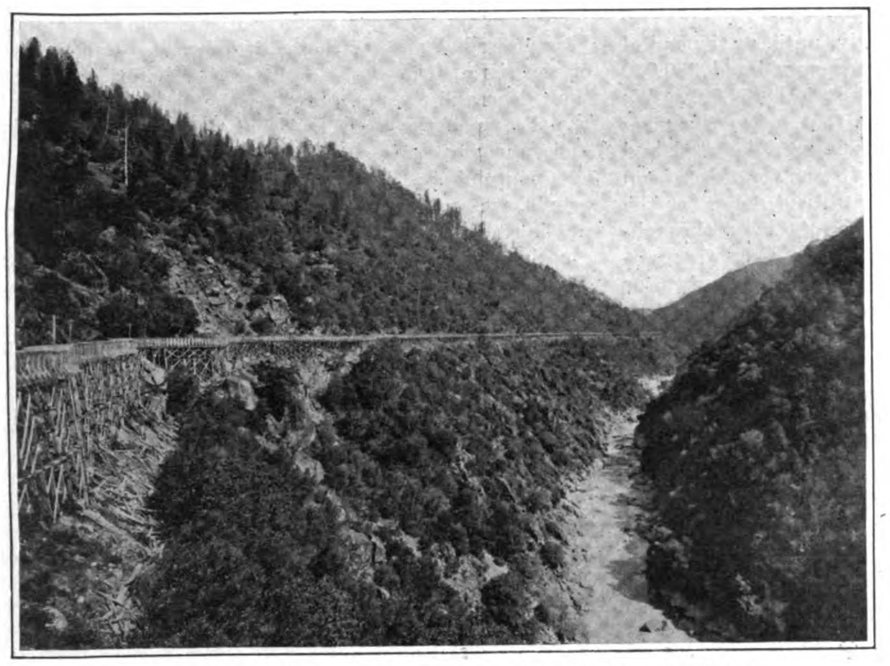
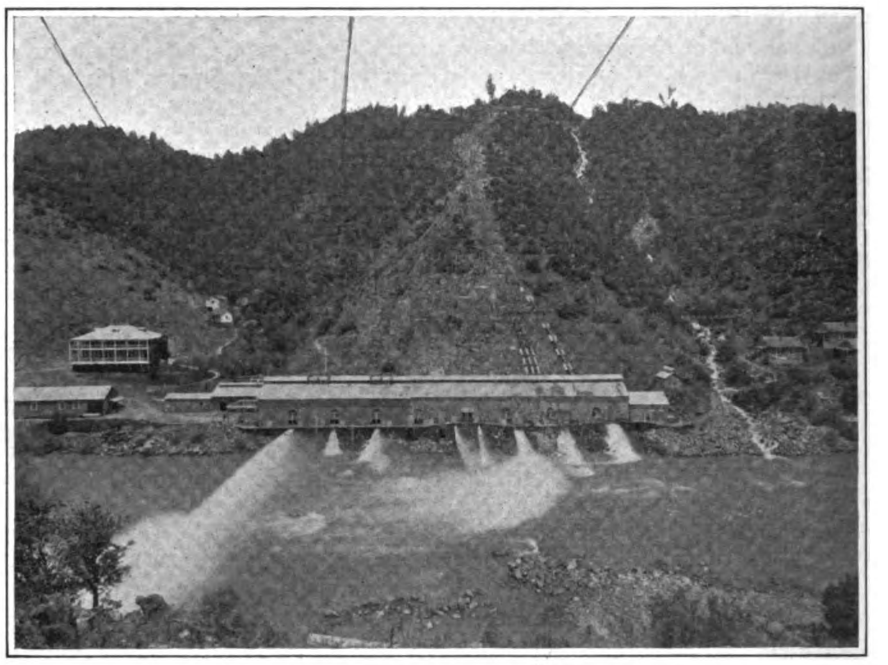


The Colgate flume—over seven and one half miles long.



Hydro-electric power plant at Colgate.

Hydro-Electric Development in California

A General Survey of the Present Situation

By John A. Britton

A GLANCE at a map of California similar to that accompanying this article, on which is portrayed the veritable network of long-distance transmission lines that mark the course of hydro-electric development from end to end of the State, might convey to one not acquainted with actual conditions, the impression that there is but little left undeveloped of the sources of water-power with which this wonderland of the West abounded when first adventurous man started out in his now far-reaching enterprise among the head-waters of our mountain streams.

This impression has, indeed, been circulated widely by those who in pursuit of a policy of so-called conservation would hinder the development of California's natural resources, and so, her progress and advancement. What foundation it has in fact may be gathered from certain statistics to hand. Mr. M. O. Leighton, Chief Hydrographer of the United States Geological Survey at Washington, in an article on "Water-power in the United States," published in the May number, 1909, of the *Annals of the American Academy of Political and Social Science*, writes: "The water-power plants in the United States make productive use of only 5,500,000 horse-power, less than one fortieth of that ultimately available." The report of the United States Geological Survey upon California, published March, 1912, gives the following figures for our State:

Potential horse-power development on a basis of 90 per cent efficiency; minimum 4,109,000, estimated maximum 9,382,000; on a basis of 75 per cent efficiency, minimum 3,424,000, estimated maximum 7,818,000.

And the total amount of water-power development in the State of California to-day stands at, in round numbers, 450,000 horse-power!

