EFFICIENCY OF MANUFACTURE DISTRIBUTION AND UTILIZATION OF OIL GAS IN CALIFORNIA

EFFICIENCY OF MANUFACTURE, DISTRIBUTION, AND UTILIZATION OF OIL GAS IN CALIFORNIA, WITH RECOMMENDATION FOR A MORE ECONOMIC STANDARD OF HEATING VALUE

FINAL REPORT OF INVESTIGATION MADE BY THE JOINT COMMITTEE ON EFFICIENCY AND ECONOMY OF GAS OF THE RAILROAD COMMISSION OF THE STATE OF CALIFORNIA

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THE JOINT COMMITTEE ON EFFICIENCY AND ECONOMY OF GAS OF THE RAILROAD COMMISSION OF THE STATE OF CALIFORNIA

L. S. READY, H. L. MASSER, C. S. JOHNSTONE,
Representing the Railroad Commission of the State of California.

W. S. YARD, W. M. HENDERSON, F. WILLS,
Representing Pacific Gas and Electric Company.

A. B. DAY, J. T. CREIGHTON,
Representing Los Angeles Gas and Electric Corporation.

F. J. SCHAFER, B. G. WILLIAMS,
Representing Southern California Gas Company.

F. S. WADE, F. CHAMPION,
Representing Southern Counties Gas Company of California.

L. M. KLAUBER,
Representing San Diego Consolidated Gas and Electric Company.

J. E. KELLEY,
Representing Western States Gas and Electric Company.

F. S. WADE, C. B. BABCOCK,
Representing Pacific Coast Gas Association.

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EFFICIENCY OF MANUFACTURE, DISTRIBUTION AND UTILIZATION OF OIL GAS IN CALIFORNIA, WITH RECOMMENDATION FOR A MORE ECONOMIC STANDARD OF HEATING VALUE.

ABSTRACT.

In order to encourage the most efficient methods of oil gas manufacture and to promote economy in utilization of gas, the gas utilities of the State of California conducted an extensive investigation, sponsored by the Railroad Commission, of all questions that might be of importance in establishing a permanent and more satisfactory standard of heating value for gas within the state. This investigation covered a period of about three years, during which time plant tests were conducted at San Jose, Santa Barbara, and at the three largest plants in the state—at San Francisco and Los Angeles—to determine manufacturing efficiencies. Other studies were made of losses in heating value during distribution of gas of several qualities produced by different types of generators. In order to determine the efficiency of utilization of gases of different heating value when the gases were used in various types of appliances, extensive laboratory tests were conducted, and data were gathered in various cities showing the actual variation of gas usage by a large number of representative consumers when the heating value of the gas was increased or reduced.

The results of the plant tests at San Jose and San Francisco showed that the thermal efficiency of manufacture with the Jones Improved Generator was practically constant with gases having a heating value of 530 to 570 B.t.u. per cubic foot. With a lowering of heating value below 530 B.t.u. there was a slight reduction in efficiency. The tests with the Jones type of generator also showed that it was easier to maintain a uniform quality with gases having a heating value of 530 to 550 B.t.u. per cubic foot than with gases having a higher heating value.

The results of the plant tests at Santa Barbara, and at the plants of the Southern California Gas Company at Los Angeles and Los Angeles Gas and Electric Corporation, showed that with the straight-shot generators as operated during the period of these tests, the thermal efficiency of manufacture was unchanged with gases having a heating value of 540 to 570 B.t.u. per cubic foot. There was a reduction in efficiency, however, as the heating value was lowered below 540 B.t.u. The ease of maintaining a uniform quality was not affected at operations between 500 and 570 B.t.u.

In the manufacture of gases of varying heating values with both the straight-shot and the Jones type generators there was found a variation in the quality and quantity of by-products produced, and a shifting in the labor costs. The difference in the value of the by-products and the total cost of labor with the different standards was not enough, however, to be considered a material factor in determining the final cost of the gas. The relative oil efficiency, quantity of steam used, and capacity of generators with the different standards were the principal factors considered in determining what heating value gas was most economical to manufacture.

The cost of gas distribution increases with an increase in the specific gravity of the gas, and decreases with an increase in the heating value, due to a change in the carrying capacity of the system. This variation in cost of distribution, with small variation in heating value and specific gravity, is comparatively unimportant compared with the large losses that occur from the condensation of illuminants from gases having very high heating values. In addition to the direct loss in B.t.u., which has to be made up by use of additional oil at the plant, there is an indirect loss due to additional expense for maintenance of the consumers' appliances when these are supplied with a variable quality of gas.

The results of the observations made to determine the loss of heating value during distribution showed that where gas was manufactured by straight-shot generators, and distributed by low pressure or intermediate high pressure, the loss in heating value was practically negligible with a heating value of 550 B.t.u. or less, but increased fairly rapidly as the heating value was increased.

With a gas of 500 B.t.u. or over made with the Jones type of generator, containing appreciable quantities of benzol, the losses in heating value are relatively much larger than the losses with gases of equal heating value made with the straight-shot gener-

ators which contain smaller percentages of the condensable hydrocarbons. From the tests on the low pressure system at San Jose and the high pressure system from San Jose to Los Gatos, it is seen that the condensation losses increase very rapidly as the heating value is increased above 550 B.t.u.

In view of the facts stated above it appears that it is not economical to distribute an oil gas of higher heating value than 550 B.t.u. per cubic foot unless the larger losses in distribution are offset by greater efficiencies in manufacture or utilization.

Extensive laboratory tests were made with gases of different heating value to determine their relative usefulness for top-burner cooking, water heating, and oven heating. From these tests it may be concluded that the usefulness of gases within the limits of 600 to 500 B.t.u. per cubic foot, made by either of the California oil-gas processes, will vary inversely in proportion to the change in heating value—conditions of uniformity of quality and pressure remaining the same.

In order to determine the variation in consumption resulting from changes in the heating value of the gas, weekly records were kept of the gas send-out at San Jose for a period of one and one-half years, and for a period of two years at Santa Barbara. These records showed that the consumption of gas in these two cities varied closely with the temperature conditions, partly due to the fact that a considerable quantity of gas was used for heating purposes. The San Jose figures clearly indicated that, whereas the consumption in cubic feet varied materially, depending upon the heating value of the gas, the B.t.u. consumption remained almost constant for any one temperature.

It has been more difficult to draw definite conclusions from the early data collected from Santa Barbara, but recent data from that city have given very definite support to the conclusions that have been drawn from the San Jose figures. After the introduction of natural gas into Santa Barbara in November, 1923, the city was supplied with a mixed gas and the heating value was increased from 550 B.t.u. to 700 B.t.u. per cubic foot—an increase of 27.3 per cent. A tabulation of the consumption by fourteen restaurants showed that they used 21.9 per cent less gas in the first week after the change than in the week preceding the increase in heating value. The average decrease in consumption for the first four weeks after the change, as compared with the four weeks preceding the change, showed a decrease of 20.8 per cent in the volume of gas used. The weather conditions during this period remained very much the same, nor was there any other condition that might have influenced the use of gas.

Based on a careful consideration of all the results of the plant tests, a study of the losses in distribution with various qualities of gas, the results of laboratory tests on many types of appliances, and observation of the consumption of gas by the consumers, the Joint Committee on Efficiency and Economy of Gas of the Railroad Commission of the State of California is of the opinion that, under the conditions existing in California where oil gas is supplied, a standard of 550 B.t.u. per cubic foot will give the most economical and satisfactory gas service, and the Committee recommends this as a general standard for the state. A modification of this standard to a higher or a lower quality should be allowed where a company is able to supply a uniform quality of gas to consumers at a less cost per B.t.u. To determine the compliance with an established standard, the heating-value tests should be made on an average sample taken at the point of delivery from the works to the transmission or distribution system.

I. INTRODUCTION.

Object and scope of the investigation.

In this final report of the investigation conducted during the past three years by The Joint Committee on Efficiency and Economy of Gas of the Railroad Commission of the State of California, the Committee wishes to present, in more complete form than have been shown in the two previous Progress Reports, the results of the investigation which have formed the basis of its recommendations for proper heating-value standards for gas in the State of California. Although the data given in this report apply to the manufacture, distribution, and utilization of oil gas, and the conclusions are, therefore, strictly applicable only to conditions in California, it is believed that this report will be found interesting and valuable in other states where the authorities and gas companies are attempting to establish the most economical standard of heating value for gas.

The Committee is of the opinion that other states will also be interested in knowing more in detail about the organization of this cooperative investigation, which has brought about closer relations between the various companies participating in the investigation, and which has established a better understanding and appreciation on the part of the state regulatory body of the problems of the gas industry.

There is still another purpose in this publication. The Committee hopes that the more detailed presentation of all the facts given herein, with the analyses of results, will be a guide to plant managers and operators for further work along this line, and will result in further improvements in the efficiency of their respective plants.

Gas service standards have received considerable attention for many years from public regulatory bodies and gas companies. The early standards of quality, based on the illuminating power of the gas, have almost entirely disappeared, and heating-value standards have taken their place. During the past few years, as a result of changes in manufacturing conditions and cost and availability of gas-making materials, it has been necessary to modify many of the earlier established standards of heating value. Often it has been necessary to reduce the standards of heating value in order to bring about economies in manufacture, which would otherwise have made necessary an increase in gas rates.

In 1912 the Pacific Coast Gas Association appointed a committee to investigate gas standards on the Pacific coast, but the following year it was forced to report that its findings were incomplete and nonconclusive, and the committee asked to be discharged. Subsequently the matter has been discussed from time to time and has been a partial issue before the Railroad Commission of the State of California in connection with certain rate proceedings.

In September, 1919, the Railroad Commission issued its General Order 58, prescribing standards for gas service in California along the general lines prescribed by other commissions and proposed by the Bureau of Standards. In this General Order the requirement which specified a 570 B.t.u. standard was, as stated at that time, based upon the best information then available.

At the meeting of the Pacific Coast Gas Association, subsequent to this order, the efficiency of manufacture and the cost of distribution of gases of various standards were the main subjects of discussion. The association thought that sufficient investigation had not been made to fix a definite standard for gas quality, although a number of its members expressed the opinion that a lower heating-value standard should be prescribed. The association decided that the whole matter was of such importance that it warranted a very complete investigation, and a resolution was adopted at its convention in September, 1919, authorizing the formation of a committee to determine all the important facts that should be considered in establishing heating-value standards.

Following the meeting of the Pacific Coast Gas Association, the representatives of the association and of the gas utilities held several conferences with the Commission's engineering staff to discuss the best means of carrying on the investigation, which was considered by all parties to be of vital importance, especially in view of the economic conditions existing during the latter part of the war period.

It was the general conclusion, following these conferences, that the investigation should be carried on, under the supervision and guidance of the Railroad Commission of the State of California, by a joint committee representing the Commission and the gas utilities. Under date of November 20, 1919, Mr. A. B. Day, president of the Pacific Coast Gas Association, communicated with the Commission, urging that the investigation on efficiency and economy of gas be placed under the general supervision of the Engineering Department of the Commission. He further suggested that the Commission on its own motion institute an investigation into the proper calorific value for artificial gas manufactured in this state, and advised that the cost of such an investigation would be readily borne by the gas utilities.

On January 13, 1920, the Railroad Commission instituted a proceeding, Case No. 1410, ordering an investigation of the production, transmission, distribution, and use of gas, and of such other matters pertaining to the gas service in California as appeared advisable. Conferences were held prior thereto between the Gas and Electrical Engineer of the Commission and the representatives of the gas utilities, and an organization was perfected for the carrying out of the proposed investigation. The first meeting of the Committee was held on January 16, 1920, at which the general plan of the organization was agreed upon and arrangement made for financing the work. A second meeting was held on January 31, 1920, at which the organization of the Committee was completed, constitution and by-laws were adopted, and various subcommittees appointed.

The charter members of this Committee, as it was organized on January 16, 1920, with their various affiliations, were:

Lester S. Ready, Gaskell S. Jacobs, Edwin S. Bryant, representing the Railroad Commission of the State of California.

E. C. Jones, W. M. Henderson, representing Pacific Gas and Electric Company.

A. B. Day, J. T. Creighton, representing Los Angeles Gas and Electric Corporation.

F. J. Schafer, B. G. Williams, representing Southern California Gas Company.

F. S. Wade, F. Champion, representing Southern Counties Gas Company of California.

L. M. Klauber, representing San Diego Consolidated Gas and Electric Company.

J. E. Kelley, representing Western States Gas and Electric Company.

F. S. Wade, C. B. Babcock, representing Pacific Coast Gas Association.

The officers of the Committee as originally organized were: Lester S. Ready, Chairman; Edwin S. Bryant, Secretary; Gaskell S. Jacobs, Treasurer.

There were several changes in the personnel of the Committee before the work was completed. Mr. E. C. Jones, representing Pacific Gas and Electric Company, resigned, and Mr. Willis S. Yard was elected to take his place. The office of Secretary was filled successively by Messrs. Edwin S. Bryant, Frank Wills, and Harry L. Masser and Clifford S. Johnstone, representatives of the Railroad Commission.

Upon completion of the organization of the main committee and a preliminary survey of the work to be done, it was found necessary to employ competent engineers to carry on the actual test work that had been outlined. Mr. F. Emerson Hoar was employed as Consulting Engineer of Field Tests, Mr. Edwin S. Bryant as Field Engineer in Charge of Tests, and Messrs. Walter M. Argabrite and Fred Champion as Assistant Engineers.

Several changes occurred in the personnel of the engineering staff during the three years covered by this investigation. Mr. F. Emerson Hoar resigned during the early part of the work, and the Field Engineer, Mr. Edwin S. Bryant, assumed full charge. Others who later became associated in the technical work were Mr. Fred B. Watkins as Chemist, Mr. Wayne Fitkin as Assistant Engineer, and Mr. Ray Trowbridge as Assistant Engineer.

Following the date of its organization in January, 1920, the Committee held meetings every two or three months for the purpose of deciding upon the detailed plans for the tests, and to examine the results of the tests as these were completed. At three of these meetings other well known engineers, who were not parties to the investigation, submitted their views regarding the work.

The financing of the work of this Committee was carried on by the gas utilities of the state whose revenues exceeded $100,000 annually; the assessments to cover expenses were made proportional to gross revenue from the sale of gas. The utilities that assisted in the financing were:

Pacific Gas and Electric Company;
Los Angeles Gas and Electric Corporation;
Southern Counties Gas Company of California;
Southern California Gas Company;
San Diego Consolidated Gas and Electric Company;
Western States Gas and Electric Company;
San Joaquin Light and Power Corporation;
Sacramento Gas Company;
Coast Valleys Gas and Electric Company;
Coast Counties Gas and Electric Company;
Central Counties Gas Company;
Modesto Gas Company;
Contra Costa Gas Company.

In addition to the financial support of the work by the utilities, which amounted to a total of over $64,000 during the three years, several meter and appliance firms assisted materially by the loan of necessary equipment, thus relieving the direct cost considerably.

The scope of this investigation was specifically defined in the original plan, which provided that the work should cover the following subjects:

1. The definite and accurate determination of the efficiency of gas production at existing gas plants and under existing methods of operation with the production of different qualities of gas.

2. The possible improvement and change in the operation of existing gas plants with a view to increasing the efficiency and thus reducing the cost of operation and ultimate cost of gas to the consumer.

3. Determination of the efficiency of distribution of different qualities of gas.

4. Determination of the relative efficiencies of ultilization of different qualities of gas.

5. Investigations of special problems confronting the gas industry in gas purification, removal of naphthalene, value and use of by-products, etc.

6. Studies and tests of different processes of gas manufacture.

Investigations into the matters set forth in the first four subdivisions above have been carried to such a point that the Committee feels justified in submitting certain definite conclusions and recommendations thereon. These conclusions and the principal test data upon which they are based are given in the following report.

II. MANUFACTURING EEFICIENCY.

1. SAN JOSE PLANT.

(a) Description of plant and operating methods.

The San Jose gas plant is one of the properties of the Pacific Gas and Electric Company. It is located at the junction of San Augustine street and the Los Gatos branch of the Southern Pacific Railroad, about one

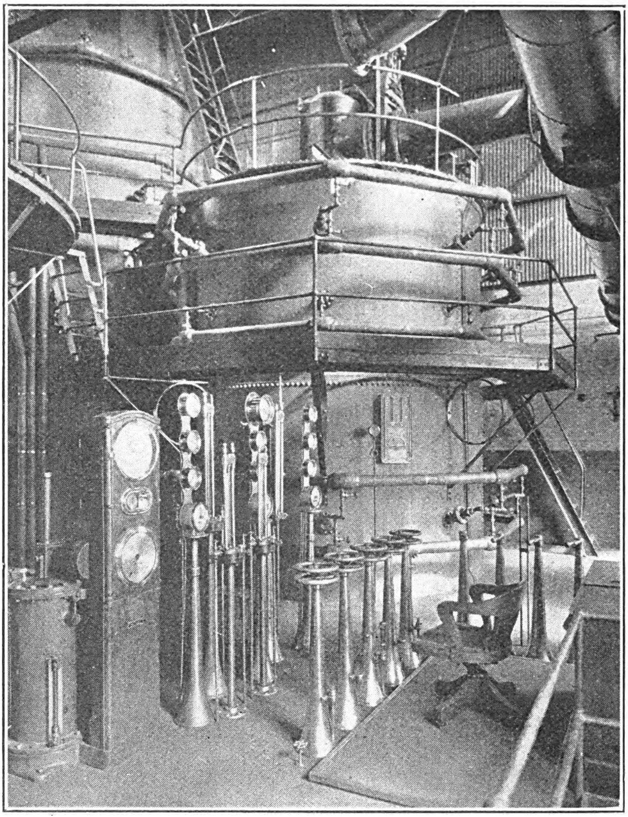


FIG. 1: Operating mechanism, No. 3 generator, San Jose plant.

mile in a westerly direction from the business center, in the district locally known as West San Jose. The equipment at this plant is modern, well maintained, and arranged for economical operation.

The oil-gas manufacturing apparatus consists of 3 sets of generators. No. 1 and No. 2 sets are two-shell machines of an old type. The No. 3 set, known as the Jones improved generator, with which all the tests reported herein were made, is also a two-shell machine similar in type to the Jones generator used at the Potrero plant in San Francisco, illustrated in figure 6. The diameter of the primary shell of this Jones generator is 12 feet; the height, 30 feet 9 inches. The diameter of the secondary shell is 12 feet; the height, 42 feet 6 inches.

Both shells of the Jones generator are lined with 2 inches of Sil-O-Cel and 18 inches of fire brick, which makes the inside diameter of brickwork 8 feet 8 inches. The checker-brick are spaced 3 inches, with straight flues; the primary shell has 4360 checkers; the secondary shell, 8860. The machine is most efficient at a capacity of about 86,000 cubic feet per hour, although a demand in excess of 100,000 cubic feet per hour has frequently been carried by this apparatus.

Operating cycle.

The operating cycle, which consists of a heat and make period, averages 4 complete runs per hour. Beginning with the blasting period, the cycle of operation may be described as follows: A dry blast is used for a period of 1½ minutes, with the admission of air at a rate of 8400 cubic feet per minute to the primary shell. At the end of each third run air is admitted through the primary valve at a rate of 3150 cubic feet per minute, and through the secondary blast valve at a rate of 6500 cubic feet per minute to clear the secondary shell. This dry blasting clears the two shells of loose carbon and, since a considerable portion of this is burned before it leaves the machine, materially assists in heating the brickwork. During the heating period the air is admitted at a rate of about 8300 cubic feet per minute at a pressure of approximately 14 inches of water pressure.

The heat oil is injected at a rate of approximately 4 gallons per minute. From 16 to 20 gallons of oil per cycle are needed to maintain the temperature in the generator. The amount of oil to be used during the making period is ascertained from the frequent heating-value tests of the gas, quality of the lampblack formed, condition of checkerwork, carbon deposits within the generator, and other factors that experienced operators have learned to take into consideration in order to secure the best results.

Use of steam during heating and making periods.

During the heating period a total of 120 to 140 pounds of steam is admitted for cooling the burners and atomizing the oil. The primary sprays require about 400 pounds per hour and the secondary sprays about 300 pounds per hour. The heat burners use 200 pounds per hour during the dry blast and 940 pounds per hour when the oil is injected.

At the close of the heating period, before the stack valve is closed, steam is turned on in the primary superheating chamber at a rate of about 850 pounds per hour. After the closing of the stack valve steam is admitted into the secondary superheater at a rate of 1050 pounds per hour, the primary superheater steam remaining at the same rate. Steam is next turned on at the primary oil nozzles at a rate of 1100 pounds per hour and in the secondary nozzles at a rate of about 900 pounds per hour. Steam is also injected into the throat at a rate of 800 to 1000 pounds per hour, depending on the temperature of the brickwork in the bottom of secondary. Steam is used for protection of the heat burners during the making period at a rate of 200 pounds per hour, and cooling steam is also left on the secondary oil sprays after oil injection at a rate of 300 pounds per hour. The total steam admitted during the making period is from 450 to 500 pounds.

About one-half minute after the steam is turned on in the oil nozzles, the make oil is started at a rate of 15 gallons per minute in the primary and 7½ gallons per minute in the secondary make chamber. The total make oil averages 90 to 100 gallons in the primary and 40 to 50 gallons in the secondary.

After the oil has been injected in both shells the steam is allowed to continue at a lesser rate for one minute in order to purge from the generator the gases remaining there at the end of the run. The steam used in purging the machine averages from 50 to 60 pounds. The total steam used in the generator during one complete cycle averages from 600 to 700 pounds, depending upon the temperature of the checker-brick, the kind of oil used, the heating value of the gas desired, and other conditions.

Temperatures in generators.

The temperature in the generator is varied according to the capacity required of the generator and the desired heating value of the gas. Temperature in various parts of the generator will average about as follows for a 550 B.t.u. gas when made from 17° Be. gas oil: primary superheater 1900 to 2100° F.; primary make chamber, 1650 to 1750° F.; bottom of secondary, 1400 to 1500° F.; secondary make chamber, 1550 to 1650° F.; secondary superheater, 1350 to 1450° F. The gases leave the generator at temperatures ranging from 1500 to 1650° F.

Washing and scrubbing.

After leaving the generator the foul gases first pass through the wash box where the free carbon is removed by the seal overflow. This carbon, commonly known as lampblack, is conveyed to settling pits and the water drained off until the lampblack has a water content of about 40 per cent, when it is removed for boiler fuel. The temperature of gas leaving the wash box averages from 165 to 190° F.

The primary scrubber, through which the gas passes after leaving the wash box, collects any lampblack remaining in the gas and also condenses the tar vapors. Water is circulated through this scrubber at a rate of about 40 gallons per thousand cubic feet of gas made. Two secondary scrubbers still further clean the gas, the amount of water circulated being about 12 gallons per thousand cubic feet in each cylinder. The gas leaving the third scrubber enters the relief holder at practically atmospheric temperature.

After leaving the relief holder the gas goes through the oil scrubber, where it is brought in contact with fresh oil which is then pumped to the generator. The gas leaves the oil scrubber at a temperature of 80 to 95° F., depending on atmospheric conditions. An exhauster forces the gas through a small oil washer, which removes all oil and vapors from the gas before it enters the purifiers. From the purifiers the gas goes through the station meter and thence to the storage holder.

Distribution of gas.

The gas pressure on the city distribution system is maintained by holder pressure at about 6 inches of water column. A boosting apparatus is used to increase the pressure as required to a maximum of 14 inches during peak hours. Additional gas pressure is maintained in the distribution system from a recently installed system of automatic district governors supplied from high pressure feeder mains.

Gas is transmitted to the suburban territory, including Campbell and Los Gatos, through a high pressure system, the initial pressure ranging from 5 to 50 pounds per square inch, depending upon the demand.

(b) Testing apparatus and facilities.

A fully equipped laboratory was provided at the plant for making gas tests. Services were run to the laboratory from the following places: inlet to the relief holder, inlet and outlet of oil scrubber, outlet to the city distribution system, and from the high pressure transmission main.

The piping in the laboratory was arranged in such manner that unpurified gases could be put through individual washers and purifiers. A 50-cubic-foot gas holder was used in collecting the gas samples for testing purposes, and a small 7-foot holder was used for work on continuous gas sampling. A new American-Junkers calorimeter with certified thermometers was used for the determination of the calorific value.

Oil measurement.

In addition to calibrated oil tanks and the master oil meter used for checking the daily withdrawal of oil from storage, the generator was provided with Empire vertical index oil meters, which metered the hot oil to the heat and make burners. A recording thermometer indicated the temperature of the oil from the oil heaters.

The specific gravity and water content of oil was determined from samples collected from each shipment received. Samples were also taken three times daily from the oil line to the generator and collected in sampling cans provided for that purpose. From the daily samples, a composite sample was made up each month and analyzed.

Steam measurement.

A Venturi meter installed in the main steam header indicated the quantity of steam per hour delivered to the generator. By cutting out the steam at all the sprays and burners, excepting those being metered, it was possible to determine accurately the rate of steam flow supplied at any point.

In addition to the Venturi meter, there was installed a 4 by 2⅛-inch orifice, equipped with standard recording differential and pressure gages. These two installations were checked against each other by means of careful condensation tests.

Air measurement.

The rate and quantity of air used for dry blasting and heating was measured by a Venturi meter, the tube being installed in the 24-inch blast line, and the manometer on the operating floor of the generating room. In addition, a Pitot tube metering device was placed in the air line at some distance from the Venturi meter.

Measurement of temperatures.

Thermocouples connected at a central point on the operating table were installed at the following locations in the generator body: primary superheater, primary make chamber, bottom of secondary, secondary make chamber, secondary superheater, generator offtake. The temperatures in the different parts of the generator at different stages in the run were observed by the operator and recorded on report forms.

Recording thermometers were used to record the gas temperatures at inlet to No. 1 water scrubber, at inlet to the relief holder, and on inlet and outlet to oil scrubber. The temperature of the gas passing through the station meter was also recorded by means of a calibrated recording thermometer. Indicating thermometers were installed at many locations in the gas mains so that records could be taken as desired of the actual temperature of the gas entering or leaving the various pieces of apparatus.

Gas pressure measurement.

The pressure within the generator was recorded by a gage installed at the secondary shell. Other gages were used to indicate and record the pressures at inlet to No. 1 scrubber, inlet to the relief holder, outlet to the station meter, and on the main gas outlet to city distributing system. Gages were also installed between each scrubbing unit and on the lines passing through the purifying system. These gages were all used to maintain constant operating conditions throughout the test periods.

Gas volume measurement.

An indicating and recording Venturi meter with tube installed in the outlet connection of the No. 3 scrubber was used as a guide in regulating the rate of introduction of the make oil. It also indicated when the generator was sufficiently purged at the end of the run and informed the operator of any marked variations in operating conditions.

The quantity of gas made each 24 hours was obtained from the registration of the station meter and the gain or loss in the relief holder. The volumes were corrected to standard conditions of 30 inches of mercury pressure and 60° F. The gas sent out each day was calculated from the corrected station-meter registration and the gain or loss in the contents of the storage holder.

Gas quality.

Uniform control of the heating value of the gas was secured by frequent calorimeter tests of the gas leaving the plant. The average heating value of the gas over a 24-hour period was determined by calorimeter tests and gas analysis of samples that were collected at a uniform rate over this period.

During special tests and experiments on the effect of changes in operation, the composition of the gases formed during successive intervals of time was determined by analyses of samples collected at one- or two-minute intervals. At the same time, the rate of gas making was obtained by noting the rise in the relief holder and calculating the quantity made during each interval of time.

Residuals.

Scales and containers were provided for the accurate weighing and measurement of the quantity of lampblack and tar formed during each change in gas quality. These special tests were made at stated intervals, and in addition a record was kept of the lampblack made over longer periods of time. The moisture content, heating value, and composition of the blampblack and tar were ascertained from analyses made by a commercial chemist.

(c) Description of tests.

After the San Jose generating plant was completely equipped with the necessary measuring and indicating instruments, the first series of tests were commenced on July 1, 1920. The plant was operated during the months of July, August, and September at a standard of 570 B.t.u. per cubic foot measured at the storage holder. From October 1 to December 31, 1920, the plant was operated at a heating standard of 535 B.t.u. per cubic foot. From January 1 to February 5, 1921, the quality of gas produced was varied from week to week. One week it was kept at 570 B.t.u.; the next at 535 B.t.u.; the next at 570 B.t.u.; and later the heat content was reduced to approximately 500 B.t.u. per cubic foot. These latter tests were carried on primarily to observe the effect on quality of service and variation in the quantity of gas used by consumers when supplied with various qualities of gas. During these plant tests, careful measurements were made of all important factors that influence the efficiency of gas manufacture, and a detailed record was kept of the output of the plant.

Owing to the necessity for recheckering the generator, the main unit was taken out of operation on April 15, 1921, and the two smaller Western Gas Construction Company double-shell generators were operated until June 4, when the Jones set was again put in operation. During the period of operation of the Western Construction generators, a relatively high heat content gas was produced. From July 1 to September 1, 1921, an average quality of 535 B.t.u. was maintained. From September 1 to October 31, 1921, air was introduced into the primary combustion chamber of the generator, which produced a gas of low quality, high in nitrogen and high in specific gravity. The gas had a heating value of approximately 510 B.t.u. This test was run primarily to determine what effect the introduction of diluents into the generator during the make period had upon the efficiency of production, the capacity of the generator, and amount of impurities in the gas. It was also desired to observe whether the reduced quality of gas of higher specific gravity containing a much higher percentage of inert constituents would have any effect on the quantity of gas used by the consumers and on the quality of service rendered to them.

During November and December, 1921, a 535 B.t.u. standard was maintained. The operations during the first six months of 1922 were varied—primarily to make it possible to determine what effect a variation in the quality of gas would have on the consumption by the consumers. The average heating value produced during the first three months was as follows: January, 529 B.t.u.; February, 544 B.t.u.; and March, 564 B.t.u. During this period it was necessary to have both the Jones improved and the auxiliary Western type generators in service, owing to the increased demands of new territory in the suburban and Los Gatos districts. The production records during these months are not directly comparable with the results of the preceding year, as it was impossible to segregate the operation of the Jones machine from the combined production totals.

(d) Results of plant tests.

The results of the plant tests are given in the following table:

TABLE NO. 1.

San Jose Plant—Gas Plant Statistics.

