Discussion.

Mr. W. Sinclair, in proposing a vote of thanks to Mr. Marriott for his paper, said that he was glad that he had had the opportunity of hearing the figures given; it would be interesting to compare them with others. Mr. Marriott was in this case in a peculiarly happy position in knowing what he wanted, and being able to collect data as he went along, so that he has been able to give us a full set of figures. The speaker's own knowledge of cooling towers was in connection with refrigerating machinery, and temperatures used are in no way comparable with those which Mr. Marriott obtained; and knowing that effect, we have to take more account of factors such as humidity of the air. In the early part of the paper there is a good deal of emphasis laid on humidity, but this does not pertain so much in the spray system. The first thing to consider is the cost of erection, then maintenance and running. In the figures shown there was plenty of area to work on, but in the city land is of greater value, and the cost of buildings has to be carefully thought out. It seems to me that the thing to remember is to keep the air and water in contact as closely as possible, as humidity of the air is the prime factor. Forty per cent. of the sprays working in the city are in disfavour because they are hard to get at; they are mostly on top of buildings, and therefore inaccessible. The sprays shown are very much larger than any I have seen. The cost of sprays is a little more than cooling by a system of water towers. I would emphasise effect of drops colliding in the spray system and causing cohesion. I have always thought that drops should be kept apart, but I may be wrong, and would like to hear Mr. Marriott's opinion of this. I would like the author to say if the figures given in Table 7 are for wet or dry bulb. He wished to move a very hearty vote of thanks to Mr. Marriott.

MR. FERRIER said that the design of cooling towers for condensing water has been to a marked degree a question of rule of thumb. Although of so much practical value, as well as scientific importance, many of the phenomena of atmospheric moisture on which cooling depends are but partially understood, while the engineering data pertaining thereto is usually incomplete and inconclusive.

I have in a measure been associated with the operation of various types of cooling towers, but regret that the opportunity has not been afforded of obtaining records over extended periods, such as are submitted to us by the author of the paper now under discussion.

The results obtained by the use of both the tower and spray cooling, as given in the paper, should be of great value to engineers; the information is very complete, and the deductions arrived at as to the relative advantages and disadvantages of the two systems described are, in my opinion, in the right direction.

The author aptly illustrates his paper with diagrams on important points, such as size of drops, quantities of condensing water required at various temperatures, and at various vacuums, etc., and although these are only approximate, a consideration of them will show that for ordinary average condensing plants there is much latitude in determining the size of a cooling system, and that only in connection with turbine plants and in certain manufactures where it is desirable to have high vacuum, and consequent low temperature, does it pay to circulate the large percentage of water to steam, ranging, say, up to 100lbs. of condensing water to 1lb. of steam.

Condensing plants situated in places with abundant supplies of circulating water require only about one-third of the above-named quantity.

The main objective to be aimed at in cooling the water is to get a maximum of surface contact between the water and the air, and in cooling condensing water as well as in another important process, namely, air conditioning, the general practice of the world seems to be to adopt the spray and atomising principle as against the cascade, film, or other devices hitherto largely used.

There is a practical limit to the degree of spraying when such large volumes of water have to be dealt with; the finer the spray the greater the power required to operate, and the greater the incidental troubles of clogging of the sprays, filtration, and, unless specially provided against, the large drift losses with high winds.

The Colonial Sugar Refining Co. would appear to have determined a good practice and comparatively inexpensive lay-out in their spray system, the high initial temperature of the condensing water and its apparent good distribution by the sprays enables the factors of radiation, convection and evaporation to have fair scope; probably the most important factor is the marked increase in the temperature of the air, and consequent increased capacity to absorb additional moisture. This brings an important principle into operation, namely, the moisture contents of saturated air at different temperatures, for instance, at 75 deg., 85 deg., 95 deg., and 105 deg. F. At maximum saturation a cubic foot of air carries, say, 9.35, 12.73, 17.12, and 22.75 grains respectively; the high initial temperature of the condensing water gives a high average rise of temperature of the air, and consequently a high rate of evaporation and resultant cooling.

At Broken Hill the question of cooling condensing water for years gave the managers and engineers great consideration. Towers with cascade, and film methods of cooling were used, but at the Broken Hill South Mine, after exhaustive investigations by the management, they decided to instal the spray system. This was effected on more elaborate lines than that described, and the sprays were surrounded by a tower to cut down drift losses and to encourage better circulation of the air.

In the "Mining and Engineering Review" of November 5th, 1912, illustrations and description of this particular plant are given, and charts of records of its working under summer and winter conditions.

The humidity at Broken Hill is usually very low. The vacuum attained at the South Mine was very high, the temperatures of the condensing water at the inlet and outlet are low, the cooling averaging about 12 to 14 degrees. Assuming a constant barometer at 30 inches, it is stated the turbine carried average vacuum in January of 27.4 inches; July, 28.2 inches, and September, 27.9. The average back pressures recorded at the condenser end of the turbine being 2.6, 1.8, and 2.1 inches mercury respectively.

In conclusion, I would like to compliment Mr. Marriott on the full and comprehensive manner in which he has submitted his data. It is a valuable addition to the records of the Association.

