The principle of the permeable dyke was probably invented in India. In India to-day *bandals* were used to silt up one, and open out the other, of alternative cold-weather channels of the Ganges. *Bandals* were rows of bamboos worked into the sand and connected and steadied by string. Permeable dykes of long Oregon piles connected in groups of three piles had been tried with varying success. The permanent permeable dykes used in Argentina were an advance on Indian practice, but before it could be said whether they would be successful in India further information would be necessary as to the seasonal variation, and maximum discharge, of the rivers in which they had been used with success in Argentina.

The Author regretted that he was unable to give more time to the remaining communications owing to the War, but he believed that Mr. Trench would find that most of his requests for information had already been complied with.

Paper No. 5143.

"The Total-Heat-Entropy Diagram for Diphenyl."†

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Correspondence.

Mr. W. L. Badger, of Michigan, observed that three substances should really be considered: diphenyl, diphenyl oxide, and Dowtherm A. Diphenyl had a boiling point of 490° F. and a freezing point of 154° F.; diphenyl oxide had a boiling point of 498° F. and a freezing point of 81° F.; Dowtherm A was an eutectic mixture of the two, having a freezing point of 54° F., and it contained 73·5 per cent. diphenyl oxide and 26·5 per cent. diphenyl. The thermal properties and stability of diphenyl and diphenyl oxide were so nearly alike that thermodynamic data derived for either might be used for the other, or for the eutectic mixture, with an accuracy probably within the limits of precision with which any basic data then available were known.

The thermal properties of those compounds had been discussed in more or less detail by a number of different authors. One of the early advocates of the binary cycle for power generation was Dr. H. H. Dow*, who presented considerable thermodynamic data for diphenyl. Two outstanding Papers giving the properties of Dowtherm A were those of

† Journal Inst. C.E., vol. 10 (1938–39), p. 227 (December 1938).

* "Diphenyl Oxide Bi-Fluid Power Plants." Journal Am. Soc. Mech. E., vol. 48 (1926), p. 815 (August 1936).

Gaffert ‡ and of Ullock, Gaffert, Konz, and Brown||, whilst data on diphenyl had been recalculated by Findlay††.

The Mollier charts given by the Author and by Gaffert checked very closely, but the specific heats of the liquid presented by them did not agree at all with those of Ullock, Gaffert, Konz, and Brown. An examination of all of that data had been made in considerable detail but the source of the difference was not yet apparent. The Author's curve for a pressure of 5 lb. per square inch absolute was not in agreement with the data given in his Tables, nor with the values in Gaffert's diagram. The values given by the Author in his Tables for that pressure did, however, check Gaffert's values.

The Author had presented several representative cycles for binary systems, and his efficiencies compared very closely with those given by Dr. H. H. Dow in the early publication, whilst Gaffert had discussed the matter in greater detail than either. Probably the greatest difference of opinion of those three authorities lay in their choice of pressure for their high-temperature turbine. The Author advocated expanding to a pressure of 1 lb. per square inch absolute; Dow suggested expansion to atmospheric pressure, or to a moderately high vacuum; Gaffert, on the other hand, had gone to considerable trouble to show that the most economical exhaust pressure for diphenyl oxide, or for similar compounds, was approximately 25 lbs. per square inch absolute. Gaffert showed the possibility of high economy from diphenyl-oxide turbines, and its advantage due to the large available supply. Dow, on the other hand, pointed out the limitations of excessive high-pressure steam due to the decrease in accessory efficiency; he stated that it was mathematically possible to demonstrate that an overall efficiency of only about 28 per cent. should be expected from steam systems, whereas those calculated for binary systems by the Author and Dow were 33 and 34 per cent.

Mr. Badger thought that it was unfortunate that the Author had apparently not taken into consideration (or at least referred to) the previous literature on the subject.

