A paper read at the meeting of the Toronto Section, A. I. E. E., January 13, 1911, and to be presented at the 259th meeting of the American Institute of Electrical Engineers, New York, March 10, 1911.

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THE COST OF INDUSTRIAL POWER

BY ALDIS E. HIBNER

It is hardly necessary to call attention to the rapidly increasing importance of industrial engineering subjects, a condition which has made possible the presentation of a paper on such a heretofore relatively unimportant subject as the cost of industrial power. To-day one can scarcely pick up a technical magazine without finding some article on an industrial engineering subject. The comparatively recent growth of this activity is evidenced to some extent by the fact that the Industrial Power Committee of the A.I.E.E. has been in existence only three years.

The editor of a technical magazine recently commented upon the slowness of the industrial world in recognizing that organized manufacturing was essentially an engineering proposition and that the industrial engineer was quite different from an electrical or mechanical engineer. The writer went on to point out that the distinguishing features were chiefly the economic and human elements of the problem.

I know of nothing which will illustrate more vividly these distinguishing characteristics than a five minute talk with a manufacturer on the subject of power. Nearly every manufactured article requires the use of power for the completion of at least one step in the process. Almost all articles require power for every step of the manufacturing process. This results in all manufacturers having some experience with the cost of power, and there are just as many opinions on the cost of producing power as there are manufacturers.

The economic features of the problem are quite clear. Every power user wishes to obtain his power at a minimum cost.

NOTE.—This paper is to be presented at the New York Meeting of the A. I. E. E., March 10, 1911. Notice of oral discussion or any written discussion should be mailed to reach the Secretary before date of meeting. Written contributions received within 30 days thereafter will be treated as if presented at the meeting.

The introduction of the human element, however, quite often produces far different results. I have in mind one manufacturer who was so anxious to obtain his power (representing about 2 per cent of the cost of production) at a low cost that he neglected his legitimate business. The result was a loss of considerable magnitude in his business and a cost of power 38 per cent higher than the cost at which his power could have been purchased from a power company.

Another example of the importance of the human element, and what it involves in the popular misconception and ignorance regarding the cost of power, is given by the manufacturer who maintained that his gas producer plant was turning out power for \$15 per horse power-year, and that water power at \$20 was of no interest. A test on this plant showed a cost of \$75 per horse power-year.

These examples are not exceptional or exaggerated aspects of the condition that exists among the average power users. The manufacturer, as a general rule, does not know within an accuracy of 100 per cent how much his power is costing per unit. He knows how many tons of coal he is purchasing each year, and the wages of his engineer and fireman, but he does not know how many horse power-hours have been produced.

A little consideration will demonstrate that this is not a surprising state of affairs. A concern is incorporated for the purpose of making shoes, or candy, or stoves. The manager is chosen for his knowledge and experience in the production of these articles. The superintendent of a shoe factory knows how to place a shoe on the market that will sell in competition with other makes of shoes, and, at the same time, pay dividends to the stockholders. If he is doing this he should have little time to devote to the manufacture of kilowatt-hours.

One would suppose that the manufacturer himself would be the first to recognize this fact and employ a consulting engineer to advise him in technical matters, but such is not the case. I know of one manufacturer who signed a contract for a power plant, costing \$40,000, upon his own inexperienced judgment and the advice of the salesman who sold him the plant. Later investigation of this contract showed that, for cleverness in concealing the real facts, it would put to shame any shell game on record.

Sometimes manufacturers retain consulting engineers on the basis of a percentage of the cost of the plant if it is installed.

The dangers of such a practice are quite evident, as it is asking a good deal of human nature for a man to lose a neat commission on the sale of a plant by recommending the purchase of power. The manufacturers themselves are largely to blame for this practice, as they persistently refuse to pay an adequate fixed sum that will obtain for them the services of the best engineers.

Unfortunately the engineering profession, like that of the medical and the legal, has its quacks, and a manufacturer has to take the same care in selecting his engineer that he uses in selecting his physician. It is to be hoped that the present agitation of this subject will result in some method of eliminating this difficulty.

