Professor Ripper.

steam at initial pressure. As to the existence of water in the presence of superheated steam, he saw no difficulty in supposing that water in the form of globules, in the process of being evaporated, might be swept forward through the lower coils, and exist for a short period in the presence of superheated steam. This seemed to be proved by the fact that a considerable fall of temperature took place in the vertical chamber connecting the second coil from the bottom with the top coil of the superheater, though the steam entering this chamber was highly superheated. The fall of temperature was probably due to the evaporation of water carried over with the superheated steam into the chamber. The length of steam-pipe between the superheater and the engine stop-valve was 48 feet. The area of the tube surface of the condenser was 46 square feet. He agreed with Mr. Davey that the number of units of work per unit of heat was a useful measure of efficiency. It was only another form of "absolute thermal efficiency," the value of which was given for all the trials and from which the form suggested by Mr. Davey might be at once obtained thus: units of work per unit of heat = 778 × absolute thermal efficiency per cent. ÷ 100.

Correspondence.

Mr. Fairley.

Mr. WILLIAM FAIRLEY thought the Paper gave abundant proof of the accurate and exhaustive manner in which the trials of the engine in question had been carried out. At the same time, it was a pity the labour expended on the trials of the small Schmidt motor had not been devoted to a plant more in accordance with usual English practice. The boiler, superheater and motor must be considered as a whole, and no element of economy in the use of steam in the cylinders should be considered, without also taking into account the want of economy in the steam-generator. The plant having been built for the special purpose of generating and utilizing superheated steam, the trials with saturated steam might have been omitted, as the motor was of a type not suitable for the economical use of saturated steam, and consequently a comparison of the results obtained with superheated against saturated steam was unfair. From the point of view of the steam-user, whose chief object was the production of power economically, it would appear that the generator, motor, &c., in question, even with a very high degree of superheat, were not more economical than many engines and boilers constructed in England of similar power, using

Mr. Fairley. saturated steam only. The trials no doubt proved the proportionate gain in economy (so far as quantity of steam used in the cylinder was concerned) as the quantity of heat carried in by the steam was increased. At the same time numerous trials, proving this point, had already been made on the Continent, the majority carried out with engines larger and more perfect in construction than that referred to in the Paper. It was almost generally agreed that large economy might result from the judicious use of superheated steam, but if it was to be more generally used, the apparatus for its production must be suitable for connecting to existing plants, with the present types of boilers and engines.

He had, during the past two years in the pumping-station of the Richmond Main Drainage Board, used superheated-steam in some eighteen sets of engines of various types, and would point out one or two of the practical difficulties which he had observed. The superheater was of the Schwoerer type, the castings having been supplied by Messrs. J. Simpson and Company. It was placed at the back of a Galloway boiler, where the temperature was high, as the gases issued from the boiler flue. No difficulties had been experienced in the regulation, within certain practicable limits, of the superheater, nor in any of the different types of engines in use had serious practical difficulties arisen from the use of superheated steam in the cylinders, although no attempt had been made to obtain such high temperatures as those obtained by the Author. The chief difficulty that had to be contended with, was one which would be experienced in any large work having a considerable length of steam-pipe in daily use, namely, the conveying of the superheated steam from the superheater through the steam-pipes without losing almost the whole of the added heat before the steam reached the engines. As to the regulation of the superheater, the Author's experience was similar to his own, although he had not found the apparatus quite so sensitive to the draught of steam as the Author had apparently found his plant. If the steam, however, was taken into a range of steam-pipes and used in the ordinary way it would be found in working that, although there was a considerable gain in using the steam in the condition in which it reached the engine, yet the amount of superheat was unappreciable, and it would appear that, not only must the steam move at a high velocity through the tubes of the superheating apparatus, but it must also be carried along the steam-pipes at a high velocity to the point where it was to be used. Numerous experiments had been made on this point, and in one case he had found a higher degree of superheat could be taken through 150 feet of steam-pipe, in a case where the steam-piping was too small to convey saturated steam to the engines, than was obtained in an engine within 50 feet of the superheater, and where the steam was moving at about the same velocity as if saturated steam had been used, the pipes being of sufficiently large diameter for all purposes. With reference to the leakage round the pistons, the Author appeared to hold the view that it was smaller with superheated than with saturated steam. This was contrary to his experience. He thought the waste with superheated steam from a leaky joint would be found much more serious than with saturated steam. Steam-piping, steam-chest covers and pistons, which to all appearances were steamtight when used with saturated steam, developed a considerable amount of leakage when superheated steam was used. Mr. Fairley.

