RECENT DEVELOPMENTS IN THE GAS-ENGINE.

A LECTURE

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IN THE CHAIR.

In selecting the period to which I propose to limit my review of gas-engine development, I was guided by the fact that in the year 1888 a very elaborate series of trials of gas- and steam-engines suitable for electric lighting purposes were carried out by a committee appointed by the Society of Arts. The results of these trials were published in the following year, and a Paper descriptive of them was read before the Society by one of the leading members of that committee—Dr. Kennedy—on 28th March 1889. The engines submitted to that committee for test probably indicated the high-water mark which had been reached in efficiency of design and in efficiency of the utilization of the heat up to that period.

Of gas-engines three types were tested: the Atkinson, or cycle gas-engine, the Griffin engine, and the Crossley engine. The Crossley engine worked on the well-known De Rochas cycle, and thus had one explosion in every two revolutions of the crank when running at full load; the Griffin was a double-acting engine with a scavenger stroke, and therefore obtained at full load one explosion for one and a half revolutions of the crank; and the Atkinson, though single-acting, with its peculiar mechanical arrangements, had one explosion for every revolution at full load.

The Crossley engine was one of the type which had then come into use, in which the slide-valve had been displaced by lift-valves, and the old method of ignition by the slide-valve flame had been replaced by hot-tube ignition. These changes, only recently made, and the simultaneous introduction of the scavenger stroke in the Griffin type of engine seemed to afford, as it were, convenient means for dividing off the gas-engines which had been in use up to that period from those which have been constructed since 1889. It is these facts which led me to select the year 1888 as the starting point from which to proceed.

The Society of Arts' trials were remarkable both on account of the extreme care with which all the operations of the tests were carried out, and also from the carefully calculated heat balance-sheets which were drawn up as a result of the trials.

No attempt was made in the trials to measure either the temperature of the exhaust or the quantity of air admitted into the cylinder with the gas; but by the use of formulæ based on the well-known physical laws of permanent gases, and by making certain assumptions as to the constancy at all temperatures of the specific heats of the constituents of the charge and of the products of combustion, Dr. Kennedy was able to calculate both the temperature of the exhaust gases and the quantity of air admitted for each charge. To do this, it was necessary to know the temperature of the charge which filled the cylinder at the moment compression was about to begin. This temperature could not be directly measured, but Dr. Kennedy was of opinion that it would not differ much from that of the cooling water as it left the jacket, and for the purposes of the calculation it might be considered to be the same. The results obtained by Dr. Kennedy from the calculations, whether the assumptions were strictly valid or not—and on this I shall have something to say later on—were no doubt fairly close in agreement with the actual facts, and though it is a twice-told tale, it is worth while drawing attention again to a very striking proof of this. In a test of another gas-engine, at a slightly earlier date than the above trials, he was able, in consequence of similar calculations, to express the opinion that combustion was not complete when the exhaust took place; and as the result of suggestions he made, more economical results were obtained in this engine by altering somewhat the valve arrangements. The following brief summary of the results obtained in these classic trials may be of service for reference purposes:—

Table of Results obtained in the Society of Arts' Trials in 1888.

Engine.	Duration of Trial.	Compression Pressure (Absolute).	Indicated Horse-Power.	Brake Horse-Power.	Total Gas used per Hour. Per Indicated Horse-Power.	Total Gas used per Hour. Per Brake Horse-Power.	Calorific Value of Gas per Cubic Foot.	Thermal Efficiency of Engine.	Mechanical Efficiency.
	hrs.	lbs. per. sq. in.					B.T.U.	p.c.	p.c.
Atkinson	6	50·3	11·15	9·48	19·22	22·61	633	22·8	85
Crossley	6	76·3	17·12	14·74	20·76	24·10	626	21·2	86·1
Griffin	6	58·7	15·47	12·51	23·10	28·56	624	19·2	80·9

In the Atkinson engine 27 per cent. of the heat received was rejected in the jacket water, and it was estimated that 37·9 per cent. passed away with the exhaust gases. (Dr. Kennedy was of opinion that in this engine combustion was not complete at the time exhaust began.) In the Crossley engine 43·2 per cent. passed off in the jacket water, and the calculated loss in the exhaust gases was 35·5 per cent. In the Griffin engine these figures were 35·2 per cent. and 39·8 per cent. respectively. The calculated maximum temperatures reached were 2,530° F., 3,000° F., and 2,120° F., while the temperatures when the exhaust valve opened were about 1,560° F., 1,670° F., and 1,400° F. respectively.

Up to this period I think I am right in saying that the limiting size of any gas-engine which had been put upon the market was 40 horse-power, and the patent rights connected with the "Otto" patent of 1876 had, to a certain extent, hindered the rapid development of the gas-engine industry, on account of the high prices which were then charged by the manufacturers. But, on the other hand, possibly the existence of this patent and the resultant continuous efforts made by other firms to produce an engine of merit and quality equal to those built by Messrs. Crossley Brothers, may have been of advantage, because most of the rival makers tried to adopt some other cycle than the De Rochas; and their efforts led to the design of the double-acting engine and other types, in order to obtain one or even two impulses per revolution in place of the one impulse per two revolutions of the "Otto" type.

