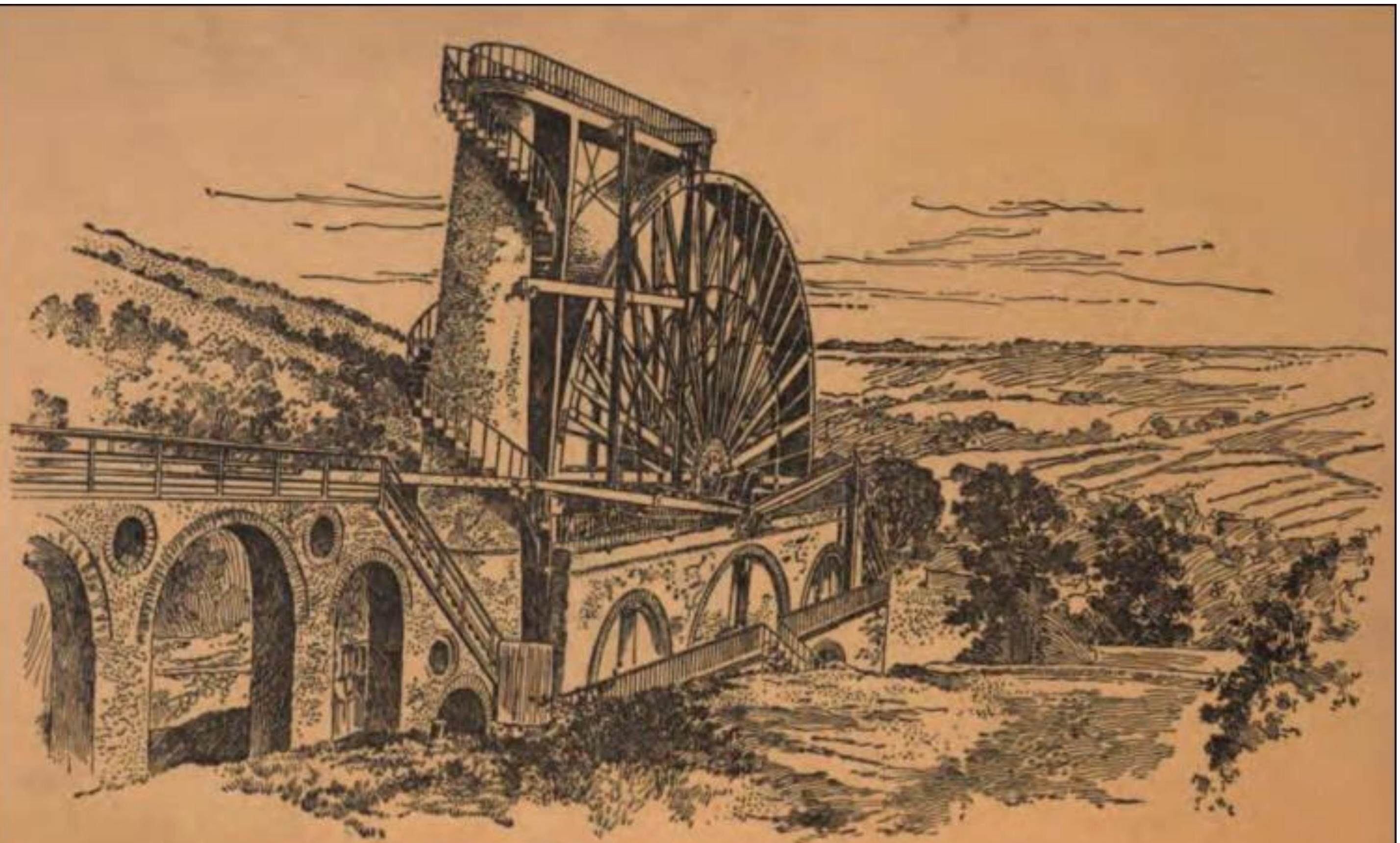

Fig. 1.—Laxy Overshot Water Wheel, Isle of Man.

WATER POWER ENGINEERING

THE THEORY, INVESTIGATION AND DEVELOPMENT
OF WATER POWERS.

BY

DANIEL W. MEAD.

Member American Society Civil Engineers

Consulting Engineer
Professor of Hydraulic and Sanitary Engineering
University of Wisconsin

First Edition.
Corrected.

PREFACE

In the development of a water power project the engineer is freqently called upon to do more than design and construct the power plant. He may be required to report on the adequacy of the supply, the head and power available and the probable variations in the same, the plan for development, the cost of construction and operation, and the advisability of the investment. A study of the entire project, therefore, becomes essential, and each factor must be carefully considered in detail to assure ultimate success. Each of the features of the development is of equal importance to the commercial success of the project. The majority of the failures in water power development have occurred from causes other than structural defects, and a knowledge of these other important and controlling factors is therefore quite as essential as a knowledge of design and construction. It must be said, however, that in respect to some of these controlling factors current practice has not been what it should be. This has resulted in many over-developments and illy advised installations, from which the power generated has not been equal to that anticipated, and in many poor financial investments amounting frequently to practical failures. The engineer has given much attention to design and construction but too little attention to the other fundamental considerations mentioned above on which the success of the project depends to an equal extent.

In the preparation of this book the author has endeavored to consider, briefly at least, all fundamental principles and to point out the basis on which successful water power development depends. The method of study and investigation outlined herein was developed by the author during twenty-five years of professional practice and in his efforts to illustrate the principles underlying the subject in his lectures to the senior class in water power engineering at the University of Wisconsin. A somewhat extended acquaintance with the literature relating to water power engineering leads the author to believe that in a number of features the principles and methods described in this book are somewhat in advance of present practice.

In current practice, the hydraulic engineer, to determine the extent of a proposed hydraulic development, commonly depends on a study of the monthly averages of stream flow and of observed maximum and minimum flows. He usually assumes from his previous knowledge and study that the development should be based on a certain minimum or average stream discharge per square mile of drainage area. The value of this method depends on the breadth of the engineer's local knowledge of rainfall and run-off relations. With a sufficient knowledge of these conditions, this method may form a safe basis for water power development but it fails to give the complete information which is essential for a full comprehension of the subject. In other cases the development is predicted on a single, or on a very few, measurements of what is believed, or assumed to be, the low water flow of the stream. This method, even when accompanied by careful study of rainfall records, is a dangerous one to employ as many over-developed water power projects demonstrate. Neither of these methods compares favorably with the more exact method of studying flow by actual or comparative hydrographs as is described in Chaps. IV, V, VIII and IX.