It is safe to say, however, that this total bids fair to be materially increased within a very short while. Important developments are now in process of construction, a very necessary undertaking in view of the rapid increase in California's population, an increase which undoubtedly will mount by leaps and bounds when the great International Exposition to be held in San Francisco in 1915 brings visitors from all parts of the world to view the marvels which Dame Nature has heaped with so lavish a hand on our Golden State. And so we should congratulate ourselves, perhaps, that the development of our natural resources is yet only in its infancy. It reveals California as a land of infinite possibilities, where there is room and plenty for all who come to settle in her spreading valleys, and by their enterprise and energy help to place her where she belongs among the great States of the world.

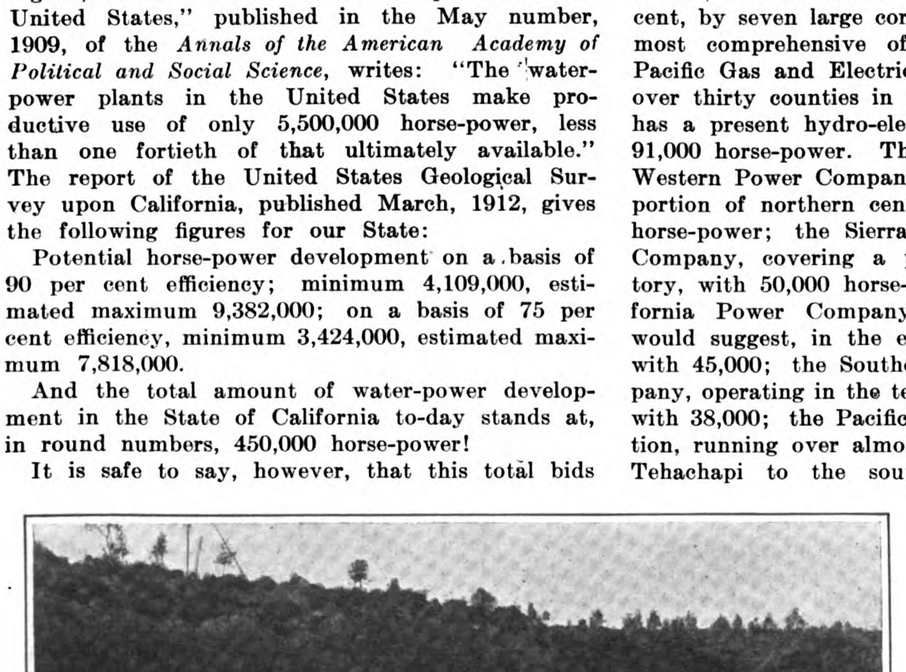
As matters stand at present it may be said that the water-power development of California is controlled, to the extent of something like 86 per cent, by seven large corporations. The largest and most comprehensive of these, of course, is the Pacific Gas and Electric Company, which operates over thirty counties in the State of California and has a present hydro-electric development of about 91,000 horse-power. The next largest is the Great Western Power Company, operating also in a large portion of northern central California, with 53,000 horse-power; the Sierra and San Francisco Power Company, covering a portion of the same territory, with 50,000 horse-power; the Northern California Power Company, operating, as its name would suggest, in the extreme north of the State, with 45,000; the Southern California Edison Company, operating in the territory around Los Angeles, with 38,000; the Pacific Light and Power Corporation, running over almost the entire territory from Tehachapi to the southern border, with about 20,000; and the San Joaquin Light and Power Corporation, operating in the San Joaquin Valley and making a sort of connecting link with the Pacific Light and Power Corporation, with about 25,000 horse-power.[1]

There are some smaller companies also worthy of mention here, as, for instance, the California-Oregon Power Company, one of whose water-power plants lies within our State limits and has a 9,000 horse-power capacity; the Oro Electric Corporation, operating in the Sacramento Valley, which has a present installed capacity of 4,000 horse-power; the Western States Gas and Electric Company, controlling the distributing system in and around the City of Stockton, with a similar amount; the Snow Mountain Power Company, in the Eel River District, with 3,000 horse-power; and the Mt. Whitney Light and Power Company, operating in the neighborhood of the oil districts, with 8,000.

Let us start, if you please, at the northern boundary of California and travel down through the State, taking in the various hydro-electric developments as we reach them and sketching briefly the organization and operating system of each, with such improvements and extensions as are known to be either in process of actual construction or in contemplation for the immediate future.