There is very little doubt, I am sure, that the amount of research and ingenuity displayed in connection with these attempts have done much to secure the great advance we have witnessed during the last ten or fifteen years. Unfortunately, however, to my mind, when the "Otto" patent expired in 1890, the bulk of the makers abandoned the various types which they had evolved and fell back on the simple "Otto" cycle—a cycle which, I consider, is by no means an ideal one for many of the purposes to which it is proposed to apply the large engines now being built. But within the last few years there has been a tendency to revert once more to gas-engines which have a greater frequency of impulse than one per two revolutions, when running under full load.

I have already mentioned that there were two distinct and important improvements introduced just about the time of the Society of Arts' trials, and I propose to say something more in detail with regard to the effect of each.

The first point to which I wish to draw attention is the so-called scavenging principle. In the Griffin engine this was secured by the following method of working. Between the exhaust stroke and the next suction stroke for drawing in a fresh charge, a pair of strokes was interposed, during which a charge of pure air was drawn in and then swept out again; thus, if the engine had been single-acting, there would have been only one impulse for every three revolutions; but as the engine was a double-acting one, two impulses were obtained every three revolutions under full load.

The effect of the scavenging stroke, however, was extremely important, the hot products of combustion were swept out, and there was comparatively little risk of any premature explosion owing to the fresh charge on entering the cylinder meeting hot exhaust gases, and in addition the scavenging charge helped to cool the cylinder sides, and in this respect assisted the cooling water of the jacket. Shortly after this period, Messrs. Crossley Brothers determined to obtain the scavenging effect by a somewhat different device. It had long been known that, in a long exhaust pipe during the exhaust, pulsations or waves of pressure were set up in the pipe, and it occurred to those responsible for the design of these engines, that advantage might be taken of this fact to sweep out the last remains of the burnt gases by means of fresh air. For this purpose the exhaust pipe has to be of a length of about 65 feet (if desired, quieting chambers can be used as usual at the outer end of this pipe), and the time of opening and closing the air and exhaust valves also requires some modification. The exhaust valve is held open a little longer than was formerly the practice, and the air-valve being also open and the pressure in the cylinder (owing to the effect of the pulsation in the exhaust pipe) being slightly below atmospheric pressure, the incoming fresh air enters with sufficient energy to drive out in front of it into the exhaust pipe all that remains of the previous burnt charge.

There is no doubt that, as in the Griffin engine, and in all others where this scavenging principle has been adopted, it has secured the possibility of much higher compression of the charge, without any risk of causing a premature explosion. Leaving a portion of the burnt charge in the cylinder to mix with the incoming charge was an obstacle to the safe use of high compression.

The marked economy brought about by this change, and the accompanying higher compression pressure which it was possible to adopt, is shown by the figures which I will now give for a test of one of these engines of more or less the same size as was tested by the Society of Arts.

A test of a 4-horse-power nominal scavenging type by Mr. Dugald Clerk in August, 1894, gave the following figures:—

Compression Pressure, Absolute.	Gas per I.H.P. Hour.	Gas per B.H.P. Hour.
lbs.	cub. ft.	cub. ft.
102·2	14·5	17

A Stockport "Otto" of 9 horse-power nominal, tested by Mr. A. R. Bellamy, of Messrs. Andrews and Co., gave the following result:—

Compression Pressure, Absolute.	Gas per I.H.P. Hour.	Gas per B.H.P. Hour.
lbs.	cub. ft.	cub. ft.
104·7	17·6	20·75

Comparing these results with those of the Society of Arts' trials, we see at once the immense gain in economy in five or six years. Taking the brake horse-power as the basis, we find an improvement of nearly 25 per cent., due largely to improvement in design, increased compression, and the use of the scavenger principle.

There was, however, still an obstacle to any marked advance in the size of gas-engines. As long as large gas-engines were compelled to use the ordinary lighting gas they could not hope to compete with the steam-engine, and a great deal of the advance of the last few years has been due to the success which has been met with in the design of gas-producers of various types.

Up to the year 1889 not much had been done in this line, but owing to the successful efforts of Mr. Dowson, Dr. Mond, and others, the problem has been solved, and as a necessary corollary to the large gas-engine we have the gas-producer.

The fundamental principle involved in the gas-producer is the conversion of the carbon of the solid fuel into an inflammable gas. Now, it is well known, that if CO_2 is passed through a sufficient depth of incandescent carbon it is converted into an inflammable gas CO or carbon monoxide. Therefore, if air is blown through incandescent C, we get CO, and if the whole of the carbon could thus be converted, we should get an efficiency of the gas-producer of

