For the past five years the best engineering talent in the world has been engaged in the attempt to utilize and apply commercially a portion of the water power of Niagara Falls. Not only does this enterprise attract scientific attention from the magnitude and difficulty of the problems presented for solution, but the effect of its success or failure on the economic questions of manufacture over a large surrounding territory, and, indirectly, the bearing that successful power transmission will have on the factories of the world, concentrates a peculiar degree of attention.

To utilize Niagara Falls has been an engineering dream for two hundred years, as in some respects no other waterfall in the world possesses such exceptional advantages. With Lakes Superior, Michigan, Huron and Erie as reservoirs, covering 95,000 square miles of area and collecting drainage from 300,000 square miles of our continent, a water supply is assured beyond the possibility of the severest drought to affect. Over the Niagara escarpment it is estimated that 300,000 cubic feet of water plunge downward 150 feet in each second of time, expending upward of 10,000,000 horse-power—an amount of energy more than equivalent to that which could be developed from the total daily coal output of the world. Topographically, however, it is difficult to appropriate any of this flow of force. Water wheels must be placed at the level of the bottom of the fall, but here the river rushes through so narrow a gorge as to preclude the possibility of advantageous mill sites. Power there is in abundance, but unless demand can be created for a very large amount the necessary improvement expense required to obtain mill locations is prohibited.

Ten years ago it was impossible, commercially, to transmit power more than a few hundred feet away from the site of its production. It was equally impractical to use in manufacturing at Niagara itself so large an amount of power as would be required to justify the cost of improvement. For though there are fine transportation facilities both by rail and water, yet the immediate environment neither produces much raw material nor affords an extensive market, and freight rates on material would soon overbalance the possible benefits from cheap power. Electrical discoveries have entirely changed the problem, and with this subtle form of energy as a servant it is now remuneratively possible to distribute power over hundreds of miles from its source. The design of the Cataract Construction Company, looking to the utilization of 100,000 horse-power, embraces such a combination as will enable it to deliver at Niagara all the power that there can be profitably used, and in addition, electrical machinery sufficient to serve all the adjacent territory with energy by transmission. The Niagara enterprise is therefore appropriately divided into two parts: First, such development as is requisite to secure power from the falls. Second, the necessary apparatus and transmission lines to distribute the energy thus obtained to distant cities.

To obtain ample and desirable building sites with adequate foundations for such purposes, combined
with access to rail and water shipping facilities, it was decided to locate the plant about a mile and a quarter east of the new suspension bridge, at the upper level of the river.

In Fig. 6 the general relation of the plant to the river and city of Niagara, together with an outline in section of the hydraulic improvements, is indicated. An ample supply of water is carried to the power house by means of a canal 12 feet deep, 250 feet wide, extending inland in a northeasterly direction a distance of 1,700 feet from the river. In order to place the wheels at the level of the bottom of the fall an enormous wheel pit is excavated 178 feet downward into the rock, from the bottom of which a tunnel 386 square feet in cross section extends 700 feet westerly around the Falls, opening into the river near the American end of the new suspension bridge, thus providing the necessary tail race facilities. Manufactories desiring to locate at Niagara can obtain from the Cataract Company mill sites and water privileges, including the use of the great tunnel tail race. The Niagara Falls Paper Company has already established a large mill upon this basis, and with its own wheels is developing upward of 2,000 horse-power. It is confidently expected that other available mill sites will be rapidly acquired, and that a large manufacturing town will be the result of a few years' growth.

With most commendable foresight the Cataract Company has secured a tract of land which, under the supervision of the best civil engineering talent of America, has been laid out as a model village. An extensive and complete system of sub-drainage is introduced, combined with ample and modern systems of sewage and water supply. The streets are carefully macadamized, nicely sidewalked and thoroughly supplied with electric light and young shade trees. A large number of cottages well plumbed and equipped with baths and electric light are at the disposal of employees at moderate rentals of from $10 to $30 per month, including water and light. A good school, town hall and public library are also among its attractions, while two electric railways connect the village with Niagara Falls. A general view of the main street in "Echota" is given in Fig. 4.

