Pulverized Coal—I*

Summary of a Report on Methods of Utilizing Otherwise Waste Coal

By Leonard C. Harvey

UNDER the auspices of the Fuel Research Board of the Department of Scientific and Industrial Research, Mr. Leonard C. Harvey, in the middle of last year, made a journey to the United States, in order to study the applications of pulverized coal to various uses in that country. On his return he made a report to the Board, which came to the conclusion that the information contained in that document would be of substantial value to the consumers of coal in British industries. It therefore published it as "Special Report No. 1," which is purchasable from agents for Government publications for the sum of 2s. 6d. net. Subsequently Mr. Harvey read before the annual meeting in May last of the Iron and Steel Institute a paper entitled "Use of Pulverized Coal, with Special Reference to its Application in Metallurgy" which was intended to form a supplement to the information contained in the report. Feeling sure that the matter will prove of interest to our readers, we propose to give in the following articles a summary of and extracts from these two documents. We may say before proceeding to do so, that both the report and the paper contain bibliographies of the subject, that in the former being the more comprehensive of the two.

At the outset it may be explained that Mr. Harvey visited twenty-three installations in which powdered coal was used commercially for, among other things, billet heating, puddling, ingot heating, tin-plating, annealing, steel, rivet heating, and reverberating melting furnaces as well as for steam boilers, cement kilns, &c. He also investigated the following systems:—The Quigley, Fuller, Holbeck, Muhlfeld, Pruden, Covert, Bergman, Aero, Kinyon, and Stroud.

The report is divided into seven chapters, and has four appendices.

In Chapter I. Mr. Harvey, after quoting an article which appeared in the Engineering Supplement of *The Times*, in February of last year, and which discussed the principles underlying the use of fuel in a pulverized form, first of all reviews in outline the several operations necessary in order to obtain a sufficient degree of pulverization of the fuel. He then considers the range of fuels suitable for use in pulverized form, referring in succession to coke, pitch, anthracite, bituminous coals, lignite, and peat.

In Chapter II. there is, first of all, a table which shows the original cost of pulverizing plants of varying sizes. It gives in parallel columns the pre-war and estimated present-day costs of plants having outputs of from 10 to 250 tons per day. For our present purpose we need only concern ourselves with the prices now ruling. It appears that a plant, with a capacity of from 10 to 40 tons per day, is estimated to cost £9,687, and will necessitate the use of one 33 in. mill. A plant capable of turning out from 50 to 90 tons per day will cost £11,562 and will require one 42-in. mill. A 100 to 130-ton plant will cost £14,062, and will need three 33-in. mills; a 140 to 180-ton plant, having two 42-in. mills, will cost £15,625; while a 190 to 250-ton plant with three 42-in. mills, will necessitate an outlay of £19,375.

As regards the cost of pulverizing the coal Mr. Harvey quotes the experience of three separate works. In the first case the possible output of the works was 80 tons and about 30 tons were actually produced. In the first case the possible output of the works was—and the output from 30 to 35 tons, while in the third the full capacity was 50 tons, and about 30 tons were produced. In case No. 1 the outgoings taken into account were for oil and grease, waste, stores and fuel for drying, labor, current at "0.02 cent."—evidently a mistake for dollars—or about 1d. per kilowatt-hour, machine shop charges, interest and taxes. The total cost, taken over a period of one month, worked out at 2.21 dols., or say 9s. 2½d. per ton. In case No. 2 the operating costs given include labor and labor insurance, stores, electric repairs, machinery repairs, engineering repairs, and electric power at 0.018 dols. No allowance was therefore made for interest and depreciation. The cost averaged over a period of six months 1.48 dols., say 6s. 2d. per ton. If, however, interest and depreciation at 14 per cent. on £11,562—the average cost of a plant to produce from 50 to 90 tons per day—be added, the total cost works out at 2.34 dols., or 9s. 9d. per ton. In case No. 3 the items taken included direct labor; repairs, labor; repairs, material; supplies, waste, &c.; insurance; and on-charges, and the

total arrived at, as the average taken over a month's working, was 2.25 dols., or, say, 9s. 4½d. per ton. As a matter of fact this total was higher than it would ordinarily be because during the month there was an unusual expenditure on repairs, &c., and the normal cost is given as being more nearly 1.489 dols., or say, 6s. 2½d. per ton. Taking this lower cost the average for the first three plants works out at 2.013 dols., or just over 8s. 4½d. per ton of pulverized coal delivered to the furnaces.