In current practice the head available is usually determined for average conditions, or, perhaps, occasionally for low, average and high water conditions, and no detailed study of the daily effect on power is attempted. In Chaps. IV and V this subject is presented in detail and a method of the investigation of this important subject, under all conditions of flow and all conditions of use, is outlined.

On the basis of the knowledge gained from the study of flow and head, the study of the power that can be developed for each day in the year and during each year for which actual or comparative hydrographs are available, is outlined. An outline of a method for the consideration of possible variations in flow during periods for which no measurements are available based on the available rainfall records, is also given in Chaps. VI, VII and VIII. A study of the effect of pondage on power, a most important matter, though not always carefully considered, or appreciated, is also discussed in considerable detail in Chaps. IV, V and XXVI.

In the selection of turbines for a water power project, the current practice has been for the engineer, while drawing certain conclusions from the tables of manufacturers' catalogues, to present to the manufacturer the conditions under which the power is to be developed and to rely largely or entirely on the manufacturer for advice as to machinery to be used. In such cases he is dependent for results on guarantees which are usually quite indefinite in character and seldom verified by actual tests, under working conditions, before the wheels are accepted and paid for. This has resulted in many cases in the installation of wheels which are entirely unsuited to the particular conditions under which they are installed.

Practical turbine analysis has not been treated except in the most general way in any publications except the various German treatises on the turbine in which the subject is discussed from the basis of turbine design. The author has developed the method of turbine analysis and selection, outlined in Chapters XIV and XVI, which applies to all wheels when tests of wheels of the series or class considered are available. These methods are based on the practical operating conditions of actual tests and are both theoretically and practically correct. The engineer should be able to intelligently select the turbines needed for the particular conditions of his installation and to determine, with a considerable degree of accuracy, the results on which he can depend during all conditions of head and flow.

It is believed that this treatment of the subject is sufficiently complete to place the selection of turbines on a better footing and that, when adopted, it will lead to the selection of better and more improved designs and assure more satisfactory results.

The subject of turbine governing has, for electrical reasons, become an important one. While a number of important papers have appeared on this subject, there is, so far as the author knows, no discussion in English which offers the engineer a basis for a complete consideration of this subject. Chap. XVIII, on the principles of turbine governing together with appendixes A, B and C, offer, it is believed, suggestions for the consideration of this subject which may prove of value to water power engineers.

The report on a water power project should involve a careful and complete investigation of the entire subject, and should be based on the broadest considerations of the project in all its relations. Many reports which have come to the author's attention have been too limited in scope and have included only general opinions which have not, to his mind, been sufficiently specific or based on sufficient information to warrant approval without extended investigations. In Chap. XXVIII the author has outlined his idea of the extent and scope of such investigation and report, which h believes is essential for an intelligent investigation and a reliabl opinion on this subject.

ACKNOWLEDGMENTS.

There can be little which is strictly new or original in any technica work, and in offering this book to the profession, the author wishes t acknowledge his indebtedness to the large number of technical ar ticles that have already appeared on various phases of the subject Many references to such literature have been given at the end of th various chapters.

Many illustrations have been taken, with more or less chang from Engineering News, Engineering Record, Cassier's Magazin and Electrical World and Engineer. Various manufacturers hav furnished photographs and, in some cases, cuts of their wheels, gov ernors and apparatus, in connection with which their names appea

The author has been greatly aided by his assistants, both of hi own private office and of the University staff. He wishes especiall to acknowledge the assistance of Mr. L. F. Harza to whor Chap. XVIII on The Speed Regulation of Turbine Water Wheel and appendixes A, B and C are largely due. Mr. Harza has als been of much assistance in the editorial work of publication. Es pecial acknowledgment is also due to Professor G. J. Davis, Jr for the preparation of the diagrams of friction of water in pipes an of Bazin's and Kutter's coefficients, etc. Mr. Robert Ewald assiste in the selection of material for illustrations, in the investigation o German literature, and the preparation of various graphical diagram including the first development of the characteristic curve.

The author also desires to acknowledge his indebtedness to h principal assistant, Mr. C. V. Seastone, for advice and assistance i the arrangement of many of the chapters in this work and assis ance in the editorial work of publication.

The sources of various other tables, illustrations, etc., are a knowledged in their proper places. D. W. M.

Madison, Oct. 1, 1908.

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WATER POWER ENGINEERING.

CHAPTER I.

INTRODUCTION.

THE HISTORY OF WATER POWER DEVELOPMENT.

1. Early Development of Water Power.—Most methods of power generation can be traced to an origin at no very remote period. Their development has been within historic times. The first development of water power, however, antedates history. Its origin is lost in remote antiquity.

Air and water, both physical agents most essential to life, have ever been the most obvious sources of potential energy and have each been utilized for power purposes since the earliest times. Beside the Nile, the Euphrates, and the Yellow Rivers, thousands of years ago the primitive hydraulic engineer planned and constructed his simple forms of current wheels and utilized the energy of the river current to raise its waters and irrigate the otherwise arid wastes into fertility. Such primitive wheels were also utilized for the grinding of corn and other simple power purposes. From these simple forms and primitive applications have gradually been developed the modern water power installations of to-day.

2. The Earliest Type of Water Wheel.—The crude float wheel driven directly by the river current developed but a small portion of the energy of the passing stream. The Chinese Nora, built of bamboo with woven paddles, is still in use in the east (see Fig. 1), and was probably the early form of development of this type of wheel. The type is by no means obsolete for it is yet used for minor irrigation purposes in all countries. These wheels, while inefficient, served their purpose and were extensively developed and widely utilized. One of the greatest developments of which there is record was the float wheel installa-

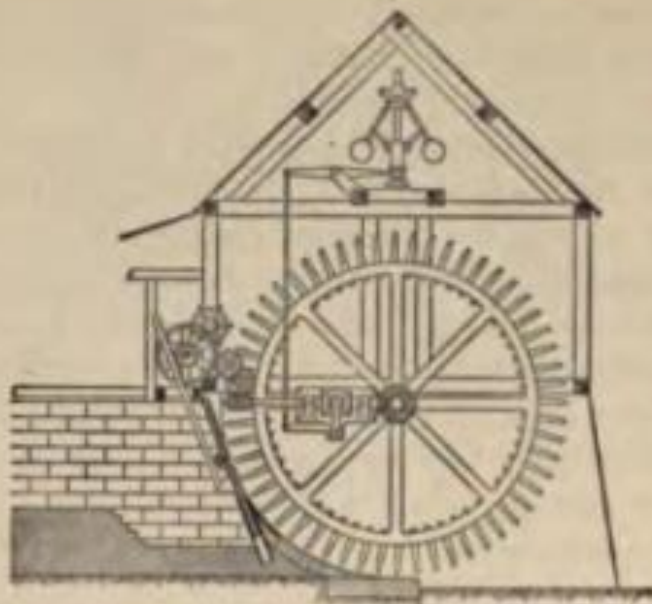

Fig. 4.—Breast Wheel About 1790 Showing Early Application of Governor. (After Glynn.)

kept sufficiently constant for the purpose to which they were then applied. (See Fig. 4.)