While the industrial development of the immediate vicinity of Niagara is attractive, both from an engineering and an economical aspect, the chief interest in the enterprise centres in the solution of power transmission problems. For this purpose the Cataract Company have constructed alongside of the canal a magnificent power station containing the necessary wheels and electric machinery.

Fig. 3 shows the power station looking northward along the canal, embracing the main station building on the left, the bridge in the centre and the transformer house on the right. Unfortunately the illustrations convey but a meagre idea of the massive and substantial character of the structures. All of the buildings, as well as the flanks walls of the canal, are of dimension limestone masonry, solidly laid in Portland cement, the large, sized blocks used conveying the idea of and occurring in reality work of the most permanent character. The power house proper, situated on the...
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western side of the canal, is a cruciform shaped structure, the arms of the cross receiving the administration offices of the company, while southward along the canal stretches the main portion of the building, devoted to the machinery proper. The wheels are placed 130 feet below the water level of the canal, in a long and narrow longitudinal slot cut in the rock. The water is conveyed to them by pen stocks consisting of steel tube some \(7\frac{3}{4}\) feet in diameter. Sections of the pen stock before their introduction into the wheel pit are shown in Fig. 5.

![Fig. 5.—Section of Pen Stock.](image)

After passing the wheels the water finds its way from the bottom of the wheel pit through the tail race tunnel into the river below the Falls. From each wheel a vertical shaft of steel tube 36 inches in diameter extends upward, and is directly attached to a huge dynamo placed on the floor of the station. The interior of the building with two of the dynamos is shown in Fig. 2, and presents a singularly simple appearance when it is considered that each of the machines will deliver 5,000 horse-power. The generators are alternating current dynamos intended for an output of 5,000 amperes at a pressure of 2,000 volts. Directly beside each of the generators is located the regulating mechanism, the office of which is to raise and lower the gate admitting water to the turbines, synchronously with changes in loading, in order that the dynamos may run at a constant speed. So perfectly is this accomplished that a variation of several thousand horse-power hardly causes a perceptible alteration in the velocity. Through the centre of the station a raised platform forms the switchboard carrying the necessary instruments and regulating appurtenances essential to the control of such ponderous machinery. The cavity beneath the switchboard opens into the bridge extending to the transformer house, and forms an outlet to receive the cables that will in the future distribute the electrical energy.

The present power station is designed for the reception of ten turbines, each of which with its appropriate generator will deliver 5,000 horse-power of electrical energy, thus providing an immediate output of 50,000 horse-power, with arrangements for doubling this capacity as rapidly as demand shall require. Such current as may be needed in the immediate vicinity will be distributed at the dynamo pressure of 2,000 volts, by means of carefully insulated cables carried in underground conduits; and already the Pittsburgh Reduction Company and the Carborundum Company have erected works for the manufacture of aluminum and the reduction of refractory ores by electricity that will consume some 4,000 horse-power.

The vital problem is the transmission of power to distant cities. For this purpose it is necessary, in order to attain requisite economy, to raise the electrical pressure to 20,000 or even 50,000 volts, and to build the most perfect and substantial transmission lines. This part of the plant is as yet entirely incomplete, though the designs have been prepared with the greatest care and forethought. As the Niagara plant has received the attention of the best engineering talent in the world, and as the work has been prosecuted so slowly and thoroughly that experience
is able to rectify errors as they occur, scientific success is assured. So it is the commercial aspect that is at once the most interesting and problematical. To what distance from Niagara can the Cataract Company deliver power, in competition with steam? If success in long distance power transmission shall be achieved by the Niagara experiment, a host of competitive power supply stations will spring into existence wherever there is an available water supply or favorable fuel location, such as the coal mining regions or oil and gas fields. Though the Niagara plant has little to fear from a rival waterfall, the probable competition with power derived from large steam central stations promises to be serious, particularly in the manufacturing cities located within a radius of 150 to 300 miles. At present no such central power supply stations exist; although their advent seems imminent. Consequently the only data on which to predicate the cost of power to such installations is the experience derivable from the largest and most carefully administered steam mills. With coal varying from $2 to $2.50 per ton, an allowance of 10 per cent. for interest and dividends on invested capital, and assuming the most careful executive administration, it seems probable that a large, continuously operating steam central station with a daily average output of 15,000 to 20,000 horse-power could produce electricity at the rate of $45 to $55 per horse-power annum. The Niagara Company have offered to sell electricity at the Falls station at $18 per horse-power annum; this figure doubtless including what the company considers a profitable margin. In each case a horse-power is to be delivered for 24 hours per day, 365 days per year. Obviously the difference between $45 and $18, or $27, may be expended to cover losses in transmission and profit on the necessary capital invested in transmission lines and still permit the Niagara Company to compete on an equal basis with the best designed central station. This difference is a very wide margin, and would seem to afford so large a radius of distribution as to easily absorb all the energy that the Cataract Company could dispense. Our more sanguine electrical engineers predict that at no distant day even New York and Chicago may be thus supplied. Steam experts, possibly a little jealous of their electrical confères, positively declare 150 or 175 miles to be the commercial limit of power transmission.