	July-Aug.-Sept., 1920	Oct.-Nov.-Dec.. 1920	Jan., 1921	Feb. 5-Mar. 12, 1921
Average quality of gas (B.t.u.)	571.2	536	556	508
Total gas made (M cubic feet)	91,471	128,775	48,552	51,565
Average make per day (M cubic feet)	994	1,400	1,566	1,473
Average operating time per day (hours)	13.0	15.9	19.7	16.5
Average make per hour (M cubic feet)	76.0	88.0	88.5	89.5
Heat oil (gallons per M cubic feet)	0.904	0.910	0.960	0.960
Make oil (gallons per M cubic feet)	6.610	6.260	6.280	5.910
Total oil (gallons per M cubic feet)	7.514	7.170	7.240	6.870
Lampblack (pounds per M cubic feet)	12.20	14.13	------------	19.45
Tar (pounds per M cubic feet)	6.25	3.76	------------	1.18
B.t.u. in gas per gallon total oil	76,000	74,800	76,800	74.000
Per cent over-all efficiency $\left(\frac{\text{B.t.u. in gas}}{\text{B.t.u. in total oil}}\right)$	51.9	50.6	52.0	50.2
Average gas analysis:				
CO_2	5.4	4.4	4.5	4.1
C_6H_6	1.0	0.5	3.4 (})	2.6
C_nH_{2n}	3.8	2.9		
O_2	0.1	0.1	0.1	0.2
CO	9.9	12.1	12.1	13.2
H_2	40.6	49.0	47.5	50.8
CH_4	31.4	27.4	28.1	25.8
N_2	7.8	3.5	4.3	3.3
Totals	100.0	100.0	100.0	100.0
Calculated B.t.u.	579.5	541.0	547.0	514.0
Average specific gravity	.520	.447	.448	.426

	June, 1921 Jones Gen. No. 3	July-Aug., 1921 Jones Gen. No. 3	Sept.-Oct., 1921 (Inerts) Jones No. 3	Nov.-Dec., 1921 Jones No. 3
Average quality of gas (B.t.u.)	555	537	512	537
Total gas made (M cubic feet)	32,940	67,797	76,855	95,438
Average make per day (M cubic feet)	1,098	1,093	1,260	1,564
Average operating time per day (hours)	14.90	13.35	12.18	17.25
Average make per hour (M cubic feet)	73.70	81.87	103.45	90.66
Heat oil (gallons per M cubic feet)	1.130	1.10	0.73	0.91
Make oil (gallons per M cubic feet)	7.310	6.83	6.755	6.845
Total oil (gallons per M cubic feet)	8.440	7.93	7.485	7.755
Lampblack (pounds per M cubic feet)	17.04	15.70	17.56	12.57
Tar (pounds per M cubic feet)	4.00	3.30	3.99	3.65
B.t.u. in gas per gallon total oil	65,800	67,717	68,403	69,245
Per cent over-all efficiency $\left(\frac{\text{B.t.u. in gas}}{\text{B.t.u. in total oil}}\right)$	45.0	46.15	46.60	47.20
Average analysis:				
CO_2	2.5	2.9	3.6	2.8
C_6H_6	2.5	------------	1.0	------------
C_nH_{2n}		2.3	3.6	2.7
O_2	Trace	Trace	0.2	0.1
CO	5.9	8.4	7.9	10.6
H_2	53.6	52.0	41.3	53.5
CH_4	31.3	29.3	24.6	27.0
N_2	4.2	5.1	17.8	3.3
Totals	100.0	100.0	100.0	100.0
Calculated B.t.u.	560.0	534	504	535
Specific gravity	.371	.397	.522	.391

TABLE NO. 1—Concluded.

San Jose Plant—Gas Plant Statistics.

	Jan., 1922 Jones and Western	Feb., 1922 Jones and Western	Mar., 1922 Jones and Western	April, 1922 Jones	May, 1922 Jones	June, 1922 Jones
Average quality of gas (B.t.u.)	529	544	564	532	521	515
Total gas made (M cubic feet)	57,680	47,494	48,327	47,959	45,511	41,510
Average make per day (M cubic feet)	1,861	1,696	1,560	1,599	1,468	1,384
Average operating time per day (hours)	23.6	20.7	19.7	18.5	15.8	15.2
Average make per hour (M cubic feet)	78.8	82.0	79.0	86.6	92.7	90.7
Heat oil (gallons per M cubic feet)	0.90	0.82	0.89	0.83	0.80	0.72
Make oil (gallons per M cubic feet)	6.82	7.07	7.16	6.73	6.48	6.58
Total oil (gallons per M cubic feet)	7.72	7.90	8.05	7.76	7.28	7.30
B.t.u. in gas per gallon total oil	68,522	68,854	70,062	70,370	71,566	70,548
Per cent over-all efficiency $\left(\frac{\text{B.t.u. in gas}}{\text{B.t.u. in total oil}}\right)$	46.67	46.94	47.72	47.93	48.75	48.05
Average gas analysis:						
CO_2	2.7	2.7	3.3	2.6	2.6	3.2
C_6H_6	2.6 (C_6H_6 and CnH_2n)	0.8	0.9	2.8 (C_6H_6 and CnH_2n)	2.2 (C_6H_6 and CnH_2n)	2.7 (C_6H_6 and CnH_2n)
CnH_2n		2.4	3.4			
O_2	0.6	0.8	0.8	0.7	0.9	0.6
CO	10.6	10.6	10.0	11.6	11.2	13.0
H_2	52.2	49.8	45.9	51.3	51.2	53.2
CH_4	24.8	25.8	28.3	25.9	26.7	23.3
N_2	6.5	7.1	7.3	5.1	5.2	4.0
Totals	100.0	100.0	100.0	100.0	100.0	100.0
Calculated B.t.u.	506	526	556	521	515	504
Specific gravity	.406	.444	.452	.415	.403	.412

From the preceding table it will be noted that there is no apparent increase in thermal efficiency of production with reduction of heat content. After recheckering the Jones generator in June, 1921, the results did not thereafter give the efficiency secured during the preceding test. This may have been due to deterioration of checker-brick resulting from some of the special tests that were carried on during this period.

Reduction in the quality of gas tended to reduce the fuel value of the main by-product—lampblack. This was especially noticeable when the quality was reduced below 535 B.t.u. per cubic foot. Actual experience indicated that the lampblack produced at the lower heating value of gas was of such a nature that it was difficult to handle under the boilers and apparently showed even poorer results than would be expected from the chemical analysis.

The relative uniformity of gas produced under the different standard qualities is indicated from the following table, in which is set forth the maximum and minimum qualities determined by test during the general operations of the plant.

Daily Variation in Heating Value of Gas During 1922 Operations.

Average quality of gas (B.t.u.)	568	551	541	539	517	508
Number days' operation	20	22	28	23	23	24
Average of daily maximum (B.t.u.)	575	558	548	547	524	518
Average of daily minimum (B.t.u.)	558	542	532	532	510	501
Average variation (B.t.u.)	17	16	16	15	14	17

Conditions during the first six months of the test showed a greater variation in quality with 570 B.t.u. than with 535 B.t.u., although this may have been due partly to the greater skill in operating during the later period.

It was quite evident, however, that it was somewhat easier to maintain a uniform quality of gas between 535 and 550 B.t.u. per cubic foot than at 570 B.t.u. The operation of generators at higher temperatures, with consequent increase in steam reaction and fewer carbon stoppages, resulted in a more uniform temperature in the generator and a more uniform quality of gas. A reduction below 535 B.t.u. was detrimental, owing to the reduced fuel value of lampblack produced, the difficulties in removal of pitch and tar, and an apparent increase in the formation of naphthalene.

The total amount of labor for operating purposes remained constant during the B.t.u. changes, but the distribution shifted somewhat. For example, more labor was required on scrubbers and less on washers as the B.t.u. decreased. During the period of changing from 570 to 535 B.t.u. all apparatus had to be carefully watched, but as soon as conditions approached normal, the total amount of labor required was about the same, whether for 570, 535, or 500 B.t.u.

With change from 570 to 535 B.t.u., there was very little increase in the number of complaints; but with the further drop to 500 B.t.u., the increase in adjustment complaints was more noticeable for a few days until the appliances were adjusted, when conditions again became normal.

(e) Conclusions from San Jose tests.

Tests made at the San Jose plant from July, 1920, to and including June, 1922, during which time the heating value of the gas was varied from a maximum of 571 to a minimum of 508, showed no apparent increase in the thermal efficiency of manufacture when the heating value of the gas was reduced. This conclusion is based on the fact that the ratio of B.t.u. in the gas to the B.t.u. in the total oil used appeared to be about the same, irrespective of the quality of the gas made. The sudden drop in efficiency after June, 1921, was due to the recheckering of the generator and change in operating conditions, and cannot in any manner be associated with changes in the quality of the gas made.

With the lower heating value the lampblack was of somewhat less value for boiler fuel. This was especially noticeable when the heating value was reduced below 535 B.t.u. per cubic foot. The total labor at the plant was not changed, and the cost per B.t.u. therefore remained constant. The figures from the first six months' test seemed to indicate that it was possible to manufacture a more uniform quality with the lower heating-value gas, but later and more complete data indicated that there was very little difference in uniformity of quality between 508 and 568 B.t.u. It appeared somewhat easier, however, to maintain a uniform quality between 535 and 550 B.t.u. than at 570 B.t.u.

Considering the thermal efficiency of the generators, the cost of labor, value of by-products, and other important items entering into manufacturing costs, there is no evidence to show that material reductions in heating value below 570 B.t.u. will decrease the cost of manufacture.

2. SANTA BARBARA PLANT.

(a) Description of plant and operating methods.

The gas works at Santa Barbara, now owned and operated by the Southern Counties Gas Company, is located at the corner of Montecito and Quarantina streets. As it lies in the manufacturing district east of the city limits, it is centrally located for supplying both the city and suburban territory around Montecito.

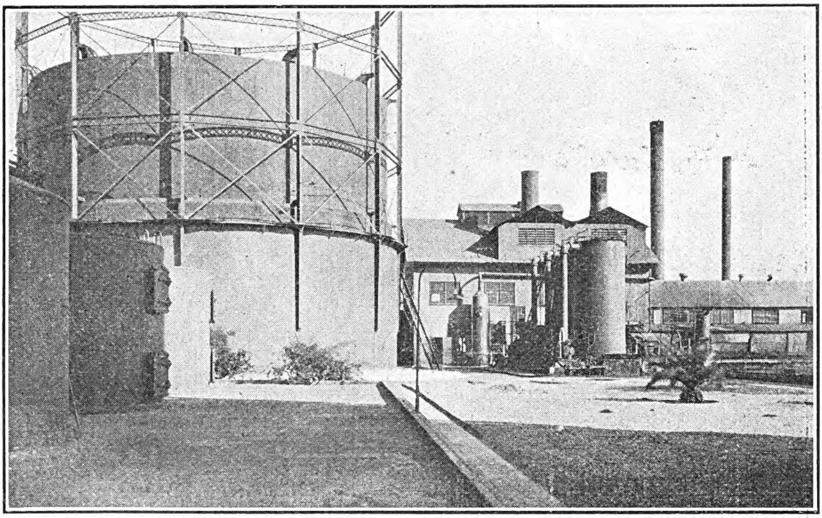


FIG. 2: General view of the Southern Counties Gas Plant at Santa Barbara.

The gas distribution system in the city proper is a medium high pressure system of the arterial type. All the gas is sent out under moderately high pressure, ranging from 5 to 10 pounds per square inch, and distributed through district regulators to the feeder mains that supply the various districts. The consumers are served through individual low pressure regulators, which are adjusted to maintain an average pressure of 6 inches of water column. In the suburban territory the gas is transmitted and distributed through high pressure mains. By means of long-distance pressure recorders located at the compression plant, the required initial pressure can always be maintained.

Generation and scrubbing.

The two gas generating units at this plant consist of single shells 14 feet in diameter and 28 feet in height, of the straight-shot design. These generators are of the same type as used in the plant of the Southern California Gas Company, illustrated in Fig. 5. The normal capacity of each generator is 50,000 cubic feet per hour, with a maximum capacity of 56,000 to 60,000 cubic feet per hour. The operation of these generators varies considerably with the condition of the machines and the quantity of gas it is necessary to produce. Repeated tests have proved that with this type of generator an operating cycle of 36 to 40 minutes is more economical than one of shorter duration.

After the gas-making period it is necessary to clear the generator of the accumulated carbon. For this purpose air is admitted at a rate of about 7500 cubic feet per minute for four minutes; however, when excessive carbon deposits occur in the upper portion of the checkers it is

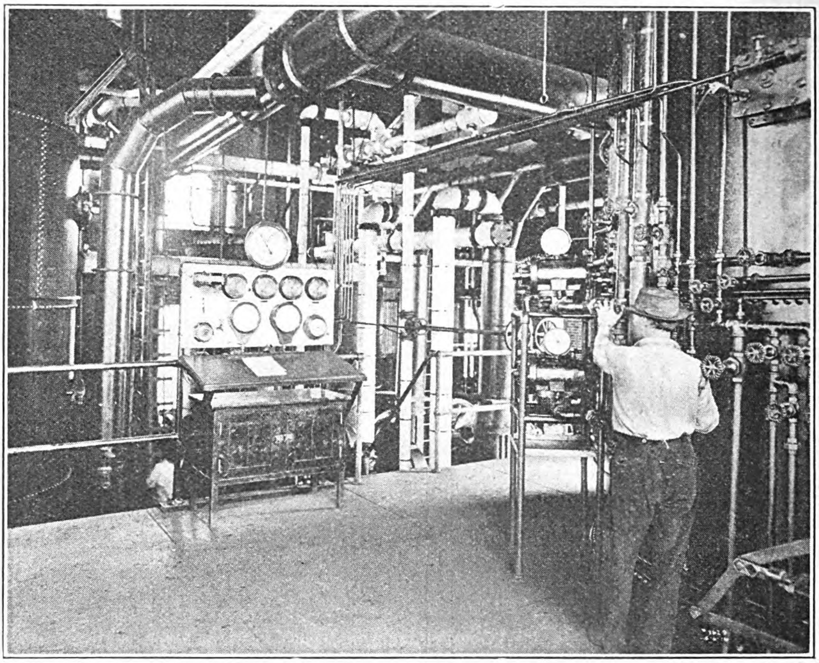


FIG. 3: Operating floor, Santa Barbara generators.

necessary to extend the blasting period. During the heating period the volume of air admitted varies from 7300 to 7800 cubic feet per minute, depending upon the rate at which oil is injected, and the condition of the generator. Sufficient excess air is used to avoid smoke at the stack.

Steam is used with the heat oil in sufficient amount and with enough pressure to provide a satisfactory spray. A small amount of steam is left on the burners during the making period to protect them from the high temperature of the gases passing through the combustion chamber.

When the generator is at the proper temperature for efficient gas making, and reasonably free from carbon, the making oil is admitted through the five nozzles at a rate of about three gallons per minute on each injector, or a total of 15 gallons per minute. The rate at which oil is admitted is somewhat dependent upon the quality of gas desired and the temperature of the checkers.

Steam is injected with the make oil to produce a finely divided spray. The amount of steam used is just sufficient to atomize the oil and to maintain a uniform pressure at the burner head. An attempt to increase the percentage of carbon monoxide gas by introducing larger quantities of steam into the vaporizing chamber, not only during the making period with oil, but also prior to the regular making period, has been found to produce no apparent benefit. The use of a very large quantity of excess steam was found to reduce the temperature of the checkers to such a point as to seriously retard the gasification of the oil. The average quantity of steam injected during the making period is about 24 pounds per minute. The total steam used per run is from 450 to 600 pounds, or about two pounds for each gallon of oil.

When the make oil is shut off, the steam used for vaporizing the oil is continued at the same rate for four to six minutes, thereby purging from the generator the gas remaining at the close of the making period. The total amount of steam used in making and purging per thousand cubic feet of gas made averages from 16 to 20 pounds. The steam used during the heating period for cooling burners and for atomizing oil averages from four to five pounds per thousand cubic feet of gas made.

The temperature carried in the brickwork of the Santa Barbara generators depends upon the quality of gas desired, rate of gas making, condition of the checkers, kind of oil used, etc. For 555 B.t.u. gas the temperature over the combustion chamber varies from 2200° F. at the beginning to 1800° F. at the end of making period; in the upper portion of the checkers, from 1900° F. at the beginning to 1650° F. at the end of the making period; the offtake gases average 1850° F.

The foul gases, upon leaving the generator, pass directly through two wash boxes connected in series, where the gas is freed of lampblack and cooled to a temperature of approximately 145° F. The total amount of water used in the two washers averages from 80 to 120 gallons per thousand cubic feet of gas made, depending on the season of the year and the amount of water available at the plant pumping system. From the second washer, the partially cleansed gas passes into the lower section of the first of a series of two water scrubbers, where it is further cooled and the tarry vapors are condensed.

The temperature of the gas in No. 1 scrubber is reduced from 145° F. at the inlet to 95° at the outlet, and in passing through scrubber No. 2 there is a further reduction in temperature to about 80° F. The amount of water used in the two scrubbers averages, for scrubber No. 1, about 30 gallons per thousand cubic feet of gas made, and, for scrubber No. 2 about 20 gallons, depending on temperature conditions. A large portion used of the water is recovered and recirculated from the cooling basin and reservoir.

From water scrubber No. 2 the gas is forced through the oil scrubber, which removes the remaining tar vapors and the major portion of the naphthalene. The oil is circulated through the scrubber at a rate of approximately 40 gallons per minute, and each batch is used until it no longer effectively removes the naphthalene from the gas. Crude oils, distillates, and regular gas oil residuums have all been used at different periods at this plant for oil scrubbing with varying success.

The relief holder receives the gas after its passage through the scrubbing system. This gas is withdrawn by the exhausters, forced through the oxide purifiers and the station meter, and stored in the large holder, from which it is pumped and distributed.

(b) Testing apparatus and facilities.

To provide accurate records during the tests at this plant, a considerable amount of additional laboratory and testing equipment was installed. Individual services were run from various locations on the manufacturing system to the laboratory, and gas samples collected in two small holders

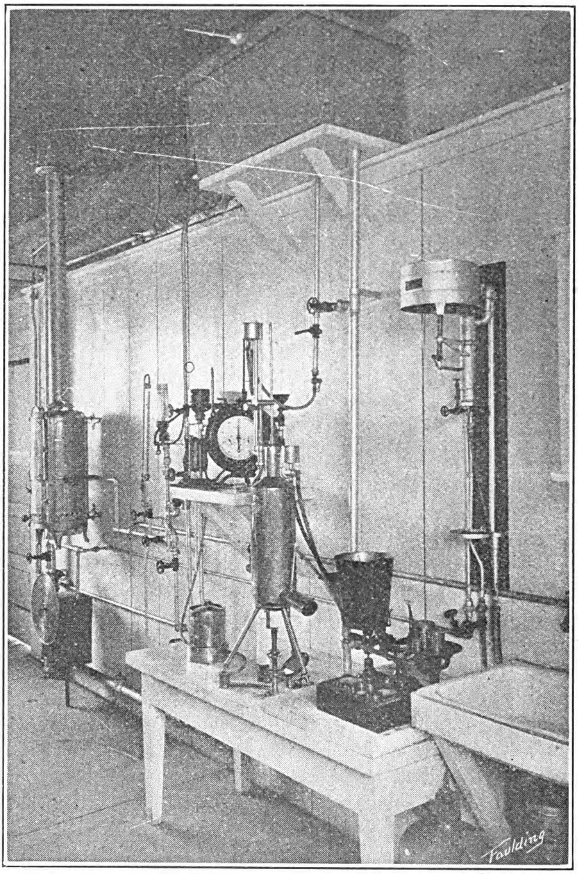


FIG. 4: Gas calorimeter installation, Santa Barbara plant.

located near the laboratory. The piping was equipped with valves and orifices so that weighted and average gas samples could be collected for analysis and testing purposes. The laboratory was furnished with a complete gas-analysis apparatus, a standard calorimeter, and equipment for making tests of sulphur, naphthalene, and hydrogen sulphide.

Frequent calorimetric observations and gas analyses were made throughout the period of tests at this plant. Continuous weighted gas samples were collected each day for test, and in addition three heating-value tests were taken each day (one on Sundays) at the uptown office of the company. Analyses were made of the stack gases at different times in the course of the tests, and the temperature of the gases was observed by means of pyrometers in order that the heat losses from this source could be accurately determined.

Oil samples were taken from each shipment received, and tests were made from a composite sample of the oil reserved for that purpose. As an additional check on the quality of the oil used, small daily samples were taken at the oil heater, and at the end of each month a composite sample was sent to a commercial chemist for report on heating-value, gravity, viscosity, composition, and distillation tests.

The steam and oil pressures in the lines supplying the generator, and the gas pressures in the generators, scrubbers, relief holder, and station meter, were determined by recording pressure gages.

The rate and quantity of steam used in the gas-making process was determined by a recording orifice meter installed in the main steam header. Air used in blasting and heating was measured by a calibrated Pitot tube meter with both recording gage and water column connections. Water meters were installed on the water supply to the wash box, on the inlet to both water scrubbers, and on the boiler feed line.

An accurate master oil meter with large dial was installed at the outlet of the oil storage tanks, and the withdrawal of the oil from storage was determined, not only by the tank measurements, but also from the daily registration of this meter. A recording thermometer located in the flowing oil at the inlet of the meter provided a means for making the proper temperature correction. Oil meters were also provided at the fuel line to boilers, and new Empire vertical dial type meters were installed at the generator operating table, both on the make and on the heat oil lines. The connections were so arranged that tests could easily be made to check the accuracy of registration of all meters used.

The quantity of gas made daily was determined from the station meter readings corrected for temperature and pressure to a standard condition of 60° F. and 30 inches mercury pressure.

Recording thermometers were installed in the feed water line to the boilers, in the foul main connections at the outlet of the second washer, and on the generator oil line at the outlet to the oil heater. Indicating thermometers were installed at the outlet of each scrubber and at the inlet to the relief holder. A recording thermometer was used at the station meter to record the temperature of the gas passing through the meter.

The temperature range within the generators in various parts of the checkerwork, as well as the average temperature of the gas leaving the machine, was determined by pyrometric measurements. Both indicating and recording pyrometers of standard make were installed on the generator floor and many observations were made during the regular and special tests.

Scales were provided for weighing all lampblack recovered in the settling pits over certain special test periods; at the same time, the quantity of tar segregated in the washers, scrubbers, and tar pits was collected and measured. The moisture content, heating value, and other characteristics of the recovered by-products were also determined from representative samples taken during these periods.

(c) Scope of tests.

The tests at Santa Barbara during the first six months of operation were very much the same as those at San Jose. Gas of 570 B.t.u. was supplied for the first three months and 535 B.t.u. for the next three months. The quality of gas manufactured during January and February, 1921, was varied, and only the January results are shown.

During the months of May and June, 1921, the entire field force of the Committee was transferred to Santa Barbara, where a series of special tests were made, the object of which was to improve the efficiency of the generators and to reduce the excessive smoke from the plant, which had become quite objectionable.

Beginning July 1, 1921, a heating standard of 540 B.t.u. per cubic foot was maintained. In November a test was made at Santa Barbara to determine the effect on capacity and efficiency of generators when inert gases were introduced during the making period. In these tests hot gases from boiler furnaces were added instead of air, as in the San Jose plant.

(d) Results of tests.

The results of all tests made at the Santa Barbara plant during the two-year period are set forth in the following table:

TABLE NO. 2.

Santa Barbara Plant—Operating Statistics.

	July-Aug.-Sept., 1920	Oct.-Nov.-Dec., 1920	January, 1921	Mar. 6-26, 1921	Mar. 27-Apr. 23, 1921	May-June, 1921
Average quality of gas (B.t.u.)	567.0	534.3	556.0	516.5	560.0	533.0
Total gas made (M cubic feet)	59,476	76,062	32,600	19,210	23,052	45,463
Average make per day (M cubic feet)	647	827	1,051	915	824	745
Average operating time per day (hours)	12.7	13.0	16.9	14.80	12.92	14.08
Average make per hour (M cubic feet)	51.0	62.4	62.2	61.8	63.8	52.9
Heat oil (gallons per M cubic feet)	1.02	1.025	1.04	1.105	0.794	1.18
Make oil (gallons per M cubic feet)	7.36	7.20	7.65	7.17	7.96	7.35
Total oil (gallons per M cubic feet)	8.39	8.225	8.69	8.275	8.754	8.53
Lampblack (pounds per M cubic feet)	21.2	22.80	No tests made			20.10
Tar (pounds per M cubic feet)	2.0	3.30	No tests made			3.61
B.t.u. in gas per gallon total oil	67,700	65,000	64,000	62,400	64,000	62,500
Per cent over-all efficiency (B.t.u. in gas / B.t.u. in total oil)	46.4	44.7	44.0	42.8	44.0	43.0
Average gas analysis:						
CO_2	1.3	0.8	1.2	1.3	1.2	1.3
C_6H_6	0.8	0.7	4.7	3.9	5.0	4.2
C_nH_{2n}	2.5	2.7				
O_2	0.8	0.4	0.2	0.6	0.9	0.7
CO	7.5	7.9	8.0	7.9	7.6	8.2
H_2	56.3	61.5	55.3	57.3	51.1	54.0
CH_4	29.0	22.7	24.8	22.1	27.15	24.1
N_2	1.8	3.3	5.8	6.9	6.7	7.5
Totals	100.0	100.0	100.0	100.0	100.0	100.0
Calculated B.t.u.	570.0	525.0	550.0	513.0	569.0	529.5
Specific gravity	.361	.338	.375	.330	.403	.391

TABLE NO. 2—Concluded.

Santa Barbara Plant—Operating Statistics.

	July-Aug.-Sept., 1921	Oct.-Nov.-Dec., 1921*	Jan.-Feb.-Mar., 1922	Apr.-May, 1922	June, 1922
Average quality of gas (B.t.u.)	537	536	539	539.5	538
Total gas made (M cubic feet)	65,451	75,793	96,477	53,260	24,404
Average make per day (M cubic feet)	700	824	1,073	874	814
Average operating time per day (hours)	13.06	13.95	19.80	15.85	12.95
Average make per hour (M cubic feet)	53.6	59.0	54.4	55.1	62.8
Heat oil (gallons per M cubic feet)	1.20	1.03	1.29	1.45	1.43
Make oil (gallons per M cubic feet)	7.52	7.40	7.24	7.82	8.00
Total oil (gallons per M cubic feet)	8.72	8.43	8.53	9.27	9.43
Lampblack (pounds per M cubic feet)	21.8	19.6	No special tests		
Tar (pounds per M cubic feet)	4.4	5.0	No special tests		
B.t.u. in gas per gallon total oil	61,580	63,600	63,200	58,200	57,100
Per cent over-all efficiency (B.t.u. in gas / B.t.u. in total oil)	42.0	43.4	43.0	39.7	38.9
Average gas analysis:					
CO_2	0.8	2.0	1.0	0.8	1.2
C_6H_6	----------	0.8	0.6	----------	----------
C_nH_{2n}	3.7	4.8	2.7	3.7	3.8
O_2	0.6	0.5	0.8	0.6	0.5
CO	7.1	6.7	7.1	6.5	6.6
H_2	58.7	46.8	60.6	60.7	59.2
CH_4	24.3	23.2	23.5	23.9	24.2
N_2	5.0	15.2	3.7	3.8	4.5
Totals	100.0	100.0	100.0	100.0	100.0
Calculated B.t.u.	----------	----------	523.0	530.5	535.0
Specific gravity	.345	.480	.375	.375	.380

*Tests with inerts made during this period.

(e) Conclusions from Santa Barbara tests.

It is to be noted from the preceding tables that the highest efficiency is shown during the first three months of operation with the 567 B.t.u. gas. During this period, however, the quality of the gas was determined by three daily tests instead of by continuous sample. Later during the investigation it was clearly demonstrated that the average of the three daily tests gave consistently higher B.t.u. averages than either the weighted or continuous samples; and after the latter methods of determining the heating value were adopted, the tests showed practically no difference between the efficiency of the 560 and the 535 B.t.u. gas.

Production efficiencies during April, May, and June of 1922 fell off, owing to the condition of the checker-brick. On account of repairs required on the auxiliary set, this generator was maintained in operation after it should have been recheckered. The total by-products increased in amount with the reduction in the heating value of the gas. However, with the reduction in the heating value below 540 B.t.u., the lampblack contained a smaller percentage of volatile matter, was more dense in structure, and less valuable as fuel, as was shown also by the experience in San Jose.

The special tests on generator efficiency to determine the effect of introduction of inerts showed that the addition of hot flue gases increased the yield in B.t.u. per gallon from 62,530 B.t.u. to 64,740 B.t.u. during the period of test. The quality of the gas was reduced from approximately 5 to 10 B.t.u. below a 535 standard and the specific gravity increased from .375 to .511. The generator capacity increased approximately 20 per cent in cubic feet, but, owing to the increase in specific gravity, a greater burden necessarily fell upon the distribution system.

The relative uniformity of gas produced under the different heating-value standards is indicated from the following table, in which are set forth the maximum and minimum heating values determined during the test period.

Variation in Heating Value of Gas During Test Period.

Monthly average (B.t.u.)	570	563	541	538	537
Number tests made	24	20	24	24	25
Average of daily maximum (B.t.u.)	580	584.5	556	557	550
Average of daily minimum (B.t.u.)	558	565	538	535	532
Difference (B.t.u.)	22	19.5	18	22	18

It may reasonably be concluded that no operating gain in maintaining uniformity of gas quality is obtained with the straight-shot type of generator with a reduction in heat content below 540 B.t.u. under the method of operation at this plant.

Considering the entire test at Santa Barbara, it appears that the efficiency of manufacture is practically constant with gases having a heating value of 570 to 540 B.t.u. per cubic foot. However, with a reduction below 540 B.t.u. there is a noticeable reduction in the thermal efficiency of manufacture.

3. SOUTHERN CALIFORNIA GAS COMPANY'S PLANT.

In March, 1922, the field staff of the Committee was transferred to the Southern California Gas Company's plant at Los Angeles, where tests were carried on in April and May to determine the operating efficiency of the new generators installed there. The object of the tests was to determine the best cycle of operation for a 570 B.t.u. gas, and to compare the generator capacity and efficiency while manufacturing gases of different heating value.

(a) Description of generators tested.

The generators turned over to the Committee for test purposes were of the straight-shot design. The No. 10 set shown in figure 6 consisted

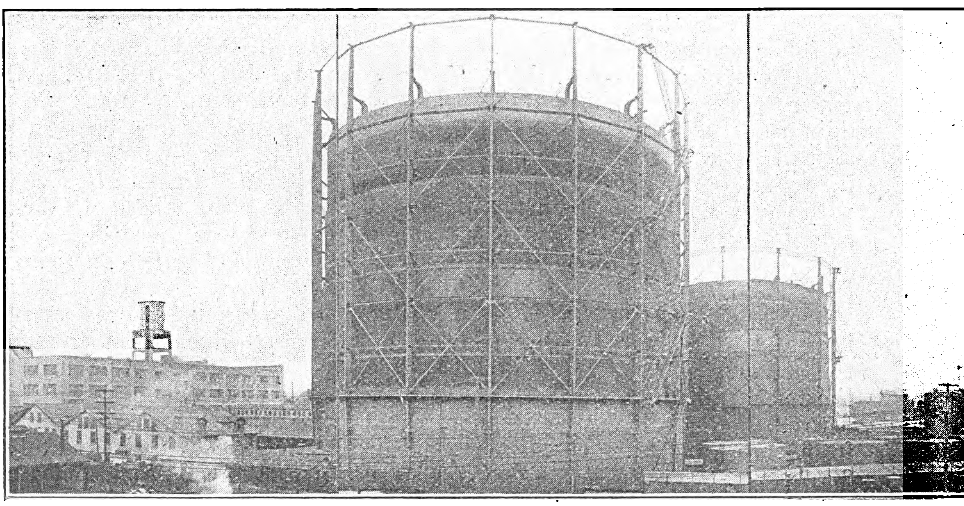


FIG. 5; General view of Southern California Gas Company's plant.

of a shell 36 feet in height and 20 feet outside diameter. The lining had two courses of 9-inch brick and one course of 4½-inch brick, and was insulated by 1½ inches of powdered Sil-O-Cel—a total thickness of two feet, making the interior diameter of the shell 16 feet. The checkers consisted of 54 courses of brick, installed with straight flue and spaced 2½ inches apart.

