Duster. By E. Warington Smyth. Victor Gollancz Ltd. London, 1946. 272pp., 9s. 6d. net.

If it is objected that a woman isn't capable, for want of personal experience, of writing a "genuine" novel about the sea, it may be answered by saying that for more than a hundred years Mrs. Warington Smyth's family have been associated intimately with the sea, and have written books and stories on the subject. Her great-grandfather, who ran away to sea and served as an ordinary seaman in the Royal Navy, not only rose to be one of Nelson's most trusted Admirals, but wrote a dictionary of sea terms and usage, *The Sailor's Word Book,* which remains a standard work until the present day. Her father was an authority on all types of sailing craft, and wrote many books about them. Her own experience dates from early childhood, when she could sail a boat alone at nine years old. As the years have passed she has voyaged far in ships of all sizes, from small sailing craft to large vessels, and has travelled the world over. Her journeys have included long deep sea cruises with one or two companions in small sailing boats, cruises along most of the western shores of Europe, and many ocean passages.

Her two previous novels, *Man of Pride* and *Nancarrow,* together with the present work, are based upon personal experiences gathered in tramp steamers, living and working amongst the merchant seamen of this ancient kingdom. Her wish is to tell their story, to present their hardships, pleasures and successes, and to bring their lives closer to those of the community they serve.

National Certificate Mathematics (Vol. III). By G. E. Mahon, B.Sc. and P. Abbott, B.A. The English Universities Press, Ltd. London, 1946. 372pp., 113 figs., 7s. 6d. net.

This volume is essentially the work of Mr. G. E. Mahon and is based on the lectures given by him for many years to engineering students at the Polytechnic, Regent Street, W.1.

The work is intended to provide a systematic and progressive text-book in mathematics for students taking mechanical or electrical engineering courses in a technical institution. This is the third of the series of three volumes, which are planned to correspond to work which is usually done in the first three years of the senior course. The books include such mathematics as would normally be taken in a technical institution in which the students are preparing for a National Certificate. They also cover the syllabuses for the examinations (S_1, S_2 and S_3) in practical mathematics conducted by the Union of Lancashire and Cheshire Institutes, the Union of Educational Institutions and the Northern Counties Technical Examination Council.

The practical requirements of technical students have been carefully borne in mind throughout the volumes, but an endeavour has also been made, within the limits necessarily imposed upon such a work, to provide a fundamental and theoretical basis such as is necessary for a more advanced study of the subject.

Combustion and Modern Coal-burning Equipment. By J. Leslie Catton, A.M.I.Mech.E., M.Inst.F. Sir Isaac Pitman & Sons, Ltd. London, 1946. 118pp., 50 figs., 10s. 6d. net.

The subject of the efficient combustion of our limited supplies of coal is uppermost in the minds of all thoughtful persons, and not the least of engineers, business executives, Government departments, local authorities and the ordinary householder. To all of these, this book is a valuable contribution, in various aspects, on the available equipment and methods of operating it efficiently. It is not a text book; the layman will be intrigued as well as the heating engineer and the executive, and all three will derive from it considerable knowledge of a subject of vital national importance.

It is specially recommended to the rapidly growing numbers of engineers, plant attendants, and fuel efficiency officers now being appointed throughout the country to grapple with the problem of fuel conservation. The text covers the past, present and future of the fuel position, co-operation of fuel distributors and appliance makers, fuel sales and service, the process of combustion, effect of chimney draught, CO_2 in flue gases, and heat losses due to excess air.

Chapter III describes and illustrates most of the modern automatic firing stokers for steam boilers, heating, and hot water supplies, from which both the engineer and layman can decide as to the most suitable plant for a specific set of conditions.

Pre-combustion and gravity stokers, forced-draught systems, special fire-bar systems, steam jets and air pre-heaters, are dealt with in Chapter V.

Automatic boiler controls are illustrated and described very fully in a manner which should be of great help to the junior draughtsman, maintenance engineer, and heating installation contractor.

A short chapter deals with the development of steam boilers from early days to the present high-pressure, high-duty power-station type, complete with superheater, etc.

Three further chapters deal with the modern central heating boiler, hot-water service boilers, pipe layouts and equipment generally for domestic, hotel, and office block requirements of heating and H.W.S. supplies.

The book is very readable, and profusely and clearly illustrated.

Carenes et Propulsion (Hulls and Propulsion).—From the Galley to the Flying Boat. By Robert Duhamel, with a preface by Admiral Lacaze. Dunod, 92, rue Bonaparte, Paris (6 e). 592pp., with 109 diagrams, 1,880 frs.