The foregoing figures relate to present-day costs. For purposes of comparison Mr. Harvey gives the cost during the year 1913, and therefore before prices were influenced by the war, of a considerably larger plant, which had a full capacity of 150 tons a day, and the output of which was 140 tons per day. The costs for fuel for drying, operating, power—steam and electric—repairs to machinery, and repairs to buildings, came out at 0.602 dols., or just over 2s. 6d. per ton. Dividing 14 per cent. on the capital outlay of £10,417 by the total yearly production—42,000 tons—and adding the result to the 2s. 6d., the figure of just over 3s. 2½d. per ton is arrived at. This figure is not strictly comparable with those of the first three plants, since, whereas two of them were working very considerably below their full capacity, plant No. 4 was producing over 93 per cent. of the quantity for which it was designed. However, the items of cost, which in all cases are given in detail, will doubtless prove to be useful guides as to past and present costs in the United States under the specific conditions mentioned.

The report then goes on to outline the various processes through which the coal passes in standard mill-house practice in American installations before it becomes pulverized fuel. The run of mine, lump coal or screenings, are delivered alongside the pulverizing mill in railway trucks, fitted preferably with bottom dumping doors, so that the coal may be discharged into track hoppers. From the latter the coal passes first of all to a crusher, in order that it may be broken down so as to pass through a screen of ¾ in. mesh, and is taken thence to the crushed coal bin, past a magnetic separator. From the crushed coal bin the coal descends by gravity to the dryers, which are thus referred to by Mr. Harvey:—"Dryers of several efficient types are in use. They are heated by means of hand-fired grates, mechanical stokers, or pulverized coal burners. The hot gases from the furnaces are latter case, the hot gasses first come in contact with the coal, or through a central tube to the end of the coal-drying cylinder, and thereafter returned along the outer space in contact with the coal, or again, a compromise is made between these two systems. For the latter case, the hot gases first come in contact with the outer shell of the dryer to about half-way along its length; they are then collected and transferred to the end of the cylinder where they enter into direct contact with the coal as the gases pass back through the cylinder to the furnace end, where they escape to the dryer chimney. As a rule the dryers are rated to comply closely with the maximum capacity of mills operating. Crushers are generally started up in advance of the pulverizing mill, and are run for a short time after the mills are closed down. In this way a sufficient amount of dry coal is available when the mills are started up. Coal should be dried to within one per cent. moisture, about 10 per cent. moisture being extracted at each passage of the coal through the dryer. When fuel contains a heavy percentage of water the coal can be passed through the dryer a second time." From the dryers the coal is taken to the top of the building by an elevator and delivered to the dry coal bins.

In addition to the several types of grinding mills used in cement works, the mills generally installed in American steel works are the "Fuller," the "Raymond," and the "Bonnot." The two last mentioned are ordinarily run with air separator fans. The Fuller mills have only been equipped with them comparatively recently. When they are not fixed the pulverized coal as it comes from the discharge spouts is taken up to the top of the mill-house by means of bucket elevators. The advantage of air-separation exhaust from the mills lies in the direct delivery of the coal dust to the bins without having to employ elevators. Moreover, there are the additional advantages of simplicity of plant, absence of dust leakage through crevices in the mills, and absence of dust from the elevator casing, because

the elevator is non-existent, while, as a consequence, there are no repairs of the elevator to pay for. On the other hand, the total power for grinding and delivering the coal by air-separation is somewhat greater than that required to run screen mills and bucket elevators. Further than that, the coal dust must pass through the suction fan at high speed, with the result that the blades are rapidly worn, and it is necessary, moreover, to install cyclone separators to deposit the coal dust from the air current. Summing up, Mr. Harvey remarks: "With the exception of power absorbed, the advantages of one method seem almost to balance those of the other."

The standard of fineness that has been adopted throughout the United States for industrial coal dust plants is 85 per cent. through a 200 mesh screen—40,000 holes to the square inch—and 95 per cent. through a 100 mesh screen—10,000 holes to the square inch. The coal as it leaves the dryer before grinding should not contain more than 1 per cent. of moisture.

In Chapter IV. Mr. Harvey discusses the various methods of transporting the coal dust to the burner under the following headings:

- (a) By screw conveyors.
- (b) By the air pressure system.
- (c) By the air mixture system.
- (d) By the enclosed pipe cable system.