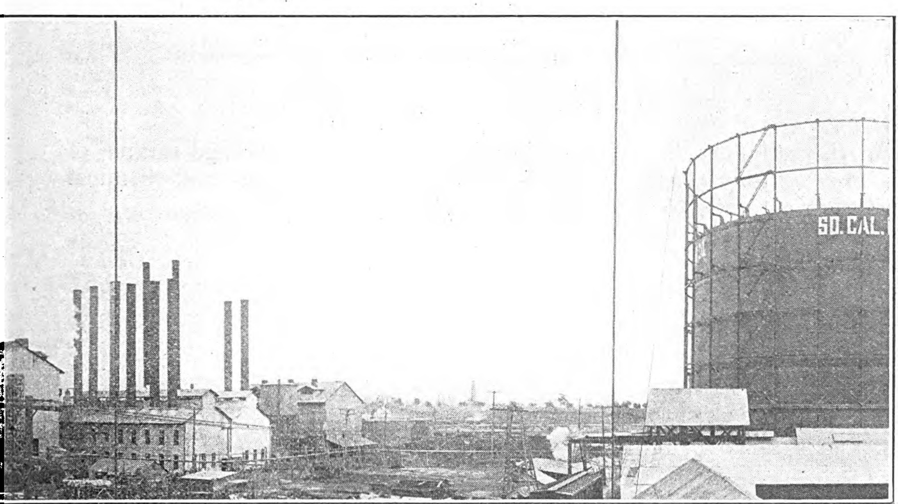
The companion generator to the No. 10 set was of exactly the same general dimensions, the only difference being in the arrangement of the checker-brick. In this generator the main body of checkers extended 14 feet 4 inches in height (36 courses), and a second body of checkers of 4 courses was located immediately under the upper steam and oil sprays.

(b) Testing apparatus and facilities.

The engineers representing the Committee installed a large amount of testing equipment and calibrated a great deal of apparatus before beginning this series of tests. Recording and indicating thermometers were installed wherever these were considered desirable. Pressure gages, oil meters, steam flow meters, pyrometers, and other apparatus were installed and calibrated. A special gas laboratory, equipped with all essential testing equipment, was built for this investigation.

The two storage tanks, each of approximately 2500 gallons capacity and calibrated to one-eighth inch (4 gallons), were used for oil storage. These tanks were filled with oil and the volume measured at the beginning and at the close of the day's operation. The amount of oil used was checked by the Assistant Engineer of the Committee and a representative of the Gas Company.

The volume of gas made each day was obtained from holder readings. The gas holder was wholly deflated before beginning the day's run and the height of the holder measured at the end of the day's make. The gas in this holder was pumped over to the large storage holder during the night hours between 11 p.m. and 2 a.m., and the volume of gas in the holder again calculated by the night foreman as a check upon the previous readings.



During the period when the gas was pumped from the relief holder to the large storage holder, a gas sample was collected at a uniform rate into the 100-cubic foot sampling holder. Each morning the gas collected

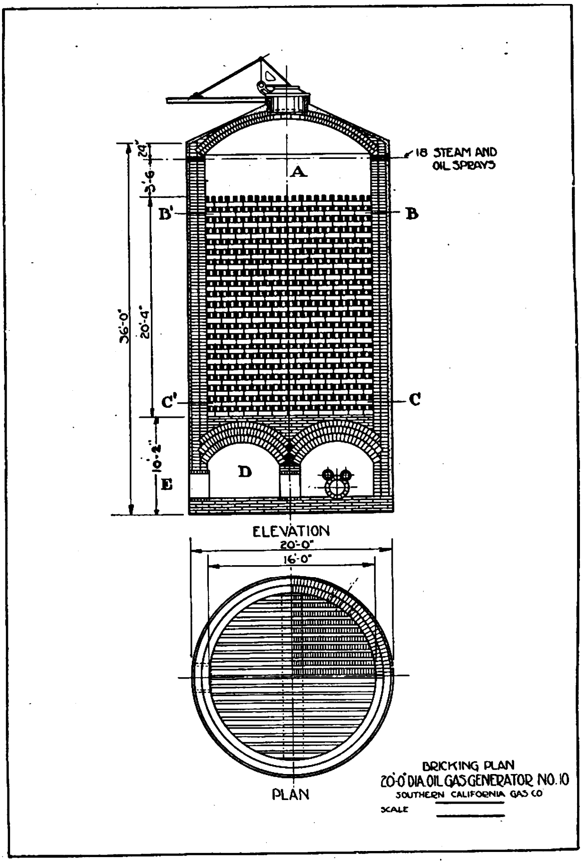


Fig. 6: Straight-shot generator No. 10, Southern California Gas Company's plant.

from the previous night's pumping (representing an average sample of the previous day's make) was tested for its calorific value, and chemical analysis was made to determine its composition.

(c) Results of tests.

The results of all tests made on the two generators at the Southern California Gas Company's plant are shown in the following tables, Nos. 3 and 4.

TABLE NO. 3.

No. 9 Generator—Operating Statistics.

Average quality gas made (B.t.u. per cubic foot)	499	537	552	560	579	581	586
Gas made (M cubic feet)	2,067	1,221	1,172	609	1,530	1,662	1,728
Number days run	3	2	2	1	3	3	3
Number hours' operation	21.70	13.06	12.82	6.00	20.50	15.46	22.00
Make per hour (M cubic feet)	95.0	96.5	91.4	101.5	74.6	107.5	78.5
Make per run (M cubic feet)	68.8	48.8	45.5	50.7	38.2	53.7	52.5
Heat oil (gallons per M cubic feet)	0.50	0.72	0.59	0.49	0.62	0.52	0.51
Make oil (gallons per M cubic feet)	6.32	6.70	7.13	7.37	7.48	7.58	7.51
Total oil (gallons per M cubic feet	6.82	7.42	7.72	7.86	8.10	8.10	8.02
B.t.u. in gas per gallon of total oil	73,167	72,373	71,505	71,247	71,480	71,480	73,067
Per cent over-all efficiency $\left\{\frac{\text{B.t.u. in gas}}{\text{B.t.u. in total oil}}\right\}$	49.32	48.82	48.23	48.06	48.38	48.38	49.28
Average gas analysis:							
CO_2	2.2	2.5	2.2	1.6	2.6	1.8	2.2
C_6H_6	0.6	0.9	1.0	1.0	0.7	0.9	0.8
C_nH_{2n}	1.1	2.1	2.0	2.1	2.8	2.8	3.0
O_2	0.5	0.3	0.3	0.3	0.2	0.3	0.3
CO	12.5	11.3	10.6	9.6	10.4	9.0	11.7
H_2	52.8	50.7	51.1	50.6	45.7	49.0	44.6
CH_4	23.8	26.7	27.8	29.0	32.1	31.3	32.2
N_2	6.5	5.5	5.0	5.8	5.5	4.9	5.2
Totals	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Calculated B.t.u.	491	537	552	560	578	584	586
Specific gravity	.418	.432	.424	.421	.452	.426	.458

TABLE NO. 4.

No. 10 Generator—Operating Statistics.

Average quality gas made (B.t.u. per cubic foot)	550	572	616
Gas made (M cubic feet)	716	1,281	501
Number days' run	1	2	1
Number hours' operating	7.00	14.13	7.00
Make per hour (M cubic feet)	101.5	90.6	72.5
Make per run (M cubic feet)	51.0	45.5	38.6
Heat oil (gallons per M cubic feet)	0.71	0.85	1.04
Make oil (gallons per M cubic feet)	6.87	7.07	7.92
Total oil (gallons per M cubic feet)	7.58	7.92	8.96
Cubic feet gas made per barrel total oil	5,541	5,303	4,687
B.t.u. in gas per gallon of total oil	72,560	72,222	68,750
Per cent over-all efficiency $\left\{\frac{\text{B.t.u. in gas}}{\text{B.t.u. in total oil}}\right\}$	48.94	48.71	46.00
Average gas analysis:			
CO_2	2.6	2.5	2.7
C_6H_6	0.8	1.1	1.3
C_nH_{2n}	2.7	3.0	4.0
O_2	0.2	0.2	0.2
CO	10.2	10.3	9.3
H_2	50.8	48.7	45.0
CH_4	27.6	28.9	32.3
N_2	5.1	5.3	5.2
Totals	100.0	100.0	100.0
Calculated B.t.u.	548	573	614
Specific gravity	.430	.445	.469

(d) Conclusions from Southern California Gas Company's plant tests.

It will be noted from a study of the preceding tables that the efficiency of production is considerably higher than that secured with the smaller sets at Santa Barbara. Part of this increased efficiency may be attributed to the greater height of the new generators, and may possibly be due to the fact that in the tests at this plant the heating value was determined prior to oil scrubbing.

The highest thermal efficiency with the No. 9 generator was obtained with the 45-minute cycle, the tests showing 49.3 per cent efficiency with gas of 500 B.t.u. and 586 B.t.u. quality. (See Table No. 3.) The thermal efficiency on the operation of a 30-minute cycle was slightly less, being approximately 48.3 per cent, but, on account of greater ease of operation and the production of gas of uniform quality, the 30-minute cycle had some advantages. The No. 10 generator, with a slightly different form of interior construction as noted under the description of the plant, showed approximately the same efficiency as No. 9. The results for this generator are given in Table No. 4.

Both of these generators showed a very uniform efficiency under a wide variation in heating value, and tend to corroborate the conclusions from the San Jose and Santa Barbara plant tests. The capacity of the generators in B.t.u. output per hour remained practically constant with variations of gas quality.

The test covered too short a period to supply any data covering labor costs with the different standards, but it is doubtful whether there would be any material difference over the range in heating value covered by these tests.

4. LOS ANGELES GAS AND ELECTRIC CORPORATION'S PLANT.

(a) Description of plant and generators tested.

The gas generating system of the Los Angeles Gas and Electric Corporation consists of three separate and distinct plants. Plant No. 1, where these tests were made, has 18 generators of the straight-shot type, 22 feet in diameter by 35 feet high. In this plant generators 2-A and 2-B were cut off from the rest of the units, and all tests were made on these sets. As the remainder of the plant was interconnected to the oil supply and also to the crude gas mains, it was necessary to segregate these lines in order that the oil delivery and the gas flow could be independently controlled and measured.

(b) Testing apparatus and facilities.

Oil measurement.

Two oil tanks of the same diameter were set aside for all oil measurements. One tank was in use during each series of tests, and the quantity of oil withdrawn during each day's run was calculated from measurements made with a steel tape. The temperature of the oil was determined from recording and indicating thermometers installed at the tanks, and the volume of oil used was reduced to standard conditions of 60° F.

On the operating table for each generator are located vertical dial oil meters for measuring the make oil and oil for heating. The flow of the oil to the generators from the storage tanks is supplied by four

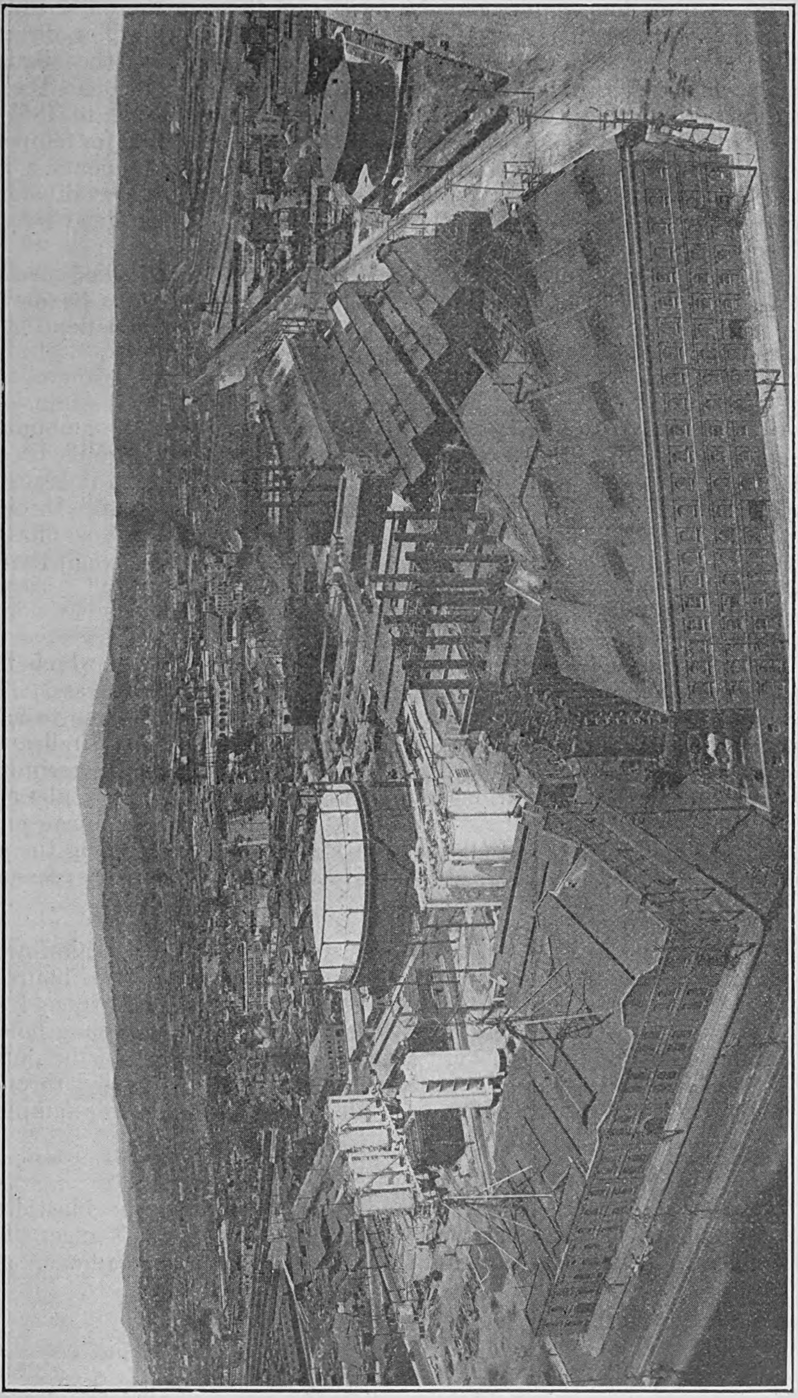


FIG. 7: General view of Los Angeles Gas and Electric Corporation's plant.

pumps, two of these pumps circulating the oil through the oil scrubber, the other two drawing the oil from the scrubber overflow, or directly from the tanks, as desired. In these tests practically all the oil used had been passed through the oil scrubber, then forced through the oil heater, and the temperature raised from approximately 75° to 185° F. The oil used, as determined by meter readings and corrected for temperature to 60° F., was compared with the oil tank measurements. The meter measurement proved to be very consistent, rarely if ever diverging more than 1½ per cent from the amount used as determined by the corrected tank readings.

Between the make-oil meter and the oil injectors, the oil passed through a 2-inch wrought iron coil located in the horizontal foul-gas header on the generator offtake. When the coil was free from carbon deposit, it was found possible to heat the oil to a temperature of 250° F.

Steam.

An orifice meter was installed in the steam header, and the amount of steam used by the injectors observed at the different periods of gas making. The steam was obtained from the main supply at a pressure of approximately 130 pounds per square inch and was passed through superheating coils located in the vertical section of the gas offtake. The amount of superheat obtained from these coils was so small that it was of no special advantage.

Gas measurement.

The finished gas was measured by station meter No. 8, which had been blanked off from the rest of the meter battery for these tests. This meter had been calibrated quite recently and may be considered to have registered correctly. A recording pressure gage and an indicating thermometer were installed at the gas inlet. On the outlet a recording thermometer gave the variations in temperature, while barometer observations taken during the heating-value tests, together with the mean pressure in the meter, provided all the data necessary for correcting the gas volume to standard conditions of 60° F. and 30 inches of mercury pressure.

Heating value of gas.

The heating value of the purified gas was determined by calorimeter tests made hourly during the daytime and at intervals of two hours at night. Daily tests were also made on an average sample taken from the outlet of the station meter and collected into a gas-sampling holder of about 40-cubic foot capacity. Another sample taken from the outlet of the relief holder before the gas was oil scrubbed was passed through a small washer and oxide purifier and collected into a second gas-sampling tank.

Air measurement.

A Pitot tube, previously calibrated, was inserted in the blast line, and the differential blast pressure read directly from a draft gage. The volume of air used was calculated from these manometer readings.

Water to wash box.

A recording orifice meter was installed on the water-supply header to the wash box of 2-B generator. As the rate of water flow to each washer was closely regulated, it has been assumed that the measurements obtained also apply to the other generator.

Pyrometric observations.

Four calibrated recording pyrometers on each generator made it possible to secure a large number of measurements of the temperature within the checkerbody and the temperature of the gas leaving the generator at various stages during the process of gasification. Special precautions had been taken to have sheaths or protecting tubes of heat-resisting metal inserted at various locations through the generator lining in order to protect the couples. Recording thermometers were installed at the outlet to the washers, at the inlet to water scrubber, and at the inlet and outlet of the oil scrubber.

(c) Results and conclusions of tests.

The following table, No. 5, gives the results of three series of short tests, during which the heating value was varied from 533 to 596 B.t.u. per cubic foot. The data show a small but definite increase in the thermal efficiency of production with the higher heating-value gas. There is a decrease, however, in the make per hour—both in cubic feet and B.t.u.—and a reduction in the quantity of lampblack made. The change in capacity was not large enough to show any difference in the labor costs.

The figures on the whole indicate that it would be more efficient to manufacture a gas of rather high heating value. A study of the analysis of the gas shows, however, why this conclusion must be modified when we take into consideration distribution costs, for the reason that the high illuminants in the 596 B.t.u. gas will result in much larger condensation loss.

TABLE NO. 5.

Los Angeles Gas and Electric Corporation's Plant Operating Statistics.

Average quality of gas (B.t.u)	533	564	596
Total gas made (cubic feet)	3,939,360	1,875.017	1,772,850
Total hours' operation	45½	23	23¼
Make per hour (cubic feet)	85,580	81,520	76,000
Make per hour (M B.t.u.)	46,097	45,977	45,290
Heat oil (gallons per M	1.05	1.00	0.90
Make oil (gallons per M)	7.14	7.48	7.71
Total oil (gallons per M)	8.19	8.48	8.61
Lampblack (pounds per M)	23.00	20.50	17.50
Tar (pounds per M)	.75	2.00	3.00
B.t.u. in gas per gallon total oil	65,080	66,510	69,220
Per cent over-all efficiency $\left\{\frac{\text{B.t.u. in gas}}{\text{B.t.u. in total oil}}\right\}$	43.7	44.6	46.5
Average gas analysis:			
CO_2	2.0	1.9	2.3
C_6H_6	0.8	0.8	0.9
C_nH_{2n}	3.2	3.6	4.4
O_2	0.3	0.5	0.4
CO	11.8	11.2	10.5
H_2	54.0	51.6	48.0
CH_4	23.6	26.5	29.6
N_2	4.3	3.9	3.9
Totals	100.0	100.0	100.0
Specific gravity of gas	.411	.420	.443

5. PACIFIC GAS AND ELECTRIC COMPANY'S POTRERO PLANT.

(a) Description and results of tests.

A short series of tests were run at the Potrero plant of the Pacific Gas and Electric Company during the months of August and September, 1922, primarily for the purpose of determining the loss of heating value of gas made with the Jones improved generator and distributed under the rather unusual conditions existing in San Francisco and vicinity. The plant was first run on a 550 B.t.u. standard, based upon a continuous sample test, for three days; then for a period of five days on a standard of about 540 B.t.u. as shown by plant tests, which was equivalent to about 535 B.t.u. on a continuous sample; and later again at the higher heating value. Careful tests were made on these days of the heating value of the gas at the Stevenson street laboratory of the company, and at the laboratory of the Railroad Commission, as well as at Redwood City and Palo Alto. The loss of heating value during distribution is shown in a following section of the report.

Table No. 6, following, shows the results of the plant tests. A slightly greater efficiency is shown for the 540 B.t.u. standard than for the 555 B.t.u. standard, but a study of the daily records indicates that no definite conclusions should be drawn from these tests covering so short a period.

During the first 6-day period, while a 555 B.t.u. standard was maintained, the records of the test indicate an average maximum variation of 13 B.t.u. during the first three days of the test, and a variation of 5 B.t.u. during the last three days. For the three days that a 540 B.t.u. standard was maintained, the average variation was 6 B.t.u.

TABLE NO. 6.

Pacific Gas and Electric Company's Potrero Plant—Operating Statistics.

	Aug. 23-25, Sept. 5-7	Aug. 28-Sept. 1
Average quality of gas (B.t.u.):		
From individual tests	554.4	541
From continuous sample	549.5	534
Total gas made (M cubic feet)	34,740	29,205
Operating time per day (hours)	11	11
Average gas made per run (cubic feet)	52,630	53,100
Heat oil (gallons per M cubic feet)	.925	.90
Make oil (gallons per M cubic feet)	6.380	6.17
Total oil (gallons per M cubic feet)	7.305	7.07
Lampblack (estimated pounds per M cubic feet)	12.0	12.0
Tar (estimated pounds per M cubic feet)	4.0	4.0
B.t.u. in gas per gallon total oil	75,850	76,450
Per cent over-all efficiency $\left(\frac{\text{B.t.u. in gas}}{\text{B.t.u. in total oil}}\right)$	51.6	51.98
Average gas analysis:		
CO_2	4.6	4.8
C_6H_6	1.2	1.1
C_nH_{2n}	3.0	2.6
O_2	0.4	0.3
CO	10.4	10.2
H_2	47.6	49.7
CH_4	27.0	25.9
N_2	5.8	5.4
Totals	100.0	100.0
Calculated B.t.u.	554	539
Specific gravity	.476	.461

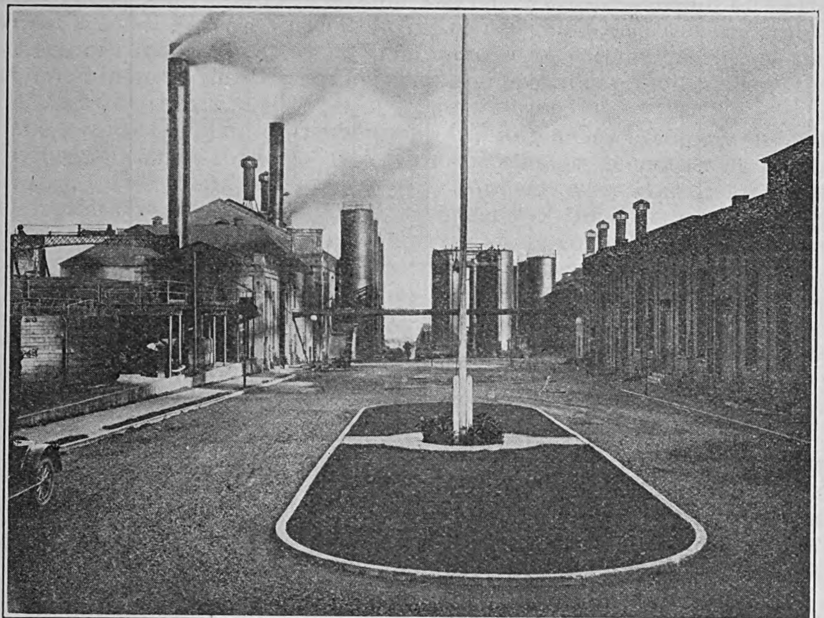


FIG. 8: General view of Portrero Gas Works.

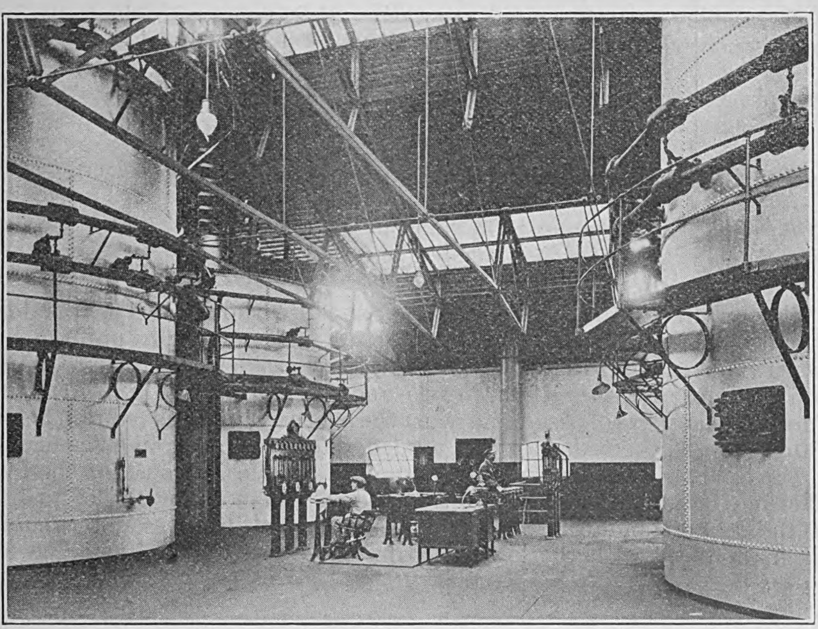


FIG 9: Operating boards for No. 7 and No. 8 generators.

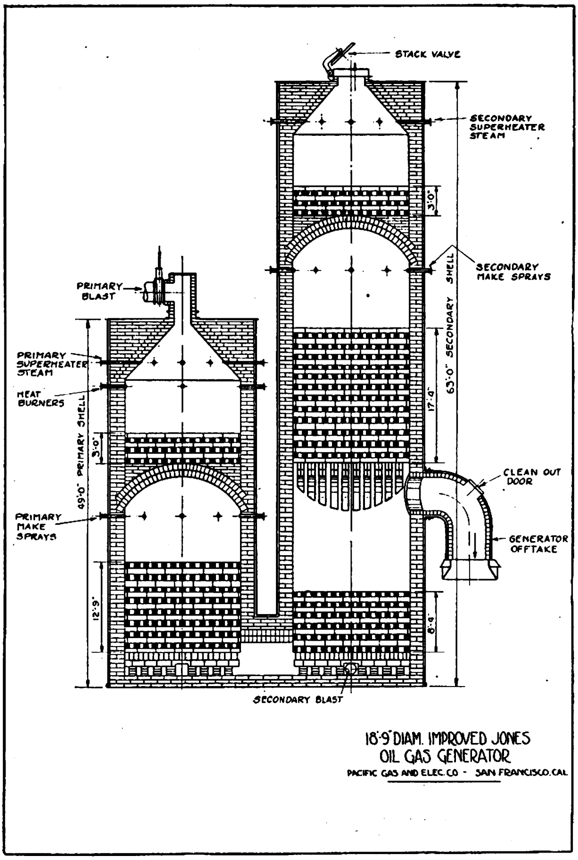


FIG. 10: Jones improved generator, 18 ft. 9 in. in diameter, Potrero plant of the Pacific Gas & Electric Company.

6. CONCLUSIONS FROM ALL PLANT TESTS.

The results of the plant tests at San Jose showed very definitely that the thermal efficiency of manufacture was practically uniform between the limits of 570 and 530 B.t.u. It was somewhat easier to maintain a uniform quality between 535 and 550 B.t.u. than at 570 B.t.u. The lampblack was of less value when the heating value was reduced below 530 B.t.u. and there was a slight tendency to a reduction in efficiency.

The Santa Barbara plant tests showed a practically constant thermal efficiency between 570 and 540 B.t.u., and no gain in uniformity of quality at the lower standard. As found from the San Jose tests, the lampblack produced with the lower heating value gas was of less value for fuel. The special tests to determine the effect of introduction of inerts showed a small increase in yield in B.t.u. per gallon and a considerable increase in cubic-foot capacity. The increase in specific gravity of the gas would increase the distribution costs and probably offset any decrease that might be shown in the cost of manufacturing.

The tests at the plant of the Southern California Gas Company showed a higher efficiency than the test with the smaller generator at Santa Barbara. The thermal efficiency was, however, very constant over a wide variation in heating value. The capacity of the generator in B.t.u. per hour remained practically constant. No data could be gathered from this short test on labor costs with different standards.

The tests at the Los Angeles Gas and Electric Corporation's plant showed a small decrease in thermal efficiency with reduction in heating value, although the make in B.t.u. per hour was slightly increased. No data on labor costs were avilable from this short test.

The following general conclusions may be drawn from all the plant tests:

The efficiency of manufacture of oil gas where straight-shot sets are used, as now operated in California, is practically constant with gases having a heating value of 570 to 540 B.t.u. per cubic foot. There is a reduction in efficiency as the heat content of the gas is lowered below 540 B.t.u. The ease of maintaining a uniform quality was not affected at operations between 500 and 570 B.t.u.

The efficiency of manufacture of gas by the use of the Jones improved sets is practically constant between the limits of 570 and 530 B.t.u. per cubic foot. With a lowering of quality below 530 B.t.u. there is a slight reduction in efficiency. In the Jones type of generator, it is easier to maintain a uniform gas quality with gases having heating value of 550 to 530 B.t.u. per cubic foot than with gases having a higher heating value.

The lampblack is of less value for fuel when produced with the lower heating-value gas, although the total quantity produced is somewhat greater.

No material difference could be observed in the labor cost with gases of different heating value.

Considering only the thermal efficiency of manufacture and the cost per B.t.u., there is no advantage in reducing the heating value of the gas below 570 or 550 B.t.u. per cubic foot.

III. TRANSMISSION AND DISTRIBUTION LOSSES.

A Comparison of the Losses in Heating Value of Various Qualities of Oil Gas as Generated and Distributed at the Different Plants.

1. Scope of the tests.

The second part of the main problem before the Committee was the determination of the relative losses in heating value during the transmission and distribution of different qualities of gas, since this is an important factor in determining the quality of gas most economical to supply to the consumers.

The heating value of the gas in the storage holder before its delivery to the distribution system can be quite uniformly maintained. The ultimate heating value that reaches the consumer depends, however, on the composition of the gas, pressure at which the gas is transmitted or distributed, velocity of flow, temperature to which the gas is exposed, etc. The removal of the unstable hydrocarbons resulting from the many variations in conditions under which the gas is distributed will cause wide variations in heating value.