This book deals with special features and details of hull designs, hull forms, and propulsive arrangements of a wide variety of craft, such as galleys, caravels, canoes, whalers, skiffs, sailing yachts, fishing boats, lighters, barges, tugs, motor boats and motor yachts, hydroplanes, semi-gliders, gliders, seaplanes and flying-boats.

It also gives details of wooden and metal hull structures, discusses the problems arising from the movement of hulls through the water, of gliding hulls, both of floating craft and seaplanes or flying-boats. The section dealing with methods of propulsion covers both marine screw propellers and air screws.

The text is in French.

Costing in the Engineering Industry. By F. R. Goody. ("Mechanical World" Monograph No. 29). Emmott & Co., Ltd., 31, King Street West, Manchester. 1946. 62pp., 16 figs., 2s. 6d.

The title of this monograph would lead one to expect more than the treatment of primary costing, but as the author says, a wide field has been covered in a small space and it is perhaps as well that the subject has been limited to a concise and useful treatment of the fundamentals of practical shop-costing.

The first chapter deals with works organization and control and its relation to the costing department—a practical and important opening for a booklet intended for shop executives, but more could have been made of the point that the costing department is an aid to their efficiency and not a policeman on their trail.

The next four chapters are concerned with materials costing. Costing for manufacture is rather discursive, and more reference might have been made to colour systems, part numbers and coding. The treatment of material schedule and standard is adequate. Under the heading Buying Department and Stores Records, the author recommends the use of master card records which has, theoretically, many advantages, but is limited in scope and might prove to be limited to use in small firms. Costing for part finished store is again discursive, ranging from a complicated master card to coding with punched card systems.

Chapters VI, VII and VIII deal with labour costing. Although I.C.W.A. definitions are quoted, it is to be noted that the Institute prefers the use of the word "overheads" to "oncosts".

The treatment of payroll and labour is satisfactory and adequate, but no firm illustration is given of how wages are analysed. Methods of remuneration are concisely handled, though necessarily sketchily. The consolidated bonus scheme for autos is sound.

The final chapter, which is on mechanical accounting, assumes that the reader knows what a punched card looks like.

On the whole, this well-written and inexpensive booklet presents the right ideas and should prove well worth reading by shopmen.

Introduction to the Electron Microscope. By F. E. J. Ockenden, M.I.E.E., F.Inst.P. With a foreword by J. E. McCartney, M.D., D.Sc.(Edin.). Monograph of the Quekett Microscopical Club. Published for the Club by Williams & Norgate Ltd. London, 1946. 24pp., illus., 2s. 6d. net.

The electron theory on which the electron microscope depends is described in simple terms and analogies. The present limitations and the future possibilities of the instrument are outlined. A detailed description is given of an electron microscope and the method of operation.

In its present form the electron microscope is a laboratory instrument. Whilst its present application to the study of metals is limited, there appears to be no doubt that in the future marine engineers will obtain considerable benefit from the knowledge which will be obtained from its use in metallurgy.

Mechanical Inspection. By H. F. Trewman, M.A.(Cantab.), M.I.E.E., M.I.Mech.E., A.M.I.E.E. Sir Isaac Pitman & Sons, Ltd. 1946. 162pp., 126 figs., 15s. net.

This is a good and interesting book and no subsequent comment is to be taken as detracting from this statement.

The book is divided into two sections; the first section deals with general factors affecting inspection and the second section with inspection and measurement apparatus. It is felt, however, that the book may be of most value to those already experienced with inspection but will in all probability be more widely read by those who are seeking guidance. For the benefit of those who are inexperienced, it is felt that the first section of the book could with advantage be extended to cover more fully such matters as the training of inspection personnel, inspection department layout, specimen test sheets or reports, and other similar matters.

On page 70 an accuracy of $+\cdot002'' - 0$ is claimed for the stick micrometer up to 20ft. length, and it is considered that some comment respecting change of length with temperature is called for here.

On page 147 a minor error occurs, the letters small "c" and capital "C" being used for the same purpose.

Crankshaft Design and Manufacture. By J. Smith, A.M.I.Mech.E., A.M.I.Mar.E., A.M.C.T., M.I.P., Chief Research Engineer, National Gas and Oil Engine Co., Ltd. Whitehall Technical Press, Ltd., 9, Catherine Place, Westminster, London, S.W.1. 1946. 64pp., profusely illus., 12s. 6d.

The contents of this book relate in general to the design and construction of crankshafts for medium- and high-speed heavy-oil engines. Much information is given in a concise form, and therein lies the value of the book.