Mr. J. F. Field felt the Author was perhaps too optimistic regarding the practical possibilities of a binary-fluid arrangement using diphenyl and steam. He described a cycle in which heat was taken in by diphenyl at a pressure of 200 lb. per square inch absolute, corresponding to an upper heat-cycle temperature of 784·3° F. The efficiency of the cycle worked out at 49·6 per cent. (Example 1) and the Author claimed near the bottom of p. 235 §, that such an arrangement might have an actual efficiency of

‡ "High-Pressure-Steam and Binary Cycles as a means of Improving Power-Station Efficiency." Trans. Am. Soc. Mech. E., vol. 56 (1934), p. 755.

|| "Thermal Properties of Dowtherm A." Trans. Am. Inst. Chem. E., vol. xxxii (1936), p. 73.

†† "Some Suggestions for Diphenyl Heat-Engine Cycles." *The Power Engineer*, vol. xxix (1934), p. 89 (March 1934).

§ Page numbers so marked refer to the Paper. (Journal Inst. C.E., vol. 10 (1938–39), p. 227 (December 1938).—Sec. Inst. C.E.

33·58 per cent. The ratio of those two efficiencies was 67·7 per cent. Reference to Mr. Field's Paper * indicated that there was no authentic record in Great Britain of a steam plant reaching a higher ratio than about 62·5 per cent. of the ideal steam-cycle efficiency, in spite of the intensive development of steam plant over many years. In a binary-fluid arrangement the inevitable temperature-drop in transferring the heat from the upper- to the lower-temperature fluid seemed to indicate the prospect of a somewhat smaller ratio between the efficiency of the engine and the ideal efficiency of the heat cycle.

The Author did not mention the specific volume of diphenyl gas, but since the ratio of weight of diphenyl to weight of steam in the cycle described was of the order of 6 to 1, the physical properties of the fluid might entail difficulties in mechanical construction of a suitable turbine.

The Author compared the diphenyl–steam engine with a mercury-vapour–steam arrangement which had been tried in America, and from which it was hoped to achieve a thermal efficiency of 35·9 per cent. There was no evidence yet that such a figure had been reached for any length of time, although experiments had been proceeding for a number of years. There was little doubt, however, that such efficiencies were possible with mercury if the various physical difficulties already met with could be overcome.

It was instructive to study the essentials of the mercury cycle from which that performance was anticipated. Mr. Field believed that the mercury took in heat at a temperature of about 884° F., corresponding to a pressure of 70 lb. per square inch gauge, and that the binary cycle had an ideal efficiency of about 57 per cent. The expected ratio of efficiency was therefore about 63 per cent. and that might be optimistic in view of the temperature-drop required between the two working fluids. There was little doubt that a diphenyl engine, taking in heat at 784° F., would be at some disadvantage with such a mercury arrangement, taking in heat about 100° F. higher; further, with mercury still higher temperatures could be arranged with comparatively easy pressure conditions.

With steam it was now technically feasible to operate at, say, 2,500 lb. per square inch gauge and 1,000° F. total temperature, with reheating at, say, 600 lb. per square inch gauge to 825° F. and with feed-heating to 550° F., which would give an ideal-cycle efficiency of 54 per cent. An efficiency-ratio of 62·5 per cent. could reasonably be expected with those conditions, giving a working efficiency of about 33·5 or 34 per cent.