The reduction in the heating value of the gas from the plant to the consumer has been frequently determined at San Jose and Santa Barbara. The loss under varying pressure conditions between San Jose and Los Gatos was also a subject of investigation over several months of tests. Comparison of the tests of the gas manufactured in San Francisco, compressed and transmitted some 30 miles down the Peninsula to Palo Alto, reveals the fact that the degree of loss is largely dependent on temperature conditions.

2. Determination of the losses in heating value at the Santa Barbara system.

The Santa Barbara distribution system operates a medium high pressure. The gas is compressed at the plant to a maximum of ten pounds per square inch and sent out under pressures varying from six to ten pounds, as required, in order to give adequate supply to the consumers. Each service is equipped with an individual governor, and the gas is reduced in pressure to approximately six inches of water column.

In this series of tests, the results of which are given in Table No. 7, a determination of the heating value of the city gas was taken at 30-minute intervals with calorimeters located at the plant and at the uptown office of the company. Before beginning this series of observations, the two instruments were very carefully checked against each other; the thermometers were compared with a Bureau of Standards certified thermometer; and the gas meter was calibrated with the California Railroad Commission's standard one-tenth cubic foot bottle.

Various qualities of gas were made during this series of tests, ranging in heating value from 600 B.t.u. to 500 B.t.u. per cubic foot. The following table shows a surprisingly large loss in heating value with the high heating-value gas, but this loss decreases rather uniformly with the decrease in heating value. Below 550 B.t.u. the loss is insignificant.

TABLE NO. 7.

Loss in Heating Value of Gas Between Plant and Office in Santa Barbara.

Average heating value of gas sent out from plant	Average heating value of gas collected at uptown office	Average loss in heating value between plant and office	
B.t.u.	B.t.u.	B.t.u.	Per cent
590–600	574–577	20	3.3
580–590	568–574	14	2.4
570–580	562–568	10	1.7
560–570	555–562	6	1.0
550–560	547–555	4	0.7
535–550	534–547	2	0.3
500–535	500–534	0	0

3. Heating value losses under low pressure distribution at San Jose and under high pressure transmission to Los Gatos.

(*a*) *Loss in heating value in low pressure system in San Jose.*

The results of observations on the San Jose system show that in the transmission of gas from the plant to the uptown office, a distance of one and one-half miles, there is a loss in heating value which varies from 15 B.t.u. for the higher quality to 4 B.t.u. for the low heating-value gas.

TABLE NO. 8.

Loss in Heating Value of Gas Between Plant and Office in San Jose.

Average heating value of gas sent out from plant	Average heating value of gas collected at uptown office	Average loss in heating value between plant and office	
Bt.u.	B.t.u.	B.t.u.	Per cent
560–570	548–553	15	2.65
550–560	540–548	12	2.16
540–550	532–540	10	1.83
530–540	524–532	8	1.50
520–530	516–524	6	1.14
500–520	498–516	4	0.80

(*b*) *Tests on high pressure transmission from San Jose to Los Gatos.*

Low pressure gas at San Jose is taken from the storage holder, compressed to 25 to 60 pounds per square inch and transmitted through a high-pressure main which terminates at the Los Gatos plant, approxi-

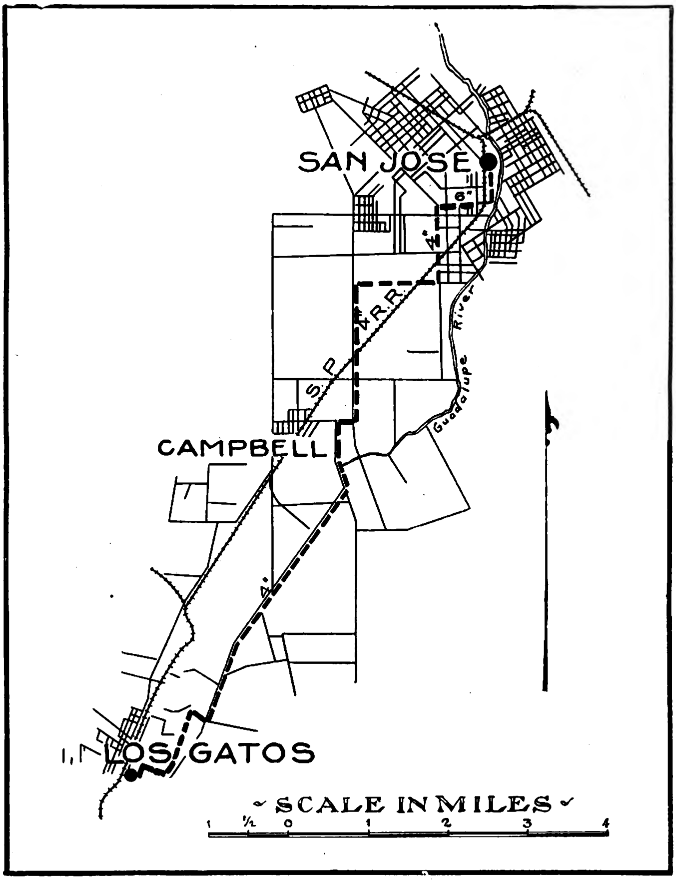


FIG. 11: Location of the transmission main from San Jose to Los Gatos.

mately ten miles away. There the gas is reduced to low pressure and distributed to the consumers through the system that was formerly used when gas was manufactured locally.

Numerous observations were taken at Los Gatos to determine the average heating value of the gas supplied from San Jose. Continuous gas samples were taken as in the tests made on the San Jose and Santa Barbara systems. The results of these observations are as follows:

TABLE NO. 9.

Loss in Heating Value of Gas Between San Jose and Los Gatos with Gases of Different Heating Values

(Transmission through High Pressure System.)

Average heating value of gas sent out from San Jose Plant	Average heating value of gas received at Los Gatos Plant	Average loss in heating value	
B.t.u.	B.t.u.	B.t.u.	Per cent
570–580	550–555	25	4.3
560–570	545–550	20	3.5
550–560	540–545	15	2.7
530–550	522–540	10	1.8
510–530	505–522	8	1.5
500–510	495–505	5	1.0

From the two preceding tables it is shown that the losses in distribution in San Jose, and from the San Jose plant to Los Gatos, are much larger than the losses with the same heating-value gas in the Santa Barbara system. This can be accounted for only by the fact that the Jones type generators produce a gas containing a larger percentage of benzol, which is quite readily condensed in compression and when subjected to low temperatures.

4. Loss of heating value in transmission and distribution, San Francisco and Peninsula district.

From observations taken over a number of years, the drop in heating value in the distribution system of San Francisco and the Peninsula district has appeared to be extreme as compared with cities elsewhere. An investigation to determine the probable cause of this large loss of heating value was begun November 1, 1921, and the first step was the installation of continuous gas sampling holders at the Potrero gas plant and at the Palo Alto substation, 34 miles down the Peninsula.

The holder at Potrero was connected to the low pressure side of the Peninsula gas compressors and adjusted by means of a mercury governor and a small orifice so that the gas could be collected in the tank at such rates as were comparable with the hourly sendouts to the Peninsula systems. These rates were adjusted throughout the day's operation by means of the pressure governor and a calibrated scale attached to the holder. Gas was taken in between the hours of 4 a. m. and 9 p. m.—the hours of transmission pumping—and the gas samples collected were representative of the weighted average heating value of the gas delivered to the low pressure side of the compressor.

Initial pressure on the Peninsula during the period of the tests varied from 80 to 90 pounds from 4 a. m. to 2 p. m.; from 70 to 80 pounds from 2 p. m. to 7 p. m., and from 50 to 65 pounds from 7 p. m. to 9 p. m. Gas was recompressed at Redwood City for the Palo Alto and intermediate territory during the hours of heavy demand in order to maintain adequate pressure at the terminal.

Gas collecting tanks similar to the one at Potrero were installed at the Pacific Gas and Electric Company's compressor station at Redwood City and in the substation at Palo Alto, and adjusted so that a continuous gas sample was collected during each 23 hours from 9 a. m. to 8 a. m. the following day.

The heating value of the gas delivered from Potrero and received at Redwood City and Palo Alto during the eight months is given in the following tabulation:

	Potrero Plant (before compression)	Redwood City	Palo Alto	Total loss
	B.t.u.	B.t.u.	B.t.u.	B.t.u.
February-March	548	523	512	36
April-May	547	529	521	26
June-July	545	538	535	10
August-September	545	540	540	5

From the above figures it is shown that the loss in heating value for the months of February and March was 25 B.t.u. from Potrero to Red-Redwood City, and 11 B.t.u. from Redwood City to Palo Alto—a total loss of 36 B.t.u., or 6.5 per cent. During the months of April and May the loss was 18 B.t.u. from Potrero to Redwood City, and 8 B.t.u. between Redwood City and Palo Alto—a total loss of 26 B.t.u., or 4.7 per cent. During the warmer months of June and July the loss was 7 B.t.u. from Potrero to Redwood City, and 3 B.t.u. between Redwood City and Palo Alto—a total loss of 10 B.t.u., or 1.8 per cent. In the hot months of August and September the total loss was negligible, amounting to less than 1 per cent.

It is clearly indicated from the preceding figures that there is a very wide fluctuation in transmission loss between winter and summer. The reason for the greater loss in transmission on the Peninsula line and at San Jose as compared with Santa Barbara is apparently the result of the larger percentage of benzine in the gas produced by the Jones improved generator.

5. Conclusions from investigation of heating value losses in transmission and distribution.

From the results of the observations in Santa Barbara it appears that where gas is manufactured by straight-shot generators, and distributed by low pressure or intermediate high pressure, the loss in heating value is practically negligible with a heating value of 550 B.t.u. or less, but increases rapidly as the heating value is increased.

The tests on the low pressure system at San Jose and the high pressure system from San Jose to Los Gatos show relatively larger losses in heating value than in the Santa Barbara system. This is explained by the fact that the Jones type of generator produces gas containing higher percentages of benzol, which is readily condensed in compression and when subjected to low pressures.

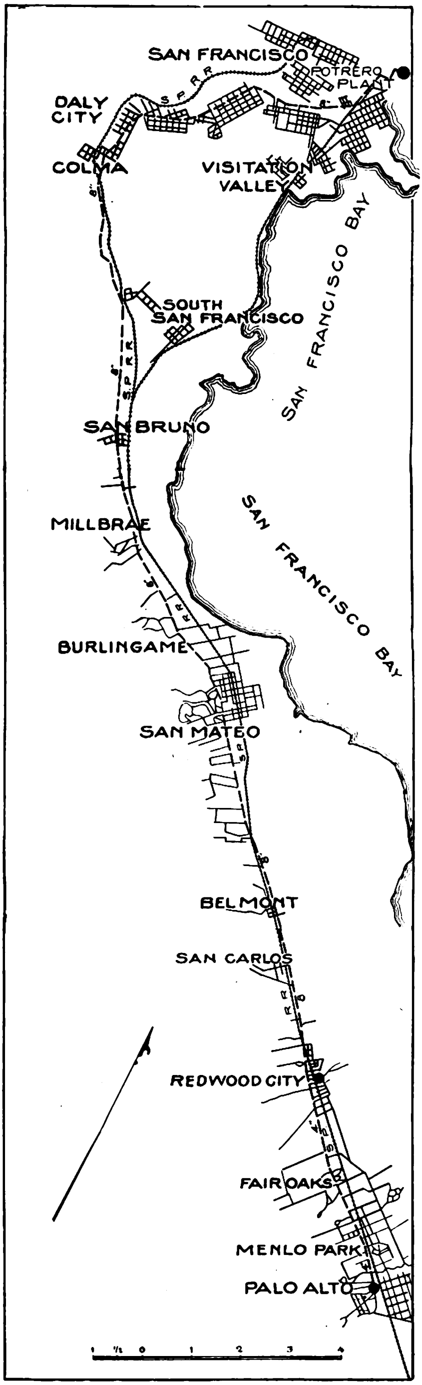


FIG. 12: Location of the transmission main from Potrero plant, San Francisco, to Redwood City and Palo Alto.

The data from the Peninsula show that there is a very large loss in heating value during the cold winter months. The original data on temperatures and pressure are not sufficiently detailed, however, that it is possible to establish a definite relationship between the heating value loss and change in temperature.

Large distribution losses result in a variable quality of gas to the consumer and in poor service. It is possible to estimate the value of the heat loss due to condensation of the illuminants, but more difficult to estimate the loss resulting from inferior service, and the work of taking care of the extra complaints. Unless the manufacturing costs indicate a substantial advantage in favor of some particular standard of heating value, it would appear that it would be an advantage to distribute gas of such low value that it would not be materially affected by changes in pressure or temperature. This matter was given careful consideration by the Committee before deciding upon what was, in their opinion, the most economical standard for California.

IV. UTILIZATION EFFICIENCY OF GASES OF DIFFERENT HEATING VALUE.

1. General considerations applying to the utilization of gases of various kinds.

In considering the probable value of gases of different heating values and composition it is necessary to consider the purpose for which the gas is used: for instance, a distinction must be made between processes where the hot products of combustion or air heated by these products are utilized for drying, baking, or similar purposes, and operation in which extremely high temperatures are required for melting or heat treating of metals.

In the drying and baking processes the flame characteristics are unimportant, since all the work is done by convected heat; and under these conditions the only variation in efficiency of different gases would be due to the difference in the heat carried away in the products of combustion. For most ordinary commercial gases, including natural gas, the percentage of B.t.u. available for useful work at temperatures below 800° F. differs by less than 3 per cent.

In the high temperature operations, we have an entirely different condition. The efficiency of a gas is determined, not only by the B.t.u. available after deducting the heat carried away in the products of combustion, but also by the velocity of combustion, which determines what is commonly referred to as "flame temperature."

Whatever the method by which is found a number that may be called the "theoretical flame temperature," the number so obtained must refer to the thermal state of the products of combustion when combustion occurs without loss of heat. In the flame, combustion is always incomplete, and the energy available at any instant from, say, one cubic foot of flame is the heat from products already burned plus energy still to be released as heat of combustion of the portion unburned. Moreover, "temperature" of a body is its thermal state considered with reference to its power of communicating heat to other bodies. The power of a flame for communicating heat to other bodies lies not only in its thermal state but also in its chemical state—that is, in the flame there is constantly a generation of heat from chemical reaction.

The important property of the flame is its "power of communicating heat to other bodies," but this power depends upon the *total heat generated per second per cubic foot of flame*. This power depends not only upon heats of reaction, and specific heats, but upon the rate of flame propagation—that is, on how much gas can be burned per second in one cubic foot of space. In other words, the important factors to be considered with reference to flames of different gases are the so-called calorific power of the gas, specific heats, and, most important, the volume of the flame at given rate of gas consumption.

The tremendous heating power of the oxy-acetylene flame lies mainly in the high velocity of flame propagation. A relatively enormous quantity of acetylene can be burned in one second in one cubic foot of space at atmospheric pressure. The value of acetylene for cutting and welding is, therefore, due to this high temperature in the combustion zone. For other purposes not requiring this intense local heating, a B.t.u. of this gas is of no greater value than a B.t.u. from coal gas or water gas.

In the case of natural gas we have a gas of high heating value but with so low a speed of combustion that for some purposes it is of less value per cubic foot than a blue water gas containing less than one-third its heating value. It is difficult, therefore, to draw any definite conclusions regarding the relative value of different gases by an examination of the chemical properties when gases are very dissimilar in composition, such as, for example, acetylene and an oil gas. Where the gases are of the same general character, but differ in heating value, it should be possible to estimate approximately what results should be secured.

In the two following tables are given the volume of air required, volume of products formed from combustion, the net available heat, and the calculated flame temperature of two typical gases used in these tests. The two gases, in which the heating value differs by 64 B.t.u., were made in the same plant by the Jones process, and from similar oil. The diluents vary somewhat, but the total is 9.1 per cent in one and 9.2 per cent in the other.

TABLE NO. 10.

Volume of Products Formed from Combustion of 495 B.t.u. Oil Gas (Jones) and Calculated Temperature of Combustion.

Constituents of gas	Cubic feet per 100 cubic feet gas	Cubic feet required			Cubic feet of products of combustion			
		O_2	N_2	Air	CO_2	H_2O	N_2	Total
CO_2	3.6				3.6			3.6
C_6H_6	0.6	4.5	17.53	22.03	3.6	1.8	17.53	22.93
C_2H_4	2.0	6.0	22.71	28.71	4.0	4.0	22.71	30.71
O_2	0.8		Used	in combust	ion—deduc	ted from to	tals	
CO	11.3	5.65	21.39	27.39	11.3		21.39	32.69
H_2	54.7	27.35	102.55	129.90		54.7	102.55	157.25
CH_4	22.3	44.60	168.81	213.41	22.3	44.6	168.81	235.71
N_2	4.7						4.70	4.70
Totals	100.0	88.10	332.99	421.09	44.80	105.10	337.69	487.59
Deduction for O_2		.8	2.78	3.58			2.78	2.78
Net cubic feet		87.30	330.21	417.51	44.80	105.10	334.91	484.81

Available heat (net)=43,897 B.t.u.

By using the values for specific heats given in Richards' Metallurgical Calculations, it is found that the theoretic temperature of combustion of this gas is about 3281° F.

TABLE NO. 11.

Volume of Products Formed from Combustion of 557 B.t.u. Oil Gas (Jones) and Calculated Temperature of Combustion.

Constituents of gas	Cubic feet per 100 cubic feet gas	Cubic feet required			Cubic feet of products of combustion			
		O_2	N_2	Air	CO_2	H_2O	N_2	Total
CO_2	4.0				4.00			4.00
C_6H_6	1.0	7.50	28.39	35.89	6.00	3.00	28.39	37.39
C_2H_4	3.2	9.60	36.34	45.94	6.40	6.40	36.34	49.14
O_2	0.5		Used	in combust	ion—deduc	ted from to	tals	
CO	10.7	5.35	20.26	25.61	10.70		20.26	30.96
H_2	48.5	24.25	91.81	116.06		48.50	91.81	140.31
CH_4	27.4	54.80	207.42	262.22	27.40	54.80	207.42	289.62
N_2	4.7						4.70	4.70
Totals	100.0	101.50	384.22	485.72	54.50	112.70	388.92	556.12
Deduction for O_2		.50	2.27	2.77			2.27	2.27
Net cubic feet		101.00	381.95	482.95	54.50	112.70	386.65	553.85

Available heat (net)=49,692 B.t.u.
Calculating the flame temperature of this gas, it is found to be about 3254° F.

Some of the interesting facts from the preceding tables are brought together in the following tabulation:

Heating value of gas (B.t.u. per cubic foot)	495	557
Volume of gas per M B.t.u. gross (cu. ft.)	2.02	1.80
Volume of gas per M B.t.u. net (cu. ft.)	2.28	2.02
Volume of air required per M B.t.u. gross (cu. ft.)	8.42	8.70
Volume of air required per M B.t.u. net (cu. ft.)	9.50	9.75
Volume of products per cu. ft. of gas (cu. ft.)	4.85	5.54
Volume of products per M B.t.u. gross (cu. ft.)	9.80	9.95
Volume of products per M B.t.u. net (cu. ft.)	11.05	11.15
Carbon dioxide in products (per cent)	9.20	9.90
Water vapor in products (per cent)	21.70	20.40
Nitrogen in products (per cent)	69.10	69.70

From the two preceding tables and the tabulation given above, the following important facts are deduced regarding gases that differ in their heating value as a result of heat treatment and not by dilution:

1. The theoretical temperature of combustion is practically the same.
2. The amount of air required for combustion is almost in proportion to the net available heat.
3. The volume of the products is also in proportion to the net available heat.

Since it is shown that each cubic foot of products from the 495 B.t.u. gas and the 557 B.t.u. gas carries away approximately the same quantity of heat, and the volume of products is in proportion to the net available heat, it would be expected that in house heating, oven heating, and in all such processes where the flame temperature is not of importance, each B.t.u. would perform the same quantity of useful work.

In top-burner cooking and other forms of direct heating where the flame temperature is of importance, the 495 B.t.u. gas, containing a larger percentage of hydrogen, would give a slightly greater velocity of combustion and a shorter flame. Under some conditions, with the appliance correctly adjusted for the quality of gas, a slightly greater efficiency might be secured than with the 557 B.t.u. gas.

The combustion of the two gases may be shown in a graphic form as in figure 13. One cubic foot of 495 B.t.u. gas is mixed with the amount of air required for combustion, which, in this case, is 4.17 cubic feet. This results in 5.17 cubic feet of mixture, each cubic foot of which has a heating value of 96 B.t.u. The 557 B.t.u. gas requires 4.82 cubic feet of air and gives 5.82 cubic feet of mixture, each cubic foot of which also has a heating value of 96 B.t.u.

Each cubic foot of the mixture, whether made from the 495 B.t.u. gas or the 557 B.t.u. gas, has almost exactly the same chemical characteristics, will liberate the same quantity of heat, and otherwise act in exactly the same manner, except as noted in the preceding discussion.

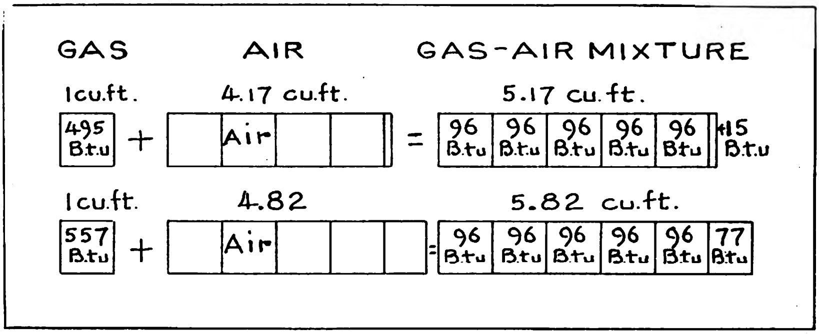


FIG. 13: Graphic representation showing the volume of air required for combustion of a 495 B.t.u. and a 557 B.t.u. gas, and the volume and heating value of the resulting gas-air mixture.

The 557 B.t.u. gas has 12.6 per cent more B.t.u. than the 495 B.t.u. gas. The 557 B.t.u. gas would give 0.65 cubic feet more of the mixture of gas and air, which is 12.6 per cent greater than the volume of mixture produced from the 495 B.t.u. gas. Judged entirely by these facts, it would be expected that the 557 B.t.u. gas would give about 12.6 per cent more useful service in the ordinary domestic appliances.

2. Relative usefulness of gases as shown by laboratory tests.

(*a*) *Scope of the laboratory tests.*

All the laboratory tests, the results of which are given in this report, were made at San Jose, where exceptionally good laboratory facilities were available. Altogether, about 250 tests were made with gases varying in quality from 500 to 600 B.t.u. Since top-burner cooking still represents the most common domestic use of gas, most of the tests were made with standard top burners, of which several types and sizes were used. Tests were also made with two sizes of automatic water heaters, and with a gas oven of standard type.

In all these tests every effort was made to adjust the appliances correctly for each condition of operation and for each quality of gas, in order to place the results of the tests on a truly comparable basis.

(*b*) *Tests with top burners.*

(1) Types and sizes of utensils used.

The efficiency of heat transfer will vary with the size and shape of the utensil, and will depend to some extent upon the material of which the vessel is made. Although no material differences were expected in the results, it was thought best to use two types of vessels in these tests. One was an aluminum kettle weighing 1.881 pounds, diameter 8¼ inches at the bottom and 8½ inches at the top, height 5½ inches. The other was a granite kettle weighing 2.453 pounds, diameter 8¼ inches at the bottom and 7½ inches at the top, height 5 inches.

(2) Types of burners used.

The variety of gas burners in use is very large, and new modifications and improvements in design appear almost every year. It would be natural to assume that certain kinds of gases would give better results with a burner especially designed for use with that gas, and this has been found to be true as a result of recent investigations by the Bureau of Standards, in which they show that burners for natural gas should have a somewhat different port area than the burners used with manufactured gas. As a practical proposition, however, it is not feasible to make a wide variety of burners to fit each individual locality; and in this investigation it was not of so much importance to know which burners would give the maximum efficiency as it was to know whether the different burners commonly used at the present time would show the same relative results when used with gases of different heating value.

Five types of burners were used in these tests. They are illustrated in figures 14 and 15. "A" is an old style slotted burner; "B" is an open star burner of the type used in the Estate range; "C" is a star disk burner used in the Clark-Jewel range; and "D" is a web disk burner used in the Eclipse range. The fifth burner is a small burner of recent design used in England, commonly referred to as the "Pleno" burner. The latter burner was included on account of the frequent statements that have appeared in the English gas journals in which it has been claimed that the newer types of burners give much higher efficiencies and are better adapted for low heating value gases.

(3) General procedure of tests.

The arrangement of the laboratory is shown in figure 16. The gas under investigation was collected in the 50-foot holder, and calorimeter test was made to obtain its heating value before starting the series. Another heating-value test was usually made at the end of the series. Gas analyses were made of each quality of the gas tested, and these are given in tables 12 and 18, together with the calculated and observed specific gravity.

The wet test meter used in all the tests was repeatedly checked with a one-tenth cubic foot bottle; a certified thermometer, reading to one-tenth of a degree, was used in all boiling tests, and a split second stop watch was used in timing all operations.

All the efficiency tests were made by determining the quantity of gas required to heat six pounds of water from 70° F. to 210° F. In order to

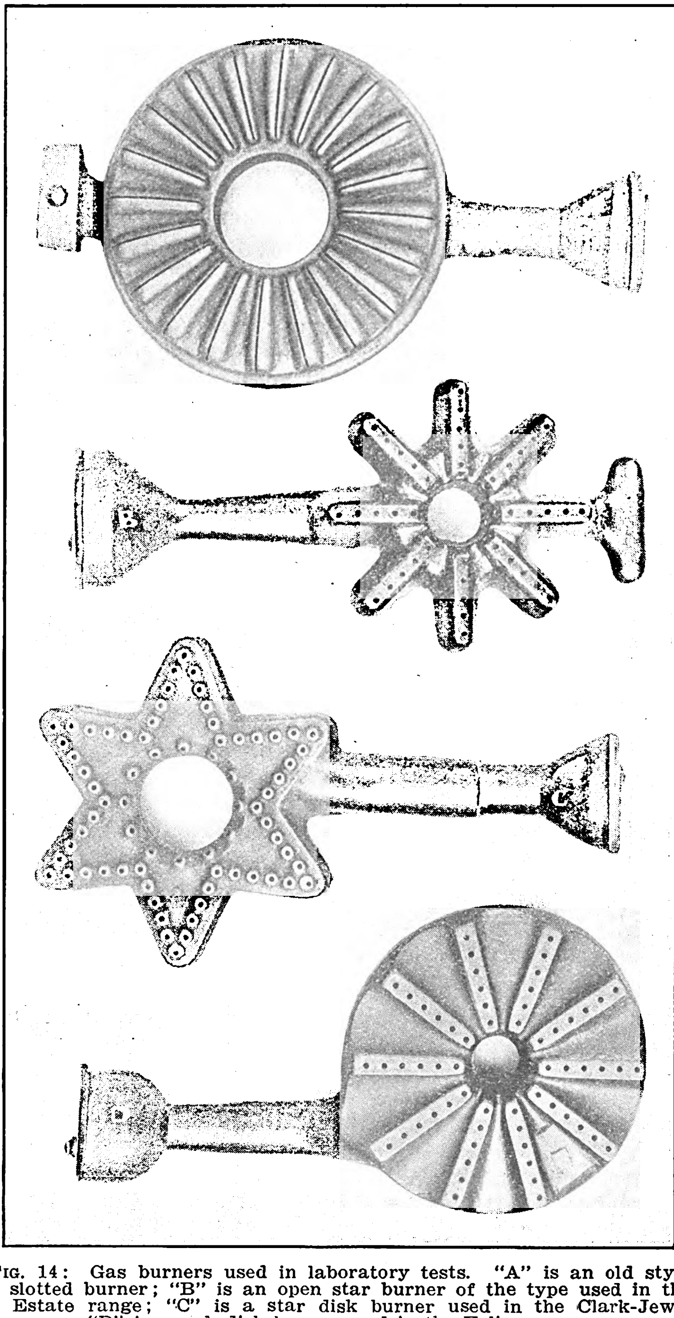


FIG. 14: Gas burners used in laboratory tests. "A" is an old style slotted burner; "B" is an open star burner of the type used in the Estate range; "C" is a star disk burner used in the Clark-Jewel range; "D" is a web disk burner used in the Eclipse range.

reproduce practical conditions as nearly as possible, the heating was continued until a definite quantity of water was evaporated. It was found, however, that the evaporation tests could be omitted without in any way changing final conclusions, and in the summaries, as shown, they are omitted for the sake of clearness.

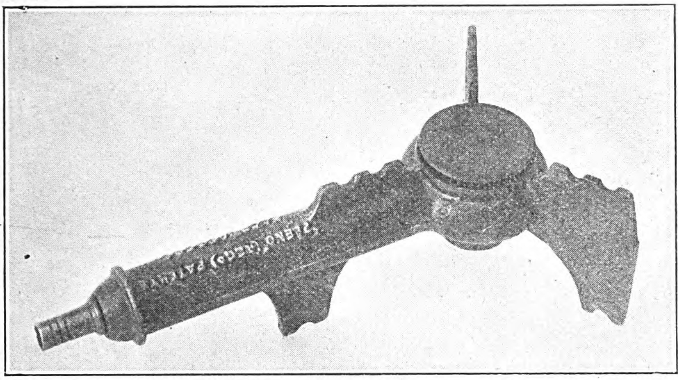


FIG. 15: Pleno or Helps burner.

No allowance was made for the heat absorbed by the utensil, and the efficiency may therefore be computed from the equation:

$$\text{Efficiency} = \frac{W \times T}{\text{B.t.u. per cu. ft.} \times V \times F}$$

where

W =Weight of water, 6 pounds in the case of the tests in this report.
T =Temperature rise of water, degrees F.
V =Uncorrected volume of gas used.
F =Correction factor, which reduces uncorrected volume to 30 inches of mercury pressure at 60° F.

TABLE NO. 12.

Average Analyses of the Gas Used During Tests With Top Burners.