Scientific exploitation constantly verifies the adage that it is the unexpected that occurs. So in the future it is not impossible that transmission plants of various kinds may from the winds and waters furnish an overflowing supply of energy, thus forever setting at rest the minds of those who fear an exhaustion of the coal fields.

WIND AS A MOTIVE POWER IN THE UNITED STATES.

BY FRANK WALDO, PH.D.

SINCE the introduction of steam, and still later electricity, as a motive power it has become the custom to treat with something like contempt the great natural motors waterfall and wind. It is true that a few waterfalls on river rapids are still made use of in turning machinery, and recently great interest has been excited by the plans for harnessing a little of Niagara’s mighty power. As for the wind power, in one great branch of its application, the propulsion of vessels, it has been superseded by artificial forces except in those cases where time is of little consequence. It would be more poetical than truthful to state that this gradual decline in the use of wind power has been as gradually made good by its increased application in another direction—because it has only been within the last few years that the marvelous increase has taken place which now exists in the number of wind wheels in actual use. I may also add that this increase is due to the improvement in wind machines made by our American manufacturers.

Of course, the windmill is an ancient institution, and the traveler in the low countries of Europe is struck by the great number which he sees in operation. Their great size and elevated exposures render them very prominent features of the flat landscapes. The occasional sight of the smaller and very much more compact wind wheels in our own country leads one to think that the idea of utilizing the wind power is slowly finding its way from the older countries to our newer land.

Such was my own impression; and it was not until I began to make a special study of the subject that anything like a true idea was reached of the question of the windmill as a motive power.

There are in the United States over one hundred firms engaged in the manufacture of wind wheels. I have seen no definite statement of the total number of wheels manufactured annually, but it must be very large. A late statement in an advertisement records the sale of over twenty thousand wheels by a single firm in one year. It would probably not be excessive to estimate the total number of wheels at present in use at upward of half a million; and the annual increase must at any rate be over fifty thousand.
1. I located on a chart the places where there were firms who manufactured wind wheels, and found that probably 60 per cent, were within 200 miles of Chicago. Of these, eight firms were east of Ohio, and there were about half a dozen on the Pacific Coast.

2. We have had collected by the United States Signal Service and Weather Bureau the most valuable series of observations of wind velocities made for any land. The continuous records, extending over a period of, in some cases, more than twenty years, are available for more than the two hundred stations which are fairly well distributed over the whole of the United States. The average amount of wind for any given hour, or day, or month, or season, during a period of a number of years, can be determined from this data for the country as a whole or for any specified regions. By noting down on a map of the United States the average wind velocities for any chosen period (say for the whole year), by putting the figures denoting the miles per hour of wind adjacent to the respective stations of observation, it is seen at once that in many cases whole regions have quite similar amounts of wind, but in looking over such a map we find a great diversity for various sections of the country. If, now, the usual process adopted in such cases is followed out, and stations having equal amounts of wind are connected by lines drawn on the map, regions of various similar wind velocities are clearly marked out and an inspection of the map will show the regions of least and greatest wind and the gradations on passing from one to the other. Such maps have been prepared for the different months of the year and for the year itself. There is, however, one very unsatisfactory feature in them which must be mentioned. It is well known that the various local conditions at the places of observation, which we term the environment of the station, greatly influence the results obtained. This is particularly true concerning observations of wind velocities, which increase very rapidly with the altitude for the first few hundred feet above the earth’s surface, also over a water surface the lower air currents are much more rapid than those over a land surface.