At present it is a too common practice for a man, who tells you that his own business has been developed by years of experience and study of conditions, to spend two weeks visiting this or that plant with a salesman, and, at the end of that time, thinks he has a thorough knowledge of the power problem. In fact he may go so far as one manufacturer and get you off in a corner and whisper in your ear that gas producers are going to shut down the water power plants.

A manufacturer can no more trust his business judgment in the purchase of a power plant than he can trust it to perform a surgical operation. The question in either case is one of technical knowledge as well as economics. The man who paid \$40,000 for his power plant was an experienced business man, but he honestly thought his power was guaranteed not to cost over one cent per kilowatt-hour, and did not notice that the sum set aside to cover interest, depreciation, insurance and taxes represented less than three per cent on the investment. Neither did he notice that the amount allowed for coal did not include charges for banking his boilers over night, and that in spite of this chicanery the contract, on the face of it, showed a cost of one and one-half cents per kilowatt-hour.

In view of this state of affairs, I believe considerable benefit may be derived by an outline of the different factors to be considered in the cost of producing power and a general discussion of the same.

The cost of producing power by large central station plants has been quite fully discussed by the Institute, but, while some of the principles involved are the same, there can be no direct application to the small industrial plants. In the one case we are dealing with stations of several thousand horse power ca-

capacity, in the latter with a plant of a few hundred. The central station is organized for the manufacture of electric power and the plant location is chosen with the object of producing power at the lowest possible cost. The industrial plant is organized for the manufacture of shoes, or what not, and other considerations are more important in its location. The former has every possible advantage in favor of cheap power, the latter very often everything against cheap power. There are other considerations which make the problem quite different, such as the use of steam for heating and industrial processes.

It is not at the present time, as formerly a question of electric drive versus mechanical drive, for nearly all the new private plants are electric. What the manufacturer wants to know is, "shall I purchase my power from a power company, or are my conditions such that I can produce it cheaper myself?" It is some of the factors entering into a solution of this question that I wish to discuss in this paper. Every factory has conditions peculiar to itself which require special attention and prevent any general deductions. This does not mean, however, that the solution of a typical case will not be of value in showing the relative importance of the different factors.

There are in general three factors involved in every industrial power problem; the investment charges, operating charges, and the cost of heating or use of low pressure steam. The investment charges are understood to cover the interest, amortization, insurance, taxes, and profit on the capital invested in the plant. The operating charges include coal, labor, repairs, and supplies. The cost of heating is the investment and operating charges of the boiler plant necessary for heating the building and supplying steam for manufacturing processes.

A typical example of the conditions ordinarily found, we will say, is the Blank Shoe Co. which has outgrown its present quarters and has decided to build a new factory and eventually double its output. The new building is to be of brick, four

FIG. 1

stories high, 250 ft. (76.2 m.) long and 60 ft. (18.2 m.) in width. This gives a total of 60,000 sq. ft. (5574 sq. m.) of floor area and a content of 750,000 cu. ft. (2023 cu. m.).

One of the first things which must be determined before starting construction is whether power will be purchased or supplied from a private plant. The first step in the solution of this problem is to determine the cost of heating the building. A heating plant is necessary in any case, as the conditions of manufacture are such that the temperature of the building must be kept above fifty degrees during the winter months.

Fig. 1 shows the mean monthly temperatures for the seven winter months at Toronto. The lower curve gives the coal per month necessary to heat the building to a temperature of 65 deg.

TABLE I
HEATING PLANT INVESTMENT.

Boiler, piping and auxiliaries, (A).....	\$1,500.00	
Building and stack, (B).....	2,500.00	
Total investment.....	\$4,000.00	
FIXED COST		
Interest 6 per cent on \$4,000.....	\$240.00	
Insurance and taxes, 2 per cent on \$4,000.....	80.00	
Amortization on A, 4½ per cent, 15 year life.....	67.50	
" " B, ½ " 50 " ".....	12.50	
		\$400.00
OPERATING COST		
Coal, 475 tons @ \$3.00.....	\$1,425.00	
Fireman @ \$15.00 per week.....	780.00	
Supplies and repairs.....	100.00	
		2,305.00
Total cost.....	\$2,705.00	

fahr., the same curve to a different scale giving the average boiler horse power required. The coal consumption is based on an evaporation of seven lb. of water per pound of coal (7 kg. of water per kg. of coal) one change of air per hour in the factory and the supplying of radiation losses. During zero weather 90 boiler h.p. will be required. Having determined the size of boiler plant necessary we are ready to take up the cost of heating.