Observed heating value (B.t.u.)	502	509	533	541	564	568	577	595	**615**
CO_2	3.8	4.0	3.8	3.6	5.5	4.6	5.5	2.9	**3.0**
Ill.	2.3	3.4	2.8	3.0	4.4	4.6	4.4	4.6	**5.6**
O_2	0.3	0.1	0.1	0.1	0.1	0.1	0.1	0.2	**0.3**
CO	9.0	10.9	9.7	8.9	11.9	11.4	11.1	8.2	**7.6**
H_2	46.9	50.0	48.5	48.2	44.0	37.4	42.7	48.9	**47.8**
CH_4	27.1	25.0	28.0	28.3	28.8	32.2	30.9	31.4	**31.6**
N_2	10.6	6.6	7.1	7.9	5.3	9.7	5.3	3.8	**4.1**
Per cent combustible	85.3	89.3	89.0	88.4	89.1	85.6	89.1	93.1	**92.6**
Per cent non-combustible	14.7	10.7	11.0	11.6	10.9	14.4	10.9	6.9	**7.4**
Calculated B.t.u.'s	501	518	528	532	561	576	575	595	**612**
Calculated specific gravity	.456	.438	.439	.438	.485	.525	.487	.417	**.443**
Observed specific gravity	--------	.487	--------	.421	.492	.494	.485	--------	--------
Used in tests Nos.	27-48	25-26	59-72	49-58	1-9	17-24	10-16	50-54"I"	**55-57"I"**

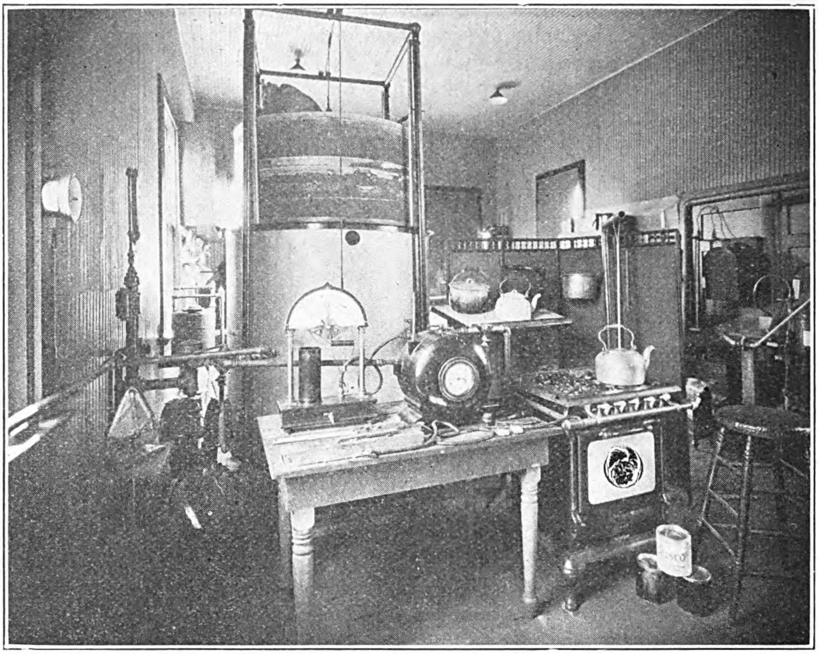


FIG. 16: Arrangement of testing equipment at San Jose laboratory.

(4) Results of top-burner tests.

(a) Tests with large disk burner and granite vessel.

The quantity of data gathered during the appliance tests is too large to be given in entirety, and only a few typical examples are shown in detail in this report. In the following table, No. 13, the results of a series of tests with the large disk burner, "D," and a granite vessel are shown. Five different heating value gases were used, varying from 509 B.t.u. to 615 B.t.u. per cubic foot. The gas rate was varied to cover all the conditions found in actual practice. These figures are plotted in figure 17 and show that the efficiency is very nearly the same with each gas. The curve is rather flat between 6000 and 12,000 B.t.u. per hour, which covers the usual range of top-burner cooking, and it makes practically no difference whether the gases are compared on the basis of B.t.u. or cubic feet per hour consumption.

TABLE NO. 13.

Efficiency Tests with 500, 540, 570, 595, 615 B.t.u. Gas.

LARGE DISK TOP BURNER.

Burner 1⅝ inches from utensil. Granite kettle.

Number of test	Heating value	Gas used	Time required to heat 6 lbs. water from 70° to 210°	Gas rate	Quantity of heat supplied	Efficiency
	Bt.u./Cu. Ft.	Cu. Ft.	Minutes	Cu. Ft./Hr.	B.t.u./Hr.	Per cent
26	509	4.296	36.28	7.10	3,614	38.41
28	503	4.125	22.32	11.09	5,578	40.46
30	503	4.046	17.66	13.75	6,916	41.28
32	503	3.958	14.30	16.60	8,350	42.19
34	496	4.086	11.72	20.92	10,376	41.44
36	500	4.129	8.92	27.77	13,885	40.68
50	541	4.217	39.83	6.35	3,435	36.82
52	541	3.775	24.03	9.43	5,102	41.13
54	541	3.720	17.57	12.70	6,871	41.74
56	541	3.783	14.52	15.63	8,456	41.04
58	541	3.754	12.24	18.40	9,954	41.36
60	536	3.843	9.16	25.17	13,491	40.78
12	579	3.757	32.73	6.89	3,989	38.61
10	579	3.663	22.90	9.59	5,553	39.60
8	563	3.614	17.89	12.12	6,824	41.28
6	564	3.576	13.74	15.62	8,810	41.65
4	563	3.548	11.57	18.40	10,359	42.05
2	562	3.670	8.90	24.74	13,904	40.73
50 "I"	595	3.42	17.51	11.72	6,973	41.2
51	595	3.44	15.06	13.70	8,150	41.0
52	595	3.41	11.32	18.07	10,750	41.4
53	595	3.52	9.18	23.00	13,685	40.1
54	595	3.68	8.75	25.12	14,946	38.4
55 "I"	615	3.40	23.41	8.71	5,356	40.1
56	615	3.39	10.85	18.74	11,525	40.2
57	615	3.44	9.28	22.24	13,776	39.7

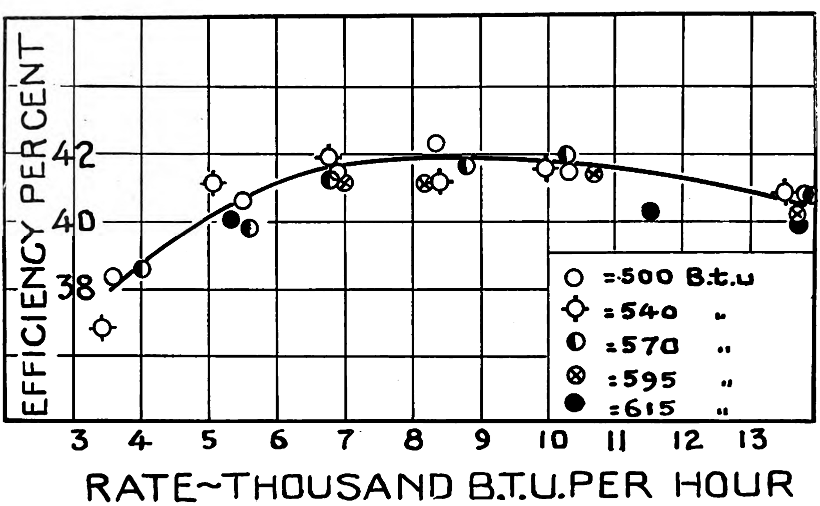


FIG. 17: Efficiency of 500, 540, 570, 595, and 615 B.t.u. gases when six pounds of water was heated from 70° to 210° F. in a large kettle with large disk top burner.

(b) Tests with large disk burner and aluminum vessel.

In similar tests, shown in Table No. 14, with the same burner, but using the aluminum vessel, the efficiency is apparently slightly less than with the granite vessel, but it appears to be remarkably constant over a wide variation in the rate of consumption. No material difference is shown in the efficiency with gases varying in heating value from 496 B.t.u. to 579 B.t.u. per cubic foot.

TABLE NO. 14.

Efficiency Tests Wi h 500, 540, 570 B.t.u. Gas.

LARGE DISK TOP BURNER.

Burner 1⅝ inches from utensil. Aluminum kettle.

Number of test	Heating value	Gas used	Time required to heat 6 lbs. water from 70° to 210°	Gas rate	Quantity of heat supplied	Efficiency
	Bt.u./Cu. Ft.	Cu. Ft.	Minutes	Cu. Ft./Hr.	B.t.u./Hr.	Per cent
25	509	4.365	37.20	7.04	3,583	37.80
27	503	4.335	23.49	11.07	5.568	38.52
29	503	4.294	18.59	13.85	6,967	38.89
31	503	4.290	15.19	16.94	8,521	38.92
33	496	4.430	12.67	20.97	10,401	38.23
35	501	4.627	9.97	27.84	13,948	36.24
49	539	4.389	39.48	6.67	3.595	35.51
51	541	3.888	24.80	9.40	5,085	39.94
53	541	4.032	19.11	12.66	6.849	38.51
55	541	3.923	14.97	15.72	8,505	39.58
57	541	3.956	12.70	18.68	10,106	39.25
59	533	4.274	10.08	25.43	13,554	36.87
11	579	3.869	33.65	6.90	3.995	37.50
9	562	3.915	24.88	9.44	5,305	38.18
7	563	3.812	18.91	12.09	6,807	39.14
5	564	3.940	15.10	15.66	8,832	37.70
3	563	3.806	12.30	18.57	10,455	39.19
1	562	4.101	9.86	24.95	14,022	36.44

(c) Tests with small disk burner and granite and aluminum vessels.

With the small disk burner, located the same distance from the vessel as in the preceding tests, the efficiency is a little higher than with the larger burner (see tables 15 and 16, and figure 18). This would be expected from the fact that the heat is more concentrated under the center of the vessel. The relative efficiency of the low and high heating value gas is, however, practically the same as in the tests with the larger vessel.

TABLE NO. 15.

Efficiency Tests With 500, 540, 570 B.t.u. Gas.

SMALL DISK TOP BURNER.
Burner located 1⅝ inches from utensil. Granite kettle.

Number of test	Heating value	Gas used	Time required to heat 6 lbs. water from 70° to 210°	Gas rate	Quantity of heat supplied	Efficiency
	Bt.u./Cu. Ft.	Cu. Ft.	Minutes	Cu. Ft./Hr.	B.t.u./Hr.	Per cent
48	498	3.846	32.80	7.03	3,501	43.86
46	492	3.818	25.40	9.01	4,433	44.72
44	495	3.750	19.92	11.29	5,586	45.00
42	497	3.720	16.32	13.67	6,794	45.42
40	512	3.560	12.96	16.48	8,438	44.94
38	505	3.540	10.81	19.65	9,923	46.98
72	537	3.615	35.52	6.10	3,276	43.27
70	537	3.538	24.20	8.77	4,710	44.21
68	533	3.213	19.30	10.00	5,330	48.90
66	535	3.424	15.49	13.26	7,094	45.85
64	537	3.333	13.59	14.71	7,900	46.92
62	539	3.350	11.76	17.00	9,163	46.51
14	578	3.373	35.74	5.66	3,271	43.07
16	577	3.234	24.92	7.80	4,500	45.01
18	570	3.336	20.03	10.00	5,700	43.65
20	569	3.196	15.82	12.12	6,896	46.19
22	568	3.243	13.86	14.04	7,975	45.65
24	569	3.231	11.84	16.37	9,315	45.95

TABLE NO. 16.

Efficiency Tests With 500, 540, 570 B.t.u. Gas.

SMALL DISK TOP BURNER.
Burner located 1⅝ inches from utensil. Aluminum kettle.

Number of test	Heating value	Gas used	Time required to heat 6 lbs. water from 70° to 210°	Gas rate	Quantity of heat supplied	Efficiency
	Bt.u./Cu. Ft.	Cu. Ft.	Minutes	Cu. Ft./Hr.	B.t.u./Hr.	Per cent
47	498	3.899	33.82	6.91	3,441	43.25
45	493	3.945	26.17	9.04	4,457	43.18
43	497	3.826	20.30	11.30	5,616	43.77
41	497	3.862	17.29	13.45	6,685	43.77
39	509	3.707	13.47	16.51	8,404	44.41
37	502	3.824	11.86	19.34	9,708	43.75
71	537	3.745	36.75	6.11	3,281	41.77
69	537	3.640	24.31	8.98	4,822	42.96
67	534	3.512	19.48	10.81	5,773	44.89
65	537	3.504	15.82	13.29	7,137	44.63
63	538	3.473	14.15	14.72	7,919	44.43
61	540	3.611	12.62	17.17	9,272	43.07
13	578	3.373	34.58	5.85	3,381	43.08
15	577	3.402	25.60	7.97	4,599	42.79
17	570	3.360	20.22	9.97	5,683	43.86
19	569	3.390	16.66	12.21	6,948	43.54
21	568	3.377	14.39	14.08	7,997	43.79
23	569	3.522	12.92	16.35	9,303	41.91

(d) Tests with small disk burner "E" and granite kettle.

Gas ranges used in England are generally equipped with much smaller burners than the ranges used in this country. The small burner, "E," which was secured for these tests, represents a type used in certain localities in England, where low heating-value gas is supplied. The high efficiency secured with this burner is due to the concentration of the flame directly under the center of the utensil, which allows the products of combustion a maximum time of contact with the utensil. The type of flame secured with this burner also makes it possible to place the burner very close to the vessel, and this results in higher efficiency. It is not

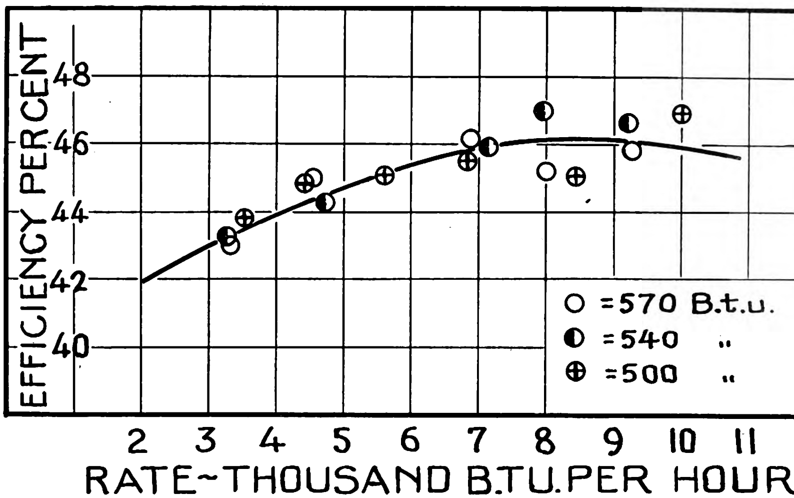


FIG. 18: Efficiency of 500, 540, and 570 B.t.u. gases when six pounds of water was heated from 70° to 210° F. in a granite kettle with small disk burner.

certain, however, that this burner would give satisfactory service under our conditions—certainly not without some modifications from its present design.

In the two series of tests shown here, the quality of gas was nearly the same, but the indications are that the efficiency secured with this burner would be practically the same, irrespective of the heating value.

TABLE NO. 17.

SMALL DISK "PLENO" BURNER.

Granite kettle placed ¼-inch above burner.

Number of test	Heating value	Time required to heat 6 lbs. water from 70° to 210°	Quantity of heat supplied	Efficiency
	B.t.u./Cu. Ft.	Minutes	B.t.u./Hr.	Per cent
1	520	9.53	9,570	55.3
2	520	10.88	8,050	57.3
3	520	12.83	6,760	57.9
4	520	15.57	5,725	58.3
5	520	20.95	4,140	58.2
6	520	30.72	2,882	56.3
1	547	9.32	9,827	55.0
2	547	10.40	8,566	56.9
3	547	12.08	7.220	58.3
4	547	15.02	5,683	59.0
5	547	20.07	4,212	59.4
6	547	28.92	2,978	58.5

(e) Tests of 524 and 526 B.t.u. gas containing a large percentage of inerts.

During the war period many of the gas companies, especially those making coal gas, found it necessary, on account of the poor quality of fuels available, to make material reductions in heating value. These reductions in heating value usually resulted in a considerable increase in the percentage of inerts in the gas. There has been considerable discussion regarding the effect of these inerts on the quality of the service, and some legislation has been proposed which would limit the quality of inerts which a company may be allowed to introduce.

In connection with this investigation, it was thought to be of some interest to make a few efficiency tests with a gas containing a high percentage of inerts, since it was probable that these same questions might come up in connection with the oil gas production and distribution.

The analysis of the gas and the results of the tests are given in the following tables. No reduction in efficiency is apparent from these figures compared with the previous figures for the same burner and vessel when using gases containing normal amounts of inerts. No special difficulty was experienced in operating the burners, although the flame showed some tendency to leave the ports, making it necessary to operate the burner with the air shutter closed.

TABLE NO. 18.

Analyses of Gas with High Percentage of Inerts.

Top-burner Tests.

Observed heating value (B.t.u)	524	526
CO_2	3.7	3.3
C_nH_{2n}	5.1	4.9
O_2	0.2	0.1
CO	6.8	7.0
CH_4	25.0	26.0
H_2	41.9	43.3
N_2	17.3	15.4
Specific gravity	.517	.497
Per cent non-combustible	21.2	18.8
Per cent combustible	78.8	81.2

TABLE NO. 19.

Efficiency Tests With 524 and 526 B.t.u. Gas with High Percentage of Inerts.

LARGE DISK TOP BURNER.

Burner located 1⅝ inches from utensil.

Number of test	Heating value	Gas used	Time required to heat 6 lbs. water from 70° to 210°	Gas rate	Quantity of heat supplied	Efficiency
	Bt.u./Cu. Ft.	Cu. Ft.	Minutes	Cu. Ft./Hr.	B.t.u./Hr.	Per cent
25	524	3.97	12.08	19.70	10,300	40.4
26	524	3.90	11.95	19.60	10,270	41.1
27	524	3.91	12.04	19.50	10,200	41.0
28	524	3.90	12.12	19.30	10,100	41.1
29	524	3.89	12.24	19.00	9,950	41.2
30	526	3.90	11.83	19.75	10,380	40.9
31	526	3.85	11.69	19.80	10,400	41.3
32	526	3.85	11.72	19.70	10,360	41.3
33	526	3.86	11.87	19.50	10,250	41.3
34	526	3.81	11.87	19.30	10,150	41.7
35	526	3.78	11.95	19.00	10,000	42.1

(*c*) *Water-heater tests.*

It would, of course, be expected that any tests of the thermal efficiency of different gases made with the common type of coil heater would show the same relative value as that found with the standard calorimeter, since the calorimeter is but a water heater of high efficiency. Notwithstanding this view, it was considered advisable to proceed with a series of experiments to determine whether or not the heaters gave as good results with one kind of gas as another, considering both the thermal efficiency and generally satisfactory operation.

All tests, a few of wlch are shown, were made with No. 1½ and No. 4 Ruud instantaneous automatic heaters. This type of heater is so well known that it needs no description. The heater was set up (Fig. 19), connected to cold water and gas supply, and thermometers were installed on inlet and outlet water connections, gas supply, and flue. A three-way cock was installed on the hot water outlet, which allowed the water to flow either to the drain or to a tank on a platform scale, where the water collected during a test was weighed.

A glass tube was installed in the flue, so that samples of the flue gases could be collected, and these were taken at different periods during the tests. The thermostatic cutoff was disconnected during the test so that a constant gas flow could be maintained without interference. All gas used was measured with a 20-light wet meter that had been carefully calibrated and found accurate to within one-tenth of one per cent.

After the heater had been started and the thermal conditions had become constant, a stop watch was started, the meter reading taken, and and at the same instant the water was diverted from the drain to a weighing tank on the scales, the tare of which had been obtained before beginning the test. Further observations were taken at one-minute intervals of the meter readings, the temperature of the gas, the inlet and outlet water, and the flue gas. The room temperature and the gas pressure at the meter were taken two or three times during each test period.

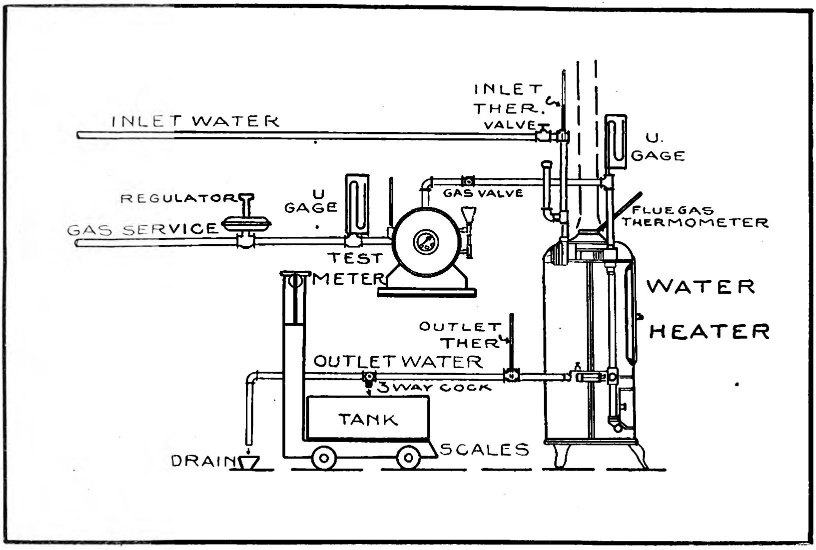


FIG. 19: Arrangement of test apparatus used in efficiency test of instantaneous water heater.

The results of a series of tests with the No. 1½ Ruud heater are shown in the following table.

TABLE NO. 20.

Efficiency Tests With No. 1½ Ruud Cottage Water Heater.
San Jose—June, 1922.

Data	Test No. 6	Test No. 5	Test No. 29	Test No. 28
1. Heating value of gas (B.t.u.)	498	507	556	564
2. Volume of gas used per hour (cubic feet)	94.4	83.2	74.7	85.8
3. Total volume of gas used (cubic feet)	23.61	27.70	31.12	28.94
4. Total heat in gas used (B.t.u.)	11,800	14,034	17,300	16,300
5. Weight of water heated (pounds)	136.31	149.69	182.13	173.25
6. Total heat in water (B.t.u.)	9,514	11,000	13,620	12,890
7. Efficiency	80.8	78.5	78.8	79.2

The average of tests 5 and 6 shows about 0.6 per cent higher efficiency than the average of Nos. 28 and 29, but since this is within the limits of accuracy for a test of this character, the small variation in results has no particular significance.

In Table No. 21 are given typical results of tests with a No. 4 Ruud heater. The results in this case show less variation than in the preceding series with the smaller heater. In this case the results with the higher quality of gas are somewhat better, the average of Tests Nos. 21 and 23 being 0.7 per cent higher than the average of Nos. 12 and 10, whereas in the preceding series the difference in favor of the lower quality of gas was 0.6 per cent.

TABLE NO. 21.

Efficiency Tests With No. 4 Ruud Cottage Water Heater.
San Jose—June, 1922.

Data	Test No. 12	Test No. 10	Test No. 21	Test No. 23
1. Heating value of gas (B.t.u.)	495	516	563	566
2. Volume of gas used per hour (cubic feet)	236.1	198.1	198.0	115.5
3. Total volume of gas used (cubic feet)	31.53	33.02	29.72	28.89
4. Total heat in gas used (B.t.u.)	15,600	17,100	16,710	16,330
5. Weight of water heated (pounds)	180.88	186.88	193.25	183.87
6. Total heat in water (B.t.u.)	12,680	13,840	13,710	13,375
7. Efficiency	81.4	81.0	82.0	81.8

The results of the tests made with the water heaters are even more conclusive than those made with top burners, for the reason that larger quantities of gas were used, and there was less likelihood of error in the observations. Within the range of heating value tested—from 495 B.t.u. to 565 B.t.u.—no essential difference could be discovered in the efficiency of the lower and the higher heating value gas, and no operating difficulties were experienced with either quality.

(*d*) *Oven tests.*

In gas-oven baking or heating the oven is heated to some extent by radiation from the hot oven bottom, but to a larger degree by the hot products of combustion and air, which, in the ordinary type of oven, circulate through the oven. A comparatively small percentage of the heat supplied to an oven is absorbed by the food; most of it is radiated through the walls of the oven and escapes through the flue in the products of combustion and the excess air with which the products are diluted. The temperature of the products of combustion is necessarily always above the minimum temperature in any portion of the oven, and there is a large and unavoidable loss of heat. Since the heat losses through the vent represent by far the largest source of heat loss, it would be expected that all commercial gases producing approximately the same volume of products per unit of heat liberated would give about the same results in an oven.

In the following tests an oven (see Fig. 20) was equipped with a temperature regulator that automatically maintained the temperature at a constant value. A small copper coil through which a stream of water was circulated was placed in the oven, and the rise in temperature of the water and the weight of water was measured. The heat absorbed through the coil may be considered as the heat that would be absorbed by the food. The total heat recovered in the water may be larger or smaller than would be found in actual cooking, depending entirely upon the amount of food in the oven. Actual results from actual cooking tests should show, however, the same relative usefulness between gases of different heating value as found by the method used in these tests.

The following table, No. 22, gives the analyses of the different gases used in the oven tests, while Table No. 23 gives the results of the tests. The tests with each heating value represent one hour's run. The temperature of the water was observed at frequent intervals, and the quantity of water heater was weighed at the end of each ten-minute period, The ratio of heat supplied to heat absorbed by the water in the coil is very constant for the whole six series of tests and demonstrates that for gases having similar chemical properties the consumption in cubic feet per hour is of comparatively little significance in oven heating, the important factor being the rate at which heat is supplied in B.t.u. per hour.

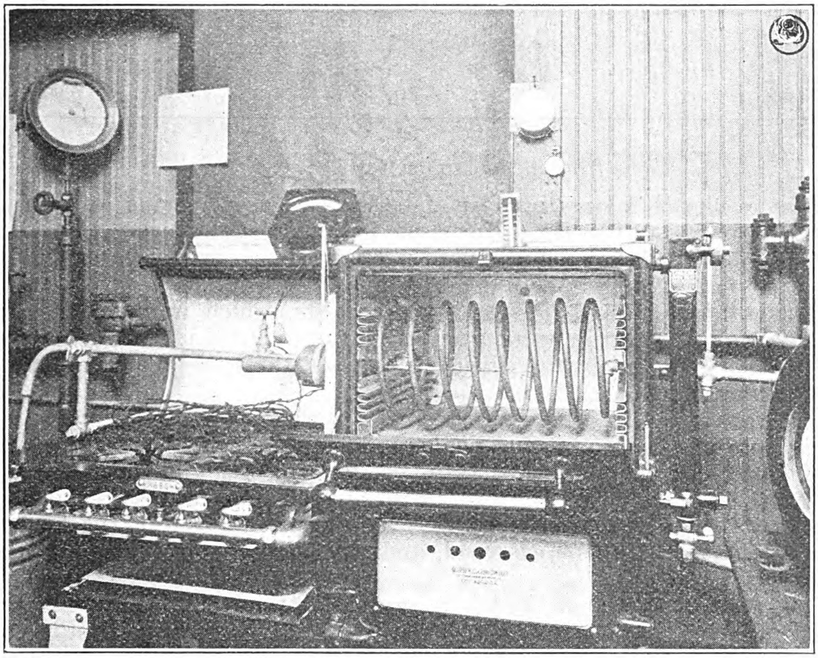


FIG. 20: Arrangement of apparatus used in oven tests.

TABLE NO. 22.

Analyses of Gases Used in Oven Tests.

Heating value (B.t.u. per cubic foot)	519	535	540	556	561	596
Constituents:	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
CO_2	3.0	3.1	3.1	3.4	3.4	1.8
Illuminants	2.5	2.9	3.0	3.2	3.5	3.7
O_2	0.1	0.1	0.1	0.2	0.1	0.2
CO	11.9	10.9	11.4	10.6	10.1	9.2
CH_4	24.0	25.2	25.2	27.2	26.5	29.4
H_2	53.8	53.2	53.5	52.9	53.2	52.6
N_2	4.7	4.6	2.7	2.5	3.2	3.1
Specific gravity (calculated)	.402	.402	.400	.400	.400	.384

TABLE NO. 23.

Summary of Oven Tests.

Heating value of gas (B.t.u./Cu. Ft.)	Water heated			Gas used		Ratio heat supplied to heat absorbed by water
	Temperature rise (Deg. F.)	Weight (pounds)	B.t.u. absorbed	Cubic feet	Heat supplied (B.t.u.)	
519	19.9	120.37	2,396	27.52	14,282	16.8
535	18.5	117.75	2,185	25.86	13,835	15.8
540	11.9	186.43	2,217	25.44	13,738	16.1
556	14.4	145.13	2,091	23.30	12,954	16.1
561	14.6	150.68	2,195	24.02	13,475	16.3
595	12.5	171.47	2,151	22.52	13,421	16.0

(*e*) *Conclusions from all laboratory tests.*

The results of a large number of tests with gases varying in heating value from 520 to 615 B.t.u. per cubic foot showed that when the same type of burner and vessel was used it required approximately the same number of heat units to do a definite amount of work.

From the results of the water-heater tests, which were made with gases ranging in heating value from 495 B.t.u. to 565 B.t.u., no difference could be discovered in the efficiency between the lower and the higher heating-value gas.

In the oven tests, where an automatic thermostatic device regulated the gas applied to the oven and kept it at a constant temperature, it was found that the number of B.t.u. required to maintain this temperature was approximately the same, irrespective of the heating value of the gas or its composition. Considering the nature of the test, the figures are as close as could be expected, and will allow of no other interpretation.

The conslusion from all the laboratory tests is that the present domestic appliances used in cooking, water heating, and oven heating, if properly adjusted for each kind of gas, will require approximately the same number of B.t.u. for the same amount of work. In other words, the reduction in the volume of gas used is proportional to any increase in the heating value of the gas supplied.

3. Variation in consumption as shown by consumers' meters.

(*a*) *Variables affecting consumers' use of gas.*

The consumers' use of gases of different heating values should be a definite measure of their relative usefulness. In general it has been shown by past experience in California that, with the introduction of natural gas into cities formerly supplied with manufactured gas, the reduction in consumption was almost always approximately in the ratio of the increase in the heating value. The statistics from Canada, some of the eastern cities, and the State of Washington, where considerable reduction has been made in the heating value, do not always show the results that might be expected, and this has resulted in considerable discussion as to the variables that influence the consumption of gas. Some of the most outstanding factors that may influence gas consumption are the following:

1. Seasonal variations due to use of gas for house heating and water heating.
2. Seasonal variations due to the shifting of the population to and from the cities.
3. Changes in economic conditions within the community.
4. Adjustments in gas rates.
5. Changes in the heating value of the gas.
6. Changes in the gas pressure.
7. Changes in specific gravity of gas.
8. Changes in the adjustment of appliances.

The variation in consumption due to economic conditions is an important factor in many localities. The economic conditions within a community will also result in a movement of the population to and from the cities, which is separate from the seasonal fluctuations.

An increase in gas rates is an important factor influencing consumption. This is well illustrated all through the natural gas districts where, with the increase in gas rates, much attention is being given to greater efficiency in utilization. In every case where increases in gas rates are made, it is certain that many consumers will attempt to economize in the use of gas.

A change in gas pressure or a change in the specific gravity of gas will vary the gas consumption to a marked degree, since it will take some time for the consumer to become accustomed to operating the appliances under the new conditions. The proper adjustment of appliances also has a material influence on consumption, since a correct adjustment for gas and air will give a higher efficiency than a flame that is not properly adjusted.