70 per cent., owing to the lower heating value of CO as compared with C, and to the fact that the heat carried away by the CO from the producer has to be wasted to a large extent, because the gas must be cooled down before it can be used in the gas-engine cylinder. But there is another chemical reaction which will produce the same effect. If steam be passed over highly incandescent carbon, the oxygen of the steam will combine with the carbon, and the hydrogen is liberated; thus, $H_2O + C = H_2 + CO$. In the actual apparatus the coal or coke is put into a brick-lined producer, thoroughly ignited, and brought up to a good heat by means of a blast, and then steam and air are blown in, in fixed proportions, and the resultant gas cooled and sent away to a gas-holder; the Dowson gas-producer works upon this principle. To start the producer, the upper cover being removed from the fuel hopper, a fire is lit upon the bars and air blown through; the fuel which is to be gasified—it may be either anthracite or coke—is then added from above till the contents are highly incandescent, and fill the producer to a depth of about 18 inches, the gases which are given off during this time being burned at the open hopper. As soon as the fuel is perfectly incandescent, the inner and outer valves of the hopper are shut, and after this the gas generated flows away through a pipe through cooling and scrubbing plant to the gas-holder; it enters the gas-holder through a coke scrubber, forming part of it, and then passes through another scrubber to the gas-engine. The complete plant therefore requires a small boiler, fitted with superheating tubes, in order to supply the superheated steam to work the air-injector, and thus force the mixture of air and steam into the incandescent fuel; and fresh fuel is constantly fed in through the hopper. Ordinary Dowson gas requires for its complete combustion about 1·13 times its volume of air (coal gas requires from five to seven and a half times its own volume of air), and its heating value is about one-quarter that of an average coal gas; hence for some time it was difficult to get a very high mean pressure in engines using it, owing to the dilution of the charge with residual burnt products; but here, again, the scavenging principle has made a great and marked improvement.

In the Lencauchez producer an attempt is made to save some of the heat leaving the producer in the hot gases, and to utilize slack or other fuel having much volatile carbon.

The gas generated is led off from the centre of the producer instead of the top, and on its way to the holder it passes in a pipe through an air and steam heater and a boiler; the steam generated in this latter (not under pressure) passes at once into the air and steam heater, where it mixes with air blown in by a positive fan, and thence the mixture of air and steam passes to the bottom of the producer. The fuel at the top of the producer is always thoroughly coked before it reaches the highly incandescent portion of the producer, and hence any tar products are broken up and reduced to fixed hydro-carbons.

The latest development of this phase of gas-engine work is the Mond gas, from which so much is confidently expected in the near future. Dr. Mond's producer is adapted for the use of cheap fuel and the recovery of ammonia. The experimental work has been carried on for many years (since 1879), and the results now achieved are exceedingly good. It has lately been described fully before the Institution of Civil Engineers (in 1897), and still more recently (in 1900) before the Institution of Mechanical Engineers by Mr. Humphrey, so that it is hardly necessary to do more than give a very brief outline of the process. Common bituminous slack is fed into the hoppers and then descends in charges of 8 cwt. to 10 cwt. into the producer bell; the first heating of the slack distils off the hydro-carbons, etc., which then pass down through a hot zone, where the tar is broken up. In the body of the producer there is the usual air blast which has been saturated with steam and superheated, the fundamental difference between this and other producers being the fact that a very large quantity of steam is used, about 2½ tons per ton of slack. The large amount of steam used keeps down the temperature and prevents the destruction of the ammonia. Half a ton of this steam is decomposed per ton of slack, giving nearly 29 per cent. of free hydrogen in the final producer gas. The gases and undecomposed steam on their way from the producer pass first through a tubular regenerator (through which the incoming air blast passes in the opposite direction), then through a washer, where by means of a spray of water they are cooled down to some 194° F., and then to a lead-lined tower filled with tiles, where they meet a down-coming current of acid liquor containing sulphate of ammonia with a small amount of free H_2SO_4; in this tower, therefore, the ammonia of the gas is recovered. Finally, the gases pass to a gas-cooling tower, where they meet a current of cold water, and are then fit for use.

One of the secrets of the success of this producer is the principle of the regenerator which is adopted throughout the process. The water heated by cooling the gas in the gas-cooling tower is pumped into the air-heating and saturating tower to warm the air, and after being cooled in doing this, it goes back once more to the gas-cooling tower, and so on. One producer of the ordinary size can deal with about 20 tons of slack per 24 hours, and about 140,000 to 160,000 cubic feet of gas are produced per ton, the value of the sulphate of ammonia recovered is about 8*s.* a ton of fuel at present prices, the calorific value of the gas (saturated at 59° F.) is about 148 B.T.U. per cubic foot, and about 1·15 volumes of air are needed to burn one volume of the gas.

The following figures are given by Mr. Humphrey as a typical analysis of Mond gas (dry):—

CO = 11 per cent. (dry volume)
H = 29 ,,
CH_4 = 2 ,,
CO_2 = 16 ,,
N = 42 ,,

The proportion of the charge by weight is as follows:—

Per cent.
Fuel (dry slack) . . . . . . = 16·03
,, (moisture) . . . . . . = 1·52
Steam (from air-heating tower) . . . . = 14·75 } = 38·12
,, (added) . . . . = 23·37 }
Air . . . . = 44·33

Mr. Humphrey estimates that he gets in this gas about 84 per cent. of the original heat in the fuel, but this calculation seems to ignore the heat required to generate a considerable portion of the large quantity of steam used in the process (some of this steam is, as noted before, obtained by the regenerator working); but in criticising this statement it must be remembered that this excess of steam is only needed when it is desired to recover the ammonia.