The importance of crankshaft design need not be emphasized, and it raises the question of materials, suitable scantlings in relation to fatigue strength, balancing and vibration characteristics. This book covers all these aspects briefly for the class of engine mentioned. The section dealing with materials has been read with interest, and it contains most of the information at present available in a concise form.

The graphs shown in fig. 5, chapter 2, indicate the trend towards increased widths and decreased thicknesses of crankwebs, resulting in the decreased overall length of the crankshaft, and a shorter engine. The graphs given in fig. 11 should prove useful to those engaged in checking WK2 and torsional rigidity corresponding to various cylinder bores. It is concluded, however, that these values refer only to one particular type of engine, *viz.* 4 S.C.S.A. trunk piston.

The remainder of the book deals with conventional calculations on similar lines to those found in most text books on engine design, but are put down in a more concise form and should serve as a useful quick reference to engine designers.

The General Principles of Quantum Theory. (Third edition). By G. Temple, Ph.D., D.Sc., Professor of Mathematics in the University of London at King's College. Methuen & Co., Ltd. London, 1946. 118pp., 4s. 6d. net.

During the present century the aim of physicists in many countries has been that of explaining the physical world in terms of the internal structure of the constituent particles of matter. The wide-spread interest now taken in the possibilities of atomic energy as a source of industrial power is a result of the remarkable success which has attended recent research in this branch of science. In order to understand the dynamical aspect of the matter and the reason why the behaviour of atoms cannot be fully described in the language of classical mechanics, we require a working knowledge of the quantum theory as enunciated by Planck and of the subsequent developments of this theory by Einstein and others.

Such knowledge is to be gathered from the monograph under review, in which an introductory account is given of the general principles that form the physical basis of quantum theory. In chapter 1 Professor Temple develops, from the simplest beginnings, the essential mathematical methods, namely, the theory of linear operators. This mathematical equipment should enable the serious student to grasp the implications of the next chapter, on the laws of measurement in atomic physics. It is hardly possible to over-estimate the importance of these laws for those approaching the subject for the first time.

These considerations are applied and amplified in the next two chapters, where the equations of motion and the spin operators are discussed in a commendably clear manner. Here, as in other parts of the book, the author expounds the theory as a branch of physics and not as a branch of mathematics and, in doing so, elucidates the formal treatment by means of numerous examples. This applies also to the final chapter, which includes useful sections on the electron configuration of ideal atoms and on quantum statistics, under the general heading of composite systems.

The work has obviously been prepared to meet the needs of students of the physical sciences, and it may be recommended as an excellent supplement to more general textbooks on this branch of scientific inquiry.

Naval Architecture of Planing Hulls. By Dr. Lindsay Lord. Cornell Maritime Press, 241 West 23rd Street, New York 11, N.Y., 1946. 293pp., 118 figs., $5.00.

Lindsay Lord is a well known American consultant who will be familiar to the readers of "The Rudder". His avowed intention was to write a scientific treatise but the text does not appear to fulfil his purpose. Readers of this book who are not familiar with the design of hard chine boats are advised to read also Sottorf's papers dealing with the theory of planing surfaces and Davidson's papers describing research with model experiments.

It is very difficult to correlate model experiments with the actual performance of this type of craft, due principally to the large variation of wetted length with speed and the enormous cavitation losses which are always present with the large, fast boats, and it is to people like Mr. Lindsay Lord that one looks for guidance. He attempts to bridge the gap, but has allowed prejudice to obscure his judgment, and although he illustrates his opinion by many diagrams these are nowhere substantiated by facts.

Two matters of very great importance such as strength and propeller performance are dealt with in a peculiarly conventional and unsatisfactory manner. Longitudinal strength is glossed over in two pages in the normal static condition to be found in any elementary text book on naval architecture, and transverse strength is not defined at all.

Twenty-six pages describe propeller design, and here one feels the need of analysis of trial results of such craft as M.T.B.'s where the nominal thrust may be as large as three times the actual figure.

The chapter on steering is very well written, and diagram 98 could be very useful, but here again acknowledgment of its origin would be informative.

This book is somewhat disappointing, its subject matter is good in parts, the text very disjointed, and one feels that Mr. Lindsay Lord while condemning the efforts of many reputable designers should have been factual if he found it difficult to be scientific.

Purchased.

The Society of Naval Architects and Marine Engineers. Index to Transactions Vols. 1 to 51, Years 1893 to 1943, including Historical Transactions. Published by the Society at 29 West 39th Street, New York 18, N.Y. 1946. Price $2.00.