In the Pacific coast cities the most important of these variables is the change in consumption resulting from a change in temperature. This is due to the extensive use of gas for house heating. In this investigation it was found that the other influences were small and their effect could generally be estimated.

Careful records were kept of the send-out per consumer at both the San Jose and the Santa Barbara plants, and the average daily send-out per consumer per week was determined, together with the average temperature as recorded at the Weather Bureau in the two cities. A record was also kept of the gas used by 200 selected consumers. Adjustment of consumers' appliances was not found possible with change of gas quality, owing to the cost of making so large a number of adjustments. These were made, however, by the company's regular employees wherever complaints of poor service were received.

(*b*) *San Jose sales.*

Records of the weekly plant send-out, heat content of gas, and number of consumers were kept, and records of the average temperature at 6 a. m., 12 m. and 6 p. m. were obtained from the Weather Bureau records at San Jose. These three temperatures were averaged and used as the average temperature for the day.

The following tabulation, Table No. 24, shows the above mentioned data for each week beginning with July, 1920, and ending with December 1921.

TABLE NO. 24.

Weekly and Average Daily Consumption.

San Jose, California.

Week ending	Send-out, M cu. ft.	Total consumers	Average B.t.u.	Average temperature	Send-out per consumer per day	
					Cu. ft.	M B.t.u.
1920						
July 3	983	11,116	578	64.9	88.4	51.1
10	923	11,137	570	65.4	82.9	47.3
17	970	11,169	572	63.5	86.8	49.7
24	972	11,189	572	65.4	86.9	49.7
31	982	11,205	566	66.0	87.6	49.6
Aug. 7	955	11,227	577	69.2	85.0	49.1
14	921	11,250	577	72.5	81.9	47.3
21	976	11,271	570	69.2	86.6	49.4
28	1,027	11,293	570	64.9	91.0	51.8
Sept. 4	1,012	11,313	567	68.0	89.5	50.7
11	1,020	11,339	572	61.2	90.0	51.5
18	1,037	11,356	565	67.2	91.2	51.5
25	1,083	11,378	575	60.5	95.3	54.8
Oct. 2	1,104	11,401	569	63.3	96.9	55.1
9	1,245	11,423	529	59.9	108.9	57.6
16	1,272	11,445	530	57.7	111.1	58.9
23	1,330	11,470	533	55.8	116.1	61.9
30	1,294	11,500	532	58.3	112.6	59.9
Nov. 6	1,406	11,529	533	52.0	122.0	65.0
13	1,404	11,559	503	52.7	121.6	61.1
20	1,311	11,585	529	57.6	113.2	59.9
27	1,395	11,604	532	53.5	120.2	64.0
Dec. 4	1,438	11,624	537	50.5	123.8	66.5
11	1,525	11,643	536	49.2	131.0	70.2
18	1,568	11,660	539	47.7	134.5	72.5
25	1,573	11,672	529	47.8	134.9	71.4
1921						
Jan. 1	1,494	11,681	540	49.8	127.8	69.1
8	1,531	11,693	537	48.6	131.1	70.4
15	1,619	11,705	563	45.0	138.1	77.7
22	1,557	11,710	547	47.5	132.9	72.7
29	1,580	11,713	534	50.3	128.1	68.4
Feb. 5	1,466	11 718	559	50.3	125.1	69.9
12	1,482	11,725	511	51.4	126.5	64.6
19	1,586	11,743	503	46.7	135.0	67.9
26	1,482	11,768	500	53.2	126.1	63.1
Mar. 5	1,397	11,796	512	55.4	118.3	60.6
12	1,428	11,826	515	52.8	120.7	62.1
19	1,329	11,856	537	55.3	112.0	60.1
26	1,319	11,887	553	53.5	110.9	61.4
Apr. 2	1,238	11,918	531	57.2	103.7	55.0
9	1,293	11,948	546	51.2	108.2	59.1
16	1,312	11,975	553	51.2	109.5	60.5
23	1,274	11,992	525	56.8	106.3	55.8
30	1,101	12,008	592	62.1	91.7	54.3
May 7	1,191	12,037	583	53.1	99.0	57.8
14	1,162	12,038	563	58.9	96.6	54.4
21	1,174	12,058	559	56.1	97.4	54.4
28	1,126	12,080	559	62.0	93.3	52.1
June 4	1,154	12,102	566	58.1	95.3	53.9
11	1,074	12,116	562	68.6	88.6	49.8
18	1,150	12,130	546	51.5	94.8	51.8
25	1,048	12,141	551	71.3	86.3	47.5
July 2	1,086	12,152	549	67.8	89.4	49.0
9	914	12,166	547	77.5	75.2	41.2
16	1,044	12,176	551	65.8	85.8	47.2
23	1,110	12,186	535	65.3	91.1	48.7
30	1,137	12,198	533	64.4	93.2	49.7
Aug. 6	1,097	12,212	533	68.1	89.8	47.9
13	1,133	12,233	542	64.3	92.7	50.2
20	1,119	12,271	548	66.1	91.3	50.0
27	1,175	12,333	520	64.0	95.3	49.6
Sept. 3	1,162	12,391	507	63.6	94.0	47.6
10	1,139	12,435	503	66.7	91.5	46.0
17	1,262	12,473	525	58.9	101.4	53.3
24	1,238	12,519	520	64.9	98.6	51.2
Oct. 1	1,194	12,575	520	68.8	95.0	49.6

TABLE NO. 24—Concluded.

Weekly and Average Daily Consumption.

San Jose, California.

Week ending	Send-out, M cu. ft.	Total consumers	Average B.t.u.	Average temperature	Send-out per consumer per day	
					Cu. ft.	M B.t.u.
1921—Continued						
Oct. 8	1,271	12,607	508	62.8	100.8	51.3
15	1,289	12,634	506	63.1	102.0	51.6
22	1,301	12,664	505	62.4	102.9	51.9
29	1,393	12,698	514	56.5	109.8	56.4
Nov. 5	1,393	13,293	534	61.0	105.0	56.0
12	1,391	13,546	546	57.9	102.8	56.1
19	1,579	13,573	538	49.4	116.5	62.7
26	1,565	13,592	538	53.5	115.2	62.0
Dec. 3	1,519	13,608	537	54.7	111.5	59.9
10	1,704	13,627	531	47.3	125.0	66.3
17	1,684	13,648	543	47.9	123.3	67.0
24	1,669	13,667	534	49.4	122.1	65.3
31	1,498	13,684	532	54.4	109.5	58.3

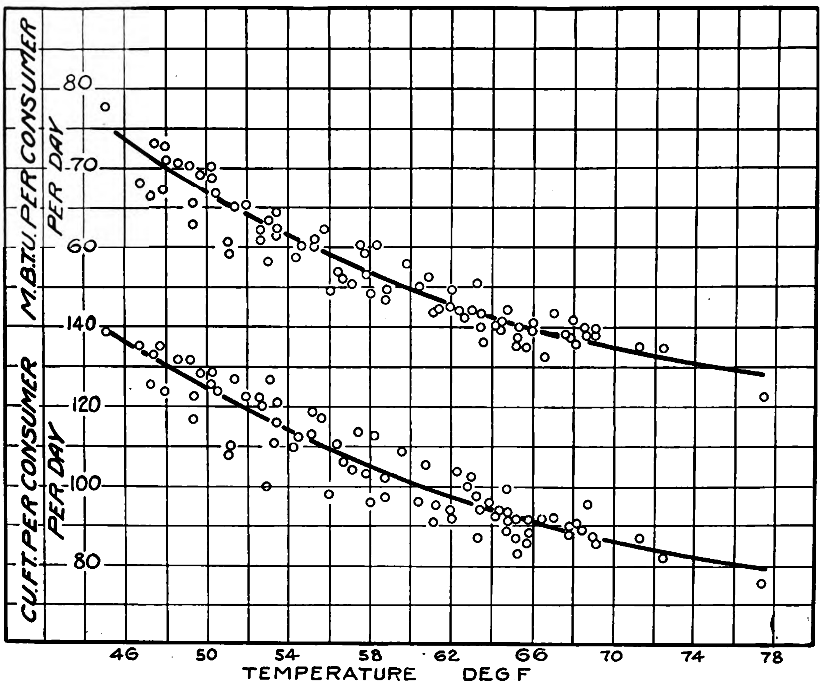


FIG. 21: Curves showing the variation of weekly send-out per consumer with a change in the mean daily temperature at San Jose.

The average daily send-out per consumer in cubic feet and in B.t.u. was plotted as a function of the mean of the three temperatures. The results of these are shown in figure 21. From this figure it is apparent that the gas used per consumer bears a fairly definite relation to the mean temperature.

The analysis of the data relative to consumers' use of gas with heat content of different qualities was made as follows:

A master curve sheet on heavy paper was prepared, showing all mean daily send-outs as ordinates, and mean weekly temperatures as abscissas. Each point was marked with its appropriate symbol and its number in the table—the symbols indicating whether the gas quality exceeded 550 B.t.u., was between 550 and 530, or was 530 or less. From this master curve sheet, different groups of points were transferred to other sheets. Thus the points for different classifications of quality of gas were separated on different charts as follows:

Chart 1—All points July, 1920, to December, 1921.
Chart 2—All points over 550 B.t.u.
Chart 3—All points 531-550 B.t.u.
Chart 4—All points 530 B.t.u. and under.
Chart 5—Points 1-14, July to September, 1920, inclusive.
Chart 6—Points 15-27, October to December, 1920, inclusive.
Chart 7—Points 43-57, April 15 to July 31, 1921, inclusive.
Chart 8—Points 62-70, Inerts September and October, 1921.
Chart 9—Points 53-60, 71-79, July, August, November, and December, 1921.
Chart 10—Points 65-70, Inerts after pressure was increased.

Five copies of each of the above ten charts were made: one on onion-skin coordinate paper, the points numbered and marked, to be retained as an original; and four copies with points unidentified and marked only with the chart and copy number. A set of ten charts was then sent to four individuals, who were requested to plot uniform curves to represent the loci of the points marked. The four separate curves of each chart were then plotted on the respective original charts and an average curve determined. The curves on the figures 22, 23, 24, 25, and 26 were prepared by this method. It was thought that by this means the personal equation was eliminated and a more accurate result obtained.

Figure 22 sets forth two curves which show the variation in the B.t.u. and cubic-foot consumption of gas with change of temperature. Curve 9 covers the period of July, August, November, and December, 1921, when the average quality of gas was 539 B.t.u. per cubic foot. Curve 10 covers the months of September and October, 1921, when inerts were introduced into the gas, the average B.t.u. being 512 per cubic foot. This curve was determined from records during the period after pressure had been increased to give satisfactory service. This chart shows that a 6.7 per cent increase in cubic-foot consumption resulted from the reduction of 5.4. per cent in the quality of the gas. There was an increase of 2½ per cent in the consumption in B.t.u. per consumer.

In figure 23 is shown a comparison of curves 5, 6, and 9. Curve 5 covers the months of July, August, and September, 1920, when the average quality was 571 B.t.u. Curve 6 covers October, November, and December, 1920, when the average quality was 531 B.t.u. Curve 9 has been described in the preceding figure.

It is to be noted by comparing 5 and 6 that apparently there was an increase in the consumption in B.t.u., as well as in cubic feet per consumer, with the reduction in quality of gas. Reference to curves 5 and 6 will indicate, however, that the trend of the two curves might easily have been changed had the higher quality continued beyond October 1,

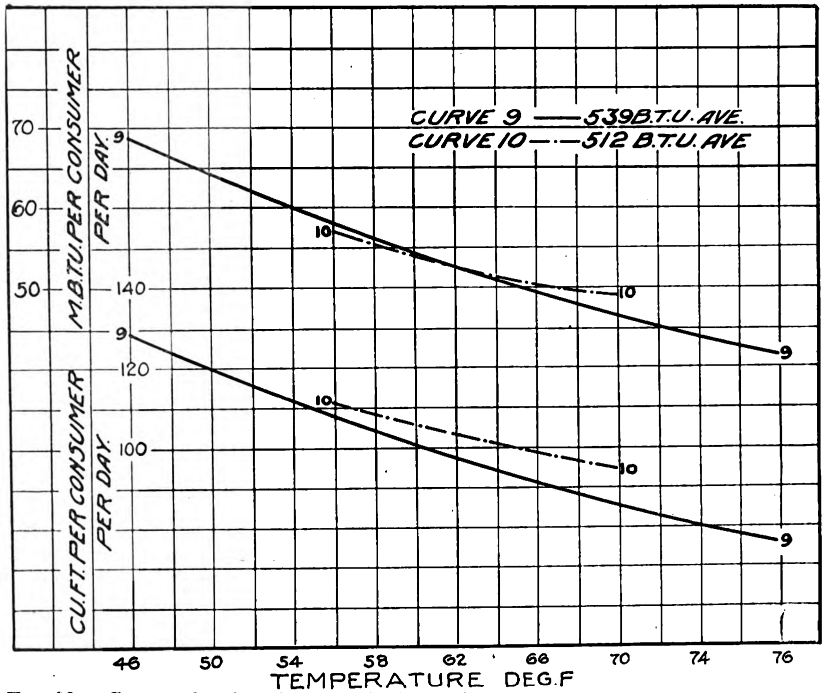


FIG. 22: Curves showing the variation in daily consumption of two heating-value gases, with a change in the mean daily atmospheric temperature at San Jose.

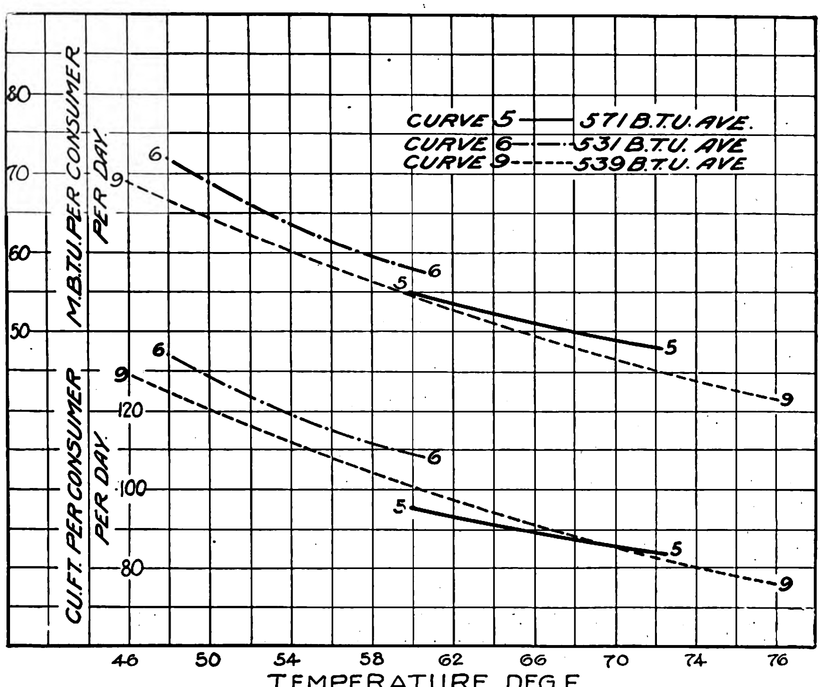


FIG. 23: Curves showing variation in gas consumption with change in atmospheric temperature when gases of 571, 531, and 539 B.t.u. per cubic foot were supplied at San Jose.

1920, or the lower quality commenced earlier. Curve 9, as compared with 6, tends to indicate reduction in the use of gas during the fall of 1921, as compared with the fall of 1920. This may have been caused by increased efficiency or an economic depression. If it was increased efficiency, it can only be explained by the assumption that with the continued use of a lower quality of gas the efficiency of the use of the gas increased without the adjustment or change of appliances. Reference

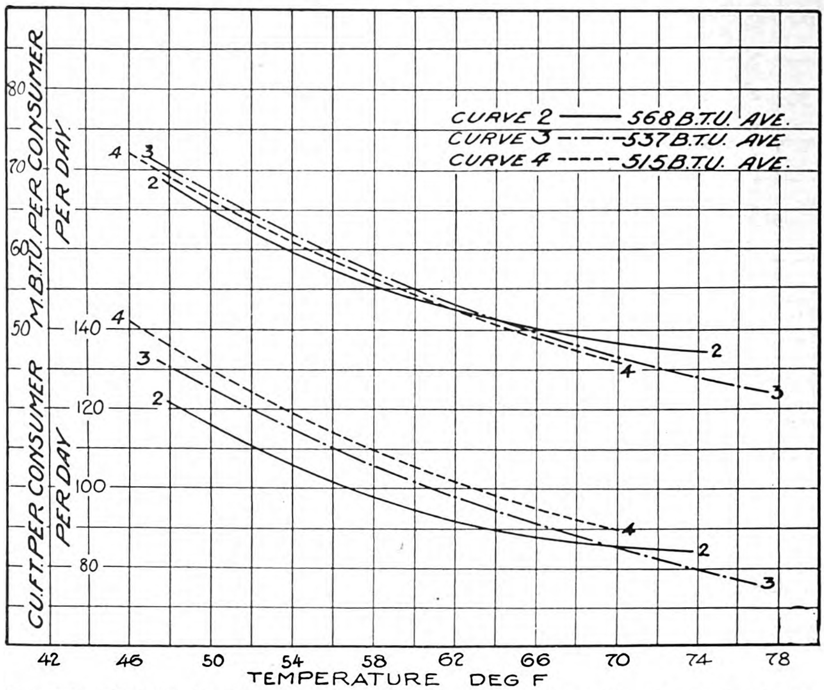


FIG. 24: Curves showing variation in gas consumption with change in atmospheric temperature when gases averaging 568, 537, and 515 B.t.u. per cubic foot were supplied in San Jose, during the period from July, 1920, to December, 1921.

to the comparison of gas send-out and sales in Fresno and San Jose, set forth herein, shows quite conclusively that an economic depression, which affected the use of gas, did occur, the exact amount of which it is difficult to definitely determine. This reduction of use would modify conclusions based on a comparison of use in the same months of different years.

Figure 24 presents three curves showing the variation in gas consumption in San Jose, with a change in atmospheric temperature, for the period from July, 1920, to December, 1921.

Curve 2 was made up of weekly averages when the heating value was rather high—the average of all these weeks being 560 B.t.u. In curve 3, the average of the numerous weekly send-outs is 537 B t u., and in curve 4, the average is 515 B.t.u.

The lower part of curve 2 was determined by the tests of July, August, and September, 1920, while the lower part of curve 3 was dominated by tests during June, July, and August, 1921. The variation in consumption in these two periods might have been due to an economic depression.

All the tests on which curve 4 is based were made during the months of February and March, September and October, 1921, and a slight economic depression during this period may have influenced this curve.

The upper section of curve 3 was influenced by the two months of November and December, 1920, but the predominance of points occurred during the winter preceding, when there were at least twice as many weeks of test. This possibly explains the higher tendency of the curve, as far as the send-out in B.t.u. is concerned.

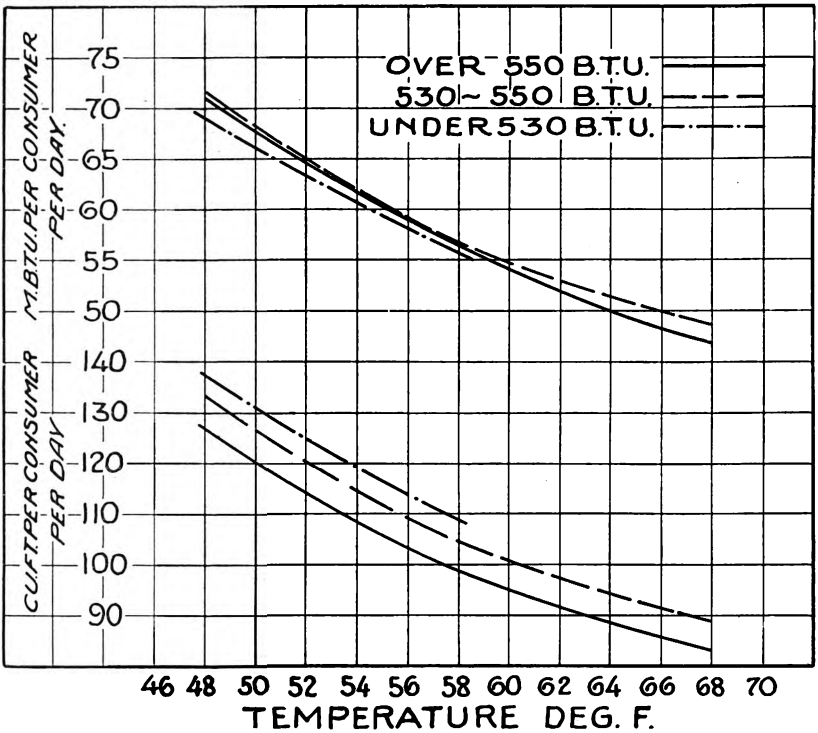


FIG. 25: Curves showing the variation in gas consumption with change in atmospheric temperature for gases of different heating value supplied in San Jose, for the period from July, 1920, to July, 1921.

Figure 25 shows the variation of weekly send-outs per consumer with changes in atmospheric temperature. One curve covers a period during which the heating value of the gas was over 550 B.t.u.; another curve covers a period when the gas was between 530 and 550 B.t.u.; and the third curve covers a period when less than 530 B.t.u. was supplied. These three curves cover the first 12 months of tests at San Jose and are also embodied in figure 24.

Figure 26 includes curve 1, which is determined from all the test data. Chart 6-A was plotted from the points representing weekly use from January 1, 1921, to April 23, 1921. During this period the quality of gas averaged 533 B.t.u., although in part of the period there was a much lower B.t.u. gas supplied. This curve, as will be noted, follows closely curve 1.

Curve 7 represents tests from April 15 to July 31. At the start of that period the main generator at San Jose was shut down and the Western generators were put into operation. For several weeks following, it was impossible to keep the quality of gas down to a 533 B.t.u. basis. The gas made was typical of the straight type of generator, having relatively low specific gravity for the quality of gas made. The left-hand part of curve 7 is dominated by the high B.t.u. gas supplied during

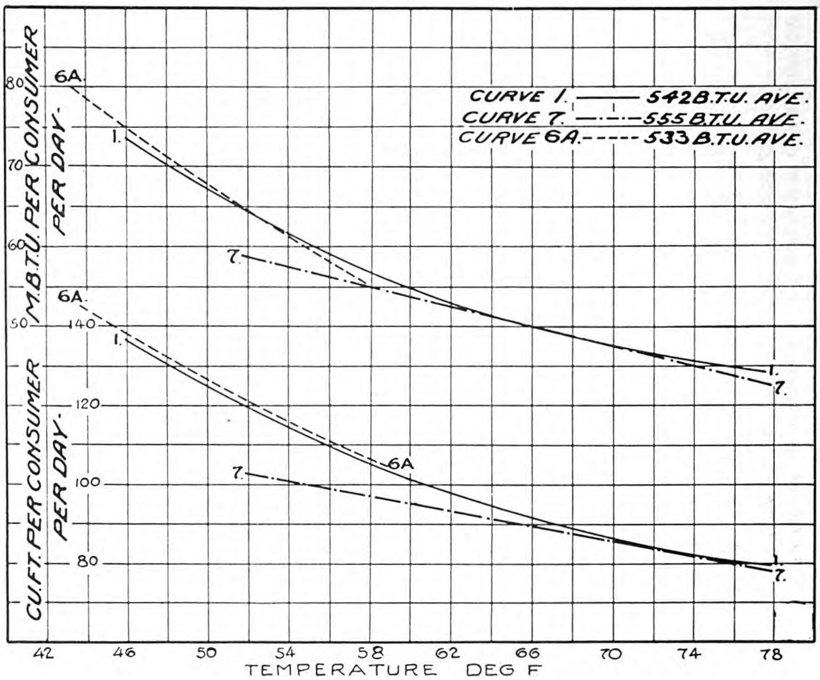


FIG. 26: Curves showing variation of B.t.u. and cubic foot send-outs with changes in temperature at San Jose.

the first several weeks, while the right-hand portion of curve 7 was dominated largely by the period of June and July, when the quality of gas had reached practically a 535 standard.

It is to be noted that with the marked increase in gas quality the send-out in B.t.u. was reduced, showing an apparent increase in efficiency. The depression of the left-hand side of the curve (7) may be due partly to the effect of the few points there located. The depression is so great, however, that this tendency must be given careful consideration.

In the tests on consumers' use of gas, it was not feasible to adjust all consumers' appliances with change in gas quality, there being approximately 12,000 consumers served. A number of consumers were selected and their appliances adjusted with each change in quality. The results of analysis of 91 of these are set forth in figure 27.

This chart is determined from a comparison of the use of gas by 91 consumers in San Jose while served with three qualities of gas. The number of consumers and the volume of data are not sufficient to justify an accurate determination of the relative efficiency, but indicate quite clearly that the consumption in B.t.u. per consumer is quite constant.

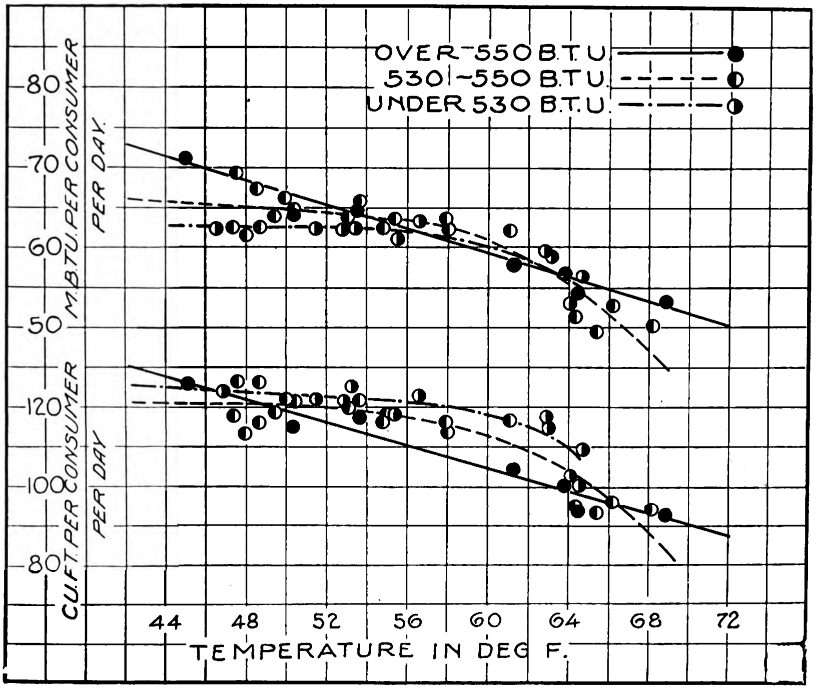


FIG. 27: Curves showing variation in gas consumption by 91 special consumers, San Jose.

(*c*) *Santa Barbara sales.*

An analysis somewhat similar to that made in San Jose was made with regard to the condition in Santa Barbara. That portion, however, of the period from January 1, to April 16, 1921, was excluded, owing to the fact that during that period there was a widely varying consumption of gas not dependent in any way upon climatic conditions. The influx of eastern people in Montecito during the winter months results in a very large use of gas, sometimes in excess of 100,000 cubic feet per month per consumer, for about three months, after which there is practically no consumption.

The following table, No. 25, gives the weekly gas send-out, the number of consumers, the average B.t.u., the temperature, and the send-out per consumer per day in cubic feet and thousand B.t.u.

TABLE NO. 25.

Weekly and Average Daily Consumption.

Santa Barbara, California.

Week ending	Send-out, M cu. ft.	Total consumers	Average B.t.u.	Average temperature	Send-out per consumer per day	
					Cu. ft.	M B.t.u.
1920						
July 3	683	5,249	569	66.4	130.0	74.0
10	639	5,257	564	62.4	121.5	68.6
17	647	5,280	566	67.6	122.7	69.5
24	639	5,299	568	69.2	120.4	68.5
31	638	5,307	572	69.8	120.1	68.7
Aug. 7	624	5,326	554	71.5	117.1	64.9
14	645	5,352	553	69.9	120.3	66.6
21	628	5,366	570	67.7	116.9	66.6
28	654	5,368	587	65.0	121.7	71.4
Sept. 4	675	5,359	555	66.8	125.9	69.9
11	667	5,352	563	62.2	124.5	70.2
18	648	5,358	570	65.0	120.9	68.9
25	643	5,356	570	65.0	120.1	68.5
Oct. 2	638	5,346	559	64.2	119.3	66.7
9	688	5,339	530	61.7	128.9	68.3
16	675	5,339	529	62.6	126.5	66.9
23	741	5,352	534	56.6	138.4	74.0
30	719	5,364	538	58.6	133.9	72.0
Nov. 6	799	5,370	532	55.1	148.8	79.1
13	839	5,374	529	55.9	156.0	82.6
20	784	5,377	538	57.1	145.7	78.5
27	856	5,374	535	53.4	159.1	85.2
Dec. 4	837	5,371	531	56.6	155.9	82.9
11	948	5,380	527	52.7	176.1	92.9
18	956	5,390	535	51.0	177.8	95.0
25	1,007	5,393	552	52.7	186.9	103.1
1921						
Jan. 1	946	5,393	542	53.2	175.2	95.0
8	958	5,395	571	55.1	177.6	101.4
15	1,088	5,399	534	51.0	201.8	107.6
22	1,073	5,399	567	50.3	199.0	113.0
29	1,098	5,396	551	52.8	203.5	112.1
Feb. 5	1,026	5,397	550	47.3	190.3	104.7
12	1,028	5,403	516	54.0	190.3	98.2
19	1,133	5,413	526	54.1	209.0	111.0
26	850	5,416	564	49.9	156.9	88.5
Mar. 5	972	5,423	537	60.9	179.0	96.2
12	960	5,432	522	54.5	176.6	92.3
19	888	5,434	517	55.0	163.3	84.5
26	895	5,433	514	57.4	164.7	84.7
April 2	832	5,414	553	60.9	153.7	85.0
9	914	5,402	563	52.2	169.1	95.2
16	812	5,407	573	55.1	150.1	86.1
23	737	5,408	551	59.7	136.2	75.1
30	709	5,399	534	65.8	131.3	70.2
May 7	825	5,392	521	53.8	152.7	79.6
14	799	5,395	526	58.2	148.2	78.0
21	765	5,403	513	56.9	141.5	72.6
28	782	5,412	519	58.2	144.5	75.0
June 4	722	5,414	541	59.6	133.4	72.2
11	764	5 412	530	60.7	141.1	74.8
18	705	5,411	539	61.4	130.3	70.3
25	662	5,400	535	64.4	123.0	65.8
July 2	674	5,397	533	66.0	125.0	66.6
9	683	5,403	542	67.5	126.5	68.4
16	661	5,417	545	68.8	122.1	66.6
23	672	5,431	537	71.2	123.8	66.5
30	696	5,425	538	67.4	128.2	69.0
Aug. 6	710	5,447	532	65.5	130.3	69.4
13	723	5,460	534	66.7	132.4	70.7
20	720	5,461	539	66.3	131.9	71.1
27	698	5,462	536	68.1	127.8	68.5
Sept. 3	705	5,457	539	67.1	129.2	69.6
10	703	5,459	542	65.1	128.7	69.7
17	751	5,451	535	61.8	137.8	73.7
24	733	5,435	521	63.7	135.0	70.3
Oct. 1	663	5,426	541	68.0	122.1	66.1
8	711	5,429	536	61.3	131.0	70.3
15	734	5,437	527	58.2	135.1	71.2
22	725	5,443	527	65.7	133.1	70.2
29	766	5 452	527	64.6	140.5	74.1

TABLE NO. 25—Concluded.