Table I gives the investment necessary, together with the fixed and operating costs of the plant.

Replacement of the plant has been provided for by a sinking fund drawing 5 per cent interest compounded semi-annually, based on a life of the various parts of the plant as given in the table. The time of the fireman has been figured for the entire

year, as steam at high pressure is required the entire year for industrial purposes. It is of interest to note that the cost of coal represents only a little over 50 per cent of the total cost of heating, and that a variation of 25 per cent in the amount of coal burned causes only 13 per cent variation in the total cost.

Having determined the expense which is absolutely necessary in connection with the power requirements, the question asked

TABLE II
COMPLETE POWER PLANT INVESTMENT

Capacity, 100 kw.	
Engine, generator, switchboard, wiring (A).....	\$5,500.00
Boilers, steam piping, auxiliaries, (B).....	5,000.00
Building, foundations, stack, (C).....	5,000.00
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	\$15,500.00
Steam heating plant.....	4,000.00
	<hr/>
Additional for power.....	\$11,500.00
FIXED COST OF POWER PLANT	
Interest, 6 per cent on \$15,500.....	\$930.00
Profit, 5 per cent on \$11,500.....	575.00
Insurance and taxes, 2 per cent on \$15,500.....	310.00
Amortization on (A), 3 per cent (20 year life).....	165.00
" " (B), 4½ " (15 " ").....	225.00
" " (C), ½ " (50 " ").....	25.00
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	\$2,230.00
Fixed cost on heating plant.....	400.00
	<hr/>
Additional for power.....	\$1,830.00
OPERATING COST OF POWER PLANT	
240,000 kw-hr.	
Coal @ 7.39 lb., 887 tons @ \$3.00.....	\$2,661.00
Banking, 181 tons @ \$3.00.....	543.00
Night heating, 202 tons @ \$3.00.....	606.00
Engineer @ \$18.00.....	936.00
Fireman @ \$15.00.....	780.00
Water.....	100.00
Oil, waste, supplies.....	150.00
Repairs.....	200.00
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	\$5,976.00
Operating cost of heating plant.....	2,305.00
	<hr/>
Additional for power.....	\$3,671.00
Total additional for power.....	\$5,501.00
Cost per kw-hr.....	\$0.0229
Cost per h.p.-year.....	\$51.40

is whether it is advisable to go a step further and make the additional investment necessary for generating power, or whether it shall be purchased from a power company. The answer, obviously, depends upon the additional cost of producing this power and the rate at which power can be purchased. Having determined the former, the rate at which power can be purchased to advantage is fixed.

The concern under consideration has a maximum demand for power of 100 kw. (134 h.p.). The average load is 80 kw. (107 h.p.) giving an 80 per cent ten-hour load factor. The engine is a Corliss non-condensing, requiring 30 lb. (13.6 kg.) of steam per indicated horse power-hour. The boiler evaporation is taken at seven lb. of water per pound of coal, (7 kg. of water per kg. of coal) giving a coal consumption of 4.3 lb. (1.95 kg.) per indicated horse power-hour. The efficiency from steam cylinder to switchboard is 78 per cent, giving a coal consumption of 7.39 lb. (325 kg.) per kw-hr. or 5.51 lb. (2.5 kg.) per h.p.-hr. at the switchboard. The factory runs 300 days per year.

In Table II is given the investment cost, fixed cost, and operating cost of the plant. Allowance is made for the cost of heating, as calculated above.

Among the items of fixed cost will be found one covering a profit on the additional investment required for a power plant. It is quite clear, I believe, that a concern is not justified in investing in a power plant, unless the capital so invested returns the same profit as if invested in the most profitable part of the business still capable of extension. When the added risk is taken into consideration, I think this could safely be raised to 10 or 15 per cent.