There was one class of engine in which it would appear superheated steam could, in a great many cases, be used with considerable advantage. He referred to the ordinary type of duplex-pump, which was much in favour, and was used in many cases on account of convenient form and handiness, without reference to its wastefulness of steam. In such an engine he had found that with a moderate degree of superheat in the cylinders, an economy varying between 20 per cent. and 30 per cent. could be effected. With the better class of engine the economy was proportionately smaller. He believed the use of superheated steam would yet become more general when the economy arising from its use was more fully known; but he thought a superheater placed in a separate, independently-fired furnace, and not, as generally attempted, in the boiler flues, would be found more convenient and not much less economical.

Mr. R. A. Hadfield asked, with reference to the important question raised in the Paper regarding the heat exchange between the steam and cylinder walls, if any definite information was available as to the value of different classes of material for this purpose. He understood considerable economy had been obtained in America by lining the cylinder-walls with a non-conducting material, and by constructing the cylinders of a material of low conductivity. It would no doubt be possible to produce alloys having much lower conductivity than the ordinary material now used, and, perhaps, the Author would say if he had any knowledge of such results. This Paper had dealt with an important development which English power-users would do well to investigate, and it was another proof that the technical schools should in the future prove of the greatest service in Mr. Hadfield.

Mr. Hadfield. calling attention to important developments which it was impossible for the ordinary manufacturer to work out amidst the ordinary high pressure of business routine.

Mr. Patchell. Mr. WILLIAM H. PATCHELL thought the question of primary importance was how to increase the economy of existing steam plants. The arrangement of superheaters shown in the Paper formed an effective application of the counter-current principle; he believed it was usual to add a water-heater in the manner suggested by the Author. Regulation of the amount of heat was the crux in superheating; with a grate-area of 2 square feet and a steady load the Author had found no trouble, but during periods of cleaning fires and varying loads, with a boiler evaporating say 10,000 lbs., or 12,000 lbs. of water per hour, such smooth running would probably not be obtained with the arrangement shown. He had frequently combated the error to which the Author had drawn attention of rating the superheating surface as boiler heating-surface. The superheating tubes could not be credited with evaporation unless there was water to evaporate, and if the superheating surface was rated as evaporating surface, it condemned the boiler as a priming one. Superheat might be used in many ways; it could be carried through to the engine as in the Author's trials, or it might be used to counteract the condensation in long steam-pipe ranges, or to increase the boiler-power; or, as he had found, these two latter alternatives might be combined with great advantage by the use of the McPhail-Simpson apparatus. If it was this apparatus to which the Author had referred as a "so-called superheater," it would be interesting to know why this epithet had been used. He had seen many tests on the apparatus, but never one in which it failed to superheat the steam as judged by the Author's definition, p. 61. The degree of superheat was predetermined by the dimensions of the pipes used, and varied in different apparatus. He had tests before him showing regulated superheats up to 240° F. above the normal temperature. Exception might be taken to the indicator springs being calibrated cold. The mechanical efficiency of the Schmidt engines must undoubtedly be of a high order, for similar results to those recorded by the Author had also been obtained by Professor Schröter in the summer of 1894 on a Schmidt single-crank vertical tandem engine indicating 70 HP. On the first day's running this engine had given 86·5 per cent. mechanical efficiency, and on the second day 82·6 per cent., being a mean of 84·5 per cent. Temperatures of 600° F. might be arranged for without much difficulty in isolated plants, but he viewed with apprehension such temperatures on long ranges of steam-pipes and connections as obtained in central-station plants unless it was steady, as the changes in temperature would fatigue the materials and lead to considerable trouble with the joints. As to the deterioration at these temperatures, he had not had the slightest trouble or found any signs of deterioration in superheating pipes after three and a half years' work day and night. He did not consider the Author's 2 square feet of grate-area sufficient premises from which to draw his conclusions for the safe and economical use of these high amounts of superheat. They might be, and in fact were, economical on the plant described, which was very poor without them; but he thought true economy in most cases, where fairly economical engines and boilers were already at work, would be rather on the lines of moderate degrees of steadily-regulated superheat, which was now easily obtainable without danger or inconvenience and brought a gain of 15 per cent. to 25 per cent. Mr. Patchell.