With regard to (b) it is explained that it was patented in 1916 by Messrs. Magarvey, Salton and Heisler, and that the process, which has been of late quite extensively adopted, is controlled by a company in New York City. In it what are called "Blowing Tanks" are installed in the mill-house. Compressed air is applied to these tanks for the purpose of forcing any given quantity of coal through small supply pipes to bins at the furnaces. The tanks are arranged on weighing platforms, so that the weight of coal delivered into them can be read off on scale dials. The coal dust travels through ordinary 3- or 4-in. screwed piping to the bins at the furnaces. In view of stoppage caused by moisture in the coal, or due to condensation within the conveying pipes, a small companion pipe with tapings into the coal delivery pipe is provided. From it compressed air can at any time be supplied through the tappings or "bleeders," as the makers have termed them, and any stoppage of coal broken up and cleared. Mr. Harvey remarks, concerning the system, that the advantages pertaining to it are considerable. By it the coal dust can be transported through relatively small pipes and normal bends, which can be led overhead or underground with just the same convenience as can water or gas pipes. An ingenious accessory to the system, designed for the semi-automatic feeding of coal dust to any number of bins throughout the works, is also discussed.

The "air mixture" method is that employed in the Holbeck patented system. In it the coal dust is mixed at the mill-house with approximately half the quantity of air required for its complete combustion. Supply is effected at a pressure of 10-12 ounces per square inch, and a speed of 90 ft. per second through the main supply pipes to the branch service at the furnaces is reached. The main supply pipe makes a complete loop from and to the mill-house, at which point the returning coal is extracted in a cyclone separator and re-delivered to the pulverized storage bin. In cases in which long lengths of main supply piping have to be used—say, in a loop of 3,000 ft.—probably one or two booster fans would be employed.

The "enclosed pipe cable system" consists of a complete circuit of delivery pipe inside which is run a central cable fitted with discs for the conveyance of the coal dust along the supply circuit. Side outlet discharge openings controlled by shut-off valves are provided at the points where the fuel is to be used. The system, Mr. Harvey explains, is only in the experimental stage, and will probably be confined to relatively short delivery distances.

Rainfall and Horsepower*

To the lay mind certainly, and to the average engineer—myself included—probably the amount of horse-power which is obtainable from rainfall does not

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readily suggest itself. Feeling much interest in a scheme—not yet matured—for utilizing the rainfall which takes place on the large Dartmoor tract of almost waste land in Devon, I have been making some numerical calculations with the idea of getting something more than an indefinite knowledge of what was the practical relation between rainfall and horse-power. As it is possible that these plain unvarnished calculations may be of some utility to those who have not closely studied the subject, I put them forward, though I do not claim that they possess any special features of novelty.

As a starting point let us take—

1 horse-power for 10 hours; this equals $33,000 \times 10 \times 60 = 19,800,000$ foot-pounds per 10 hours.

Now, 1 cubic foot of water = 62.28 lb.; therefore 1 horse-power for 10 hours = $\frac{19,800,000}{62.28} = 318,000$ cubic

feet of water falling 1 ft. during 10 hours, or 318 cubic feet falling 1,000 ft. during 10 hours.

For one year this is

$$\frac{318 \times 365 \times 24}{10} = 278,500 \text{ cubic feet.}$$

Also 50 in. of rainfall—which is much below the Dartmoor average—per year is equivalent to

$2,323,200 \times 50 = 116,160,000$ cubic feet per square mile of surface; hence this would, with a fall of 1,000 ft. give

$$\frac{116,160,000}{278,500} = 417 \text{ horse-power.}$$

That is to say, 50 in. of rainfall per square mile for one year will, with a fall of 1,000 ft., give 400 horse-power (approximately) for 10 hours per day for one year.

Of this theoretical 400 horse-power it is probable that but about 200 horse-power could be practically utilized, owing to various losses.

In the case of Dartmoor there is plenty of area where a fall from a reservoir—of which there is room for many—to the lowlands of 1,000 ft. could be obtained.

It should be noted that in the calculation a catchment area of 1 square mile only is assumed. This is but a very small portion of the Dartmoor area at a height of 1,000 ft., which is available, and on which the rainfall would much exceed 50 in.

A reservoir of 1 square mile area and $4\frac{1}{4}$ ft. deep would contain 118,480,000 cubic feet of water, *i. e.*, sufficient with a 1,000 ft. fall to give the 400 (or 200 practical) horse-power for 10 hours per day for one year; that is to say, would hold one year's reserve. If the reservoir were, say $5 \times 4\frac{1}{4} = 21\frac{1}{4}$ ft. deep, with a total catchment area of 5 square miles, then 1,000 practical horse-power could be obtained with a one-year reserve. It would seem therefore that the amount of power constantly available would be very large.—H. R. KEMPE.