Another mode of applying water to wheels under low falls was introduced by M. Poncelet. (See Fig. 5.) Various changes and improvements in the form of buckets, in their ventilation so as to permit of complete filling and prompt emptying, and in their structure, took place from time to time, and until far into the middle of the nineteenth century these forms of wheels were widely used for water power purposes.

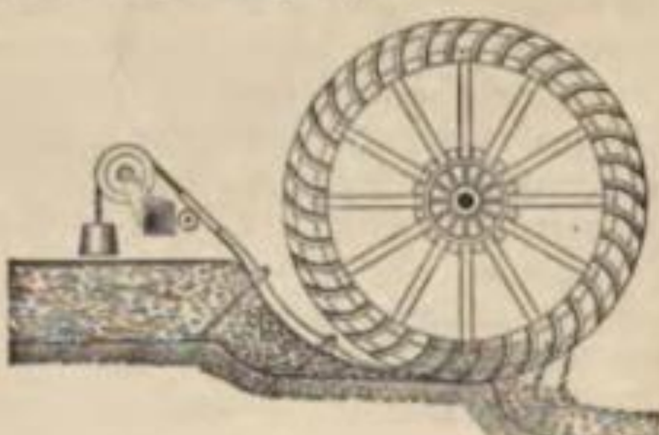

Fig. 5.—Poncelet's Wheel.

5. The Development of the Turbine.—The invention of any important machine or device is rarely the work of a single mind. In general such inventions are the result of years of experience of many men which may be simply correlated by some designer, to whom often undue credit is given. To the man who has gathered together past experiences and embodied them in a new and useful invention and perhaps through whose energy practical applications are made of such inventions, the credit is frequently assigned for ideas which have been lying dormant, perhaps through centuries of time. Every inventor or promotor of valuable improvements in old methods and old construction is entitled to due credit, but the fact should nevertheless be recalled that even in the greatest inventions very few radical changes are embodied, but old ideas are utilized and rearranged and a new and frequently much more satisfactory combination results. Improvements in old ideas are the improvements which are the most substantial. Inventions which are radically new and strictly original are apt to be faulty and of little practical value.

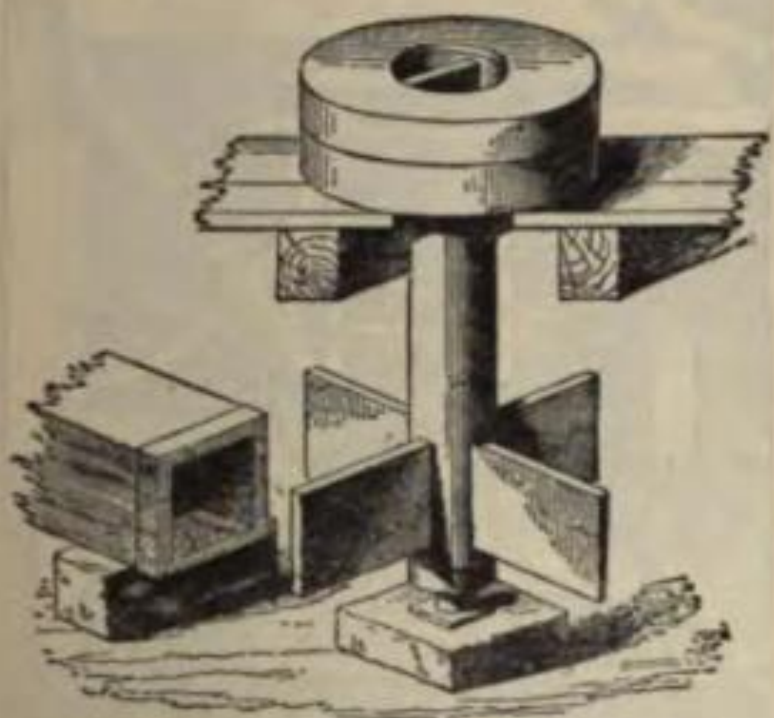

Fig. 6.—Ancient Indian Water Wheel. (After Glynn.) Containing Fundamental Suggestion of Both Turbine and Impulse Wheels.

6. **Fundamental Ideas of the Turbine.**—The embryo turbine may be distinguished in the ancient Indian water mill (see Fig. 6). A similar early type of vertical wheel used in Europe in the sixteenth century, the illustration of which was taken from an ancient print (see Sci. Am. Sup. Feb. 17, '06) is shown in Fig. 7. Barker's mill in its original form or in the form improved by M. Mathon de Cour, embodied the principal idea of the pressure

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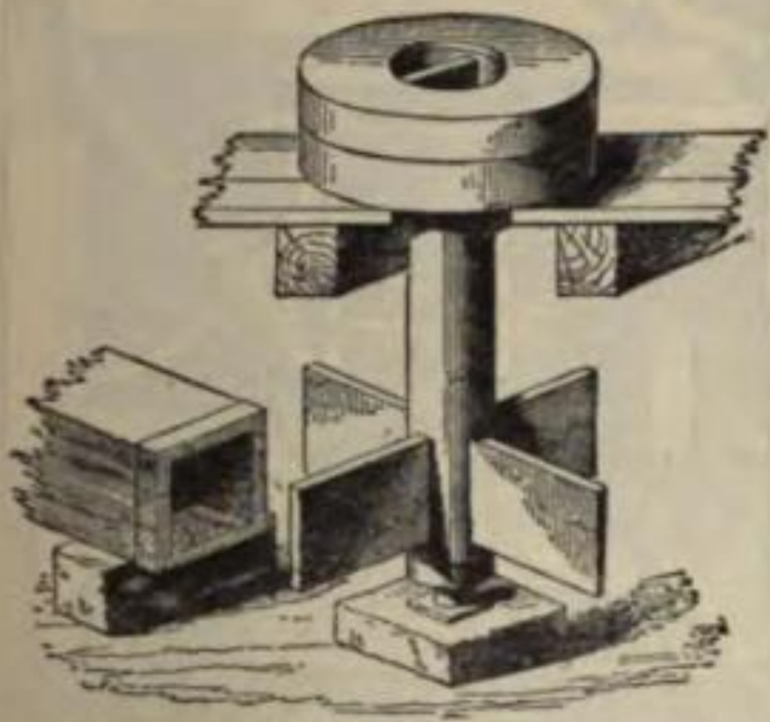

Fig. 6.—Ancient Indian Water Wheel. (After Glynn.) Containing Fundamental Suggestion of Both Turbine and Impulse Wheels.