Weekly and Average Daily Consumption.

Santa Barbara, California.

Week ending	Send-out, M cu. ft.	Total consumers	Average B.t.u.	Average temperature	Send-out per consumer per day	
					Cu. ft.	M B.t.u.
1921—Continued.						
Nov. 5	701	5,464	530	67.8	128.2	68.0
12	751	5,462	533	59.3	137.4	73.3
19	845	5,498	525	56.3	153.6	80.7
26	878	5,546	535	58.1	158.3	84.7
Dec. 3	905	5,562	537	57.7	162.6	87.4
10	882	5,578	538	57.7	158.1	85.1
17	921	5,585	523	56.0	164.8	86.3
24	985	5,594	524	56.3	175.9	92.2
31	927	5,603	541	60.3	165.3	89.5
1922						
Jan. 7	7,481	5,593	542	51.5	191.0	103.5
14	7,309	5,597	546	54.6	186.4	101.8
21	8,398	5,598	526	49.1	214.3	112.7
28	8,130	5,652	537	52.1	205.4	110.3
Feb. 4	8,931	5,665	544	47.6	225.1	122.5
11	7,349	5,683	547	55.7	184.7	101.0
18	7,014	5,703	535	56.5	161.4	86.3
25	7,666	5,716	536	51.9	192.0	102.9
Mar. 4	7,344	5,700	540	53.2	184.0	99.4
11	7,394	5,720	532	54.0	184.6	98.2
18	7,355	5,732	546	53.3	183.3	100.1
25	6,662	5,726	541	57.1	166.2	89.9
April 1	6,398	5.716	539	58.3	160.0	86.2
8	6,604	5,722	533	55.6	164.9	87.9
15	6,714	5,730	532	55.6	167.3	89.0
22	5.619	5,711	537	52.2	140.5	75.4
29	6.238	5,716	542	54.4	156.0	84.6
May 6	5,969	5,701	546	54.0	149.6	81.7
13	5,564	5,700	538	62.0	139.5	75.1
20	5,210	5,708	539	59.4	130.4	70.3
27	4,755	5,712	545	63.8	119.0	64.9
June 3	4,809	5,690	542	61.8	120.7	65.4
10	4,767	5,673	537	63.8	120.0	64.4
17	4,686	5,683	541	65.0	117.8	63.7
24	4.671	5,685	532	67.2	117.4	62.5

Figure 28 sets forth a comparison for Santa Barbara of the curves determined from gas in excess of, and less than, 545 B.t.u. in quality. At first glance this curve would tend to justify the same conclusion arrived at from the San Jose figures.

In these curves, the one representing gas of less than 545 B.t.u. is largely dominated by the summer and fall of 1921; while the curve representing higher quality gas is almost entirely determined by the months of July, August, and September, 1920. These curves, therefore, do not eliminate economic conditions.

(1) Change in consumption resulting from introduction of natural gas into Santa Barbara.

The change in the use of gas, resulting from the introduction of natural gas of 1000 B.t.u. or more in place of manufactured gas, has uniformly shown a reduction in use very nearly equivalent to the increase in heat content. In November, 1923, the heating value of the gas at Santa Barbara was increased, as a result of the introduction of natural gas, from 550 B.t.u. to 700 B.t.u. per cubic foot—an increase of 27.3 per cent. A tabulation has been made of some fourteen downtown restaurants using gas for general top-burner and baking operations. During the last week of the 550 B.t.u. gas, these restaurants had a combined use of 195,300 cubic feet; and in the first week of the 700 B.t.u. gas, a combined use of 152,400 cubic feet—a decrease of 21.9 per cent. The average weekly use for four weeks prior to the change in quality was 196,900 cubic feet; and for the four weeks following the change, it was 155,900 cubic feet—or a decrease of 20.8 per cent. The weather conditions during these periods were not noticeably different; nor were there any changes in activities that would affect the consumption of gas in the restaurants.

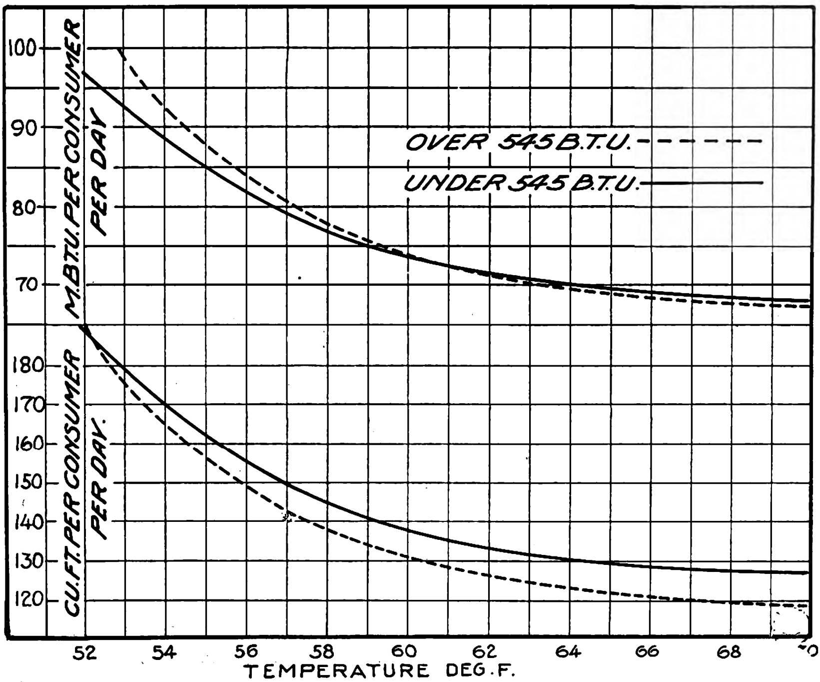


FIG. 28: Curves showing a comparison of weekly gas send-outs per consumer with gases in excess of, and less than, 545 B.t.u. at Santa Barbara.

(*d*) *Los Gatos sales.*

Prior to November, 1921, the city of Los Gatos was supplied with gas manufactured locally, which tested somewhat in excess of 600 B.t.u. After that date, the Pacific Gas and Electric Company began supplying gas to Los Gatos from a high-pressure transmission line from San Jose, a distance of ten miles. The quality of this gas was approximately 525 B.t.u., being by test 10 B.t.u. less than that supplied in San Jose. Shortly after the introduction of high-pressure gas from San Jose, the company found it necessary to adjust all appliances in Los Gatos, as there were complaints received regarding poor quality of gas.

It appeared to the Committee that the material lowering in heat content of gas in this city would provide an opportunity to check the results that were obtained in San Jose as shown by the charts heretofore discussed. Analysis was made of the books of the company in order to determine the number of consumers and sales by months for the years

1918, 1919, 1920, and 1921. The results of this investigation are shown in Table No. 26. In this table, it is assumed that the quality of gas supplied to consumers prior to November, 1921, was approximately 600 B.t.u., this figure being based upon the weekly record of the analysis of the gas distributed.

TABLE NO. 26.

Gas Sales in Los Gatos and Mean Temperatures for Month.

Year	Month	Gas sold, cubic feet	B.t.u.	Number of consumers	Cubic feet per consumer	Temperature			Rainfall	
						Mean maximum	Mean minimum	Mean	Number of days	Inches
1919	January	877,400	600	453	1,937	59.3	38.8	49.0	5	2.48
1920	January	1,110,500	600	537	2,068	56.9	40.7	48.8	2	0.55
1921	January	1,550,900	600	639	2,426	54.8	39.4	47.1	12	13.71
1922	January	2,087,800	*519	783	2,667	53.4	34.6	44.0	9	2.83
1919	February	813,700	600	464	1,753	56.4	40.3	48.8	15	12.00
1920	February	980,000	600	547	1,791	60.3	40.1	50.2	8	1.34
1921	February	1,266,100	600	649	1,950	61.1	41.2	51.2	7	2.34
1922	February	2,033,700	*534	785	2,590	56.7	40.4	48.6	16	11.20
1919	March	745,100	600	460	1,620	60.1	40.7	50.4	8	4.42
1920	March	941,800	600	553	1,703	60.0	39.9	50.2	10	7.38
1921	March	1.246,900	600	669	1,864	64.9	44.4	54.6	7	2.19
1922	March	1,911,300	*554	787	2,428	61.1	40.2	50.6	10	2.32
1919	April	840,400	600	468	1,800	70.4	43.3	56.8	1	0.05
1920	April	1,058,600	600	566	1,870	69.1	42.0	55.6	5	2.99
1921	April	1,516,600	600	688	2,204	69.3	41.9	55.6	5	0.59
1922	April	1,726,300	*522	795	2,171	67.7	40.2	54.0	2	0.32
1919	May	900,600	600	481	1,872	74.5	46.0	60.2		
1920	May	1,110,800	600	572	1,943	75.4	43.5	59.4		
1921	May	1,597.800	600	715	2,234	66.9	44.7	55.8	8	0.98
1922	May	1,953,800	*511	839	2,328	75.2	46.6	60.9	2	0.48
1919	June	1,003,300	600	484	2,073	80.3	47.6	64.0		
1920	June	1,068,600	600	615	1,736	78.9	50.5	64.7		
1921	June	1,479,500	600	753	1,965	80.7	51.7	66.2		
1922	June	2,010,300	*505	880	2,284	83.3	51.7	67.5		

*San Jose average less 10 B.t.u.

Note: High-pressure gas sent out from San Jose plant to Los Gatos, November, 1921.

(e) Comparison of sales in San Jose, Fresno, and Los Gatos.

A comparison of the operations in San Jose, Fresno, and Los Gatos was made to determine whether any economic conditions had affected the use of gas during the period of the tests. Table No. 27 sets forth a comparison of the sales per consumer for the first six months of 1919, 1920, 1921, and 1922; and Table No. 28 gives the same data for the second six-month period of these years. Of these three communities, Fresno and San Jose are about the same size, and similarly dependent upon agriculture although not located in the same part of California.

It is to be noted from Table No. 25 that there was a large increase in consumption in both San Jose and Fresno during 1921. In 1922 the consumption was slightly reduced in both cities. In Los Gatos, where a material reduction in heating value occurred in 1922, the cubic feet sold increased very materially, whereas the B.t.u. sold per consumer remained almost exactly the same as during the preceding year.

During the second six-month period, as given in Table No. 28, there was much less variation in send-out in Fresno. In San Jose there was a larger increase coincident with the decrease in heating value. There was a further increase, however, in cubic feet and B.t.u. sold in 1922, although the heating value was higher for this period than in 1921.

Heating value was lower in Los Gatos during the second six-month period of 1920 and 1921 than during 1919 or 1922. The sales per consumer in cubic feet were also reduced, but not to the same extent as the reduction in B.t.u. per consumer.

The percentage variation in the B.t.u. of the gas, and the change in consumption in B.t.u. and cubic feet, at Fresno, San Jose, and Los Gatos are shown for each six-month period for the years 1919, 1920, 1921, and 1922 in figures 29 and 30.

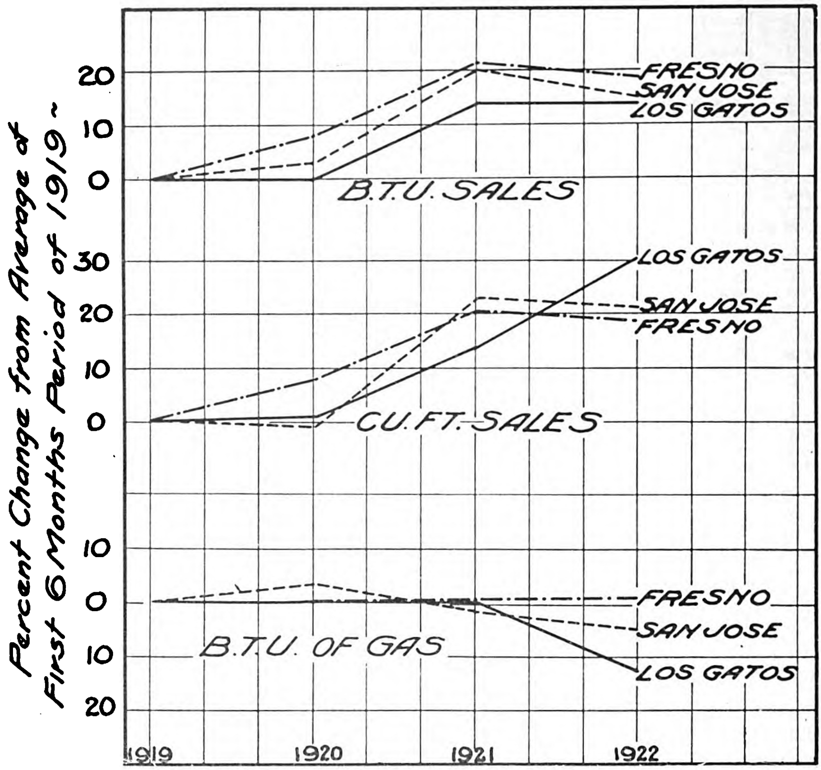


FIG. 29: Curves showing the percentage change in B.t.u. and sale of gas for the first six months of 1920, 1921 and 1922 over the first six months of 1919, in San Jose, Fresno, and Los Gatos.

TABLE NO. 27.

Comparison of Heating Value and Sales of Gas at Fresno, San Jose, and Los Gatos During First Six-Month Period of 1919, 1920, 1921, and 1922.

	1919	1920	1921	1922
Fresno				
Sales per consumer (M cubic feet)	18.24	19.68	21.94	21.62
Increase over 1919 (per cent)	----------	7.9	20.3	18.5
Sales per consumer (million B.t.u.)	10.39	11.22	12.58	12.44
Increase over 1919 (per cent)	----------	8.0	21.1	19.7
Average B.t.u.	570	570	573	573
Increase over 1919 (per cent)	----------	0.0	0.5	0.5
Average temperature (degrees)	59.7	57.1	59.6	58.0
San Jose				
Sales per consumer (M cubic feet)	14.37	14.30	17.63	17.43
Increase over 1919 (per cent)	----------	—0.5	22.7	21.3
Sales per consumer (million B.t.u.)	8.04	8.29	9.67	9.32
Increase over 1919 (per cent)	----------	3.1	20.3	16.0
Average B.t.u.	559	579	548	534
Increase over 1919 (per cent)	----------	3.6	—1.9	—4.5
Average temperature	54.5	54.7	51.9	53.0
Los Gatos				
Sales per consumer (M cubic feet)	11.08	11.10	12.63	14.44
Increase over 1919 (per cent)	----------	0.2	14.0	30.3
Sales per consumer (million B.t.u.)	6.64	6.66	7.59	7.58
Increase over 1919 (per cent)	----------	0.3	14.3	14.2
Average B.t.u.	600	600	600	524
Increase over 1919 (per cent)	----------	0.0	0.0	—12.7
Average temperature	55.0	54.1	55.1	54.3

TABLE NO. 28.

Comparison of Heating Value and Sales of Gas at Fresno, San Jose, and Los Gatos During Second Six-Month Period of 1919, 1920, 1921, and 1922.

	1919	1920	1921	1922
Fresno				
Sales per consumer (M cubic feet)	16.15	17.22	16.79	16.03
Increase over 1919 (per cent)	----------	6.6	4.0	—0.7
Sales per consumer (million B.t.u.)	9.22	9.87	9.63	9.17
Increase over 1919 (per cent)	----------	7.0	4.4	—0.5
Average B.t.u.	570	572	573	570
Increase over 1919 (per cent)	----------	0.3	0.5	0.0
Average temperature	66.6	65.8	68.4	----------
San Jose				
Sales per consumer (M cubic feet)	13.39	14.75	15.41	16.05
Increase over 1919 (per cent)	----------	10.1	15.1	19.8
Sales per consumer (million B.t.u.)	7.62	8.22	8.27	8.99
Increase over 1919 (per cent)	----------	7.9	8.5	18.0
Average B.t.u.	569	557	537	560
Increase over 1919 (per cent)	----------	—2.1	—5.6	—1.6
Average temperature	58.8	60.2	61.0	----------
Los Gatos				
Sales per consumer (M cubic feet)	12.11	11.85	11.76	13.74
Increase over 1919 (per cent)	----------	—2.1	—2.9	13.5
Sales per consumer (million B.t.u.)	6.76	6.48	6.19	7.55
Increase over 1919 (per cent)	----------	—4.1	—8.5	11.7
Average B.t.u.	559	547	527	550
Increase over 1919 (per cent)	----------	—2.1	—5.7	—1.6

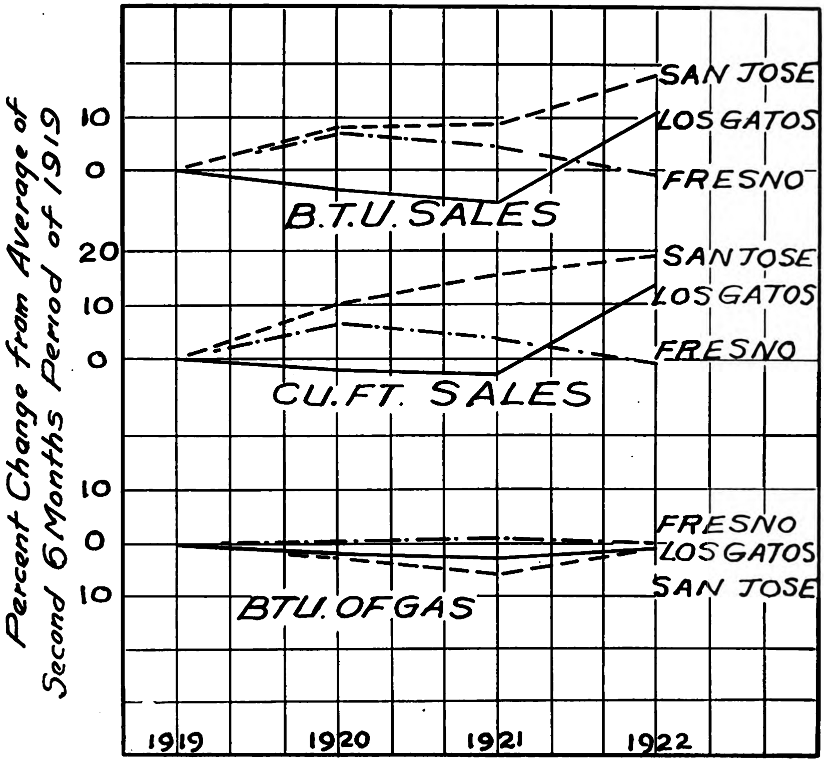


FIG. 30: Curves showing the percentage change in B.t.u. and sale of gas for the second six months of 1920, 1921, and 1922 over the second six months of 1919, in San Jose, Fresno, and Los Gatos.

V. CONCLUSIONS AND RECOMMENDATIONS.

The results of the plant tests at San Jose and San Francisco showed that the thermal efficiency of manufacture with the Jones improved generator was practically constant with gases having a heating value of 530 to 570 B.t.u. per cubic foot. With a lowering of heating value below 530 B.t.u. there was a slight reduction in efficiency. The tests with the Jones type of generator also showed that it was easier to maintain a uniform quality with gases having a heating value of 530 to 550 B.t.u. per cubic foot than with gases having a higher heating value.

The results of the plant tests at Santa Barbara, and at the plants of the Southern California Gas Company and Los Angeles Gas and Electric Corporation, showed that with the straight-shot generators as operated during the period of these tests the thermal efficiency of manufacture was practically constant with gases having a heating value of 540 to 570 B.t.u. per cubic foot. There was a reduction in efficiency, however, as the heating value was lowered below 540 B.t.u. The ease of maintaining a uniform quality was not affected at operations between 500 and 570 B.t.u.

In manufacturing gases of varying heating values with both the straight-shot and the Jones type generators there was a variation in the quality and quantity of by-products produced, and a shifting in the labor costs. The difference in the value of the by-products and the total cost of labor was not enough, however, with the different standards, to be considered a material factor in determining the final cost of the gas. The relative oil efficiency, quantity of steam used, and capacity of generators with the different standards were the principal factors considered in determining what heating-value gas was most economical to manufacture.

The cost of gas distribution increases with an increase in the specific gravity of the gas, and decreases with an increase in the heating value, due to a change in the carrying capacity of the system. This variation in cost of distribution, with small variation in heating value and specific gravity, is comparatively unimportant compared with the large losses that occur from the condensation of illuminants from gases having very high heating values. In addition to the direct loss in B.t.u., which has to be made up by use of additional oil at the plant, there is an indirect loss due to additional expense for maintenance of the consumers' appliances when these are supplied with a variable quality of gas.

The results of the observations made to determine the loss of heating value during distribution showed that where gas was manufactured by straight-shot generators, and distributed by low pressure or intermediate high pressure, the loss in heating value was practically negligible with a heating value of 550 B.t.u. or less, but increased fairly rapidly as the heating value was increased.

With a gas of 500 B.t.u. or over made with the Jones type of generator, containing appreciable quantities of benzol, the losses in heating value are relatively much larger than the losses with gases of equal heating value made with the straight-shot generators, which contain smaller percentages of the condensable hydrocarbons. From the tests on the low pressure system at San Jose and the high pressure system from San Jose to Los Gatos, it is seen that the condensation losses increase very rapidly as the heating value is increased above 550 B.t.u.

In view of the facts stated above it appears that it is not economical to distribute an oil gas of higher heating value than 550 B.t.u. per cubic foot unless the larger losses in distribution are offset by greater efficiencies in manufacture or utilization.

Extensive laboratory tests were made with gases of different heating value to determine their relative usefulness for top-burner cooking, water heating, and oven heating. From these tests it may be concluded that the usefulness of gases within the limits of 600 to 500 B.t.u. per cubic foot, made by either of the California oil-gas processes, will vary inversely in proportion to the change in heating value—conditions of uniformity of quality and pressure remaining the same.

In order to determine the variation in consumption resulting from changes in the heating value of the gas, weekly records were kept of the gas send-out at San Jose for a period of one and one-half years, and for a period of two years at Santa Barbara. These records showed that the consumption of gas in these two cities varied closely with the temperature conditions, partly due to the fact that a considerable quantity of gas was used for heating purposes. The San Jose figures indicated rather clearly that, whereas the consumption in cubic feet varied materially, depending upon the heating value of the gas, the B.t.u. consumption remained almost constant for any one temperature.

It has been more difficult to draw definite conclusions from the early data collected from Santa Barbara, but recent data from that city have given very definite support to the conclusions that have been drawn from the San Jose figures. After the introduction of natural gas into Santa Barbara in November, 1923, the city was supplied with a mixed gas and the heating value was increased from 550 B.t.u. to 700 B.t.u. per cubic foot—an increase of 27.3 per cent. A tabulation of the consumption by 14 restaurants showed that they used 21.9 per cent less gas in the first week after the change than in the week preceding the increase in heating value. The average decrease in consumption for the first four weeks after the change, as compared with the four weeks preceding the change, showed a decrease of 20.8 per cent in the volume of gas used. The weather conditions during this period remained very much the same, nor was there any other condition that might have influenced the use of gas.

Based on a careful consideration of all the results of the plant tests, a study of the losses in distribution with various qualities of gas, the results of laboratory tests on many types of appliances, and observation of the consumption of gas by the consumers, The Joint Committee on Efficiency and Economy of Gas of the Railroad Commission of the State of California is of the opinion that, under the conditions existing in California where oil gas is supplied, a standard of 550 B.t.u. per cubic foot will give the most economical and satisfactory gas service, and the Committee recommends this as a general standard for the state. A modification of this standard to a higher or a lower quality should be allowed where a company is able to supply a uniform quality of gas to consumers at a less cost per B.t.u. To determine the compliance with an established standard, the heating-value tests should be made on an average sample taken at the point of delivery from the works to the transmission or distribution system.

APPENDIX A.

Comparative Operating Data, Weight and Heat Balance for Five Plants on 550 B.t.u. Gas.

Comparative Operating Data, Weight and Heat Balance for Five Plants on 550 B.t.u. Gas.

TABLE 1.

Comparative Operating Data for Representative Plant Tests on 550 B.t.u. Gas.

Items	Potrero	San Jose	Santa Barbara	Southern California Gas Company	Los Angeles Gas and Electric Corp.
GENERAL GAS PRODUCTION DATA.					
Operating Cycle					
1. Average length dry blast (minutes)	5	2	5	3	5
2. Average length heat (minutes)	5	4½	9	7	10
3. Average length make (minutes)	8	6½	20	15	22
4. Average length purge (minutes)	2	2	6	5	8
5. Average length operating cycle (minutes)	20	15	40	30	45
6. Average runs per operating hour	3	4	1.5	2	1.33
Gas Data					
7. Calorific value, observed (B.t.u.)	550	550	550	550	550
8. Average gas made per run (M cubic feet)	66	22	37	50	87
9. Average gas made per hour (M cubic feet)	200	88	55	100	116
10. Average gas analysis—	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Constituents:	*Vol.* / *Wgt.*	*Vol.* / *Wgt.*	*Vol.* / *Wgt.*	*Vol.* / *Wgt.*	*Vol.* / *Wgt.*
CO_2	4.6 / 14.9	4.5 / 14.1	1.2 / 4.7	1.8 / 6.6	3.0 / 10.5
C_6H_6	1.2 / 6.9	0.8 / 4.5	0.8 / 5.5	0.9 / 5.8	0.9 / 5.6
C_nH_{2n}	2.5 / 5.2	3.0 / 6.0	3.9 / 9.7	1.9 / 4.4	3.4 / 7.6
O_2	0.3 / 0.7	0.1 / 0.2	0.2 / 0.6	0.3 / 0.8	0.5 / 1.3
CO	12.9 / 26.7	12.7 / 25.4	8.0 / 20.0	9.9 / 23.5	11.6 / 26.0
H_2	48.7 / 7.2	45.2 / 6.5	55.3 / 10.0	51.2 / 8.5	51.3 / 8.2
CH_4	26.4 / 31.3	28.1 / 32.2	24.8 / 35.2	28.5 / 37.9	25.4 / 32.3
N_2	3.4 / 7.1	5.6 / 11.1	5.8 / 14.3	5.5 / 12.5	3.9 / 8.5
11. Calculated B.t.u. per cubic foot	553	550	549	551	549
12. Ultimate analysis—					
Constituents:	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
H_2	16.2	15.7	20.5	19.1	17.8
C	49.7	48.1	49.6	49.3	49.9
O_2	26.8	25.0	15.3	18.7	23.7
N_2	7.3	11.2	14.6	12.9	8.6
13. Specific gravity of purified gas (air=1)	.467	.484	.389	.415	.434
14. Weight of gas per M cubic feet (pounds)	35.77	37.06	29.77	31.80	33.25
15. Average temperature gas in holder, assumed (deg. F.)	60	60	60	60	60
16. Average temperature gas entering wash box (deg. F.)	1,600	1,600	1,600	1,600	1,600
17. Specific heat of gas (at 60°)	.557	.537	.658	.617	.593
Specific heat of gas (at temperature entering wash box)	.797	.768	.942	.870	.842
18. Sensible heat gas entering wash box above 60° (B.t.u.)	44,293	44,303	46,562	41,610	45,012
By-Products Recovered					
19. Average weight dry lampblack (pounds per M)	12.0	13.0	22.0	19.6	21.7
20. Average heating value dry lampblack (B.t.u. per pound)	15,000	15,000	14,500	14,500	14,500
21. Heating value lampblack (B.t.u. per M cubic feet of gas)	180,000	195,000	319,000	284,200	314,650
22. Specific heat of lampblack (per pound)	.30	.30	.30	.30	.30
23. Average temperature lampblack entering wash box (deg. F.)	1,600	1,600	1,700	1,550	1,750
24. Sensible heat in lampblack above 60° F. (B.t.u.)	5,544	6,006	10,164	9,055	10,025
25. Average weight tar—moisture free (pounds per M)	4.0	4.5	2.5	1.5	1.5
26. Water equivalent (heat value) of tar (pounds)	2.6	2.9	1.6	1.0	1.0
27. Average heating value tar (B.t.u. per pound)	15,400	15,400	15,400	15,400	15,400
28. Heating value tar cubic feet gas made (B.t.u. per M)	61,600	69,300	38,500	23,100	23,100
29. Water vapor from steam and oil (pounds)	22.4	17.6	12.8	14.7	9.0
30. Total weight water and tar vapor (pounds)	25.0	20.5	14.4	15.7	10.0
31. Sensible heat from water and tar vapors (B.t.u.)	26,270	19,200	16,960	16,450	12,400
32. Latent heat from condensation water vapor (B.t.u.)	24,250	17,070	13,960	15,230	9,700
Oil Data (General Items)					
33. Specific gravity of oil used (deg. B.)	17.5	16.9	17.1	15.0	16.0
34. Weight of oil per gallon (pounds)	7.912	7.937	7.928	8.047	7.992
35. Heating value per pound, dry basis (B.t.u)	18,950	18,870	18,800	18,500	18,650
36. Heating value per gallon, dry basis (B.t.u)	149,932	149,800	149,000	148,869	149,050
37. Average make oil (gallons per M cubic feet of gas)	6.38	6.43	7.38	7.20	7.39
38. Average make oil (pounds per M cubic feet of gas)	50.48	51.03	58.51	57.94	59.06
39. Average heating value, dry basis (B.t.u. per M cubic feet)	956,596	962,936	1,099,988	1,071,890	1,101,469
40. Average temperature of oil used make period (deg. F.)	200	190	200	150	250
41. Sensible heat from make oil (B.t.u.)	3,611	3,390	4,186	4,145	5,734
42. Average heat oil (gallons per M cubic feet)	0.87	0.92	1.02	0.65	1.01

TABLE 1—Concluded.

Comparative Operating Data for Representative Plant Tests on 550 B.t.u. Gas.