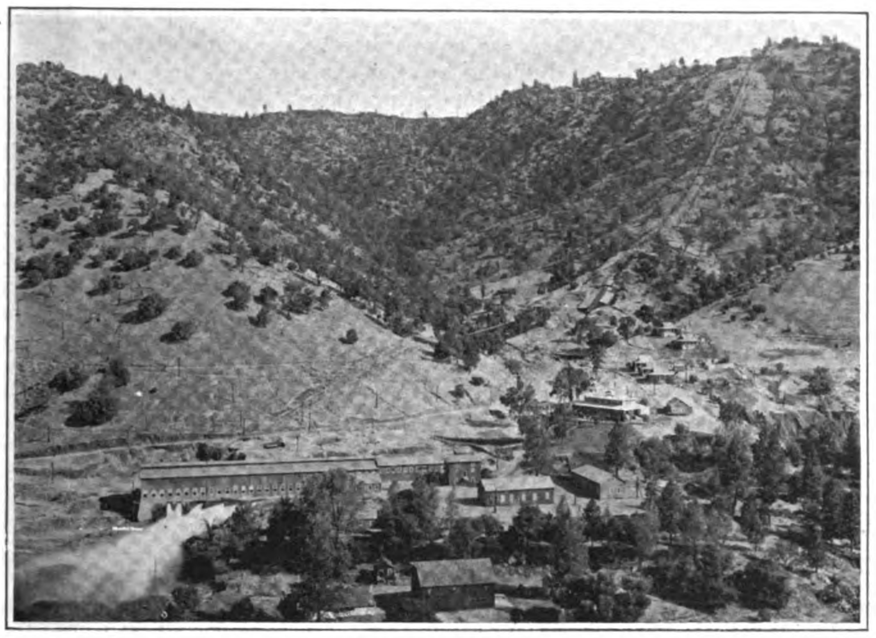
We begin with the California-Oregon Power Company, which operates in both States named. This is an amalgamation of the Siskiyou Electric, Rogue River Electric and Klamath Falls Electric Power Companies and was organized in January, 1911. Its territory ranges from Merlin, above Grant's Pass, in Oregon, on the north to a point about ten miles south of Castella, in Shasta County, California; an area of about 10,000 square miles. It has two power-plants located in California, one

[1] See SCIENTIFIC AMERICAN SUPPLEMENT, March 8, 1913, p. 152

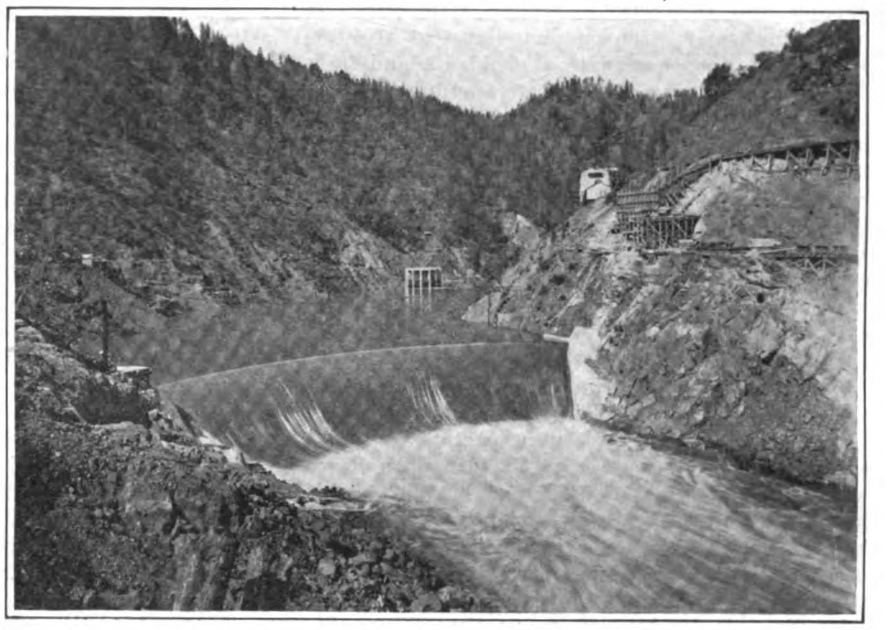


Dam and intake of canal on American River—Folsom power system.

Power plant at Folsom—the oldest in service.



General view of the hydro-electric plant at Electra.



Intake on the Feather River.

on Falls Creek, the other on Shasta River, both streams being tributaries of the Klamath River which rises in the mountains of Oregon.

Running across country in an easterly direction we strike a small system constructed by the North Mountain Power Company but now owned and operated by the Western States Gas and Electric Company. It is situated on the Trinity River, near Weaverville, and is of about 2,000 horse-power capacity. Then, due south, we reach the plant of the Snow Mountain Company, which takes its power from Eel River in the Mendocino County mountains. This company is strictly in the wholesale business and disposes of a large proportion of its output to the Pacific Gas and Electric Company, while purchasing during low water periods its supply from the same company, the balance to California Telephone and Light Company and other minor distributing companies.

Returning to Shasta County, the rapidly-inlarging system operated by the Northern California Power Company is reached. This company is a consolidation of companies beginning with the taking over of the Keswick Electric Power Company's plant in 1900. It owns three water-sheds located, respectively, on Battle Creek, Cow Creek and Burney Creek, all streams rising in the vicinity of Mt. Lassen. The system embraces five water-power stations, Volta, of 8,500 horse-power capacity; South, 8,000; Inskip, 8,000; Kilarc, 4,000, and Coleman, 16,000 horse-power; total, 44,500 horse-power. The company has 258.43 miles of transmission lines at 22,000 voltage, and 126 at 66,000, distributing electric energy through the upper section of the Sacramento Valley, and reaching as far as Willows, in Glenn County. The Pacific Gas and Electric Company is a purchaser from the Northern California to the extent of 10,000 horse-power.