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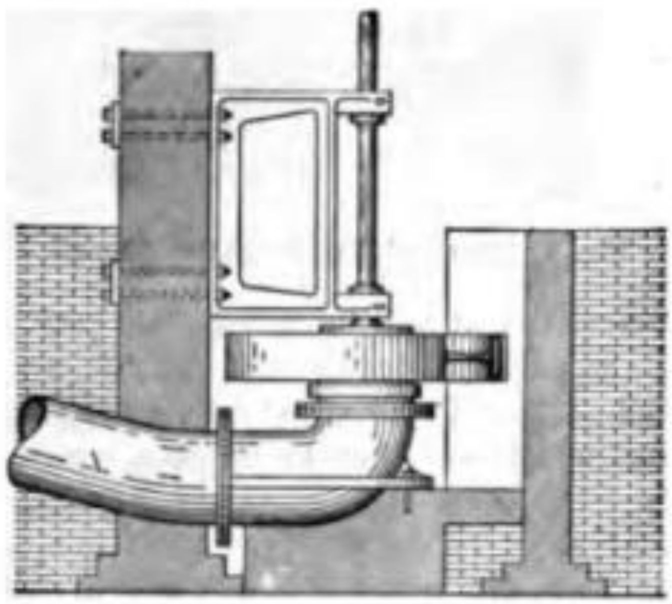
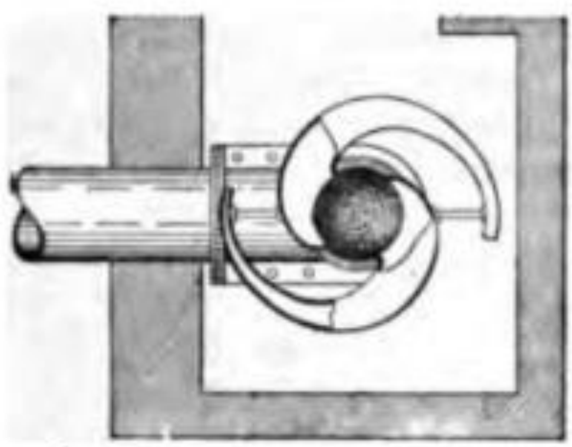
the hoops, but this proportion may be varied, or even reversed, according to the situation of place, proportion of the wheel, and quantity of water. The buckets are made of winding timber, and placed inside of the wheel, made fast by strong wooden pins drove in an oblique direction; they are fitted to the inside of the tub or wheel, in such a manner as to form an acute angle from the wheel, the inner edge of the bucket inclining towards the water, which is poured upon the top, or upper end of it about twelve and a half degrees; instead of their standing perpendicular with the shaft of the wheel they are placed in the form of a screw, the lower ends inclining towards the water, and against the course of the stream, after the rate of forty-five degrees; this, however, may be likewise varied, according to the circumstances of the place, quantity of water, and size of the wheel."



Elevation.



Plan and Partial Section.

Fig. 8.—Early Vertical Wheel. Containing Fundamental Suggestion of the Turbine. (After Glynn.)

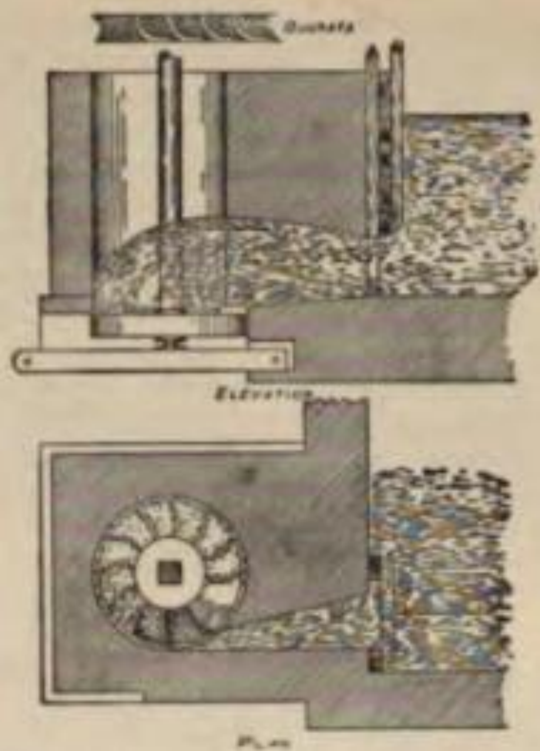


Fig. 9.—Roue A' Curves (After Glynn).

From the description it will be noted that, with the exception of the chutes, the principal features of the modern turbine were here anticipated. The "Wry Fly" wheel was an improvement on the "tub" wheel which was then in use to a considerable extent in the country.

These various early efforts received their first practical consummation and modern solution through various French inventors early in the nineteenth century. The "Roue à Cuves" (Fig. 9) and the "Roue Volant" (Fig. 10) had long been used in France, and were the subject of extensive tests by MM. Piobert and Tardy at Toulouse. Those various wheels received the water tangentially through an opening or spout, being practically an improvement on the old Indian mill by the addition of a rim and the modification of the form of buckets.

7. The Modern Turbine.—The next improvement in the United States consisted in the addition of a spiral or scroll case to the wheel, by means of which the water was applied equally to all parts of the circumference passing inward and downward through the wheel. To the French inventors, Koechlin, Fourneyron and Jonval, is largely due the design of the turbine in a more modern and practical form. By the middle of the nineteenth century these wheels had met with wide application in France and been

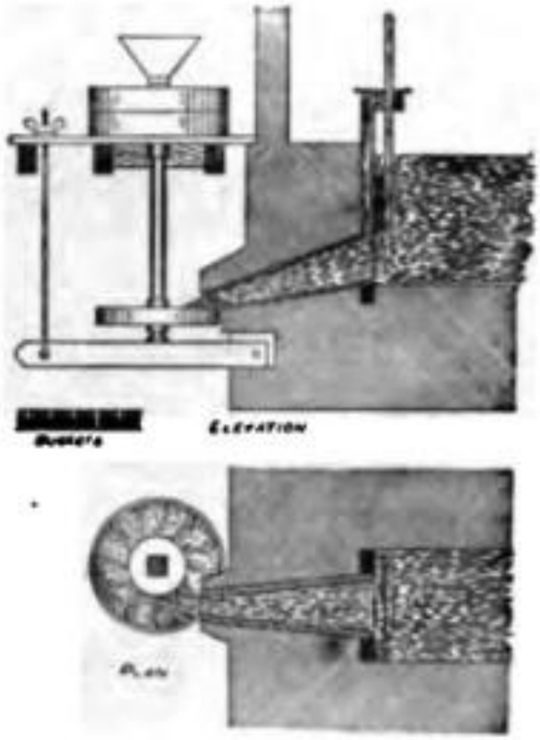


Fig. 10.—Roue Volant (After Glynn).