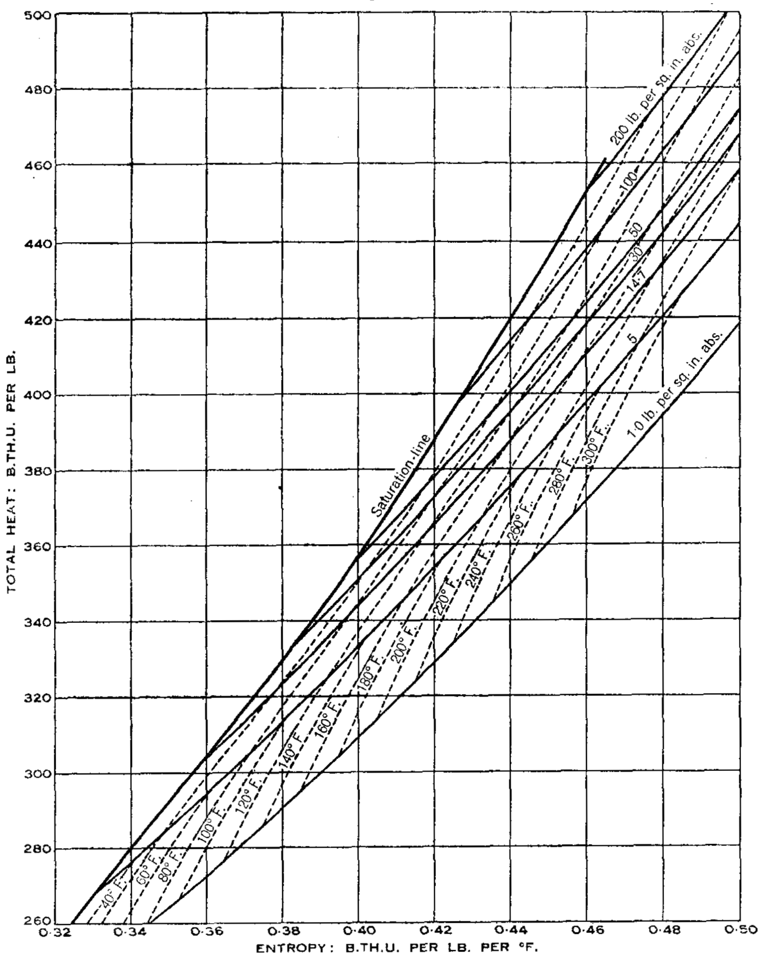
In those circumstances it seemed difficult to justify the use at the present time of any fluid other than steam, which had physical properties of unique convenience which were not always appreciated. Efficiency depended mostly on the upper limit of temperature, irrespective of pressure, and

* "A Suggested Basis of Comparison for the Efficiency of Steam Turbo-Generators and of Steam–Electric Generating Stations." *Journal Inst. C.E., vol. 10 (1938–39)*, p. 241 (December 1938).

Mr. Field felt that if the metallurgical problem were solved for any relatively low pressure, suitable mechanical designs for the higher pressures required with steam would follow.

Mr. J. R. Finniecome observed that diphenyl and diphenyl oxide, and the mixture of both, known as "Dowtherm", were known principally as heat-transfer media at temperatures of from 500° to 700° F. and at corre-

Fig. 4.



spondingly low pressures of from 15 lb. per square inch absolute to 115 lb. per square inch absolute for reheating steam and for preheating air.

The use of skew co-ordinates for the total-heat–entropy diagram was more suitable for indicating, graphically, the complete cycle of diphenyl for the liquid, the saturated and the superheated regions. Mr. Finnicome found that the rectangular co-ordinates generally used for total-heat-entropy charts for steam, air, and other gases, had the advantage that the heat-drop could be scaled directly off the vertical line for any specified conditions. He had prepared such a chart (*Fig. 4*) for the superheated region based on the Author's data contained in the Tables. Incidentally, he wished to point out that there was a misprint in Table V (p. 237 §): for a temperature of 60° F. the entropy should be 0·3319, not 0·3219.

Mr. Keith Fraser observed that an interesting allied use of diphenyl occurred in the Bremo Bluff power-station of the Virginia Public Service Company, in the United States, where a "Dowtherm" economizer was located directly above a single-pass boiler with a heating surface of 19,830 square feet, which was extremely high, making the gas outlet and source of heat for preheating air a considerable distance from the pulverizers on the ground floor. The heat was then transmitted through the "Dowtherm" system to the air-heaters to pulverizers at ground-floor level.

