The increase in economy due to increased vacuum is also greater than in the steam engine. For every inch increase in vacuum between 23 inches and 28 inches the increase is 3 per cent. for 100 kw. units, 4 per cent. for 400 kw. units, and 5 per cent. for 1,000 kw. units.

(18) Obviously, the use of a high vacuum is important in turbine work, and efforts for obtaining this vacuum have met with every success. Only by using a vacuum of 28 inches and 100 to 150° F. superheat can the best results be obtained from turbines. Sometimes a reciprocating engine can be run non-condensing economically, but the advantage of condensation is so much greater with the turbine that the only reason for running non-condensing is the need of steam for other purposes. By instaling cooling towers in a non-condensing plant the output can practically be double without adding to the operating cost.

Recently turbines carrying expansion to as many as five stages have been introduced, and from large units of this construction it is possible to secure economy equal at least to that of a first-class triple expansion engine.

Gas Engines.

The gas engine has probably developed more slowly than any other piece of apparatus, and it is only within the last ten years that the larger type of engine, from 500 to 2,000 h.p. in size, has appeared. For highly intermittent service gas engines are undoubtedly cheaper than steam, and in ordinary units the cost of operating is very low, but against this we have a high first cost and much depreciation. The delay in the success of the gas engine may be said to have been due to the difficulty experienced in bringing forward an efficient and inexpensive method of making gas.

The chief objections to this prime mover are lack of uniform angular velocity, uncertainty of action, high cost of maintenance and inability to carry heavy overloads. Of late years the first two of these have been removed, and vigorous development has placed the gas engine in the front rank. The cost has been so reduced that to-day it is very little more than a high-class reciprocating engine, and with natural gas has, perhaps, outdistanced all competitors. The most economical load is at between 50 to 90 per cent. full load, and this is a serious defect. It has been found that a combination of the gas engine and the steam turbine gives good results, and the water from the gas engine may be used for boiler feed, as it is above 100° F.

Curve No. 3.

(19) The jacket water necessary for an internal combustion engine is about 40 pounds per kw hour, and, assuming that jacket water enters at 50° F., then the discharge temperature will be $50 + \frac{19 \times 12,500}{40 \times 100} = 109.4^\circ$ F. from special example considered. As the steam turbine will only require about 15 pounds per kw. hour, including auxiliaries, it is evident that only 37.5 per cent. of this heat or 7.1 per cent. of the jacket water loss can be utilized. The other loss in the exhaust gases of 30 per cent. can be utilized either in economizers or directly in boilers or superheaters.

Considering the combination of gas engine and turbine, we may say that it is reasonable to expect a maximum thermal efficiency in the turbines of 15 per cent. Referring to Table No. 1, we note a loss of 2.4 per cent. due to ash, which is now evident does not exist, and that loss of 22.7 per cent. in slack can be reduced to about 5 per cent. as the process of combustion is complete in the gas engine. The total efficiency of conversion of this 30 per cent. of heat from the waste gases when used in turbine plants will then be $15 + 2.4 + (22.7 - 5) = 35.1$ per cent.

The heat recoverable from the jacket water was shown to be 7.1 per cent. of the total heat in the coal, so that there is 30 per cent. plus 7.1 per cent. = 37.1 per cent. of the original heat of the fuel returned from the gas engine, and this can be converted into electrical energy at an efficiency of 35.1 per cent.

For each kw. delivered by the gas engine plant 3,918 B.t.u will be turned over to the steam plant, and this in turn will give 403 watts to the steam engine free of cost. The steam plant will then have only to furnish 1,000 — 403 or 597 watts per kw. at a thermal efficiency of 15 per cent.; in other words, the economy of the steam part of the plant will be raised to $\frac{15}{0.597} = 24.5$ per cent.

Gas engines on this continent run with pea anthracite as fuel. Anthracite screenings, coke, charcoal, sawdust, and many waste products may be used to advantage. Gas engines from 20 to 150 h.p. use about 1¼ pounds of coal per break horse-power, or 1½ pounds per e.h.p.

(20) For large work three types are represented:—

1. Four cycle double-acting engine.
2. Two cycle double-acting type.
3. Two cycle double-acting opposed type.

Of these three, the four-cycle engine has become standardized for general power station work. European practice has tended towards single crank units, and the horizontal double-acting type has become the standard in this respect. The single crank units give far greater flexibility in central station work. They can be loaded more economically, and there is more opportunity for inspection and repairs.

The largest power plant using producer gas is located in Madrid, Spain, furnishing light and power to the entire community. It is equipped with six 1,250 kw. Numberg gas engines, operating in parallel, supplied by a Mond producer gas system using low-grade slack coal. This is an example of a successfully operated gas engine plant on a large scale. The greatest development of the gas engine has taken place in connection with blast furnaces and availing industry centres where the waste gases and cheap fuel are largely used for power.

Gas engines have hardly been used with the same general success in this country as they have had in continental Europe. Nevertheless, there is in operation in San Francisco a large plant showing very high thermal efficiency, giving a break horse-power on one pound of coal.

The main trouble is that only every fourth stroke is a working stroke, so that for a given number of impulses per revolution of the flywheel the gas engine becomes far more heavy and complex than the steam engine. Nevertheless, the gain in fuel is so great that one is apt to discount its weak points.

The initial high cost and high depreciation, coupled with the gas engine's inefficiency, are as yet a serious drawback to its general adoption. These facts are illustrated by noting the results of a test on a six horse-power gas engine, gas costing $1.70 per thousand feet:—

Cost of operation, including maintenance at full load, equals 41 cents per hour.

Cost of operation, including maintenance at no load, equals 20 cents per hour.

Allowing $10 per horse-power year for interest and depreciation, we can easily estimate for a 3,080-hour year at full load:—

3,080 hours at 41 cents....................	$1,262 80
Interest and depreciation..................	60 00
Total	$1,322 80

Cost per horse-power hour equals $7.15, of which interest and depreciation amount to 31 cents per horse-power hour.

Secondly, suppose engine in use three hours a day and running idle rest of the time:—

924 hours at 41 cents....................	$378 81
2,156 hours at 20 cents..................	431 20
Interest and depreciation..................	60 00
Total	$870 00

(18) W. L. R. Emmett, A.I.E.E., March, 1906.

(19) "Power Plant Economics." Stott, A.I.E.E., January, 1906.

(20) Rudolph Wintzer, A.I.E.E , February, 1906.