adopted and considerably improved by American and German engineers, but were scarcely known in England. (See "Power of Water," by Jos. Glynn, 1852.) The turbine was introduced into the United States about 1843 by Elwood Morris, of Pennsylvania, but was developed and brought to public attention more largely through the inventions of Uriah A. Boyden, who in 1844 designed a seventy-five horse-power turbine for use at Lowell, Mass. (See Fig. 132, page 251.) The great advantage of the turbine over the old style water wheel may be summarized as follows: (See Figs. 11 and 12).

First: Turbines occupy a much smaller space.

Second: On account of their comparatively high speed they can frequently be used for power purposes without gearing and with a consequent saving in power.

Third: They will work submerged.

Fourth: They may be utilized under any head or fall of water. (Turbines are in use under heads as low as sixteen inches and as high as several hundred feet.)

Fifth: Their efficiency, when the wheel is properly constructed, is comparatively high.

Sixth: They permit a greater variation in velocity without material change in efficiency.

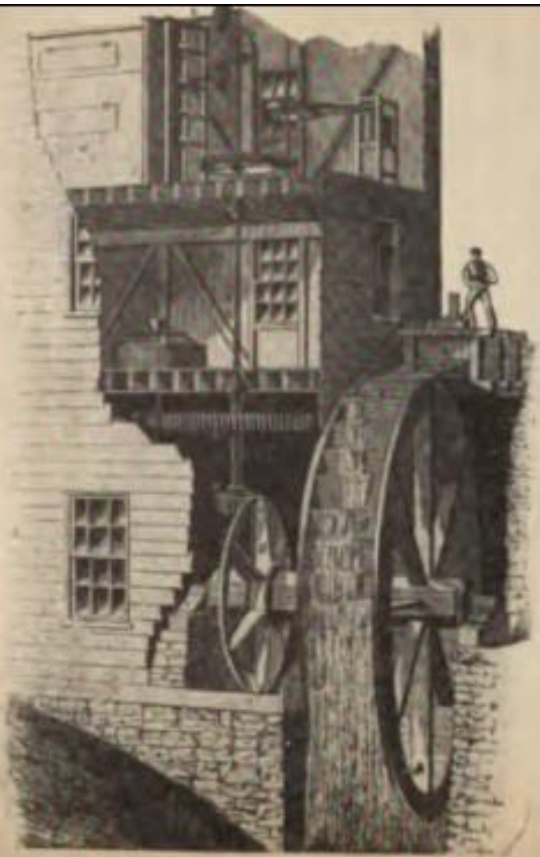


Fig. 11.—Installation of Overshot Wheel.

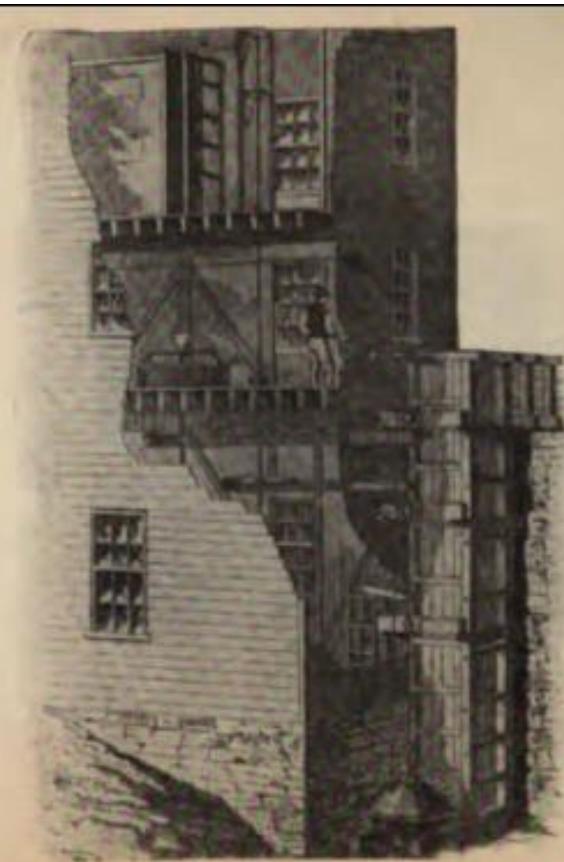


Fig. 12.—Installation of Turbine.

Seventh: They are more readily protected from ice interference.

8. The American or Francis Turbine.—Through the efforts of Uriah A. Boyden and James B. Francis (1849), the Fourneyron turbine became the leading wheel in New England for many years.

In 1838 Samuel B. Howd of Geneva, New York, patented the "inward flow" wheel, in which the action of the Fourneyron turbine was reversed. This seems to have been the origin of the American type of turbine, and the Howd wheel was followed by a large number of variations of the same general design on which American practice has been based for many years. About 1849, James B. Francis designed an inward flow turbine of the same general type as the Howd wheel. Two of these wheels

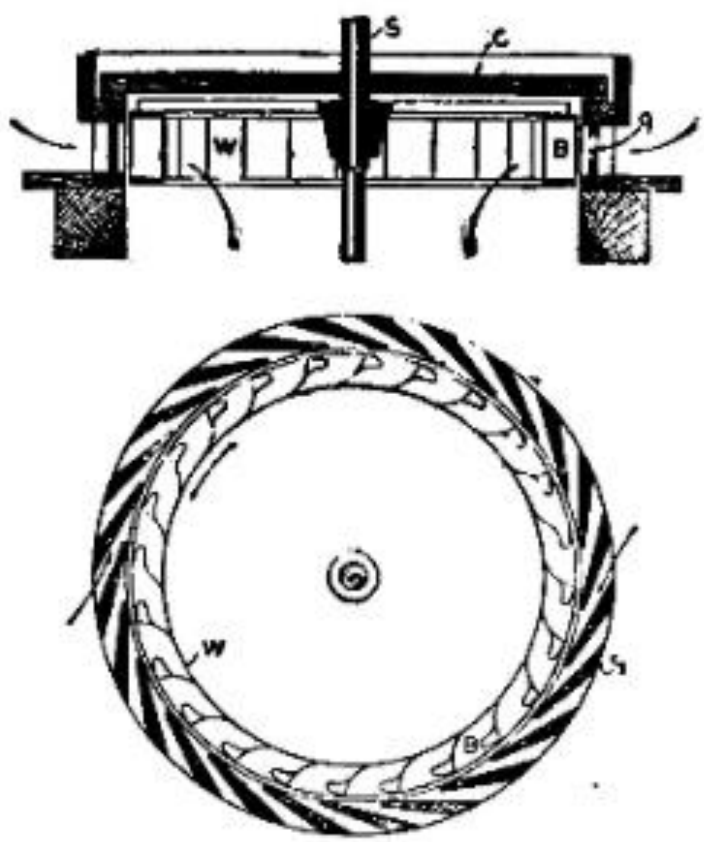


Fig. 13.—Inward Flow Wheel by S. B. Howd (After Francis).