Multiple-Engined Airplanes

At the outbreak of the war, the idea of constructing planes to be driven by two engines had been broached and discussed, detailed designs had been made for such machines and their powerplant equipment, experiments had been conducted, and at least one multiple-engined airplane, the Sikorski, had been constructed. Nevertheless, it was not until June, 1915, that information was received of the definite appearance at the front of a twin-engined German airplane. Although the Germans were thus the first to employ such a machine for active military service, they were probably anticipated as regards actual construction by the French twin-engined Caudron biplane and the British twin-engined Dyott machine. The last-named, it is interesting to note, was actually designed before the war and in many respects anticipated the design of the German Gothas of 1917. It was built in 1915, and subsequently flew successfully, although it failed to receive official approval, for some reason or other.

The three-engined airplane had also received some attention when the war broke out, notably so from the Italian Caproni, who, in 1914, built and flew a biplane equipped with two 80 h-p. tractor engines and a 90-h-p. pusher engine. Subsequently, in 1915, the same designer built a successful biplane fitted with three 150-h-p. engines. As the war progressed and the demand arose for heavy bombing machines, the twin-engined airplane took a permanent place in the aeronautical services of all the belligerents. Of these, the Gotha with two 260-h-p. engines and the Handley-Page with two 350-h-p. units may be taken as typical.

Toward the end of the war the four-engined machine had definitely appeared, and was being built in considerable numbers, in England, at least, while a five-engined German machine was brought down in France in August, 1918. Since the armistice was signed, the

four-engined machine has become quite familiar, and the development of the five-engined design has progressed to the extent that there is now in existence a large British seaplane equipped with five Rolls-Royce engines which has flown successfully. We have as yet not heard anything definite about a six- or seven-engined machine, but we have Major-General Seely's authority for saying that the designs for a huge seaplane equipped with eight separate engines have been completed.

THE POWERPLANT PROBLEM.

The airplane powerplant problem at the present moment is a peculiarly complicated one, and in no respect is its complexity greater than in multiple-engined machines. A very strong reason for fitting an airplane with more than one engine, at least so far as civilian flying is concerned, is, of course, the increased safety insured by so doing. With a twin-engined machine the chances of both failing before a safe landing can be effected are now very small. During the war, it may be said by way of illustrating this remark, a Handley-Page bomber as a result of a direct hit had its lower wings reduced to shreds and tatters and one of its engines put out of action; yet this machine flew back 60 miles to its airdrome, and alighted there safely. With a three-engined machine, it may be taken that all chances of having to make a forced landing as a result of engine trouble developing are eliminated. A four-engined airplane possesses the same characteristic, and with something over. Indeed, it can be asserted that as regards the avoidance of forced descents the four-engined machine possesses a factor of safety which is, or should be, satisfactory to all concerned. To increase the number of engines above four on the grounds of safety is clearly superogatory.

Setting aside such cases, if there be any, in which the multiplicity of engines is dictated by a desire to utilize existing stocks left over from the war program, it might be suggested that several small units are preferred to one or two larger units because the design and production of the former have been brought to a considerable degree of perfection, whereas the large aircraft engine possessing an equal trustworthiness has yet to be built. So far as air-cooled engines are concerned, it may be true that large units are not installed because large units are not yet available. On the other hand, the largest size at present made, we have recently seen an air-cooled engine developing 500 b. h-p., is sufficient to effect a reduction of some 25 per cent. in the number of engines fitted on the four-engined Handley-Page machine.

Water-cooled engines of 500 h-p., such as the eighteen-cylinder, three-row Sunbeam, have been manufactured in this country for some time, while engines of 1,000 h-p. are within reach of present-day production. In support of the latter assertion, it may be said that a twelve-cylinder Liberty engine has, under special conditions, developed 526 h-p., and that a twenty-four-cylinder engine of the same design has been made recently and tested with satisfactory results.

It seems clear, then, that the tendency to multiply the engine units on an airplane cannot be set down wholly to a deficiency of large powered engines. The true reason, or a large part of it, for adopting a multiplicity of engines lies, in fact, not with the aircraft engine builder, but with the makers of the airplane itself and of its propellers. The eight-engined seaplane referred to by General Seely will probably have a horse-power of nearly 3,000. Even were a thoroughly trustworthy 1,000-h-p. aeronautic engine available, it is doubtful if in the present state of the aircraft building art the designers would have chosen to do other than employ eight small engines rather than three large; for by splitting up the power between a number of units, they effect a corresponding distribution of the flying stresses in the structural parts of the machine. Further, it can be asserted that the airplane propeller capable of using 1,000 h-p. on a scale of efficiency comparable with that manifested by smaller existing propellers has yet to be designed and made. It is to be noted that, as with the marine propeller, the higher the engine speed the more difficult is it to provide a propeller which will utilize the available power efficiently, and that aeronautic engine builders are already sacrificing something to meet the shortcomings of the propeller by fitting reduction gearing on their higher speed engines. Thus the Rolls-Royce, Sunbeam, Hispano and Cosmos engines, all of which run at or over 2,000 r.p.m., are forced to employ reduction gearing, of approximately a 5 to 3 ratio, because of the present impossibility of obtaining propellers capable of utilizing the full speed economically.—*Engineer* (London).