Mr. W. SCHMIDT, of Aschersleben, Magdeburg, remarked that in November, 1896, trials had been made at Nuremberg of a 100-HP. tandem compound Schmidt motor by the Bayrischen Dampfkessel-revisions Verein. They had extended over four ordinary working days of eight hours, during which the engine was working at the rate of 105 I.HP., that was to say, at an uneconomical rate of expansion. The consumption of steam, however, had not exceeded 9·46 lbs. per I.HP. per hour, while a consumption of only 10·56 lbs. had been guaranteed. The plant included two vertical transverse tubular boilers, with superheaters, fired with Westphalia coal, the rate of evaporation being 7 and the feed-water temperature only 11° C. During 1896 a superheated steam-engine of 500 HP. to 650 HP. had been installed at the Thale Ironworks, and had since been working day and night. It drove a plate-rolling plant, and was therefore subjected to unusual variations of load; it had nevertheless from the first worked with perfect regularity. More than one hundred superheated-steam engines had been put to work, and all had satisfied the highest expectations with regard to economy. Mr. Schmidt.

Mr. M. SCHROETER, of Munich, observed that at the time of his trials at Cassel, referred to by the Author, the feed-water consumption of the 60-HP. compound engine of the Schmidt type, built by Messrs. Beck and Henkel, was the lowest ever recorded by any steam-engine, viz., 12·2 lbs. per brake HP. per hour. It had since been surpassed by a 100-HP. compound engine, built by Messrs. Dingler at Zweibrucken and tested by Professor Gutermuth, who obtained 11·5 lbs. steam per brake HP. per hour Mr. Schroeter.

Mr. Schroeter. with the same steam-pressure and superheating temperature (350° C.). A larger engine had given still better results; and feed-water consumptions of 10·29 lbs. per I.HP. per hour had been obtained[1] with an 800-HP. Corliss engine of the ordinary double-acting-type, built by Messrs. Berger André at Thann, and similar numbers for other engines.

The feed-water consumption would, no doubt, be brought down to 10 lbs. per brake HP., or 9 lbs. per I.HP. with large engines, and a temperature of the steam of 350° C., and his own experience led to the same conclusion at which the Author arrived, that in the use of highly superheated steam lay the means by which the theoretical limits of the steam consumption fixed by the well-known thermodynamic formulas might be approached, if not reached. The number of superheating plants was daily increasing in Germany. Of the Schwoerer type of superheater there were now running more than eight hundred plants, combined with boilers of every description and pressures up to 20 atmospheres. Seven hundred of these were producing about 120,000 HP., and about 200,000 HP. were now produced by superheated steam. The economy over saturated steam was considerable, but in some cases the resultant gain was much smaller, all things being considered, and this influenced the cost of the effective HP. Not only the coal burnt for superheating, but also the excess of oil required and the interest on the capital must be taken account of, for as the Author justly observed: "It is not the steam that does the work, but the heat." It was thus of the greatest importance to have as high an efficiency as possible for the boiler and superheater taken together, otherwise the economy in coal might be far less than the economy in steam. As to the causes of the latter the Author had added a new proof of the usefulness of the temperature-entropy diagram. He could corroborate the statement that the practical difficulties, formerly so dreaded, had almost entirely disappeared, even large double-acting engines of the ordinary type were working quite satisfactorily with high degrees of superheating.

Concerning the use of superheated steam in the low-pressure cylinders of compound engines, he might quote an experiment[2] made by Prof. Gutermuth, with the 100-HP. engine referred to. Superheating the steam in the receiver from 173° C. to 244° C. was found to lower the steam-consumption from 4·806 kilograms

[1] "Report of the Association Alsacienne de Propriétaires d'Appareils à Vapeur" of 1896.

[2] Zeitschrift des Vereins deutscher Ingenieure, vol. xxxx., 1896, pp. 1390, 1417.

Mr. Schroeter.

per I.HP. to 4·736 kilograms, but at the same time the coal consumed increased from 0·766 kilogram to 0·808 kilogram per I.HP. This result could not be generalized. In this special case a second boiler was used for the intermediate superheating, and so the unfavourable result might easily be explained. It was interesting to note that even a superheating of 111° C. above the temperature of saturation was not sufficient to hinder the condensation on the walls of the low-pressure cylinder.

Professor Sinigaglia.