were constructed by the Lowell Machine Shop for the Boott Cotton Mills. In the Lowell hydraulic experiments (page 61) Mr. Francis refers to the previous patent of Howd and says: "Under this patent a large number of wheels have been constructed and a great many of them are now running in different parts of the country. They are known in some places as the Howd wheel, in others as the United States wheel. They have uniformly been constructed in a very simple and cheap manner in order to meet the demands of the numerous classes of millers and manufacturers who must have cheap wheels if they have any."

Fig. 13 shows a plan and vertical section of the Howd wheels as constructed by the owners of the patent rights for a portion of the New England states. In this cut g indicates the wooden

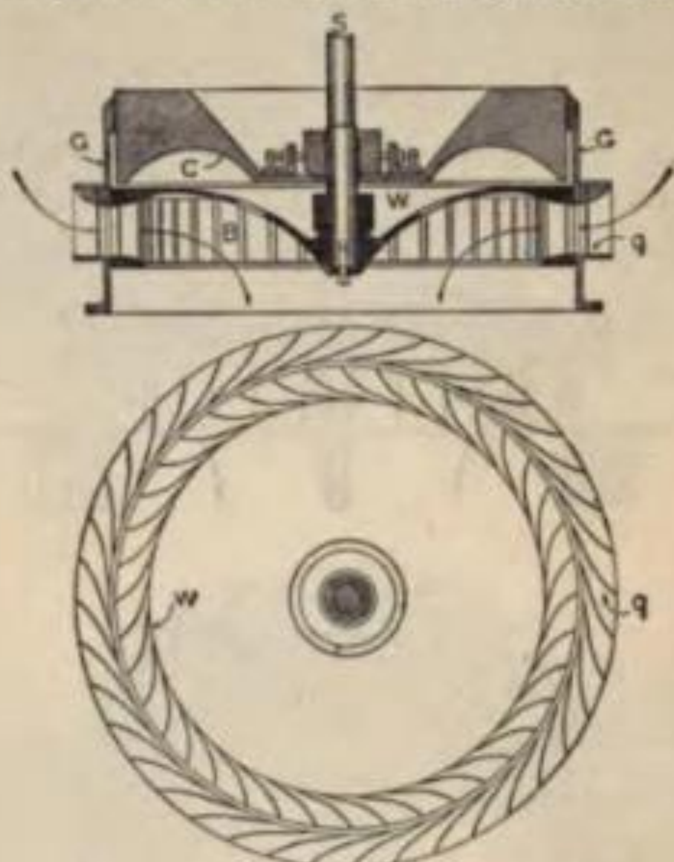


Fig. 14.—Original Francis Turbine.

guides by which the water is directed on to the buckets; W indicates the wheel which is composed of buckets of cast iron fastened to the upper and lower crowns of the wheel by bolts. The upright crown is connected with the vertical shaft S by arms. The regulating gate is placed outside of the guides and is made of wood. The upright shaft S runs on a step at the bottom (not shown in the cut). The projections on one side of the buckets, it was claimed, increased the efficiency of the wheel by diminishing the waste of the water.

The wheel designed by Francis was on more scientific lines, of better mechanical construction (see Fig. 14) and is regarded by many as the origin of the American turbine. The credit of this design is freely awarded to Francis by German engineers, this type of wheel being known in Germany as the Francis Turbine. The Francis wheel was followed by other inward flow wheels of a more or less similar type. The Swain wheel was designed by A. M. Swain in 1855. The American turbine of Stout, Mills and Temple (1859), the Leffel wheel, designed by James Leffel in 1860, and the Hercules wheel, designed by John B. McCormick in 1876, are among the best known and earliest of the wheels of this class.

9. Modern Changes in Turbine Practice.—A radical change has taken place in later years in the design of turbines by the adoption of deeper, wider and fewer buckets which has resulted in a great increase of power as shown by the following table from a paper by Samuel Webber (Transactions of Am. Soc. M. E. Vol. XVII):

TABLE I.—*Showing Size, Capacity and Power of Various Turbines Under a 26-foot Head.*

	Inches Diameter.	Cubic Feet Water per Second.	Horse Power.
Boyden-Fourneyron	36	22.95	55
Risdon	36	35.45	89
Risdon "L. C."	36	48.27	121
Risdon "L. D."	36	80.	199
Leffel, Standard	36	40.45	96
Leffel, Special	35	60.	148
Tyler	36	40.7	95.8
Swain	36	58.2	140
Hunt, "Swain bucket"	36	48.8	121
Hunt, New Style	36	98.	239.74
Leffel, "Samson"	35	109.1	264
"Hercules"	36	107.6	253.5
"Victor"	25	108.8	266
New Swain	36	89.5	216

By 1870 the turbine had largely superseded the water wheel for manufacturing purposes at the principal water power plants in this country. The old time water wheel has since become of comparatively small importance, but it is still used in many isolated places where it is constructed by local talent, and adapted to local conditions and necessities.

The current wheel is still widely used for irrigation purposes and in many instances is a useful and valuable machine.

10. Historical Notes on Water Power Development.—Water mills were introduced at Rome about seventy years B. C. (see Strabo Lib. XII), and were first erected on the Tiber. Vitruvius describes their construction as similar in principle to the Egyptian Tympanum. To their circumference were fixed floats or paddles which when acted upon by the current of the stream drove the wheel around. Attached to this axis was another vertical wheel provided with cogs or teeth. A large horizontal wheel toothed to correspond with it worked on an axis, the upper head of which was attached to the mill stone. The use of such water wheels became very common in Italy and in other countries subject to Roman rule.