The great value of these gas-producers when used in connection with large gas-engines is shown in the results obtained during recent tests of very large engines, the figures of which I will give you. The first one I propose to deal with is a test of a large gas-engine using a cycle very different to that of the "Otto" cycle in many respects.

Koerting two-cycle 350 *B.H.P. Gas-engine.*—This engine is double-acting, the stuffing-box being water-jacketed. There is one admission valve at either end of the cylinder driven by the crank-shaft; the exhaust ports are at the centre of the cylinder, and are uncovered by the piston as it gets to the end of its stroke. The gas and air have each their own double-acting pump, of equal stroke, and driven by an auxiliary crank set at 110° ahead of the main crank; their valves are of the piston type driven by an eccentric on the crank-shaft, the gas and air being each delivered through their own pipe into openings in front of the admission valve.

Working Cycle.—At the end of the working stroke the piston uncovers the exhaust openings, and the spent products rush out of the cylinder; when the pressure is about atmospheric, the admission valve for that end of the cylinder opens, and air and gas enter and sweep out the rest of the burnt exhaust gases. On the return stroke, as soon as the exhaust closes, the charge is compressed, and then, when the crank is on its dead centre, ignition takes place, and the working stroke is secured; thus each revolution of the crank gives one explosion. To prevent the new charge coming in contact with the hot exhaust gases, and a premature explosion taking place, a scavenger charge of air is interposed between them. The diameter of the air-pump is so proportioned that its capacity is more than is needed for the supply of the air for combustion, and the piston valves of the gas-pump are so set that a certain portion of the charge of gas drawn in by this pump on the suction stroke goes back to the gas-main, the valve which controls this not closing till the gas-pump piston has completed four-tenths of its return stroke; meanwhile the air-pump has been delivering air freely into the air-pipe and the chamber in front of the admission valve, and has also filled the greater part of the gas-pipe with air. Thus, when the admission valve is opened, all this scavenging air has to enter the cylinder and sweep out the products of combustion before any gas can enter. In order to distribute the incoming charge thoroughly through the cylinder, there is a projection just below the admission valve, against which the entering stream of gas and air strikes. Ignition is obtained electrically, and there are two ignition ports at each end.

Governing is secured by varying the period during which, on the return stroke of the gas-pump piston, the connection between the pump and the gas-main is kept up, and communication with the gas-pipe to the cylinder kept shut, with full load as stated before this continues for four-tenths of the stroke; at lighter loads it is longer.

The cooling water for the piston and its rod is conveyed by tubes of the telescoping type moving with the crosshead.

A test of this engine was carried out by Professor Meyer in June, 1900.

Dimensions of Engine and Methods of Test.—Cylinder diameter, 21·6 inches; stroke, 37·7 inches; air-pump diameter, 24·4 inches; gas-pump diameter, 19·6 inches; stroke of both, 27·5 inches. Diagrams were taken every five minutes, and the brake horse-power was determined electrically. The gas used was producer gas from a Koerting producer using gas coke, its heating value being determined by a Junkers calorimeter.

Results.

Indicated horse-power, motor	533
,, ,, pumps	62
Net indicated horse-power	471
Brake horse-power	334·7
Mechanical efficiency (neglecting pumps) . . .	71 per cent.

Results (continued).

Heating value of gas (lower), per cubic foot	129 B.T.U.
Gas used per net indicated horse-power per hour	59·1 cubic feet.
Gas used per brake horse-power per hour	83·1 ,,
Heat efficiency per net indicated horse-power	33·5 per cent.
Heat efficiency per brake horse-power	23·8 ,,
Mean revolutions	101

It is interesting to note the pressures reached in the cylinder at full load. The compression pressure was 12½ atmospheres absolute =184 lbs. per square inch, and the maximum pressure was 27½ atmospheres absolute=404 lbs. per square inch.*

In his Paper on "Power Gas and Large Gas-Engines," Mr. Humphrey gives the following results obtained in a six-hour trial of a 400-horse-power Crossley engine using Mond gas and coupled direct to a dynamo. This engine has two cylinders, each 26 inches in diameter by 36 inches stroke, one on either side of the crank-shaft, both connecting-rods working on to the one crank-pin.

Brake horse-power	359·6
Revolutions per minute	148·5
Mechanical efficiency (including fluid losses)	83 per cent.
Mond gas used per brake horse-power per hour	75·5 cubic feet.
Calorific value of gas per cubic foot (lower value)	142·5 B.T.U.
Thermal efficiency of engine on brake horse-power	23·76 per cent.

In this engine the compression was kept at a comparatively low figure—under 100 lbs. absolute, and as a result the efficiency is not as high as it otherwise would have been.

A 500 horse-power "Premier" gas-engine, also in use at Winnington, gave better results even when working at two-thirds full load. This engine has two cylinders of the tandem type, each 28⅛ inches in diameter by 30 inches stroke.