Professor FRANCESCO SINIGAGLIA, of Naples, observed that the importance of superheating had long been undisputed, even before Hirn had found, in his celebrated experiments, economies of 20 per cent., 31 per cent., and 47 per cent. with steam superheated 210° C., 225° C., and 245° C. respectively. The trials described in the Paper showed the application of steam superheated 163° C., by the method of mixture which was the best for regulating the amount of superheat. The system had hitherto not been applied on so large a scale as was to be expected, but, like all industrial problems, it was complex, and its final result ought to be counted by the saving effected, having regard to the cost of installation, the repairs, the idle time, etc. It was only by an active propaganda that the benefits of the application of scientific truth were to be shown in practice. To popularize, then, the methods of the laboratory and the results of well-conducted experiments was a means of contributing to the progress of the steam-engine. The experimental work of the Author was, on this account, very important. His engine, however, possessed extraordinary features. The advantage of superheat, which was now regarded as the most efficient method of improving the economy of the steam-engine, was clearly shown in the Paper, the entropy diagram threw theoretical light upon the questions, and the heat-exchange diagrams, after Prof. Dwelshauvers-Dery, limited by the Author to the period of admission of the steam, showed the influence of the cylinder-walls at different degrees of superheat. The Paper was of great theoretical and practical importance, and dealt with many details useful to engineers.

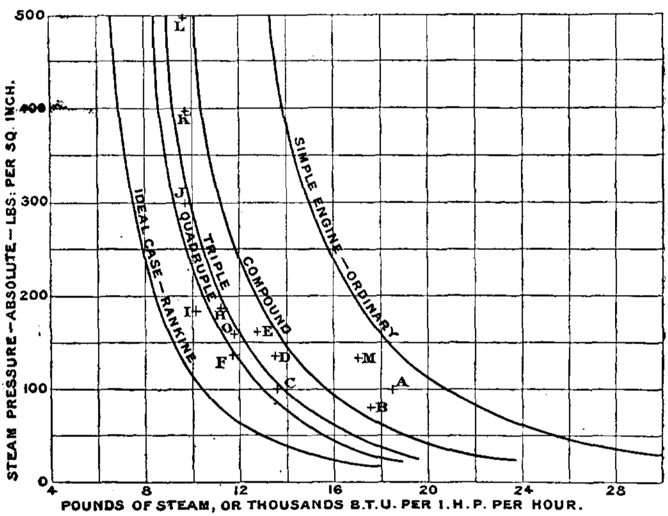
Professor Thurston.

Professor R. H. THURSTON had read the Paper with unusual interest, as he had but recently had occasion to look into the whole subject of superheating, and to collate the evidence bearing upon this important and growing question.[1] His con-

[1] "Superheated Steam: Facts, Data and Principles relating to the Problem." By R. H. Thurston, Transactions of the American Society of Mechanical Engineers, vol. xvii. p. 488.

Professor Thurston. clusions were substantially those expressed by the Author in the introduction to the Paper. Among all the records of engine-trials in which the effect of superheating the steam was exhibited—and there were many—he had found none as complete and as satisfactory in its detailed illustration of the method and the result of this system of increasing efficiency, as that given in the Paper. In no case had superheating been carried to such extent in regular working as in the Schmidt engine, so that it was well suited for illustration and measurement of the value of the process. On the other hand, so small an engine was subject to great "cylinder-

Fig. 70.



A, Sulzer, 1; B, Corliss, 1; C, Sulzer, 2; D, Sibley College, 3; E, Rockwood, 2; F, Reynolds, 3 G, Sulzer, 3; H, Leavitt, 3; I, Schmidt, 2; J, K and L, Sibley College, 4; M, Schmidt, 1.

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condensation," and thus excessive superheating was demanded to extinguish that form of heat-exchange. This, in turn, prevented the full value of the process being realized as in a larger engine; it required 350° of superheat to insure complete suppression of initial condensation. He considered 100° of superheat, in ordinary large mill-engines, would reduce this waste to nearly a minimum. This was also why, even with 326° of superheat, and with steam at more than 130 lbs. per square inch pressure, the steam demanded amounted to 17 lbs. per I.HP. per hour—50 per

Professor Thurston.