There is nothing, I believe, among the items of operating cost that requires explanation, with the possible exception of the night heating. The engine is only running ten hours per day. It is evident then that, unless live steam is supplied to the heating system during part of the remaining 14 hours, the temperature will fall below that safely allowable. This feature is too often overlooked by the average power user. He thinks that if he installs an engine his heat will cost him nothing, forgetting that every night his watchman is turning live steam into the heating system for a length of time depending upon the temperature outside.

In Fig. 2 an attempt is made to show graphically the relative quantities of coal necessary for power and heat. The area double cross latched represents the saving in coal effected by using the engine exhaust for heating the factory.

It is evident from these results that if power can be purchased for 2.3 cents per kw-hr. there is no advantage in installing a steam power plant. At the present time, however, an engineer would scarcely make any decision without investigating the cost of producing power by means of a gas producer plant. Before

taking up this question, I wish to call your attention to the fact that a 50 per cent increase in the amount of coal required for heating causes only a 9 per cent reduction in the cost of power. I should like, in contrast to this, to show the effect of a variation in the ten-hour load factor.

By load factor I mean the ratio of the average load to the maximum load for a given period of time; in this case ten hours. I wish to mention here that 90 per cent of power users do not know the load factor of their factory. Nearly all of them will tell you that their load is absolutely constant. The point was brought home very forcibly to one manager when a graphic wattmeter was installed and he could see with his own eyes that it took half an hour for the men to get their work started in the morning, that they began to stop working half an hour before

FIG. 2

FIG. 3

noon, and that the same performance was repeated in the afternoon in starting and stopping. Under the best conditions it is difficult to get a load factor of 80 per cent, while printing and machine shops only have 40 or 50 per cent.

In the assumed conditions the load factor was taken at 80 per cent. It is seen from Table II that the only items which will be affected by a reduction of the plant output are the first item of coal, and the water. The amount for water is so small as to be negligible. The first item of coal represents roughly 48 per cent of the net cost of power. A decrease in the load factor from 80 per cent to 40 per cent will, therefore, decrease the output 50 per cent and the cost of production 24 per cent, increasing the cost per kilowatt-hour 52 per cent or to $3\frac{1}{2}$ cents per kw-hr. Plotting a curve for different load factors and the corresponding cost, we get the result shown in Fig. 3.

The heating is assumed constant, and this introduces a slight error for load factors under 30 per cent, as the average load on the engine then becomes less than the average heating requirements and necessitates supplying live steam to the heating system during the daytime. The main idea is to show that, while the average manufacturer does not know the load factor on his factory, it is the most important element in his power cost.

The curve will further serve to show the mistake which nearly every manufacturer makes of figuring his power on a horse power-year basis. In the case of the above plant the manufacturer would consider that he had a load of 134 h.p., the maximum demand. As the maximum demand remains constant for all load factors, the cost per horse power-year figured on that basis would be about \$41 at 80 per cent load factor and \$31 at 40 per cent load factor, a decrease of 25 per cent instead of an increase of 50 per cent. The cost per horse power-year based on the average load is \$51, as given in Table II, for 80 per cent load factor and \$78 at 40 per cent load factor. In this latter case the actual cost per unit is over 2.5 times that figured by the manufacturer.

It is interesting to note the effect of the use of exhaust steam on the cost of power.

If all the exhaust steam from this plant were necessary for industrial purposes, the only additional investment necessary to produce power is the \$5,500 for an engine and generator. The fixed cost on this amounts to 16 per cent or \$880 per year. The extra operating cost is an engineer at \$936 and \$250 to cover oil, waste and repairs, giving a total of \$2,066 for generating 240,000 kw-hr., giving a net cost of 0.86 cents per kw-hr. It is quite evident from this that the amount of low-pressure steam that can be utilized plays a very important part in the cost of power.