Brake horse-power	368·2
Revolutions per minute	128·05
Mechanical efficiency (including fluid losses)	75·3 per cent.
Mond gas used per brake horse-power per hour	69·2 cubic feet.
Calorific value of gas per cubic foot (lower value)	143·8 B.T.U.
Thermal efficiency of engine on brake horse-power	25·6 per cent.

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* Professor Meyer on "Engines Driven with Power and Blast-Furnace Gas."—*German Gas-Lighting Journal*, 1900.

The compression pressure adopted in this engine was much higher than in the Crossley engine, being over 140 lbs. absolute. Mr. Humphrey stated in the discussion on his Paper that the Crossley engine had improved its performance since the above test, and was now working with an efficiency 1 per cent. greater than it gave on the day of the official trial.

Use of Blast-Furnace Waste Gases.—About 1894 attention began to be drawn to the possibility of using blast-furnace waste gases in place of producer-gas for working gas-engines, and there is very little doubt that the idea was taken up at almost the same time in Great Britain, in Belgium, and in Germany.

Mr. Thwaite, who was the first—in May 1894—to propose such a scheme in England, was enabled in February 1895 to fit up an "Acme" gas-engine at Wishaw, at the Glasgow Iron and Steel Works, where it drove a dynamo. This engine had a 12-inch cylinder with a 20-inch stroke; it ran at 190 revolutions, and generated about 15 horse-power, and was tested in August 1896. The blast-furnace gases used had a heating value of 126 B.T.U. per cubic foot, and contained 27·8 per cent. of combustible gas; the furnace at the time was supplying 170,000 to 180,000 cubic feet of such gas per ton of iron made. The engine used about 84 cubic feet of gas per horse-power-hour; or, in other words, one electrical horse-power was secured for 1·6 lb. of coal burnt in the furnace—that is to say, 1·6 lb. of coal in the furnace not only did the smelting work as before, but the otherwise waste gases from this amount of fuel were able to give in addition one electrical horse-power. The fuel in this blast-furnace was coal, and therefore the waste gases had to be purified from ammonia and tar before they could be sent to the gas-engine. This somewhat complicated the process.

The next attempt in England was in 1897, at the Frodingham Works, where a 15 horse-power "Acme" was set to work with a waste gas of a heating value of 102 B.T.U. per cubic foot. This engine ran with a consumption of 110 cubic feet per horse-power per hour.

The development in England, however, of the utilization of blast-furnace gases has been somewhat slow, and our enterprising rivals across the North Sea have been much quicker in taking up this question than we have been in Great Britain. There are, however, a 400-horse-power Thwaite-Gardner engine at the Clay Cross Ironworks working a vertical air-blower; a 500-horse-power Crossley at Wolverhampton, driving direct air-blowing cylinders, the engine cylinders (there are two, working on to the same crank-pin) being 31 inches in diameter, and the stroke 36 inches, and the speed 130 revolutions a minute; and a 600-horse-power Seraing type engine is now in process of erection at Middlesbrough.

In Belgium the first idea of the utilization of blast-furnace gases was due to the Cockerill Company. This company was at that time about to embark in the manufacture of gas-engines, and eventually decided to adopt the "Simplex" single-cylinder four-cycle engine, with electrical ignition. This type of engine, as it happened, was very suitable for experiments on the utilization of blast-furnace gas, as, in order to work with a high compression, the end of the cylinder had been carefully rounded inside, thus doing away with all sharp corners and edges where dust could collect and cause trouble. Ignition in this engine is obtained by means of a slide-valve, the electric arrangement securing a continuous stream of sparks in the ignition chamber, and then at a certain definite time the slide-valve puts the cylinder in communication with this ignition chamber. The engine also has special arrangements in regard to the inlet valves; there are two—one for air and one for gas—opening into a mixing chamber, and from this chamber the mixed charge passes into the cylinder by means of a third inlet valve, which is water-jacketed, and is the only one of these inlet valves subjected to the direct effects of the explosion.

An 8-horse-power engine of this type was set to work in 1895, and ran for a considerable period of time, using gas from the blast-furnaces; the quantity of gas used was about 187 cubic feet per horse-power-hour.

The company were so well satisfied with the result of this experiment, that in 1898 an engine of 150 brake horse-power was put down to work an air-compressor. This engine was tested by Professor Witz in 1898, and was found to have a thermal efficiency of about 20 per cent., the compression pressure adopted being 114 lbs. per square inch.

In November 1899, a larger engine, rated as a 600-horse-power engine, was erected, and this has also been most carefully tested both against a brake and when working the air-compressing cylinder. This engine has a cylinder 51 inches in diameter with a 55-inch stroke, the air-cylinder having the same stroke and a diameter of 67 inches; the motor plunger piston is jacketed as well as the cylinder barrel and end.

Results of Tests when Driving Blowing Cylinder.