Some of the early applications of water power are of interest. In 1581 a pump operated by a float wheel was established at London Bridge to supply the city of London with water. In 1675 an elaborate pumping plant driven by water wheels was established on the Seine river near Saint Germain. For this plant a dam was constructed across the river and chutes were arranged to conduct the water to the undershot water wheels. These were twelve or more in number, each operating a pump that raised the waters of the Seine into certain reservoirs and aqueducts for distribution.

The pumping of water for agricultural irrigation and drainage, domestic supplies and mine drainage, was undoubtedly the first application of water power, and still constitutes an important application of water. Fig. 15, from an article by W. F. Dupfee, published in Cassier's Magazine of March, 1899, illustrates a primitive application of the water wheel to the pumping of water from mines. The frontispiece also shows the great Laxy overshot water wheel in the Isle of Man which is still used for mine drainage. The wheel is about seventy feet in diameter and the water is brought from the hills a considerable distance for power purposes.

11. Development of Water Power in the United States.—In this country one of the first applications of water power was the old tidal mill on Mill Creek near Boston, constructed in 1631, which was followed by the extensive developments of small powers wherever settlements were made and water power was available. Often availability of water power determined the location of the early settlement.

About 1725 the first power plant was established along the Niagara River. This was a water-driven saw-mill constructed

Chronological Development of Water Power of the United States to 1898.

	Year.	Fall Ft.	Minimum Horse Power.	Drainage Area Sq. Miles.
Lowell, Mass.	1822	35	11,845	4,083
Nashua, N. H.	1823	36	1,200	516
Cohoes, N. Y.	1826	104	9,450	3,490
Norwich, Conn.	1828	16	700	1,240
Augusta, Me.	1834	17	3,500	5,907
Manchester, N. H.	1835	52	12,000	2,839
Hooksett, N. H.	1841	14	1,800	2,791
Lawrence, Mass.	1845	30	11,000	4,625
Augusta, Ga.	1847	50	8,500	6,830
Holyoke, Mass.	1848	50	14,000	8,000
Lewiston, Me.	1849	50	11,900	3,200
Columbus, Ga.	1850	25	10,000	14,900
Rochester, N. Y.	1856	236	8,000	2,474
St. Anthony Falls, Minn.	1857	50	15,500	19,736
Niagara, N. Y. (Hy. canal)	1861	90	15,000	271,000
Turner's Falls, Conn.	1866	35	10,000	6,000
Fox River, Wis.	1866	185	....	6,449
Birmingham, Conn.	1870	22	1,000	2,000
Bangor, Me.	1876	9	1,767	7,200
Augusta, Ga.	1876	50	8,500	6,830
Palmer's Falls, N. Y.	1882	30	1,125	2,650
Mechanicsville, N. Y.	1882	20	3,636	4,478
St. Cloud, Minn.	1885	14	4,500	13,250
Little Falls, Minn.	1887	14	4,000	11,084
Spokane, Wash.	1888	70	18,000	4,180
Howland, Me.	1888	22	6,000	....
Great Falls, Mont.	1890	42	16,000	22,000
Austin, Texas.	1891	60	10,000	40,000
Sault Ste. Marie, Ont.	1891	18	10,000	51,600
Folsom, Cal.	1891	55	6,200	....
Concord, N. H.	1894	13	5,000	2,350
Niagara, N. Y. (tunnel)	1894	170	50,000	271,000
Ogden, Utah	1896	446	2,940	360
Helena, Mont.	1897	32	10,000	14,900
Minneapolis, Minn.	1897	18	6,000	19,737
Mechanicsville, N. Y.	1898	18	3,270	4,478

by the French to furnish lumber for Fort Niagara. Mr. J. T. Fanning gives the following list of the dates of establishing some of the principal water powers of the United States:

The last few years have witnessed a still more rapid development. The increase in manufacturing industries and other demands for power and energy, the increased cost of coal, an improvement in electrical methods of generation and tran sion have all united to accelerate the development of water p plants. Water powers once valueless on account of their tance from centers of manufacturing and population are accessible and such powers are rapidly being developed and energy brought into the market.

Fig. 15.—Early Application of Undershot Water Wheel to Mine Dr Date Unknown (from *Cassiers Mag.* March, 1899).

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CHAPTER II.

POWER.

12. The Development of Potential Energy.—The development of natural sources of potential energy, the transformation of such energy into forms which can be utilized for power, and its transmission to points where it can be utilized for commercial purposes, constitutes a large portion of the work of the engineer. The water power engineer primarily deals with energy in the form of flowing or falling water, but his knowledge must extend much further for he encounters other forms of energy at every turn. Much of the energy available from the potential source will be lost by friction in bringing the water to and taking it from the wheel. Much is lost in hydraulic and mechanical friction in the wheel; additional losses are sustained in every transformation, and, if electric or other forms of transmission are used or auxiliary power is necessary for maintaining continuous operation, the engineer will be brought in contact with energy in many other forms.

13. Definition of Energy.—Energy is the active principle of nature. It is the basis of all life, all action, and all physical phenomena. It is the ability to exert force, to overcome resistance, to do work. All physical and chemical phenomena are but manifestations of energy transformations, and all nature would be rendered inactive and inanimate without these changes.

14. Solar Energy the Ultimate Source.—A brief consideration of the various sources of potential energy makes the fact manifest that solar energy is the ultimate source from which all other forms are directly or indirectly derived. The variations in solar heat on the earth's surface produces atmospheric currents often of tremendous power. This form of energy may be utilized, in its more moderate form, to drive the sailing vessel and the windmill, and in other ways to be of service to man. The energy of fuel is directly traceable to solar action. Through present and past ages it has been the active cause of chemical and organic change and growth. From this has resulted fuel supplies available in the original form of wood, or in the altered forms, from ancient vegetation to the forms of coal, oil and gas, and from which a large portion of the energy utilized commercially is derived.

A brief study of meteorological conditions shows that through the agency of solar heat, and the resulting atmospheric movement, a constant circulation of water is produced on and near the earth's surface. Hundreds of tons of water are daily evaporated from the seas, lakes, rivers and moist land surface, rise as vapor into the atmosphere, circulate with the winds, and, under favorable conditions, are dropped again upon the earth's surface in the rainfall. Those portions of the rain that fall upon the land tend to flow toward the lower places in the earth's crust, where lie the seas and oceans, and such portions of these waters as are not absorbed by the strata, evaporated from the surface or utilized in plant growth, ultimately find their way to these bodies of water to again pass through this cycle of changes which is constantly in progress. Thus we find water always in motion, and always an active agent in nature's processes. Due to its peculiar physical properties and chemical relations, it is one of the essential requisites of life, and is also of great importance in nature's processes through the energy of which it is the vehicle.