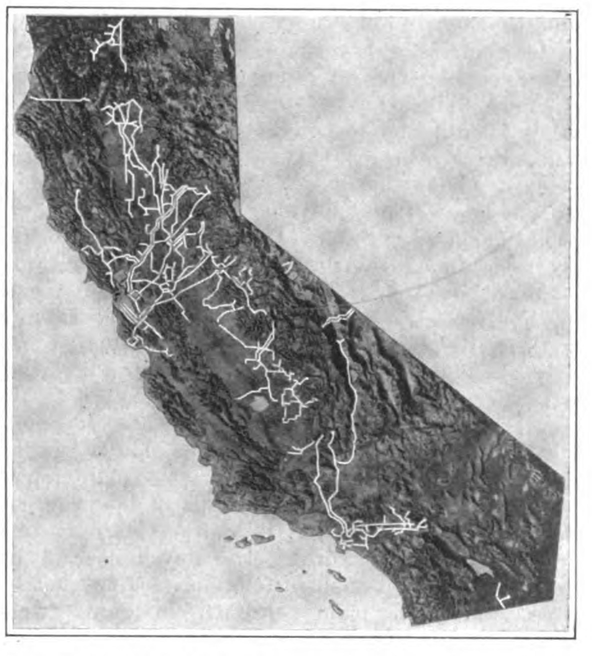
In the mountains of Butte County, northeast of Chico, we enter upon the spacious territory covered by the Pacific Gas and Electric Company's system. This is an amalgamation of power companies dating from the very inception of long-distance transmission of electric energy for commercial purposes in this part of the world, including the Bay Counties Power, Valley Counties Power, Standard Electric, Yuba Electric, Nevada County Electric Power, Butte County Electric Power and Light and Central California Electric Companies. These, with three water systems and fifteen distributing companies, formed the California Gas and Electric Corporation, which was incorporated in December, 1901. Four years later this comprehensive enterprise purchased the San Francisco Gas and Electric Company and reorganized under the name and style of the Pacific Gas and Electric Company.

This vast hydro-electric system stretches over a territory which, if superimposed upon a map of the far Eastern States, would start at about Albany, N. Y., and run all the way down to Philadelphia, Penn. At the present time its system includes eleven water-power plants, nine of which are in active operation, and its distributing lines cover an area of about 37,500 square miles.

Its most northerly plant is situated, as stated, northeast of Chico, on Butte Creek. It is named "de Sabla," after Mr. Eugene J. de Sabla, Jr., one of the founders of this great organization. The amount of energy generated here is about 17,500 horse-power under a head of 1,531 feet, and the water as it escapes from the power-house is taken up and used a second time under a head of 577 feet at a point called Centerville, eight miles down stream, where the installed capacity is 8,500 horse-power.

Southeast of this, in Yuba County, the Colgate power-plant is located on the North Fork of the Yuba River. This is one of the oldest of the large power-houses and was built in 1899 to convey electric "juice" to the city of Sacramento, and the original installation of 4,000 horse-power has since been increased to 20,000. The static head is 700 feet. It is named after Mr. R. R. Colgate, of New York, who at one time was a partner of Messrs. John Martin and Eugene J. de Sabla, Jr., in hydro-electric enterprises.

Some twenty miles to the east of Colgate is situated one of the company's earliest plants, on the South Fork of the Yuba River near Nevada City. It was built in 1896 to supply power to the mines, and has a present capacity of 533 horse-power under a head of 292 feet. Still further east, however, a useful plant is found located on Deer Creek, where there is an installed capacity of 7,350 horse-power under an 831 foot head. And a few miles to the southeast there is a 4,000 horse-power station at Alta, head of 660 feet, on the overland line of the Southern Pacific.



Map of California, showing network of long transmission lines.

The company's largest hydro-electric plant at present in operation is that at Electra, in Amador County. The water for this is taken from the Mokelumne River and, also, from Blue Lakes, Meadow Lake and Twin Lakes, a chain of storage reservoirs in Alpine County, and the Bear River Reservoir in Amador County, and is conveyed by two canals, upper and lower, to a point on the Mokelumne River where there are static heads of 1,460 and 1,260 feet, respectively. The installation here is of 26,800 horse-power capacity. This is the company's show-plant, at present, having been expensively constructed by the Standard Electric Company in 1902, and inlarged in 1907 by the Pacific Gas and Electric Company.

The remaining power-plants belonging to the Pacific Gas and Electric Company are of lesser importance, save for the historical associations connected with that at Folsom, whence in September, 1895, the mysterious energy called electricity was first conveyed along high voltage wires to the City of Sacramento, 22 miles distant. This, indeed, marked the beginning of the great system operated by the Pacific Gas and Electric Company. The Folsom plant is still operated under heads of 55 and 27 feet, the supply of water from the American River on which it is located being sufficiently large to produce results.

But this aggregate of some 91,000 horse-power developed by the Pacific Gas and Electric Company from its water-power sources bids fair to take a big jump in the not far-distant future. Up in the high Sierras, where the company owns a chain of twenty-three lakes, there is construction work in progress which, when completed, will add no less than 160,000 horse-power, with an aggregate head of 4,370 feet, to the company's hydro-electric system. The work starts at Lake Spaulding, in Nevada County, near the summit of the Sierras, where a dam 305 feet in height is to convert the lake into a storage reservoir of 30,000,000,000 gallons capacity. From this the water is to be conveyed by tunnel and ditch down the Bear River Valley and used, first at a point in the Bear River gorge, where the initial installation will be 53,600 horse-power capacity, and, after that, at five separate points down stream, the most southerly being in the Auburn canyon near the town of that name in Placer County.

These additions to the Pacific Gas and Electric Company's equipment are costing several millions of dollars. It is expected that the first supply of "juice" from this new quarter will be available before the close of the present year.