cent. more than the best present record. The results reported[1] for an earlier engine of the Schmidt type formed a better example. The best results with saturated or nearly saturated steam hitherto obtained, and those of Professor Unwin for another Schmidt engine, were compared in *Fig. 70* with the ideal and proportional efficiencies computed by now familiar processes.[2] The ordinates represented absolute pressures, and the abscissas lbs. of steam per I.HP. per hour and equivalent heat, assuming that, with return of jacket-water in usual proportions, the steam received, at the boiler, 1,000 B.T.U. per lb. In many cases, however, this figure was more nearly 1,100 B.T.U. The curves showed the performances of well-known engines using ordinary steam. That marked H, was Leavitt's Chestnut Hill pumping-engine; I, was the case of the larger Schmidt engine reported by Professor Unwin; J, K, L were figures obtained from the 20-HP. four-cylinder experimental engine of Sibley College at various pressures up to 500 lbs. per square inch. Were this latter engine reproduced on a large scale, it would carry its figures over beyond the line designated as that which should be reached by good quadruple-expansion engines. The base-curve was marked "ideal," and represented the work of the ideal engine with saturated steam, worked in a non-conducting cylinder, and in the Rankine cycle. The parallel curves were those for multiple-cylinder engines, assuming the internal waste inversely as the number of cylinders in series. The figures attached to each name indicated the number of cylinders in series. One Sibley College engine was rated at 20 I.HP. at 500 lbs. pressure. The other was rated at 175 HP. at 175 lbs. pressure; but it has only been worked as yet at 100 lbs. or 125 lbs. He had inserted at M the point indicating the relative standing of the engine which was the subject of the Paper. He had found that increased speed of rotation of a shaft might improve lubrication by promoting the supply of the lubricant sufficiently to sensibly reduce the friction-waste of the machine. He thought, however, there was a limit to this particular effect; the friction of fluid becoming after a time sensible, increasing, as it did, as the square of the velocity of rubbing. Similar results to those summarized in his own conclusions had been obtained by Mr. Dixwell in his Massachusetts Institute of Technology investigation at Boston twenty years ago.[3] It was interesting to find such complete accord

[1] Professor W. C. Unwin, Minutes of Proceedings Inst. C.E., vol. cxxii. p. 179.
[2] "Manual of the Steam-Engine," vol. i. New York: J. Wiley and Sons.
[3] Transactions of the Society of Arts, Boston, 1875.

Professor Thurston.

with these later researches and more scientifically complete investigations. In the Paper[1] referred to he had stated the conclusions to which he had been led by the results of his research. The present value and the future potentialities of superheating could not be now disputed. A good and durable superheater, capable of giving the degree of superheat required at any stated cut-off, and adaptable to any size of engine, in such manner as to just extinguish the condensation due to the heat-exchange between the entering steam and the cylinder-wall, was the one thing necessary in the improvement of the existing machine with metal cylinder-wall.

Professor Ripper.

Professor RIPPER, in reply to the Correspondence, observed that the difficulty felt by Mr. Fairley, and by many other engineers, was that of conveying the superheated steam from the superheater in long ranges of steam-pipes without losing almost the whole of the added heat before the steam reached the engines. On the other hand, Mr. Patchell asked why an arrangement should be spoken of as a "so-called superheater" which first superheated the steam and then deliberately turned it into pipes standing in the comparatively cold water-space at the bottom of the boiler in order to cool it; after which it superheated it again, and again turned it into the water-space of the boiler to again cool it. After this treatment it was sent forward to the engine. It might be contended that there was no loss of heat by this arrangement, because the heat lost by the steam was used to evaporate water. That was so, and to that extent the "superheater" was not really a superheater, but an extension of boiler heating-surface, as was all surface which transferred heat, directly or indirectly from the furnace gases to evaporate water as distinguished from superheating the steam. This accounted, he thought, for the increased power, and perhaps also for the increased efficiency of boilers fitted with this device. He considered the best remedy for the difficulty pointed out by Mr. Fairley was to supply saturated steam at the boilers, and to fix separately-fired superheaters as close as possible to the respective engines. The experience of Mr. Fairley that the steam must move at a high velocity, not only in the superheater but also between the superheater and the engine, appeared to be different from that of Mr. Chatwood, who had maintained that while high velocity in the superheater tubes assisted the flow of heat to the steam, velocity

[1] "Superheated Steam: Facts, Data and Principles relating to the Problem," *loc. cit.*

Professor Ripper.

would have an opposite effect, and accelerate the rate of cooling after the steam had left the superheater. With reference to Mr. Hadfield's question as to the value of material of low conductivity for cylinder walls, Professor Thurston had recorded several experiments[1] as to the effect of coating the cylinder covers and ports and piston faces with non-conducting substances; and Dr. Kennedy had used sheet-lead linings for the same purpose. But although advantage had been found to result therefrom, the use of such substances had never passed beyond the experimental stage. If such a metal could be found, as was suggested by Mr. Hadfield, the present loss by cylinder condensation in ordinary engines might be much reduced, though the effect of the material of the walls would be modified by the presence of moisture and oil in the cylinder.

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19 January, 1897.

JOHN WOLFE BARRY, C.B., F.R.S., President, in the Chair.

The discussion upon the Paper "Superheated Steam-Engine Trials," by Professor W. Ripper, was continued and concluded.

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[1] "Superheated Steam: Facts, Data and Principles relating to the Problem," p. 488.