Mr. C. S. Jeffrey: Mr. Corin has kindly handed me a copy of Mr. Marriott's paper with a request that I should make a few remarks thereon.

The subject is one which I investigated some years ago in Rangoon. The results of the experiments I carried out then are embodied in a paper published in the Proceedings of the Institution of Electrical Engineers, Vol. 53, page 250, June, 1915.

Very little information is available on this subject, and Mr. Marriott's paper is extremely valuable in that it gives very complete results of practical tests under varying conditions.

Although I fully realise the difficulties in designing apparatus of this kind, I am inclined to disagree with Mr. Marriott's statement that the laws governing evaporation, radiation, convection, etc., are of little value in determining the amount of cooling which might be expected.

The theory of the forced draught cooling tower, which is essentially an evaporative apparatus, is comparatively simple. If a given quantity of air at a certain temperature and relative humidity is passed through falling water, this air is capable of extracting a definitely ascertainable number of heat units from the water. The number of heat units is limited by the saturation of the air, and the temperature of the inlet water to the cooling tower. For example, 100 lbs. of air at 140 deg. F. is capable of carrying off approximately 16lbs. of water vapour. If this quantity of air enters the tower at 80 deg. F. and 50 per cent. relative humidity, it already contains 1.1 lbs. of water vapour. The water which this quantity of air with 100 per cent. efficiency might be expected to be capable of evaporating from the tower is therefore 14.9 lbs. The latent heat of vaporisation of 14.9 lbs. of water is approximately 15,200 B.T.Us. This quantity, neglecting the comparatively small amount of heat required to raise the temperature of the air, is the heat which, with perfect efficiency, might be extracted from the condensing water. Actually a certain percentage is obtained in practice which, when known, enables the temperature drop to be calculated.

The minimum temperature to which water can be cooled by evaporation is that indicated by the wet bulb thermometer. In my experiments I had no difficulty in cooling water 10 deg. F. below the shade temperature, and within 2 deg. F. of the wet bulb reading. The quantity of air required to obtain such results in a cooling tower would be excessively high, however.

Mr. Marriott draws attention to the rapid increase of efficiency with increase of inlet water temperature. The quantity of water vapour which a given quantity of air can carry off increases very rapidly as the temperature increases, so that it is of much more importance as regards the quantity of air necessary for a given temperature drop that it should leave the cooling tower at as high a temperature as possible, than it is that it should enter the tower at a low temperature and low relative humidity. A few degrees higher temperature of the inlet water to the tower will compensate for a much greater increase in the temperature and the humidity of the air entering the cooling tower.

I have worked out from the figures given by Mr. Marriott in Table I, Test No. 4, that the evaporative efficiency of his tower regarded in this way is 76 per cent. The figures are as follows:—

Weight of air per minute $= \frac{2 \times 46750}{13.146} =$ 7,110 lbs. (approx.)

Water inlet temperature, 117 deg. F.

Water content of 7,110 lbs. of saturated air at 117 deg. F., approximately, 476 lbs.

Water content of air entering the tower, approximately, 146 lbs.

Maximum possible evaporation, 476—146=330 lbs.

Latent heat of vaporisation of 330 lbs. water at 1023 B.Th.Us. per lb., approximately=337,600.

Water per minute $\frac{47,000 \times 10}{60} =$ 7,833 lbs.

Temperature drop, 33 deg. F.

Heat units extracted from water, 7,883 x 33=258,000

Evaporative efficiency, $\frac{258,000}{337,600} =$ 76 per cent.

In this example the air outlet temperature is 17 degrees below the water inlet temperature. Perhaps Mr. Marriott will say how this air temperature was measured? I ask this question because I recognise that the difficulty of making accurate observations on cooling towers is very great. If this is correct, the hypothetical cooling effect would appear to have been exceeded.

Mr. Marriott has emphasised the importance of wind velocity. A forced draft cooling tower is the most reliable form of cooler, because the velocity and quantity of air can be controlled. Natural draft towers are less reliable, because the air is not completely under control; while in open type towers, sprays and cooling ponds, the supply of air is entirely dependent on the weather conditions.

Where sufficient storage capacity can be provided to tide over the period during which the weather conditions are unfavourable, there is no doubt in my mind that open type sprays or cooling ponds are to be preferred. If sufficient surface area and volume can be provided in a cooling pond, in my opinion this is the best system to adopt.

The reliability of a forced draft tower has to be paid for in the cost of operating the fans and pumping the water to the level required. With natural draft and open type cooling towers and sprays the cost of operating the fans is eliminated, but the cost of additional pumping remains. With a cooling pond there is no energy cost to be added to the capital cost. Cooling ponds unfortunately can only be used in open positions, where they are fully exposed to the winds.

The table given by Mr. Marriott showing the increase in surface area exposed, as a gallon of water is divided into drops of decreasing diameter, is valuable. If we can ascertain the exposed area, a simple matter in the case of a cooling pond, it is, in my opinion, possible to predetermine the amount of cooling which can be effected.