The Battle of the Atlantic—The Official Account of the Fight Against the U-Boats 1939-1945. Prepared for the Admiralty and the Air Ministry by the Central Office of Information. H.M.S.O. London, 1946. 104pp., 8 charts, 1s. net.

Centrifugal Casting of Metals. British Intelligence Objectives Sub-Committee. (F.I.A.T. Final Report No. 81). H.M.S.O. London, 1945. 20pp., 2s. net.

Spur Gear High Pressure Pumps Designed by Egerdoerfer. British Intelligence Objectives Sub-Committee. (F.I.A.T. Final Report No. 625). H.M.S.O. London, 1945. 12pp., 9 illus., 1s. 6d. net.

Fire Protection of Oil Installations in Germany. British Intelligence Objectives Sub-Committee. (B.I.O.S. Final Report No. 697. Item Nos. 30, 31). H.M.S.O. London, 1945. 30pp.+29 figs. and photographs, 4s. net.

German Types of Heaters and Coolers for Marine and Land Application. British Intelligence Objectives Sub-Committee. (B.I.O.S. Final Report No. 540. Item Nos. 29, 31). H.M.S.O. London, 1946. 35pp.+approx. 100 figs. and photographs, 18s. net.

MEMBERSHIP ELECTIONS.

Date of Election, 3rd December, 1946.

Members.
Hugh Beck.
James Benjamin Bryce.
Alexander Niven Campbell.
Joseph Beaumont Collingwood.
Harry Cooper, Lieut.(E.), R.N.
Collingwood Cowan.
Dadabhoy Burjorji Daruvala.
Herbert Arthur Dawson.
Andrew Lawson Ellerington.
Herbert Heseltine.
William Lawrence Larsen.
Richard Heaton Layfield.
Andrew McFall.
Francis Orlando Egbert May, Lt.-Com.(E.), R.N.(ret.).
Robert Mothersdale.
Harold Ernest Palmer.
Douglas Richard Palmer.
Robert Norman Richardson, Lt.-Com.(E.), R.N.V.R.
John Gordon Clunes Smart-Dalgleish.
John Robert Storey.
Peter McClelland Wilson.

Companion.
J. Isdale.

Associate Members.
Derek Ralph Dibben, Lieut.(E.), R.N.(ret.).
Michael John Hodgson, D.S.C., Lt.-Com.(E.), R.N.
John Richard Seear, Lieut.(E.), R.N.

Associates.
Albert Stanley Carter.
Frederic Bowes d'Enis.
Hamish Ferguson.
Arthur Kracko.
Philip Lowe.
George Edward Milner.
Raymond Freeland Scarffe.
Kenneth Stubbs.
James Hills Taylor.
John Norman Young.

Students.
William Raymond Mathers.
Guy Scott Sanders-Hewett.

Transfer from Associate to Member.
James Carmichael.
John Ambrose Cornish-Bowden.
Joseph Giorgio.
Robert Douglas Farrar Kidd.

Transfer from Associate to Associate Member.
Frederick Yates Whitham.

Transfer from Graduate to Associate.
Charles Gundry Alexander, B.A., Ty. Lieut.(E.), R.N.
James Denny.

Transfer from Student to Associate.
Kenneth Henry Marsh.

Transfer from Student to Graduate.
Harry Kay, B.Sc.

PERSONAL.

Sir Wilfrid Ayre (Member) has been elected senior vice-president of the Shipbuilding Employers' Federation.

G. Beal (Associate) has been appointed an engineer surveyor to The Municipal Mutual Insurance Ltd.

A Bird (Associate) has been appointed an engineer surveyor to The Municipal Mutual Insurance Ltd.

Lt.(E.) J. W. Brand, D.S.C., R.N. (Member) has been appointed second assistant to the Rear-Admiral(E) on the staff of the Flag Officer, Rosyth.

F. W. Dugdale (Member) has been elected a vice-president of the Shipbuilding Employers' Federation.

G. E. Dunk (Associate) has been appointed to the staff of Lloyd's Register of Shipping at Middlesbrough.

J. W. Firth, O.B.E. (Member) is now serving as chief engineer with The Montreal Shipping Co., Ltd.

J. Garden (Associate) has been demobilized from the Royal Navy and appointed a mechanical surveyor to the British Engine, Boiler & Electrical Insurance Co., Ltd.