The Pacific Gas and Electric Company has 3,895 miles of electric transmission lines of which, approximately, 1,500 miles are of high voltage, 60,000. The new plant is to have 118 miles at 115,000 volts. The main lines run down through the Sacramento Valley and cross San Francisco Bay at the Straits of Carquinez, between Benicia and Port Costa, to a sub-station on the hills back of Oakland, while another line reaches San Francisco and the peninsula from Electra, crossing the bay at a point near San Jose.

Next in importance to this great system is that of the Great Western Power Company, which harnesses the waters of the Feather River for its energy. To locate this we have to travel back to Butte County where, at a point a few miles north of Oroville, stands the Las Plumas power-house. This has a scenic advantage in that it is on the main line of the Western Pacific, and travelers overland that way are permitted a full view of the power-house across the river, with the water gushing from the tail-race. The water is diverted at Big Bar, eighteen miles upstream, but the river pursues so crooked a course that the tunnel conveying the water across country to the point where it is shot through the penstocks to the power-house is but three miles in length. This system is operated at a static head of 420 feet and has a present installed capacity of 53,600 horse-power.

The Great Western Power Company was incorporated in September, 1906, as successor of the Golden State Power Company, the Western Power

Company and the Eureka Mining Company. It operates its main transmission lines at 100,000 volts. These lines terminate at Oakland, and from this point a cable at 11,000 volts conducts a portion of the "juice," approximately 5,000 horse-power, across San Francisco Bay.

In the district around Oroville also operates the Oro Electric Corporation, a comparatively small undertaking so far as its present scope is concerned, but one which is seeking to branch out through the valley counties. This system includes two water-power plants located on the west branch of the Feather River, near Oroville, whose generating capacity aggregates 4,000 horse-power.

Running southward down the eastern border of the State as far as El Dorado County we reach the properties of the Western States Gas and Electric Company, successor to the American River Power Company which was formed in 1902. This organization operates a power-plant at the junction of Rock Creek on the South Fork of the American River, 7 miles north of Placerville, where the installation is of 4,000 horse-power. The transmission lines from this run to Stockton, where is located the head office of the Western States Company, which owns the distributing system in and around Stockton. The Company is helped out in its enterprise by the purchase of power from the Pacific Gas and Electric, Great Western Power, and the Sierra and San Francisco companies.

Mention has already been made above of the plant which this company, which is owned by the Byllesby Company of Chicago, operates in Trinity County.

Pursuing our southward journey as far as Tuolumne County we reach the water-power source of the Sierra and San Francisco Power Company, an organization which is owned by the interests that control the United Railroads of San Francisco, and which supplies power for the operation of that street-railroad system. The main water-power plant is situated on the Middle Fork of the Stanislaus River, about 14 miles from the historical Angel's Camp, of which Bret Harte has written so much. The installation here is in the neighborhood of 35,000 horse-power. There is another power-plant on the South Fork of the same river of 2,000 horse-power capacity and a third one, very much smaller, at Knight's Ferry, near Oakdale, in San Joaquin County.

This company's development dates from 1906, and the first line was built into San Francisco in 1910. The main transmission lines cross the Bay at Dumbarton Point and run to the company's Bay Shore station in San Mateo County. The company has a sub-station in the San Joaquin Valley whence electric "juice" is supplied to all the towns lying between Stockton and Modesto. Another branch of its distributing system furnishes power from a sub-station at Alviso to the Santa Clara and Salinas valleys. The company has 275 miles of double construction steel towers across country; 100 miles of double line to San Francisco Bay and a single line into San Francisco from the San Mateo sub-station. There are thirty miles of single line from the Santa Clara Valley.

The next system of consequence reached in our southward journey is that of the San Joaquin Light and Power Company, the northern section of an enterprise which covers practically all the territory from Merced down to the southern border of the State. The lower connecting link is supplied by the Pacific Light and Power Company, which is operated by the same interests that control the San Joaquin Company. However, they are operated as separate companies and for the purposes of this article may be treated as such.

The first San Joaquin plant was built in 1911, replacing an old one constructed five years previous. It is located on the North bank of the San Joaquin, about 36 miles northeast of Fresno. The installation here is of about 17,350 horse-power. The water for this plant comes through the Crane Valley reservoir, a branch of the North Fork of the San Joaquin. Before it reaches the big plant it passes through a smaller one where there is an installed capacity of 4,000 horse-power. There is a third plant now under construction. It is located between the two others mentioned and will have a capacity of about 4,000 horse-power. The company also has a plant at the mouth of the Kern River canyon about 10 miles east of Bakersfield. This is one of the earlier California plants and was built in 1897 and 1898. Its installed capacity at present is 2,000 horse-power, but that is to be replaced by a more modern installation of more than double the capacity. There are two main lines running from the power-plant, one on the east side and one on the west side of the San Joaquin Valley to Bakersfield, and a line running from Fresno to the coast of San Luis Obispo and the surrounding country. The California oil fields furnish a considerable portion of this company's income.

Right here in Fresno County we strike the trail of the connecting link referred to, namely, the Pacific Light and Power Company's developments. With the assistance of the Stone and Webster Construction Company this organization is at work on two large hydro-electric plants on Big Creek, a tributary of the San Joaquin River and at a high altitude in the Sierra Nevada Mountains, about 60 miles northeast of Fresno. The second plant will take the water from the discharge of the first one. The total amount of power generated will be about 100,000 horse-power. A large reservoir at the upper end of this system will supply sufficient water during the low period, and the water will be carried to both plants through tunnels and pipes.