15. No Waste of Energy in Nature.—Active continuous energy transformation is a most important natural phenomenon. Changes from one form to another are constantly in progress. In nature's transformations energy is always fully utilized. As the running stream plunges over the fall, the potential energy, due to its superior elevation, is transformed into the kinetic energy of matter in motion, and through the shock or impact the kinetic energy is transformed into thermal energy due to a higher temperature, which again may be partially changed in form by radiation or vaporization. Thus the quantity of energy is continually maintained, while its quality or conditions constantly vary. There is, and can be, no waste or loss of energy as far as nature itself is concerned. Wasted or lost energy are terms that apply only to energy as utilized in the service of man. Nature itself never seems to utilize the entire quantity of energy from one source for the development of energy of a single form, but always differentiates from one form into a number of other forms. When the engineer therefore attempts to utilize any source of potential energy for a single purpose, he at once encounters this natural law of differentiation and finds it impossible to utilize more than a portion of the energy used in the manner in which he desires to utilize it. Much of this loss may be due to the form of energy available; much to the medium of transformation and transmission, and much to physical difficulties which it is impossible to overcome.

16. Laws of Energy Conservation.—Primarily it should be fully understood and clearly appreciated that matter and energy can neither be created nor destroyed. Both may be changed in form or they may be dissipated or lost so far as their utilization for commercial needs is concerned. But in one form or another they exist, and their total amount in universal existence is always the same. In any development for the utilization, transformation or transmission of energy, the following fundamental axioms must be thoroughly understood and appreciated:

First: That the amount of energy which can be actually utilized in any machine or system can never be greater than the amount available from the potential source.

Second: That the amount of energy which can be utilized in any such system can never be greater than the difference between the amount entering the system and the amount passing from the system as waste in the working medium.

17. Efficiency.—Efficiency is the ratio or percentage of energy utilized to energy applied in any system, part of a system, machine or in any combination of machines.

The efficiency of a given machine or mechanism, or the percentage of available energy which can be obtained from a given system of generation and transmission therefore can never be greater than represented by the equation:

$$\text{Efficiency or amount of available energy} = \frac{E - E'}{E} \text{ in which}$$

E equals the energy in the working medium entering the machine
E' equals the energy in the working medium passing from the machine.

18. Natural limit to efficiency.—The total energy in a working medium such as water, steam, air, etc., is the energy measured from the basis of the absolute zero for the medium which is being considered. For example, the average surface of Lake Michigan is 580 feet above sea level; each pound of water, therefore, at lake level contains 580 foot pounds of potential energy. This amount of energy must therefore be expended in some manner by each pound of water passing from the lake level to the ocean level, which may be regarded as the absolute zero reference plane for water power. This energy cannot be utilized at Chicago for there no fall is available. A small portion of this energy is now utilized in the power plants at the falls of Niagara. Some energy will be ultimately utilized on the Chicago Drainage Canal, where a fall of some thirty-four feet is available from the controlling works to Joliet. Perhaps ultimately in its entire course one hundred and seventy feet of fall may be utilized by the waters of the drainage canal, in which case the absolute available energy of each pound of water cannot be greater than shown by the following equation:

$$\text{Available energy} = \frac{580 - 410}{580} = \frac{170}{580} = .2931, \text{ or } 29.31 \text{ per cent.}$$

With any other form of energy the same conditions also prevail. Consider a pound of air at 760 degrees absolute temperature Fahr., and at 75 pounds absolute pressure. The number of heat units contained will be given by the equation:

$$\text{Heat units} = \text{temperature} \times \text{weight} \times \text{specific heat.}$$
$$\text{B. T. U.} = 760 \text{ degrees} \times 1 \times .160 = 128.$$

To utilize all of the energy in this air, it would be necessary to expand it down to a temperature of absolute zero and exhaust it against zero pressure. In any machine for utilizing compressed air, it will be necessary to exhaust it against atmospheric pressure. This will expand the air 3.10 times, and if expanded adiabatically it will have a final temperature of 474 degrees. The heat units in the exhaust will therefore be as follows:

$$\text{B. T. U.} = 474 \text{ degrees} \times 1 \times .160 = 80,$$

and the available energy will be as follows:

$$\text{Available energy} = \frac{128 - 80}{128} = \frac{48}{128} = .375, \text{ or } 37.5 \text{ per cent.}$$

In this case also the temperatures vary directly as the heat units, and are therefore a measure of available energy:

$$\text{Available energy} = \frac{760 - 474}{760} = .375 \text{ or } 37.5 \text{ per cent.}$$

In the ideally perfect furnace the efficiency is somewhat higher. The fuel may be consumed at a temperature of about 4,000 Fahr. absolute, and the gas may be cooled before escaping to about 600 Fahr. In this case the possible efficiency or available energy is:

$$\text{Available energy} = \frac{4000 - 660}{4000} = .832 \text{ or } 83.2 \text{ per cent.}$$

The above examples show, therefore, the limits which nature itself places on the proportion of energy which it is theoretically possible to utilize. For such losses the engineer is not accountable except for the selection of the best methods for utilizing such energy. The problem for his solution is, what amount of this available energy can be utilized by efficient machines and scientific methods.

19. Practical Limits to Efficiency.—The preceding equations are the equations of ideally perfect machines. Of this available energy only a portion can be made actually available. In practice we are met with losses at every turn. Some energy will be lost in friction, as radiated heat, some in the slip by pistons, or as leakage from defective joints. In many other ways the energy applied may be dissipated and lost. From this it follows:

The amount of energy which can be utilized can never be greater than the difference between the amount supplied to any given machine or mechanism, and the amount lost or consumed in such machines by friction, radiation or in other ways. Hence it follows that the efficiency of a given machine, or the percentage of energy available, or which can be obtained from the machine, can never be greater than the following:

$$\text{Efficiency} = \frac{E - (E' + E'' + E''' + E'''' \text{etc.})}{E} \text{ in which}$$

E = total energy available

E' E'' E''' etc. = the energy lost in friction and in various other ways, in the machine or system, and rejected in the exhaust from the same.

Every transmission or transformation of energy entails a loss, hence, starting with a given quantity of energy, it gradually disappears by the various losses involved in the mechanism or machines used. Other things being equal, the simpler the transmission or transformation, the greater the quantity of the original amount of energy that can be utilized.

The term efficiency as here applied represents always the ratio between the energy obtainable from the mechanism or machine and the actual energy applied to it.

Therefore the efficiency of a pumping engine is the ratio between the energy of the water leaving the pump and the energy of the steam applied to the engine.