The result of a series of tests made by me in Rangoon was to indicate that the cooling effect was mainly dependent on wind velocity and absolute humidity. Mr. Marriott, in his paper, and the other writers who have dealt with this subject, give values of atmospheric temperature and relative humidity. I am of the opinion that these terms can be, for all practical purposes, reduced to the one term, "absolute humidity." The cause of variations in relative humidity is usually a change of atmospheric temperature, and although these change rapidly and frequently, the change in absolute humidity is relatively small when the temperature does not fall below the dew point.

Turning to Table A of Mr. Marriott's paper, I have compared the values of absolute humidity of the tests given for No. 1 plant. In these tests the inlet water temperature and the temperature drop in the water are practically constant, but the values of air temperatures and relative humidity vary very much. Comparing the absolute humidity values of these tests, I find that the weight of water in the air in all three cases is practically the same. The figures are 1.35, 1.31, and 1.36 lbs. per 100 lbs. of air. I am therefore of the opinion that Mr. Marriott's assumption with regard to the influence of radiation and convection during these tests is incorrect, and that the rate of cooling is constant because the absolute humidity is constant. I agree that the effect of radiation and convection is relatively greater at low temperatures, and is of importance when the wind velocity is low. For practical purposes, however, the air velocity should be sufficiently high to render these factors negligible. In my opinion, the factor of evaporation is the only one which should be considered in the design of cooling apparatus.

If it is assumed that the cooling effect is dependent upon water temperature, wind velocity, and absolute humidity, a series of curves can be prepared from which the rate of cooling to be expected under any given conditions can be ascertained. Such curves are shown in Figure 6 of my paper referred to above. I think the subject is worthy of investigation on these lines over a wide range of temperatures. There should be no insuperable difficulty in designing suitable cooling apparatus when the weather conditions are known.

The problem is one which is of greatest importance in tropical countries, and it is to the engineers who have to operate these plants under adverse conditions, such as Mr. Marriott, to whom we much look for the solution. Mr. Marriott is to be congratulated on the excellent paper which he has prepared.

Mr. Vicars: He had made some experiments with a view to testing the relative efficiency of sprays and cooling towers which showed that the best form for a cooling tower was found to be a triangular piece of timber with notches $1\frac{1}{2}$ inches apart with a saw cut an inch deep. The water dropping on the apex of the sections gradually spread over the sides, and thus gave the best results and smallest amount of trouble.

The Cunningham spray of Broken Hill was adopted, but would not be suitable for localities to which the author has referred. Of course, the jet is a very fine one, but has very little spread. Another experiment was carried out, where a canister was used very much of the type shown for garden spraying, 6in. in diameter, 3in. depth, top slightly curved, inlet 1in. diameter, with a pressure of 50lbs., a spray of 50ft. was obtained, but this was not so good as Cunningham's type. The drops were too large, and the cooling effect bad. In calculations he considered that the humidity of the air played a very important part, and on looking up information on the subject it always appears that this was so. The temperature of the air has also been of considerable moment, as is also the temperature at which the air leaves the system for the reasons mentioned by Mr. Ferrier. As regards the impact of the drops, if the upper drop impinges on a lower one, they will not combine. The upper one will be deflected at an angle corresponding with that of the impact. When two objects of the one nature are projected in the one direction, after impact they will combine, and stay combined, and drop together.

Mr. Tournay-Hinde, in referring to the spray, said that if a very fine subdivision of water is required, would it not be economical to pump a small quantity of air through the jet, and by that means atomise the jet? Or, perhaps, could the author say if the loss due to drifting would be too excessive to use this method of delivery?

Mr. Marriott, in reply, said he thanked those present for the way in which they had received his paper. Before replying, he would like to remind them that when he started to investigate the subject, the tower plant existed, and the cost of maintenance was high. The question was—How to put something less costly in? As regards the size of nozzles, the small one is better for spraying, but the maintenance was to be considered. To put in fine installations is a greater risk. We were aiming at reducing the cost if we could get the same amount of cooling.

With regard to Mr. Sinclair's remarks about the collision of drops, the question as to whether they would adhere or break would depend on the velocity; it is a matter of impact. There is another point in this collision of drops: A drop falling in an ordinary way would have some outside surface which would be cool and the inside would be hot; on colliding with another drop they would be squeezed, and the inner part would come to the outside. It is difficult to tell whether the drops are increasing or decreasing in size. Mr. Sinclair laid stress on humidity. It does play a large part; but in running out the actual figures we got the effect of humidity was apparently obliterated.

Mr. Ferrier's remarks about maximum and minimum figures: These could be given, but since they all come within the hatched area of the curve in Fig. 9, they could readily be obtained. The question of a large nozzle: The object has been stated for using a large nozzle in dealing with a large quantity of water, a great deal of labour would be required for keeping the nozzles clean, and for this reason it is better to use large nozzles, it having been found that there is also less trouble with blockage of the orifice.

Mr. Ferrier also remarked on the moisture carrying capacity of air with increased temperature. The higher the temperature the better the carrying capacity; but in the spray systems you do not know the actual amount of air you are handling, and it had to be ignored more or less, being dependent upon the weather conditions at all times.