For construction purposes a railroad has been built to the site of these plants from Polaskey, the terminus of a branch of the Southern Pacific, a distance of over 40 miles. The magnitude of this undertaking can be appreciated from the fact that it is proposed to conduct power from the big plants directly to the City of Los Angeles, a distance of about 250 miles. The voltage of this transmission will probably be 150,000.

The Pacific Light and Power Company's territory takes in all the districts south of Tehachapi, including Los Angeles. At the present time it has four hydro-electric generating stations in operation. Of these the largest is the Borel plant on Kern River about 30 miles east of Bakersfield, where the installation is of 13,400 horse-power; but it is of record that this plant has never been able to operate at its full capacity. There is a double transmission line from Borel to Los Angeles, 110 miles. Near Azusa, about 30 miles due east of Los Angeles on the San Gabriel River, is another plant of the company's earliest hydro-electric development. It is a comparatively small installation of 1,600 horse-power. A third plant, situated in Santa Ana canyon directly north of San Bernardino, supplies about 1,500 horse-power.

Over in Tulare County is found the system owned and operated by the Mt. Whitney Light and Power Company, whose headquarters are at Visalia. This company has three power plants, two on the Kaweah River and the other on the Tule River. They are comparatively small installations.

Running to Los Angeles, we find another corporation operating there, the Southern California Edison Company, a successor to the West Side Lighting Company, the Redlands Electric Light and Power Company, and the Edison Electric Company. It was originally built to carry power from Redlands District to Los Angeles. This company has no less than seven water-power plants in operation at the present time, one on Kern River, three on Mill Creek, two on the Santa Ana River and one on Lytle Creek. That on Kern River is the only large one, having an installed capacity of 26,800 horse-power. The Mill Creek plant is of 4,000 horse-power, and there is an installation of a similar capacity at one of the Santa Ana River plants. The other plants are very small. The Southern California Edison Company operates over a territory taking in Orange, Kern, Ventura and San Bernardino Counties, and a slice of Riverside.

Two other companies might be mentioned, the South Sierras Power Company and the Truckee River General Electric Company. The first is a successor of the old Nevada-California Power Company, whose development is located on Bishop Creek, a tributary of the Owens River, where are three water-power plants of an aggregate generating capacity of 18,000 horse-power. But this company, while having its headquarters at Los Angeles, disposes of its output in the adjoining State of Nevada for the main purpose of operating the mines there. However, it is planning to bring its transmission lines into San Bernardino where it operates a steam plant.

The Truckee River Company claims acquaintance with California for the reason that Lake Tahoe is its reservoir. However, this is used only on the Nevada side and the power is all distributed in that State.

This article has touched the high spots only of hydro-electric development in California. Nothing has been said about steam plants, though it is understood that most of the big companies reinforce their water-power development by this means in the big cities. The present total installation of steam plants for light and power purposes aggregates, approximately, 200,000 horse-power. It is safe to say, however, that as matters are at present, there is no likelihood of steam ever displacing water-power for general commercial purposes.

So, as long as the snows shall gather on the summits of California's high mountains so long shall men penetrate the mountain fastnesses and compel the waters of the streams to do their will. It is all in the line of progress and development, and by means of the great storage reservoirs and irrigating systems which form part of many of the big power companies' developments, comfort and prosperity are offered to the farmers and the residents generally in many sections of the State that under ordinary circumstances would be crying for water during a considerable portion of the year, due to the climatic condition of a long summer period of absence of rainfall. This period generally extends from absence of rainfall. This period generally extends from April to October, when the fruit, alfalfa and grain lands are dependent upon stored waters for irrigation after the natural flow of the streams has subsided.

The hydro-electric companies, therefore, are benefactors in this respect and are conservationists in the most liberal and generally accepted interpretation of the term.

The Principles of Fuel Oil Engines—III*

The Chemical and Physical Basis of Their Operation

By C. F. Hirshfeld

Concluded from Scientific American Supplement, No. 1960, Page 64, July 26, 1913

It is a matter of practical experience that the use of water in kerosene and other oil engines materially improves operating conditions. The explanations which have been offered are numerous and varied and there is probably truth in most of them. There are, however, some which have not yet been suggested so far as my knowledge goes. We will consider all of them, new and old, very briefly in such a way as to bring out the essential points. They are:

1. The use of water serves to maintain low temperature during compression and thus prevents cracking. This is due to the absorption of heat during vaporization and subsequent superheating of the water vapor. It should be noted that such cooling will materially retard the rather difficult vaporization of the fuel.

For maximum cooling effect the water should be introduced as finely divided liquid spray at the beginning of the compression stroke or earlier; for minimum cooling it should be introduced in the form of superheated vapor as late as possible in the compression stroke. The best conditions will vary with fuel, engine, and load. Observe that if the conditions of water injection (quantity, condition and time) remain constant from no load to full load they can be correct for one load only and must be more or less wrong for all other loads. Suppose, for instance, that the water is regulated properly for full load. At lighter loads the cooling effect will be too great; vaporization of the fuel will be retarded, condensation on cold walls will become excessive, and low temperature and pressure will cause slow flame propagation of pressure during combustion.

* Paper read before the American Society of Agricultural Engineers and published in the *Gas Review*.

2. The use of water probably leads to a water gas reaction with the hydrocarbons or with some of the carbon liberated from those hydrocarbons, resulting in the formation of CO_2, CO, and H_2. This would prevent the deposition of some carbon which would not otherwise be burned and would therefore result in a cleaner engine. These water gas reactions start at a temperature of about 1,000 deg. Fahr. and are very active at a temperature of 1,800 degrees; they cannot, therefore, occur to any extent during compression as has been assumed by some.