Silk Calculations

Two old French coins were called deniers. Like the écu, the word survives in French literature just as we use the word "mite." The denier Tournai was a small copper coin, value one-twelfth of a sou, weighing 27 Paris grains, *i. e.*, 19.6728 English grains. Two systems of calculating silk are in use, viz., the denier and the dram system. Raw silk is generally indicated by the denier system, whereas thrown silk is mostly indicated by the dram system. The legal denier in the United States is a skein of silk 450 meters long, wound in 400 turns on a reel of $112\frac{1}{2}$ centimeters in circumference and weighed by a unit of 5 centigrams, known as denier. One meter equals 39.36 inches, therefore one legal denier equals 450 meters, or 492.12 yards. One lb. equals 453.6 grams, one ounce equals 566.99 legal deniers, one gram equals 20 legal deniers; hence 1 lb. equals 9,072 legal deniers. Since one legal denier equals 492.12 yards, consequently 9,072 legal deniers are equal to 4,464,513 yards. The standard of the denier varies considerably in different parts of Europe, viz.:

International, 500m—0.05 grams.

Turin, 476 m—0.05336 grams.

Milan, 476 m—0.0511 grams.

Old Lyonesse, 476 m—0.05311 grams.

New Lyonesse, 500 m—0.05311 grams.—*Amer. Silk Jour.*

Physical and Chemical Tests of the Commercial Marbles of the United States

THIS paper is the first report of the Bureau of Standards in connection with an extensive co-operative program for investigating the building stones of the United States. The other Government departments participating in the work on different phases of the investigation are the U. S. Geological Survey, Bureau of Mines, and Office of Public Roads.

The paper comprises the results of strength tests, water absorption, porosity, specific-gravity, freezing, thermal-expansion, electrical-conductivity and chemical tests on 552 different types of marbles produced in this country. The purpose of the work is to determine the relative value of the different types for building purposes and other special uses.

Compressive-strength tests were made on specimens in the original condition and on specimens after being soaked in water for two weeks. The dry specimens have strength values ranging from 7,850 to 50,205 lb. per sq. in. As a rule the soaked specimens gave lower compressive strengths than the dry, and in a few cases the loss due to soaking was over 25 per cent.

Transverse, and tensile-strength tests are included and show the strength of the specimens when broken perpendicular and parallel to the bedding planes.

The freezing tests made for this report consisted in determining the loss in weight and strength due to 30 freezings and thawings. While these losses were considerable in most cases, some samples showed practically no loss and occasionally a gain in strength was indicated. Hence it was decided that 30 freezings were not enough to give a trustworthy indication of the durability of such materials. An apparatus has been installed which automatically shifts the specimens back and forth between a cold chamber and warm chamber at certain intervals. With the use of this apparatus it is possible to make a great number of freezings which will correspond to several years of exposure to the weather. It is purposed to make extensive weathering tests with this apparatus to determine more definitely the relative effect of frost action on the different marbles as well as other types of building stones.

Electrical-resistivity tests were made on a number of different types to determine their relative value as insulators and resistivity under different conditions of moisture. The results show a considerable range of values, indicating that there is a choice of marble for use in switchboards and allied purposes.

Measurements of the thermal expansion made on a few samples of marble in this investigation show that this material does not expand at a uniform rate even at ordinary temperatures. As the temperature is increased the rate of expansion increases, hence it is not possible to state a coefficient of expansion for marble that will hold good for any very great range of temperatures. Another peculiarity brought out by these tests was the fact that marble when expanded by heating does not contract to its original dimensions as the temperature is lowered, but retains a part of the increase permanently. A number of successive heatings show the same effect, each adding an increment of length to the specimen.

A few cases of warped marble slabs are illustrated and a discussion is made of the causes which may be instrumental in bringing about this warping. (Abstract from Bureau of Standards Technologic Paper No. 123.)—*Mechan. Engineering.*