Indicated horse-power	886
Brake horse-power (deduced from work done in compressing air)	725
Revolutions	93
Mechanical efficiency	81 per cent.
Maximum pressure	250 lbs. absolute.
Heating value of the blast-furnace gas per cubic foot (lower value)	99·7 B.T.U.
Gas used per brake horse-power-hour	101 cubic feet.
Thermal efficiency on the indicated horse-power . .	31·2 per cent.
Thermal efficiency on the brake horse-power . .	25·3 ,,

The compression adopted in this engine was 135 lbs. absolute.

It should be stated that the heating value of the fuel was determined experimentally, both by a Junkers calorimeter and also by a bomb calorimeter, and it also was in addition calculated from the chemical analysis. The mean results varied from 99 to 111 B.T.U. per cubic foot, the lower value being given by the Junkers calorimeter.

In Germany the first attempt at this utilization of blast-furnace gases was in 1895, at the Hörde Iron Works, in Westphalia, where a 12 H.P. "Otto" type of engine was tried, the compression being 6½ atmospheres. So satisfied again were the users with the result, that they determined to proceed with the experiments, and they adopted as their type of gas-engine the Oechelhaeuser two-cycle gas-engine, which has only so far been used with blast-furnace gases. The arrangements of this engine are somewhat like those of the Atkinson differential gas-engine. There is one long horizontal water-cooled cylinder, in which there are two pistons working in opposite directions; the front piston is attached by its connecting-rod to a crank set at 180° to two other cranks, which are driven by connecting-rods attached to the crosshead of the back piston. This back crosshead also works the piston of a double-acting air-pump, delivering pure air on one side and mixed gas and air on the other. There is no cam-shaft and practically no valves; the pistons themselves open and close the admission and exhaust, the exhaust being so arranged as to prevent any possibility of any of the exhaust gases remaining in the cylinder to mix with the fresh charge. The cycle of this engine is as follows: the two pistons being as close together as possible, and the space between being filled with a mixture of gas and air at a pressure of about 135 lbs. absolute, the charge is fired electrically and both pistons move out, making their working stroke. As the main pistons reach the end of their outstroke the front one uncovers the exhaust openings, and the other immediately after uncovers a port through which clean cool air at a slight pressure enters the cylinder; this acts as a scavenger charge to sweep out all the remains of the previous burnt charge, next the same piston opens a second port by which the compressed charge from the air-pump enters the cylinder, driving out the scavenging air. On the return stroke of both pistons the ports are closed and the charge is compressed, ready to begin the cycle again. The cylinder is most carefully water-jacketed, and the scavenging air at Hörde is supplied from the blowing engines driven by the gas-engine. The cylinder for an engine designed to give 1000 horse-power is 36·8 inches in diameter, and the 600-horse-power engine has two 300-horse-power cylinders, each 19 inches in diameter by 31½ inches stroke, running at 135 revolutions. The Deutsche Kraft Gas Gesellschaft are now making very large engines of this type, engines to give 1000 horse-power with a single cylinder, and they have proposed to construct a 2000-horse-power single-cylinder engine.

One of the main difficulties, which had to be overcome in the use of blast-furnace gases for gas-engine work, was the removal of the dust which was carried out from the blast-furnace along with the gases. It was thought at first that much trouble would also be caused by the considerable variation in the composition of the gas and by its high temperature; but both these latter difficulties turn out in practice to be of no great importance. The variation in the composition is prevented by mixing the gases delivered from several furnaces, and as a result the average composition does not vary to any marked extent, and as the proportion of hydrogen present in the gases is small, a small variation makes but little difference. The high temperature difficulty is also got rid of by the cooling, which is brought about in the process of cleansing the gases from the dust; the dust is mainly metallic particles mixed with lime; a certain amount is deposited in the exhaust mains as they pass from the blast-furnace.

In connection with the trouble experienced from the dust in the blast-furnace gases, attention may be drawn here to a Paper read by M. Greiner before the Iron and Steel Institute in May, 1901.* M. Greiner stated in that Paper that the Cockerill Company had had a 200-horse-power gas-engine running at Seraing for three years, since 1898, which has never required the cylinder to be cleaned once on account of the dust, though the engine ran night and day, and the blast-furnace gases were used entirely without any purification; and that a 600-horse-power gas-engine at the same works, also using unpurified gases, had so far given no trouble.

On the other hand, at Differdingen, where the Cockerill Company were putting up nine 600-horse-power gas-engines, great trouble had at once been experienced, due to the fact, as was ascertained on making investigation, that the blast-furnace gases at Differdingen contained on an average from 4 to 5 grammes of dust per cubic mètre, while at Seraing the proportion was not more than 0·25 to 0·5.

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* Journal, Iron and Steel Institute, 1901, No. 1, page 56.