A very common error in this connection is to assume that the hydrogen of hydrocarbons burns first and leaves the carbon behind, and that the deposition of carbon is due to the great difficulty of making the oxygen combine with this carbon. So far as experiment has gone, it shows that carbon burns first and that it forms CO. The hydrogen then burns with such oxygen as is left in the neighborhood unless the temperature is so high that it cannot combine with oxygen, that is unless the temperature is above the dissociation temperature of water. The carbon deposit with which we are so familiar must therefore be formed by the cracking of hydrocarbons which have not yet started combustion, much as was explained in previous paragraphs. This all indicates that fine spraying, which will result in a uniform distribution of combustion, will tend to prevent the formation of carbon.

3. It has been suggested that the presence of water or of superheated steam prevents the cracking of hydrocarbons because of some unknown chemical action. So far as has yet been shown this is not correct. The argument is based upon the fact that the oil refiners use superheated steam to prevent cracking during distillation, but the action in this case is purely mechanical; the steam carries the vapors out of the heated zone in which cracking would ensue. Obviously we need not further consider this case.

4. The presence of water is supposed to prevent excessive rise of pressure during combustion by dissociating and absorbing heat. This is probably true to a certain extent, but the amount of dissociation of the kind ordinarily meant is probably small and its effect of corresponding magnitude. The principal effect of the water at this part of the cycle is probably due to the following four phenomena.

5. As cracking continues during combustion in the way already explained, the water gas reactions which all absorb heat probably continue and thus keep down temperature and pressure.

6. The water vapor has a relatively high specific heat and since its temperature must be raised with that of the surrounding gases, this tends to keep the ultimate temperature and pressure low.

7. The water serves as a diluent of the combustible mixture just as any other gas or vapor would and it thus decreases the ultimate maximum pressure. Its action in this way would be particularly noticeable at the higher loads when the velocity of flame propagation in the undiluted mixture would reach its maximum value.

8. The water vapor is the same chemically as one of the products of combustion and hence increases the concentration of the mixture with respect to this constituent. But the chemists have shown that in reactions of this kind the velocity of the reaction is determined by the concentration; it is greatest when the concentration of one of the resultants is least and it decreases as the concentration with respect to that resultant increases. Thus the presence of water vapor retards the formation of more water vapor by combustion and thus retards the rate of combustion, which in turn means a lower final temperature and pressure.

Other possible actions of water vapor which would have a beneficial effect, and which probably occur, are the following:

9. The water must vaporize very rapidly during the compression stroke since its vapor pressure will be high at the temperatures attained during this part of the cycle. In vaporizing rapidly and diffusing through the mixture it must cause considerable commotion and thus churn up the other constituents and assist the diffusion of the hydrocarbon vapors which are more sluggish.

10. It seems probable that the small particles of carbon which are cracked out of the hydrocarbon vapors adsorb water vapor to a certain extent and are thus prevented from agglomerating so that they remain small and light enough to float instead of becoming large, heavy particles which will collect on the walls or pass out with the exhaust as visible smoke. Such suspension would naturally assist in promoting combustion because the small particles would remain floating in the midst of a hot turbulent mass of gas containing oxygen instead of collecting on the relatively cool walls.

From this collection of the probable activities of water in the engine cylinder it is evident that the behavior of water under these circumstances is very complicated and that no single explanation of such action is possible.

It will also be evident that within limits the action of the water will be dependent upon its quantity. Too little will give all the troubles with which the engineer is familiar; too much will cause similar troubles. The proper quantity in any engine varies with the load, though not in direct proportion. In every engine so far constructed the quantity which is correct for full load is far from correct for light loads, and will, in general, cause the deposition of considerable soot and give a smoky exhaust. It is also true that the correct quantity will vary with the size of the engine, the proportions of the cylinder and clearance space, the degree of compression, the speed, the average temperature maintained in the various metallic parts, and the method and time of introducing the fuel. Each engine and each size of engine therefore presents its own individual problem and the solution must be determined experimentally.

We may conclude in a general way that in the case of small engines it will be possible to obtain fairly satisfactory results without the use of water if we maintain a fairly high wall temperature, do not use too high a compression pressure, and introduce the fuel in a very fine spray during the suction stroke or near the beginning of the compression stroke. It will be necessary to clean the engine periodically, but this is not a great commercial drawback in small sizes. The use of water adjusted to give best results for from half to three quarters load will probably improve conditions somewhat and allow cleaning at longer intervals.

The regulation of the water so that it varies with, but not as, the load will give still better results and will permit of higher compression.

The use of water in this way can be made to give almost perfect results with kerosene, but even this arrangement falls short of all that is desirable with the heavier and cheaper fuels. The reason is obvious, but it should be noticed that very fine spraying of the fuel will counteract increased density and viscosity to a very great extent in any type of engine.

Thus far we have confined our attention to the external preparation of fuels by means analogous to those used with gasoline. There is, however, another distinctly different means employed which may be called the retort process. The fuel, or the fuel and some or all of the air, with or without water, are passed through a retort or pipe heated by means of the exhaust gases. The products of distillation and cracking or these combined with the products of reactions between water and carbon are then carried into the engine cylinder for combustion. This method is capable of giving very satisfactory results with kerosene, particularly when water is used and when the load is fairly steady, but when heavier fuels are used it generally leads to trouble by the formation of excessive quantities of carbon and pitch. These collect in both the cylinder and the retort. The most prominent difficulty is that of temperature control; the retort temperature which is correct for full load is far from correct for fractional loads. Therefore, with decreasing loads there is a tendency toward excessive cracking, while with increasing loads the vaporization of the fuel is incomplete. Either effect will, of course, give trouble.