GAS PRODUCERS

The most active competitor of the steam engine for power production is the gas producer plant. This type of plant, which has developed since 1900, has shown remarkable economy of coal consumption when handled by experienced operators. The United States Geological Survey Report on Gas Producer Plants shows that for an average of a great many tests the non-condensing steam plant requires 2.7 times as much coal per unit as the producer plant. Their results give a thermal efficiency at the switchboard of 4.86 per cent for the steam plant and 13.5

per cent for the producer plant. The maximum attainable efficiency is probably 10.3 per cent for the steam plant and 21.5 per cent for the gas producer under present conditions. In view of this known economy a great many producer plants have been installed in the last few years.

For the factory under consideration the conditions will require the installation of a 175-h.p. engine and producer, and in addition a heating plant for heating the building. As this heating plant is required in any event, the cost of heating is eliminated as a comparative factor in the problem. The investment, fixed costs, and operating costs of this plant are given in Table III. The cost of the plant is somewhat higher than the corresponding steam plant. The life of the plant is also shorter. This gives a higher fixed cost than for the steam plant.

TABLE III
GAS PRODUCER PLANT
INVESTMENT

Engine and producer (A).....	\$11,900.00
Generator, switchboard, wiring, (B).....	2,500.00
Building, (C).....	2,500.00
	<hr/>
	\$16,900.00
FIXED COST	
Interest, 6 per cent on \$16,900.....	\$1,014.00
Profit, 5 per cent on \$16,900.....	845.00
Insurance and taxes, 2 per cent on \$16,900.....	338.00
Amortization on A, 15 year life, $4\frac{1}{2}$ per cent.....	535.00
" B, 20 " " 3 " 	75.00
" C, 50 " " $\frac{1}{2}$ " 	12.50
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	\$2,819.50
OPERATING COST	
240,000 kw-hr.	
Coal, 3 lb. per kw-hr. @ \$4.00, 360 tons.....	\$1,440.00
Engineer @ \$18.00.....	936.00
Oil and waste.....	125.00
Repairs.....	300.00
Water.....	133.00
Emergency service.....	300.00
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	\$3,234.00
Total.....	<hr/>
	\$6,053.50
Cost per kw hr.....	\$0.025
Cost per h.p.-yr.....	\$56.20

The operating costs of the producer plant are only about one-half that of the steam plant. This, however, is counterbalanced by the cost of heating. The final result gives a slightly higher cost for the gas producer plant. The ratio of the fixed cost to operating cost in the two cases, however, produces a very marked effect where the load factor is poor. The only items effected by the output of the plant are coal and water. These represent

only about 27 per cent of the total cost, as against 50 per cent with the steam plant, the result being a very much higher cost for the gas producer at low load factors. The poor fuel economy on light loads would further exaggerate this effect. Fig. 4 gives the cost at different load factors.

The dotted lines are a reproduction of the steam plant costs given in Fig. 3.

It is quite evident that where the use of exhaust steam amounts to anything, a steam plant can show greater economy than a gas producer plant. For a 24-hour load with only a small demand for steam to heat the building, the gas producer is the most economical.

FIG. 4

cost of the manufactured article. A saving as large as 25 per cent in the cost of power then only reduces the total cost $\frac{1}{2}$ per cent. Balance this against the item of labor which often represents 50 per cent of the cost of production. A saving of one per cent in this factor accomplishes the same result as a 25 per cent reduction in the cost of power. It seems to me that the chances of a one per cent reduction in labor cost is greater than a 25 per cent saving in power cost, when it is considered that a manufacturer is quite expert in labor matters and inexpert in power conditions.

Recently I read an article on the effect of factory ventilation on improving the efficiency of workmen, and it appeared that an increase of 25 per cent in the factory output was possible under certain conditions, if a proper ventilating system was installed.

Compare the relative importance of this saving with a few hundred dollars possible in the case of the same money invested in a power plant.

The time is rapidly coming when the small power user will take all these economic and technical questions to a consulting industrial engineer for solution, just as he takes his legal questions to a lawyer. The large manufacturing companies are already doing so; and in a few years the purchasing of power plants by factory owners, without any consulting engineering advice, will be a thing of the past.