M. Greiner instituted an inquiry into the variation of dust in blast-furnace gases, and came to the conclusion that with furnaces using hematite ores, as a rule the amount of dust was small; but where oolitic ores were used a great deal of dust was carried forward, even when the gases passed through long lengths of pipe before they reached the point where they were utilized, and that it was impossible to separate the dust by using long lengths of pipes or any other such simple plan; the dust was in such a fine state of division that it was readily carried forward. He said there were at present practically two plans in use for cleansing the gases: one, which may be called the "static system," where the gases are passed through a series of scrubbers (which are sheet-iron towers containing coke or sawdust cooled with water spray), a plan due to Mr. Thwaite, to whom so much of the credit for the use of blast-furnace gases belongs; and the other, which may be called "dynamic," where the gas is passed through an ordinary centrifugal fan into which a jet of water enters at the axial part. The latter was the more convenient for use at Differdingen, and apparently experience has shown that the expectations formed as to its working have been justified. The plan adopted there was to use a fan about 60 inches in diameter running at 900 revolutions a minute; through this the gases pass, drawn in by the central aperture, and a stream of water also enters the axial part through a pipe about 1 inch in diameter; the gas is driven out through the ordinary discharge, and the dust and water pass away in a 2-inch pipe, taken off from the lower part of the casing. Examination of the gas showed that, before entering the centrifugal fan, it contained as much as 4 grammes per cubic mètre, and after passing through only 0·25 gramme, and it was then in a fit state for use in the gas-engines. The water used amounted to about 1 to 1½ litres per cubic mètre. It was stated that the total cost of this apparatus for dealing with the amount of gas which would be required for six 600-horse-power engines was only £400, and M. Greiner strongly advocated the adoption of a similar plan for purifying the blast-furnace gases, even when they were only burnt in heating stoves. It should be mentioned, however, that in the discussion on this Paper a good deal of scepticism was expressed, mainly by English iron and steel experts as to whether purification by this simple process would prove successful in the long run; it seems to have been satisfactory so far, where it has been tried.

The heat value of blast-furnace gases necessarily varies very much with the type of furnace, the rate of working it, and the proportion of the charges and various other conditions.

As a result of a series of analyses of blast-furnace gases in England, Belgium, and Germany, it appears that about 28·8 per cent. of the gas is carbon monoxide, about 2·5 per cent. hydrogen, about 7·25 per cent. carbon dioxide, and about 61·3 per cent. nitrogen. If a blast-furnace is in good work as regards the reduction of the metal, the more CO_2 in the exhaust gases the better, and of course this is a distinct disadvantage when the waste gases are used for gas-engine work. The heating value per cubic foot ranges from about 105 to 115 B.T.U., using the higher value for the hydrogen constituent; but, as the proportion of hydrogen is comparatively small in these gases, there is not much difference in the heating value, whether we take the higher or lower values for the hydrogen.

Opinions differ very much as to the probable amount of power available by the utilization of blast-furnace exhaust gases, and probably some of the estimates that have been made are somewhat rash.

Mr. Lürmann, the German authority, expressed the opinion that of the total gas produced in blast-furnaces, about 10 per cent. was lost in leaks in the pipe and in the smelting; about 28 per cent. was required for heating the blast, and that in most ironworks at the present day about another 40 per cent. was used for the generation of steam. This left about 22 per cent. passing to waste, and he estimated that there would be about 28 horse-power-hours available per ton of iron smelted, if this waste were utilized in gas-engine work. To take one example at Seraing, where about 600 tons of iron are made per day, there was waste gas sufficient to develop 17,000 horse-power; and in Germany, as a whole, where 7,400,000 tons of pig are made a year, he estimated there is available some

570,000 horse-power. Whatever opinion we may have as to these figures, there is no doubt that this plan of making use of gases, which were previously to a considerable extent wasted, is bound to have a great future. In a Paper read last March before the German ironmasters at Düsseldorf, Mr. Lürmann gave some statistics as to the amount of power now being developed in Germany from this source; at that time it amounted to a total of 44,000 horse-power, which is a somewhat remarkable record, when it is remembered that it is only five years since the idea was first mooted. In Belgium, France, and Italy there were engines developing about 17,000 horse-power at work.

Though it is never safe to prophesy, it is, as a rule, pretty safe to forecast future lines of development in engineering practice by carefully watching the present trend, and I do not think, therefore, I shall be too rash if I forecast for the utilization of blast-furnace gas a very remarkable future in this country.

In America, in place of the large engines using producer or blast-furnace gases, we have the Westinghouse three-cylinder type of engine using natural gases. Until quite recently—owing probably to the high price of coal gas—the gas-engine had not met with much success in the United States; but since the question was taken up by such an energetic company as the Westinghouse Company, a complete change has been brought about. Large three-cylinder gas-engines, developing from 600 up to 1,500 horse-power on the brake, are now being extensively used in central station work in suitable districts. The heating value of this natural gas being about 1,000 B.T.U. per cubic foot, it is a comparatively easy matter to govern these engines by controlling the richness of the charge, and thus ensure very steady running conditions. I have not been able to find any very complete records of lengthy tests of this type of gas-engine, but the heat efficiency when using about 10 cubic feet of gas per brake horse-power per hour appears to be 25 per cent.—a very good figure indeed.