Another source of trouble is the condensation of fuel within the cylinder. The retort prepares a mixture of fixed gases and vaporized liquids at a comparatively high temperature and some of these vapors have a tendency to condense on the cooler cylinder walls.

There is one property of hydrocarbons which should be of great importance in connection with the retort method, but it seems to have gone unnoticed up to the present time. Hydrocarbon liquids can be maintained at high temperatures for long periods of time without any appreciable cracking if the vapors which distill off are not allowed to remain in contact with hot surfaces. The heaviest hydrocarbon liquids can also be entirely vaporized at very low temperatures by bubbling air through them. Thus solid paraffines which melt at temperatures in the neighborhood of the boiling point of water can be entirely vaporized without cracking if they are melted, maintained at such a temperature that they are limpid liquids, and have air bubbled through them. The liquid will entirely disappear and no carbon or pitch will remain behind. This method looks very promising from a theoretical view point and warrants investigation.

Since external retorts are found to lead to difficulties of the kinds mentioned, the next logical step is to place the retort in such a position that it will be least subject to the things which cause these difficulties. This leads to the combination of the retort with the cylinder giving the familiar hot bulb or hot head type of engine. Such constructions do not entirely eliminate the difficulties previously spoken of, but they can be made to partly do so.

They vary all the way from the original Hornsby-Akroyd type in which practically all the fuel vaporization, mixing and ignition occur within the hot bulb to the De la Vergne Type F. H., in which the function of the bulb is pre-eminently that of an ignition device, and very little that of a vaporizer.

With low compression pressure and without water injection, the forms in which fuel is sprayed into the interior of the bulb at such a time that vaporization and cracking are almost complete before the entrance of any appreciable quantity of air to the bulb are fairly satisfactory. They can be used with very heavy fuels, but there is naturally a collection of carbon in the bulb and more or less of this is always carried into the cylinder. Periodic cleaning of the retort is therefore necessary and the cylinder and valves will also require cleaning occasionally.

Engines of this type are difficult to keep in best working adjustment, and when operating imperfectly there is a rapid and cumulative collection of carbon and pitch which continuously tends to make matters worse. The boundary region between perfect and imperfect operation is very narrow and the engine must be operated in this region. The difficulties come largely from inability to maintain the same bulb temperature from day to day and the impossibility of regulating this temperature to suit the load being carried at the time. There is also the difficulty of obtaining a good mixture as this has to be made in a short time and is largely dependent on natural diffusion.

When water is used, more liberties can be taken with the vaporizing process. Thus the fuel can be injected into the clearance space during suction or compression, the direction of the jet being such as to bring it against a heated projecting lip or something of the sort. Means may be introduced to mechanically assist mixing since the presence of water makes it unnecessary to keep vapors and air separated to prevent early ignition. It is also possible to carry a higher compression without danger of preignition for reasons which have already been explained.

As in previous cases, the finer the spraying of the fuel the better the operation, provided the water is properly regulated. The simplest way of looking at this part of the problem is the following. The fuel is to be sprayed as fine as is commercially possible in the type of engine to be constructed. In this way the vaporization will be made as perfect as possible. Water will be used in such proportion as to prevent the early ignition of the vapors formed, but not in sufficient quantity to cool to a greater extent.

This matter of fine spraying is of the greatest importance and does not seem to have been fully appreciated by many of the engine builders. A number of otherwise perfect engines have failed because of this simple imperfection, the author having very vivid recollections of the wild speculations which were indulged in at the time in vain attempts to explain the trouble.

It is obvious that if we are to utilize the heavier fuels we must use heat in some way so as to assist in vaporization and mixing. The retort has been found to be subject to certain imperfections which are inherent in the retort method. These imperfections are largely due to inability to keep temperatures where we want them and to prevent cracking of vapors in contact with the hot walls of the retort. If we could devise a means of maintaining a very high temperature at all times, irrespective of the load, we could vaporize the fuel in a very short time if we sprayed it fine enough. If we further did not inject it into the engine until we desired combustion there would be no necessity of keeping the hot vapors out of contact with the air and we could use any means available for producing perfect mixture.

Observe that these things are just what are done in the Diesel engine, which is really an example of the interior retort type, the hot surfaces being replaced by hot gases which owe their high temperature to the previous compression by the engine piston. The fuel must be sprayed very fine so that vaporization is practically instantaneous, and it must be very forcibly injected so as to produce perfect mixture in the short time available.

It must be admitted that from the theoretical standpoint the Diesel type is the most perfect for the utilization of the heavier liquid fuels. Practical experience also shows that it is the most perfect. It is, however, very seriously handicapped by high pressures which call for great strength and weight and by very delicate mechanism which calls for fine workmanship and a high class of attendance. As a result, the Diesel engine is not available for agricultural and similar purposes and we must make up our minds that we must find methods which may not be as perfect, but which will be more commercially applicable. It is hoped that the various things pointed out in this paper may enable those interested to arrive at a clearer understanding of the problem, which after all, is the first step in its solution.