The particular reason for using the eutectic mixture referred to in the Paper was that the vapour was also in the same proportions of diphenyl and diphenyl oxide as the liquid, and the condensate was therefore in the same proportions, thus maintaining equilibrium in the system. In addition to that, the eutectic had a lower freezing point (52·7° F.) than pure diphenyl, which froze at 154° F. The eutectic would therefore appear to be a more suitable medium than pure diphenyl as described by the Author. It was of interest to note that further methods of freezing-point depression had been used by Lucas * and others. The physical properties of the eutectic did not differ, so far as was known, very greatly from those given by the Author.

Dr. H. H. Dow advocated the use of diphenyl oxide as a rival to mercury and binary-fluid plants†. It did not decompose at the temperatures required in the boiler, and its vapour was about 9·4 times the weight of steam vapour, with the result that a turbine with that substance would run at lower speed with higher torque at the same horsepower. Mr. Fraser might draw attention to Dr. Dow's patent||, while interesting data on heat-transfer coefficients †† and liquid-film heat-transfer coefficients ‡ had been given by Mr. W. L. Badger.

The Author, in reply, observed that he was indebted to Mr. Badger

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§ *Ibid.*

* British Patent Nos. 398,492 and 427,170.

† "Diphenyl Oxide Bi-Fluid Power Plants." Journal Am. Soc. Mech. E., vol. 48 (1926), p. 815 (August 1926).

|| U.S. Patent No. 188–311.

†† W. L. Badger, "Heat Transfer Coefficients for Condensing Dowtherm Films." Industrial and Engineering Chemistry, vol. 29 (1937), p. 910 (August 1937).

‡ D. S. Ullock and W. L. Badger, "Liquid-Film Heat Transfer Coefficients." *Industrial and Engineering Chemistry,* vol. 29 (1937), p. 905 (August 1937).

for the references to previous Papers. The Author's Paper had been completed in midsummer 1936, and although the usual search had been made he had failed to find any reference to the excellent Paper by Gaffert (to which the Author had now had limited access), or to the later one by Ullock, Gaffert, Konz, and Brown.

The specific heats of liquid diphenyl given in the latter Paper had been checked with those in the Author's Paper, and, contrary to the opinion expressed by Mr. Badger, they appeared to agree very well. Perhaps Mr. Badger was considering the vapour, rather than the liquid. On the other hand, the specific heats of the superheated vapour of diphenyl taken from Mr. W. S. Findlay's curves did not agree with the specific heats of the vapours specified in Gaffert's Paper, and differed considerably from the values given in the Paper by Ullock, Gaffert, Konz, and Brown, which themselves differed from Gaffert's earlier values. That difference appeared to be a matter for further investigation. The Author had checked the curve for a pressure of 5 lb. per square inch absolute, and it appeared to be consistent with the tabulated data.

The comments of Mr. Field on the more practical possibilities were very interesting. He apparently considered an efficiency ratio of 67 per cent. too high by comparison with the figures tabulated in his own Paper. It would appear, however, that the efficiencies stated in Mr. Field's Paper referred to overall station efficiencies averaged over a period of 12 months, and covering losses not normally incurred under simple test conditions. Mr. Field remarked that efficiency depended mostly on the upper limit of temperature irrespective of pressure. That, of course, was substantially true, but the modern steam cycle obtained its high efficiency by a combination of high temperature and high pressure, as could be seen from the last Table in Mr. Field's Paper *.

The practical interest in binary-fluid systems lay in the possibility of obtaining the advantages due to high temperature without the disadvantage of high pressure, thereby making it possible to utilize cheaper materials of construction, with a consequent great saving in capital cost.

The Author was obliged to Mr. Finniecome for pointing out the error in Table V (p. 237 §), and for the chart for the superheated region. He was also indebted to Mr. Fraser for his remarks on the "Dowtherm" economiser, and for the references, which would be of value to other workers in the field.

* Footnote (*), p. 334.
§ *Ibid.*