3. I think that about 650 feet above the ocean, it will be four; on the exposed seashore, three; on the top of the highest buildings, two; on the low buildings and, say 20 or 30 feet from the ground.

4. I have therefore given on charts of the United States the average wind velocities for the whole country as they are found: First (say) on the roofs of well琬ned buildings, and, second (say) on the tops of the highest city buildings. Since brevity is necessary here, I have given the wind conditions in the midwinter month of January and the midsummer month of July—although there is some what more wind in March than in January and slightly less in August than in July. The regions of greatest and least wind can be seen by inspecting the charts. At places along the line marked 8, for instance, the average wind velocity is 4 miles per hour—that is, the total amount of wind for the month divided by the total number of hours in the month given 8.

5. It is seen from charts 1, 2, 3, and 4 that the wind velocities on the great plains are nearly as great in summer as in winter, which is most advantageous, since the use of wind power, especially for pumping water, is most frequent at the season of crop growing.

6. These charts show fairly well the average wind in the windiest and calmest seasons of the year. As a matter of fact there is a regular progressive change in the amount of wind from one month to another—an increase during the fall and early winter and a decrease during the late spring and early summer months.

7. There is likewise a diurnal change in the wind velocities. They are oftener quite strong early morning hours and increase until about 2 or 3 o’clock in the afternoon, when they begin to decrease again. In cloudy weather or over a body of water this diurnal change is still more marked, while it is greatest in clear weather and over dry continental regions. I have shown in charts 5 and 6 the amount of wind, at the windiest hour of the afternoon, exceeds the wind at the calmest hour of night. Of course these are average values. The differences are usually greatest in summer and least in winter. In some places this diurnal change is so great that the sun heats the land surface more rapidly than the ocean, and in such cases the wind flows off the land into the ocean during the day, and returns during the night. For this reason the wind is in the day light and night dark, or wind is the diurnal force.

8. The wind direction is also of importance in this matter because those winds coming from the west are stronger than those coming from the east. The stronger winds are usually more rapid at night and also are more frequent in clear weather. In cloudy weather the wind is usually more rapid during the day and at night is weaker and less frequent. In the latter case the wind is more frequent in clear weather.

9. As a matter of fact, the wind in this region is in some cases quite as strong as that of the high plains. It is likewise quite as rapid, since the use of wind power, especially for pumping water, is most frequent at the season of crop growing. In some cases the amount of wind is three times as great as that of the high plains. In cloudy weather or over a body of water this diurnal change is still marked, while it is greatest in clear weather and over dry continental regions. I have shown in charts 5 and 6 the amount of wind, at the windiest hour of the afternoon, exceeds the wind at the calmest hour of night. Of course these are average values. The differences are usually greatest in summer and least in winter. In some places this diurnal change is so great that the sun heats the land surface more rapidly than the ocean, and in such cases the wind flows off the land into the ocean during the day, and returns during the night. For this reason the wind is in the day light and night dark, or wind is the diurnal force.

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the wind should not strike it. If such a wheel is made to revolve horizontally around a vertical axis it could be placed in a fixed position and the light shelter box could be made adjustable for any side, so that the wind from any direction could be utilized. In fact, such a box screen or shield could be made automatically adjustable by having it revolve around a vertical spindle at its centre and by being controlled by a large long-tailed arrow wind vane. Such a wind wheel, and a very effective one, too, could be made at home at the cost of the material and labor.