In considering the future prospects of large gas-engines, the questions of freedom from breakdown and steadiness of running are most important. My own experience, extending now over a period of twelve years, is that in the smaller sizes the gas-engine is singularly free from breakdown troubles, and costs but a merely nominal sum annually in repairs, even when you work the engine under a heavy and constant load. For larger engines we now have equally strong testimony from those who have used them, the long period during which the large engines at Seraing have run without any need of repairs, and the testimony of Mr. Humphrey as to the long runs of a 60-horse-power nominal Crossley engine, are fairly conclusive. This latter engine ran for two years for 96·6 per cent. of the whole possible time of running, and had actually run for six months, day and night, without a single stop, and this with only the most trifling repairs. Such evidence requires no comment from me; it is clear that gas-engine makers, by careful attention to details and by extreme care in the jacket arrangements, are able to turn out large gas-engines which will give as little trouble in working as the very best types of steam-engines now on the market. As regards steadiness of running, we have again plenty of testimony. In the case of the two large engines at Winnington, already mentioned, the variation of speed was comparatively small; with the ordinary "hit and miss" method of governing, the total variation was under 2 per cent., and with the engine allowed to explode every possible time, the variation was under $\frac{2}{10}$ of 1 per cent. It is clear that one of the chief obstacles to the more extended use of gas-engines in central station work has been removed when such steady running as this can be guaranteed.

I cannot within the limits of this lecture deal with the question of relative cost of gas- and steam-engines, but all the figures I have been able to collect go to prove that the gas-engine supplied with producer or blast-furnace gases is a most formidable rival, even to the finest high-speed steam-engine; while my own experience convinces me that for driving a small workshop, where the power used fluctuates a good deal, the small gas-engine even using town gas is much more economical than a similar sized steam-engine and boiler. I would refer you for further details to the elaborate cost figures given in Mr. Humphrey's Paper, and in several other recently published papers.

I cannot conclude this brief summary without some reference to the two valuable Reports already issued by the Gas-Engine Research Committee of the Institution of Mechanical Engineers, though, of course, it is quite out of the question that I should attempt to summarise two Papers which are themselves a condensed account of experiments lasting for many months. I would merely say that the difficulties already encountered in measuring the temperatures in the cylinder show how extremely difficult this problem is; and until some knowledge is available as to how the temperatures vary throughout the mass of gas present at any instant in the cylinder, I am afraid that the use of these measured temperatures in any calculations as to loss or gain of heat during expansion or compression is liable to quite as serious errors as those introduced by the assumptions made by Dr. Kennedy in connection with the Society of Arts' trials. When one remembers that it is the temperature absolute which is used in these calculations, an error of even 50° F. in the accuracy of the temperature, at the instant that compression begins, does not seriously throw out the final results, nor does the assumption of uniformity of specific heat; comparing the specific heat at constant volume of nitrogen at 1,000° F. with that at 32° F., the increase is only some 7 per cent., and therefore the mean specific heat over the range differs by a still smaller percentage from the usually accepted value. As long, therefore, as we have to depend, either on measured temperatures when we can only measure it at one point of the mixture, or on calculations based on an analysis of exhaust gases in order to determine the temperature of the mixture at the point where compression begins, it appears that we may still safely continue to use the older approximate methods, especially when the engine has good scavenging arrangements, and none of the burnt charge remains in the cylinder.

It is interesting to note in the last report of the Committee that the increased efficiency due to raising the compression pressure before firing from 55 lbs. to 124 lbs. amounted to 2·7 per cent., or an increase of about 20 per cent. The figures below, extracted from the Report, show the gradual increase in efficiency :—

Compression Pressure. lbs.	Efficiency on B.H.P.
55	13·2
71	14·0
93	13·4
124	15·9

The CHAIRMAN said that some years ago Professor Beare and himself had attended many lectures together—the one as lecturer, and the other as student. To-night, however, their original positions were reversed, to the great enjoyment of himself. He thought that Professor Beare had managed capitally to compress into a small space of time the modern history of the gas-engine. It was the fault of the subject and not of the lecturer that each point had had to be so briefly touched upon. In the days when he himself made the trials for the Society of Arts, gas-engines of 16 and 20 horse-power were thought to be of considerable size. Moreover gas-engine makers did not at that time encourage but rather threw cold water on the introduction of larger sizes. Now things were altered, large engines were being continually made, special researches (particularly by our Institution) were carried out as to their theory and mode of working, and the era of a large industry in the manufacture of large gas-engines seemed to have commenced. He wished to express on behalf of those present to Professor Beare their heartiest thanks for the interesting lecture they had heard, and the great appreciation of the trouble he had taken in coming specially from Edinburgh for this purpose.

The vote of thanks was carried with acclamation.

Professor BEARE thanked them most heartily for the kind way they had received his lecture, and the patience with which they had listened to him. He felt that, in compressing a great amount of material into so short a time, he had only been able to touch briefly

(Professor Beare.)

upon the main outlines of gas-engine history of the last eleven or twelve years. He would therefore earnestly recommend them to refer to the original sources of information, which were to be found in the Proceedings of this and kindred Institutions.

Mr. P. H. Stevens, Graduate, in proposing a vote of thanks to Professor Kennedy for acting as Chairman that evening, desired to say how much the Graduates appreciated the keen interest taken by the Council in helping them to make the Association a success.

Professor Kennedy suitably acknowledged the vote.