S. G. Gilmore (Member) has been appointed chief engineer and clerk of works to the City Mental Hospital, Mapperly.

A. E. C. Gregg (Member) has entered the service of the Sudan Government Railways as dockyard manager.

A. Hanna (Associate) has re-entered the service of The Anglo-Saxon Petroleum Co., Ltd. as second engineer.

J. Ivor Jones (Member) has been appointed superintendent engineer of The Montreal Shipping Co. of Montreal.

S. Jones-Frank (Associate) has been elected a Member of the South Wales Institute of Engineers and an Associate of the Institution of Naval Architects.

J. A. Leslie (Member) has joined the staff of Messrs. G. & J. Weir, Ltd. as a draughtsman.

V. S. Mangham (Member) has been elected vice-chairman of the Conference and Works Board of the Shipbuilding Employers' Federation.

D. S. Marsh-Jones (Associate) has entered the service of The Union S.S. Co. of New Zealand, Ltd.

P. Martin (Graduate) has been appointed a scientific officer at the National Gas Turbine Establishment, Whetstone.

R. J. Pescod (Associate) has joined the staff of Messrs. Smith's Dock Co., Ltd., Southbank.

F. E. Potter (Member) has been appointed engineer superintendent of The India Steamship Co., Ltd.

D. Rebbeck, M.A., B.Litt. (Member) has had the degree of M.Sc. (Belfast) conferred on him by Queen's University, Belfast.

C. J. Saliaris, B.Sc. (Associate) has been appointed an engineer surveyor to Lloyd's Register of Shipping and is stationed in London.

W. A. Smellie (Member) has been appointed assistant surveyor to The Hul Steam Trawlers Mutual Insurance & Protecting Co.

Lt.-Cdr.(E) R. F. Swain, R.C.N.(R) (Member) has been placed on the Reserve List of the Royal Canadian Navy and has been appointed superintendent engineer of the marine section of Foundation Maritime, Ltd., Canada.

Henry Taylor (Member) is now stationed at Buenos Ayres as ship and engineer surveyor to Lloyd's Register of Shipping.

Eng. Com. S. B. Trenoweth, R.I.N., ret. (Member) has been elected a Member of the Institution of Naval Architects.

E. W. Triolo (Member) has been appointed to the staff of the Ministry of Works.

F. Whitham (Associate) has passed the Extra-First Class Certificate examination of the Ministry of Transport, and has been appointed a surveyor to Lloyd's Register of Shipping.

A. L. Young (Member) has been appointed engineer representative (marine) for the North-East Coast area by Messrs. C. C. Wakefield & Co., Ltd.

The Secretary regrets that in the list of candidates for Membership of Council, as given in the voting papers recently issued, the name of Mr. David Dunn was incorrectly followed by the designation, O.B.E. The latter distinction belongs to Mr. Douglas Dunn (Member).

ANNUAL CONVERSAZIONE.

The Annual Conversazione was held on Friday, 6th December, 1946, at the Connaught Rooms, Great Queen Street, W.C.2. The company on this occasion numbered 575.

The members and their guests were received between 5 and 5.30 p.m. by the President and Lady Ayre, supported by Mr. J. A. Rhynas (Chairman of Council) and Mrs. Rhynas. Dinner was served immediately afterwards, Sir Amos Ayre presiding.

After the customary toast to His Majesty the King, Mr. J. A. Rhynas proposed the toast of "The President", which was received and honoured with enthusiasm. Mr. Rhynas expressed the Council's gratification on having succeeded, after strong persuasion, in obtaining Sir Amos's consent to continue as President for a further year. They looked forward with confident anticipation to another year of successful activity under Sir Amos's capable guidance.

Sir Amos Ayre, responding, thanked Mr. Rhynas for his remarks concerning himself. He took advantage of the occasion to express thanks for the many handsome donations which had been made to the Marine Engineers' National War Memorial Building Fund, and in particular for the prompt and pleasing gesture in the shape of a donation which had been received from The Todd Shipyards Corporation, one of the well-known shipbuilding firms of our American Ally. Sir Amos added that while the Fund was now reaching gratifying proportions, in view of the very large sum still required their efforts must not be relaxed.

The remainder of the evening until 11 p.m. was devoted to dancing, with an interval from 9.30 to 10 p.m. for the presentation of a cabaret featuring Eric Ross and his Eight Grosvenor Girls. In their finale, the Eight Grosvenor Girls were supplemented by some Eight Elderly Gentlemen, Members of the Institute, who rendered a startlingly acrobatic performance attired in their pyjamas.

Music throughout the evening was rendered by Sidney Jerome's Dance Orchestra. Mr. H. Dean officiated as Toastmaster and M.C.