So far I have confined myself to the presentation of the average wind velocities (in miles per hour) for the various regions of the United States, to the exclusion, however, of all observations made on mountain peaks or even on high hills. I had hoped to be able to supplement this by making a more or less accurate estimate of the actual amount of work which could be accomplished by these wind velocities as I have found them distributed. While this result has not been attained—owing to inadequate data concerning the amount of work which wind wheels can do under various wind conditions—yet a study of the question has resulted in the bringing together of a number of interesting facts concerning this practically important subject.

It is, however, safe to state the relation between the wind velocity and its force on a plate exposed squarely to the wind. Many experimenters have busied themselves with this problem, but I have used the results obtained by Professor Marvin of the United States Weather Bureau, and which have been adopted by that bureau. The following little conversion table is based on the experiments made by Marvin, chiefly on Mount Washington:

<table>
<thead>
<tr>
<th>Wind velocity, Miles per hour.</th>
<th>Corresponding pressure in pounds per square foot.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.004</td>
</tr>
<tr>
<td>10</td>
<td>0.80</td>
</tr>
<tr>
<td>20</td>
<td>1.60</td>
</tr>
<tr>
<td>30</td>
<td>3.00</td>
</tr>
<tr>
<td>40</td>
<td>6.00</td>
</tr>
<tr>
<td>50</td>
<td>10.00</td>
</tr>
</tbody>
</table>

For barometric pressure 30 inches.

At such high altitudes as Denver these pressures would be reduced by 20 per cent., due to decrease of air density with altitudes. The density of the air varies also with changes in the temperature, the results given in the table being for a temperature of about 50 degrees Fahrenheit. For other temperatures slight corrections must be applied to the results given in the table. In a marked case of extremes of temperature, such as occurs in Dakota and Montana, the summer temperature may reach 100 degrees Fahrenheit, in which case the pressures of the wind given in the table would have to be divided by 1.10; while for a winter temperature of 50 degrees Fahrenheit below zero the numbers in the table would have to be divided by 0.80. This shows how the actual power of the wind may vary 30 per cent. for the same wind velocity in one locality as the result of changes in temperature alone.

There is a somewhat approximate method which I had hoped might be used in connection with the estimation of the actual amount of work done by wind wheels. Inquiries were instituted among the various wind wheel manufacturers in order to find out if any of the users of their wheels had had the curiosity to keep a record of the work done by their wheels during any considerable length of time, such as a month or even a year. If a considerable number of such records could be obtained from various sections of the country, and especially from the immediate neighborhood of stations for which we have wind data, we should have material by means of which the average wind velocities mentioned above could be expressed in terms of work. Not a single such complete record could be found, although half a million wheels were in use. A few fragmentary reports of occasional work done by wind wheels were received, some of which I will mention merely to show what they accomplish.

In Texas a wheel 12 feet in diameter raised from 50,000 to 100,000 gallons of water per month to a height of 50 feet. In Wisconsin a wheel 10 feet in diameter raised 50 barrels of water per day to a height of 50 feet. In Iowa a 10-foot wheel raised water 40 feet in sufficient quantity for 300 cattle. A 16-foot wheel in Missouri has ground 20 bushels of corn in one hour. A 10-foot wheel in Nebraska raises 1,000 gallons of water per day to a height of 70 feet.

A case deserving more notice is one reported by P. H. James of Cortland, Neb. He used a wheel 10 feet in diameter for pumping water a distance of 130 feet through a 3-inch pipe. Most of the available wind was used. On one day 100 barrels were pumped in eleven hours. The interesting feature is the record kept of water pumped for over a year, which is as follows: January, 1,500 barrels; February, 1,500; March, 2,000; April, 2,500; May, 2,500; June, 2,500; July, 2,500; August, 2,500; September, 2,500; October, 2,000; November, 2,000; December, 1,500. How much could have been pumped had all the wind been utilized it is impossible to say, but the pumping of 35,000 barrels in a year's time is certainly a practical demonstration of the usefulness of these wheels. It is to be hoped that that wished for experimental work will soon be done, so that the amount of available wind power, or rather, the work that can be accomplished by using wind as a motor, can be determined for any region of the United States for which we have wind observations.