Items	Potrero	San Jose	Santa Barbara	Southern California Gas Company	Los Angeles Gas and Electric Corp.
43. Average heat oil (pounds per M cubic feet)	6.88	7.30	8.08	5.23	8.07
44. Average heating value, dry basis (B.t.u. per M cubic feet)	130,376	137,750	151,904	96,755	150,505
45. Average temperature oil as used heat period (deg. F.)	200	170	175	150	200
46. Specific heat of oil	.511	.511	.511	.511	.511
47. Sensible heat from oil (B.t.u.)	492	410	474	240	577
48. Analysis of oil (moisture free)—					
Constituents:	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
C	85.42	88.22	87.34	85.10	86.84
H_2	12.06	10.96	10.08	10.93	10.45
S	0.80	0.82	1.42	1.22	0.74
N_2	0.50	----------	----------	0.68	0.46
O_2	1.22	----------	1.16	2.07	1.51
Steam Data					
49. Steam admitted for dry blast per M (pounds)	1.5	1.2	0.8	0.8	0.9
50. Steam admitted, heat period per M (pounds)	5.9	5.0	4.0	2.7	3.0
51. Steam admitted, make period per M (pounds)	24.8	23.5	14.2	12.2	10.5
52. Steam admitted, purge period per M (pounds)	6.4	3.5	2.0	7.6	6.0
53. Total steam per M cubic feet (pounds)	38.6	33.2	21.0	23.3	20.4
54. Steam temperature (deg. F.)	338	330	350	366	366
55. Heat content of steam used during heat period, B.t.u. per pound above 60° (B.t.u.)	6,843	5,792	4,633	3,151	3,501
56. Heat content of steam used during make (B.t.u.)	36,192	31,277	22,010	23,107	19,255
57. Heat content steam used during purge and blast (B.t.u.)	1,740	1,390	927	933	1,050
Blast Air and Stack Gas Data (General Data)					
58. Assumed weight of air per cubic foot with water vapor (pounds)	.07699	.07699	.07699	.07699	.07699
59. Assumed average air temperature (degrees)	60	60	60	60	60
60. Assumed relative humidity (per cent)	70	70	70	70	70
61. Weight of water vapor per cubic foot of air (pounds)	.000588	.000588	.000588	.000588	.000588
62. Assumed specific heat of air	.243	.243	.243	.243	.243
Blast Period Data					
63. Average temperature of stack gases (deg. F.)	1,470	1,350	1,600	1,425	1,150
64. Volume of air per M cubic feet of gas (cubic feet)	1,460	569	1,146	624	1,000
65. Weight of air per M cubic feet of gas (pounds)	112	44	88	48	76
66. Steam admitted during blast (pounds)	1.5	1.2	0.8	0.8	0.9
67. Temperature of steam (deg. F.)	338	330	350	366	366
68. Total heat of steam (B.t.u.)	1,740	1,390	927	933	1,050
69. Weight of stack gases per M cubic feet (pounds)	112	42	86	48	77
70. Specific heat of stack gases (at 60°)	.234	.234	.234	.234	.234
Specific heat of stack gases (at the temperature leaving the stack)	.278	.274	.282	.276	.266
71. Total heat lost in stack gases	47,068	17,192	39,198	19,814	24,032
72. Stack gas analysis (instantaneous sample)—					
Constituents:	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
CO_2	12.8	11.60	11.5	13.5	12.0
O_2	4.3	3.6	4.5	4.0	5.9
CO	0.3	0	0	0	0
N_2	82.6	84.8	84.0	82.5	82.1
Heating Period Data					
73. Average temperature of stack gases (deg. F.)	1,450	1,420	1,800	1,500	1,400
74. Volume of air per M cubic feet of gas (cubic feet)	1,274	1,688	1,833	1,550	2,000
75. Weight of air per M cubic feet of gas (pounds)	97	129	140	119	153
76. Volume of air per gallon heat oil (cubic feet)	1,464	1,835	1,800	2,380	1,980
77. Volume of air per pound heat oil (cubic feet)	185	231	226	296	247
78. Average weight stack gases per M cubic feet (pounds)	94.0	122.2	129.6	114.0	149.4
79. Average weight stack gases left in generator (pounds)	3.3	5.3	5.4	5.3	3.8
80. Specific heat of stack gases (at 60° F.)	.208	.234	.236	.234	.234
Specific heat of stack gases (at the temperature leaving stack)	.278	.282	.296	.280	.276
81. Sensible heat in stack gases (B.t.u.)	36,661	47,144	66,839	46,143	55,591
82. Pounds of steam admitted	5.9	5.0	4.0	2.7	3.0
83. Total heat of steam and water vapor (B.t.u.)	25,246	23,344	24,987	15,462	19,596
84. Total heat lost in stack gases (B.t.u.)	61,907	70,488	91,826	61,605	75,187
85. Stack gas analysis (instantaneous sample)—					
Constituents:	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
CO_2	15.4	14.8	13.2	14.0	14.3
O_2	0.6	0.8	0.8	3.3	2.5
CO	0.3	0.0	0.0	0.0	0.0
N_2	83.7	84.4	86.0	82.7	83.2

TABLE 2.

Weight Balance per M Cubic Feet of Gas Made. 550 B.t.u. Gas. Comparison of Five Plants.

Weight in pounds.

Items	Potrero	San Jose	Santa Barbara	Southern California Gas Company	Los Angeles Gas and Electric Corp.
WEIGHT OF MATERIALS INTO GENERATOR					
Make Period					
Make oil	50.48	51.03	58.51	57.94	59.06
Steam	24.80	23.50	14.20	12.20	10.50
Steam (purge)	6.40	3.50	2.00	7.60	6.00
Combustion products	3.30	5.30	5.40	5.30	3.80
Totals	84.98	83.33	80.11	83.04	79.36
Blast Period					
Air	112.00	44.00	88.00	48.00	76.00
Steam	1.50	1.20	0.80	0.80	0.90
Totals	113.50	45.20	88.80	48.80	76.90
Heat Period					
Air	97.00	129.00	140.00	119.00	153.00
Oil	6.88	7.30	8.08	5.23	8.07
Steam	5.90	5.00	4.00	2.70	3.00
Totals	109.78	141.30	152.08	126.93	164.07
Totals of all materials in	308.26	269.83	320.99	258.77	320.33
WEIGHT OF MATERIALS OUT OF GENERATOR					
Make Period					
Purified gas	35.77	37.06	29.77	31.80	33.25
Lampblack	12.00	13.00	22.00	19.60	21.70
Tar	4.00	4.50	2.50	1.50	1.50
Water vapors	22.40	17.60	12.80	14.70	9.00
Totals	74.17	72.16	67.07	67.60	65.45
Blast Period					
Stack gases	112.00	42.00	86.00	48.00	77.00
Water vapors	1.50	1.20	0.80	0.80	0.90
Totals	113.50	43.20	86.80	48.80	77.90
Heat Period					
Stack gases	94.00	122.20	129.60	114.00	149.40
Water vapors	13.05	12.33	11.16	7.83	10.35
Totals	107.05	134.53	140.76	121.83	159.75
Totals of all materials out	294.72	249.89	294.63	238.23	303.10
Difference (including carbon deposited on bricks, H_2S, naphthalene, and losses)	13.54	19.94	26.36	20.54	17.23
Per cent difference	4.4	7.3	8.2	7.9	5.4

TABLE 3.

Heat or Energy Balance per M Cubic Feet of Gas Made. 550 B.t.u. Gas.

Comparison of Five Plants.

Items	Potrero	San Jose	Santa Barbara	Southern California Gas Company	Los Angeles Gas and Electric Corporation
HEAT ENTERING GENERATOR	(B.t.u.)	(B.t.u.)	(B.t.u.)	(B.t.u.)	(B.t.u.)
Make Period					
Make oil, fuel value and sensible heat	960,207	966,326	1,104,174	1,076,035	1,107,203
Steam, heat above 60° and 30''	36,192	31,277	22,010	23,107	19,255
Combustion products, sensible heat	1,284	2,060	2,778	2,162	1,408
Totals	997,683	999,663	1,128,962	1,101,304	1,127,866
Blast Period					
Blast air, sensible heat (60 degrees)	0	0	0	0	0
Steam, heat above 60° and 30''	1,740	1,390	927	933	1,050
Totals	1,740	1,390	927	933	1,050
Heat Period					
Blast air, sensible heat (60 degrees)	0	0	0	0	0
Oil, fuel value and sensible heat	130,868	138,160	152,378	96,995	151,082
Steam, heat above 60° and 30''	6,843	5,792	4,633	3,151	3,501
Totals	137,711	143,952	157,011	100,146	154,583
Total heat entering	1,137,134	1,145,005	1,286,900	1,202,383	1,283,499
HEAT OUT OF GENERATOR					
Make Period					
Gas made, fuel value and sensible heat	594,293	594,303	596,562	591,610	595,012
Lampblack, sensible and latent heat	185,544	201,006	330,163	293,255	324,675
Tar, sensible heat	61,600	69,300	38,500	23,100	23,100
Water vapors, heat above 60° and 30''	50,520	36,270	30,920	31,680	22,100
Totals	891,957	900,879	996,145	939,645	964,887
Blast Period					
Stack gases, sensible heat	44,143	14,968	37,552	18,284	22,505
Water vapor, heat above 60° and 30''	2,925	2,224	1,646	1,530	1,527
Totals	47,068	17,192	39,198	19,814	24,032
Heat Period					
Stack gases, sensible heat	36,661	47,144	66,839	46,143	55,591
Water vapors, heat above 60° and 30''	25,246	23,344	24,987	15,462	19,596
Totals	61,907	70,488	91,826	61,605	75,187
Total of all heat out of generator	1,000,932	988,559	1,127,169	1,021,064	1,064,106
Heat unaccounted for (B.t.u.)	136,202	156,446	159,731	181,319	219,393
Heat unaccounted for (per cent)	12.0	13.6	12.4	15.1	17.1

TABLE 4.

Thermal Efficiency. 550 B.t.u. Gas. Comparison of Five Plants.

Items	Potrero		San Jose		Santa Barbara		Southern California Gas Company		Los Angeles Gas and Electric Corporation	
	B.t.u. per M cu. ft.	Per cent	B.t.u. per M cu. ft.	Per cent	B.t.u. per M cu. ft.	Per cent	B.t.u. per M cu. ft.	Per cent	B.t.u. per M cu. ft.	Per cent
HEAT IN										
Heating value of make oil	956,596	84.1	962,936	84.1	1,099,988	85.5	1,071,890	89.2	1,101,469	86.0
Heating value of heat oil	130,376	11.4	137,750	12.0	151,904	11.8	96,755	8.0	150,505	11.7
Sensible heat in oil above 60°	4,103	0.4	3,800	0.3	4,660	0.3	4,385	0.3	6,311	0.5
Heat in steam used	44,775	4.0	38,459	3.4	27,570	2.2	27,191	2.3	23,806	1.7
Sensible heat combustion products	1,284	0.1	2,060	0.2	2,778	0.2	2,162	0.2	1,408	0.1
Total heat in	1,137,134	100.0	1,145,005	100.0	1,286,900	100.0	1,202,383	100.0	1,283,499	100.0
HEAT RECOVERED (Thermal Efficiency)										
Heating value of gas at holder	550,000	48.4	550,000	48.0	550,000	42.9	550,000	45.8	550,000	43.0
Heating value of lampblack	180,000	15.8	195,000	17.0	319,000	24.8	284,200	23.6	314,650	24.5
Heating value of tar	61,600	5.8	69,300	6.1	38,500	2.8	23,100	1.9	23,100	1.7
Total recovered heat	791,600	70.0	814,300	71.1	907,500	70.5	857,300	71.3	887,750	69.2
HEAT LOSSES										
Sensible heat lost cooling gases to 60°	44,293	4.0	44,303	3.9	46,562	3.6	41,610	3.5	45,012	3.5
Sensible heat lost cooling lampblack to 60°	5,544	0.5	6,006	0.5	10,164	0.8	9,055	0.7	10,025	0.8
Heat in vapors condensed	78,691	6.9	61,838	5.4	57,553	4.5	48,672	4.1	33,223	2.6
Stack gases, dry blast	44,143	4.0	14,968	1.3	37,552	2.9	18,284	1.5	22,505	1.7
Stack losses, heat period	36,661	3.2	47,144	4.1	66,839	5.2	46,143	3.8	55,591	4.3
Miscellaneous losses	136.202	11.4	156,446	13.7	159,731	12.5	181,319	12.1	219,393	17.9
Total losses	345,534	30.0	330,705	28.9	379,400	29.5	345,083	28.7	395,749	30.8

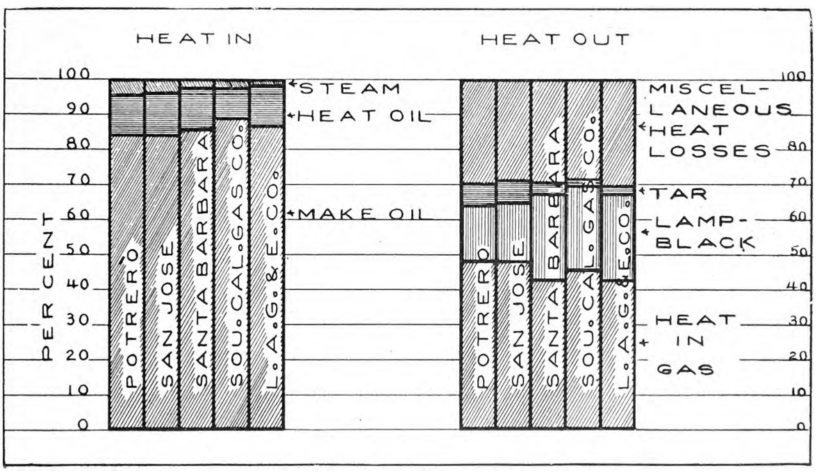


FIG. 1: Heat balance for five California plants for gas of 550 B.t.u.

APPENDIX B.

1. The use of Oil in an Oil Gas Plant and a Method for Checking Oil Results by Examination of the Gas Analyses.

2. Comment on Results of Plant Tests Made in Connection with Joint Committee Investigation.

By Frank Wills.

1. THE USE OF OIL IN AN OIL GAS PLANT AND A METHOD FOR CHECKING OIL RESULTS BY EXAMINATION OF THE GAS ANALYSES.

It is very important that every production superintendent and manager give close attention to the consumption of oil in his plant. He may determine whether his plant is using a relatively high or low amount of oil by comparison with the amount of oil used in other plants. The conclusion from such a comparison, however, may be misleading, as the operating conditions of the different plants vary greatly. It is possible that the plants having high oil consumption are justified under their conditions, while those with comparatively low results have conditions which indicate that still lower results would be more reasonable. The following analysis of oil results of oil gas plants is intended to furnish a few ideas which may help the manager or superintendent to check and improve the results of his plant.

The principal uses of oil in an oil gas plant are for boiler fuel (if any is used for that purpose), maintaining heat in idle generators, heating generators during operation, and gas making. There may be shortages in shipment and leakage of oil from storage, which must be watched carefully in order to properly account for total oil received.

Shortage in shipment and leaks from storage.

Every shipment of oil should be carefully measured and the temperature taken at the time of measuring in order that proper corrections can be made to standard conditions. Daily readings should be made of the quantity of oil in the storage tanks to check against the total daily consumption as shown by the meters. Special tests should be made from time to time for the purpose of locating leaks from underground pipe lines and tanks.

Boiler fuel.

The equipment in the plant determines to a large extent whether it is necessary to use oil under the boilers. By carefully watching the daily operations to balance the use of steam against electric equipment, much can be done to prevent the use of oil for boiler fuel. The same procedure in other plants may assist in consuming excess lampblack on hand. The prevention of the use of oil for boiler fuel and of electric power when there is sufficient lampblack fuel on hand, requires strict supervision.

Maintaining heat in idle generators.

In some of the plants the oil used for the maintenance of heat in generators when these are idle is a considerable item, but this cannot be prevented. Good insulation inside the shell, and aluminum paint on the outside, will lessen the radiation losses. The plant men should be constantly watching the condition of the machine from this standpoint as well as others.

Some of the smaller plants burn out the carbon on the checkers during the idle period. Where this carbon cannot be utilized during the operating cycle, it is possible, by burning it at a very slow rate, to maintain an operating temperature for many hours. If the burning proceeds at a very rapid rate, the heat is dissipated and there is danger of fusing the bricks. With a restricted natural draft, the combustion proceeds at a very slow rate, the heat of combustion equals the losses, and a uniform temperature is maintained. The procedure of burning out the carbon should, therefore, begin with an extremely slow combustion, and the rate should be gradually increased until the proper rate is found. Thereafter the same results can be expected if the draft openings are maintained constant.

Under unusual conditions, such as exist when the checkers are fairly well plugged with carbon, the burning process may open up restrictions, so that the draft will increase. In this case the machine should be watched closely.

When the layover periods are long, the draft opening should be closed before all the carbon is consumed; otherwise, after all the carbon is exhausted, the cold air passing through the machine will cool it rapidly.

The amount of oil used for maintaining the heat at operating temperature in idle generators varies with the conditions in the plant and should be segregated before making comparisons between plants.

Oil for heating during operation.

The actual heat utilized in the production of a thousand cubic feet of gas is very nearly the same in the various plants, it being somewhat higher for those using large quantities of steam. However, the amount of heat oil shown on the reports is not uniform. This is due to the fact that in some instances the oil for maintaining heat in idle generators is included, and sometimes the oil meters are not accurate, especially when the oil is hot. There is, however, a difference in actual utilization of the heat of the oil.

The amount of heat stored in the checkers, when heating with oil, depends upon the number of courses of checkers and the rate of heating. For comparative purposes, the following table of approximate efficiencies of heat absorption may be used where the rate of heating is .07 gallons of oil per square foot of internal cross-section area per minute and the spacing of the checkers is 3 inches.

Approximate Efficiencies of Absorption of Heat.

Courses of checker-brick	Average per cent efficiency during heating	Reasonable allowance of heat oil gallons per M, 570 B.t.u. gas
20	20.5	1.72
30	27.0	1.35
40	32.0	1.15
50	37.0	.99
60	41.0	.86
70	44.0	.80
80	47.0	.75
90	49.5	.71
100	52.0	.67

This means that a machine of twenty courses would require about twice as much heat oil as one having sixty courses, provided they were heated at the same rate and other conditions were equal. A slower rate of heating will be of advantage to the shorter machines, and, by using a slow rate, the efficiency need not be so low for these machines as indicated by the table given above. The slower rate of heating for the short machines will save heat oil but will decrease the hourly make in proportion to the amount of time lost.

Where the dry blast period is carefully regulated, as high as 40 per cent of the heat required during the regular cycle for gas making is derived from the carbon on the checkers. The percentage available depends upon the number of courses of checkers in the machine and varies somewhat with the type of generator. The above table refers to the "heat down" type. Those machines that are heated from the bottom have certain characteristics to which none of the factors given herein apply.

Temperature of oil.

The temperature of the oil, both for heating and making, should be maintained as constant as possible, and this temperature should be about 200° Fahrenheit. The primary purpose of heating the oil is to reduce the viscosity so that the sprays will work more effectively. Over wide ranges of quality the oils used for gas making will have about the same viscosity at this temperature. Thus some of the difficulties arising from variations in quality will be avoided.

Proper temperature for the heat oil makes it possible to obtain a fine spray at the burners which produces more rapid combustion, resulting in the storage of a greater portion of the heat near the top of the generator, and in a lower stack gas temperature. The heating of the make oil is most important. There are two very good reasons. First, it assists in getting a fine distribution to the checkers; second, the greater the amount of sensible heat stored in the make oil, the less will be required from the checkers. Heat can be stored in the oil cheaper than it can be stored in the checkers.

Amount of air used.

It is possible to control the amount of air used during the heat period so that there is practically no excess. The amount of air necessary for combustion is somewhat in excess of the theoretical requirement of the oil due to the carbon, which is usually deposited on the bricks. By regulating the blast and the rate of heat oil so that the least increase in the oil rate will cause smoke, the operator has a practical guide by which he may "feel out" the efficiency of his heating.

Excess air decreases the efficiency of heating gas generators tremendously. High stack temperatures are responsible for this fact. The following figures show the percentage of heat losses due to 25 per cent excess air when burning oil at various stack temperatures.

	Stack temperatures				
	400° F.	800° F.	1200° F.	1600° F.	2000° F.
Per cent loss with 25% excess air	1.9	4.4	8.8	12.4	19.4

The temperatures of the stack gases leaving the generators range from 1400° F. to 1600° F., while those leaving the boilers range from 400° F. to 600° F. It is therefore evident that the heat losses due to excess air in generators are four or five times as large as those resulting from excess air under boilers.

Gas-making oil.

The make oil required for the production of a thousand cubic feet of any oil gas depends upon the amount of steam that has been caused to enter into the reaction, the heating value of the gas, and character of oil. However, the present variations in quality of oil are not sufficient to influence greatly the actual gas-making qualities so much as they do the viscosity and the ease of spraying, and the resultant production of tar and lampblack. A study of the analysis of the gas made by oil-gas generators will illustrate this point.

A method for the interpretation of oil gas analysis.

This method consists of a separation of the constituents of the gas, as shown by the analysis, into groups according to the source from which they came.

Air.

Gas always contains a small amount of oxygen which is carried into the gas by small leaks of air on the lines where there is a slight suction. It may also come from the excess air in the blast gases trapped in the machine. Since the source of oxygen is air, it will always carry with it four times as much nitrogen. Thus a small portion of the gas may be set aside and called air.

Combustion products.

At the end of the heating period the generator is full of products of combustion, and under ordinary operation a portion of this will be included with the gas of the make period. The products of combustion at the end of the heat should be CO_2 and N_2. There will be, no doubt, an excess of oxygen and nitrogen, but their segregation as "air" is provided for above. The separation of the products of combustion depends upon the remaining nitrogen after the deduction for air. It is to be admitted that, since nitrogen in the analysis is determined by difference, it is subject to considerable error. There is also a small amount of nitrogen in the oil, but, in view of the fact that some cyanogen is formed, the error from this source is negligible. The error in the average determination of nitrogen is of little effect upon the final results.

The "combustion products" may be separated upon the basis of the nitrogen remaining after the deduction for "air." The relation of this nitrogen to the CO_2 is determined by the percentage of carbon in the oil and the amount of carbon burned from the checkers. This is ordinarily uniform enough for practical calculation. The usual stack gas analysis indicates that this should be about six to one, and it will be assumed that the remaining nitrogen will be accompanied by one-sixth its volume of CO_2.

Steam Gas.

The remaining carbon dioxide, all the carbon monoxide, and a portion of the hydrogen have been derived from the action of the steam upon the carbon. Just what becomes of the hydrogen produced by the decomposition of the steam is not clear. For our purpose it makes no difference just what the exact reactions are. We have assumed that the hydrogen from the decomposed steam remains as free hydrogen, and by its partial pressure retards the splitting off of hydrogen from the hydrocarbons of the oil. Upon this assumption we are able to set aside the blue water gas, or, as it is most often called in connection with oil gas manufacture, the "steam gas." The volume of the hydrogen produced from the action of steam on hot carbon is equal to the volume of the carbon monoxide plus twice the volume of carbon dioxide produced. Thus, since the carbon monoxide and carbon dioxide are known, the hydrogen is readily calculated, and the separation of "steam gas" easily made.

True oil gas.

The remaining portion of the gas is made up of benzene, CnH_2n compounds, hydrogen, and methane, which come directly from the decomposition of the oil and constitute the portion of the gas which may be called "true oil gas." Since this "true oil gas" comes directly from the oil, the percentage of "true oil gas" bears a definite relation to the amount of oil required per one thousand cubic feet of the total mixture. The relation, however, is not directly proportional. This relation depends upon the degree to which the oil gas has been "cracked," which in turn is determined by the quality of the oil, the temperature of the generator, the time and intimacy of contact, the percentage of "steam gas" present, etc. This can not be exactly calculated but from such experimental data as are available we may adopt factors that make it possible to estimate quite closely the oil required.

The above explanation of the method of separating the groups is lengthy and probably not very clear, but the actual work is very easily and quickly done. A study of the following example will clear up any difficulties. The calculations used are indicated in the following table. It may be of assistance, when following the calculations of each group, to refer back to the paragraph explaining that group.

Constituents of the gas		Air	Combustion products	"Steam gas"	"True oil gas"
CO_2,	4.3%		0.9 (5.2÷6=approx. 0.9)	3.4 (4.3—0.9=3.4)	
C_6H_6,	0.7%				0.7
CnH_2n,	3.7%				3.7
O_2,	0.1%	0.1			
CO	10.7%			10.7	
H_2,	43.6%			17.5 (3.4×2=6.8) (6.8+10.7=17.5)	26.1
CH_4,	31.3%				31.3
N_2,	5.6%	0.4 (0.1×4=0.4)	5.2 (5.6—0.4=5.2)		
Total,	100.0%	0.5	6.1	31.6	61.8

Calculated B.t.u. per cubic foot city gas—578.0.

	"Steam gas"	"True oil gas"
B.t.u. per cubic foot city gas from steam gas and oil gas	91.7	486.3
B.t.u. per cubic foot "steam gas" and "true oil gas"	290.0	786.9

This gas, therefore, consists of 0.5% air, 6.1% combustion products, 31.6% "steam gas," and 61.8% "true oil gas." By calculation, it is found that the heat units supplied by the "steam gas" are 91.7 B.t.u. The remaining (578.0—91.7) 486.3 B.t.u. is derived from "true oil gas." Dividing each of these by the respective percentage of each gas gives the B.t.u. per cubic foot of each gas in the mixture. (91.7÷.316=290 and 486.3÷.618=786.9). The "steam gas" alone contains 290 B.t.u. per cubic foot and the "true oil gas" alone contains 786.9 B.t.u. per cubic foot.

The amount of true oil gas produced from a gallon of oil is dependent upon the extent to which it is cracked, which varies with the time and thoroughness of contact with, and the temperature of, the checkers, and also the amount of steam gas present. The combined effect of all these factors is indicated by the resulting heating value of the true oil gas. The following curve (Fig. 1) shows the percentage of the heat of the oil retained in the true oil gas for qualities of 455 to 900 B.t.u. per cubic foot. These percentages are plotted from operating and test data reported by a number of plants.

In the foregoing example the B.t.u. per cubic foot of the "true oil gas" portion is 786.9. Reference to the curve shows that for a 787

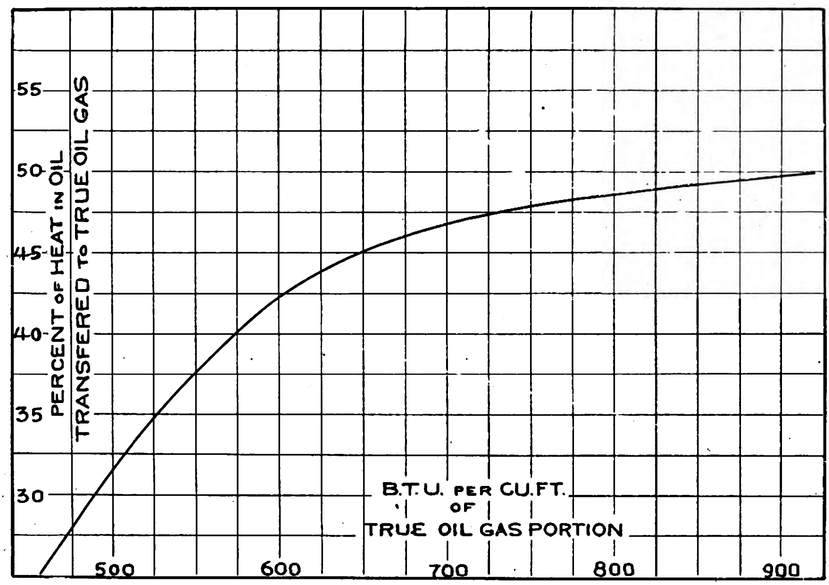


FIG. 1: Curve showing the increase in the percentage of heat in oil transferred to true oil gas with increase in the heating value of the gas.

B.t.u. "true oil gas," 48.4 per cent of the heat of the make oil is transferred to the gas. Knowing that the "true oil gas" in 1000 cubic feet of the city gas contains (1000 x 486.3) 486,300 B.t.u., it is thus determined that this energy is obtained from a quantity of oil containing (486,300 ÷ .484) 1,004,750 B.t.u. This amount (1,004,750) divided by the B.t.u. per gallon of the oil used gives the gallons of make oil reasonably required per 1000 cubic foot of this city gas.

For those who do not have determinations of the heating value of the oil, it will be necessary to use an assumed value which, for qualities being supplied at present, may be taken as 146,000 B.t.u. per gallon. With such an oil the above city gas would require (1,004,750 ÷ 146,000) 6.75 gallons make oil per thousand cubic feet.

It is important when making these checks upon the oil results of any plant that the sample of gas be truly representative and that there be no losses of oil or gas in the plant or errors in the station meter and oil measurements.

The method described herein for estimating oil requirements is not considered as infallible, but judged by the present available data it appears to be quite accurate.

2. Comment on results of plant tests made in connection with joint committee investigation.

At the time the work of the Joint Committee was begun, a large number, if not all, of the operators of oil gas plants in California believed that a reduction in heating value standard would result in higher efficiency in generation. Although it is common knowledge that the higher temperaature or more thorough contact necessary to produce lower B.t.u. gas would crack the true oil gas portion of the gas still further, and such additional cracking would actually decrease the efficiency of direct transfer of heat units from oil to gas, it was expected that there would be an increase in production of steam gas as a result of the higher temperatures. Evidently those expectations were based upon certain periodic conditions in the plants. There are times when generators become "carboned," and when it is necessary to run them "hot" in order to clean out the excess carbon. At such times the percentage of steam gas produced is unusually high, the B.t.u. of the gas is low, and the oil requirements low. Naturally, it was expected that similar results would be secured when the standard was lowered in the experimental plants. This, however, occurred to only a limited extent when the periods of operation at higher temperatures were long, and the amount of steam gas produced was not constant and never absolutely under control. The improved efficiency, which had previously been observed on short periods of operation at high temperatures, was probably due to the excess carbon in addition to the high temperature; but under long periods of operation, this excess of carbon in the generator was not maintained.

The oil requirements for the lower quality of gas were reduced, but not to the extent of showing an increase in thermal efficiency. The small increase in the percentage of steam gas was offset by the slight reduction in efficiency of transfer of B.t.u. in oil to gas. Unless there was a substantial increase in thermal efficiency, it is not probable that there would be any economic advantage in the production of a lower quality gas by this process.

It can be shown by the foregoing analysis of oil results and by an explanation of the general principles of the process that still lower heating value standards would require a very high percentage of steam gas at the expense of the hydrocarbons. Even had this been possible with the present generators, it would not have been economical, since a large excess of steam is required for the reaction, and the quantity of boiler fuel would be greatly increased.

APPENDIX C.

Influence of Inerts on Generator Efficiency and Capacity.

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INFLUENCE OF INERTS ON GENERATOR EFFICIENCY AND CAPACITY.

Certain developments in the last few years have resulted in considerable discussion regarding the advantages and disadvantages of high percentages of inerts in the gas. The use of lower grade fuels, the steaming of retorts, and other modifications in manufacture have all tended to lower the heating value of the gas, but this has not necessarily been a disadvantage to the consumers, since they have received gas service at lower cost than if the company had been compelled to supply a high heating value gas.

In the Jones oil-gas process we have an attempt to secure a condition within the generator that will allow the cracking of the oil under a more favorable condition. The principle is somewhat similar to that of water-gas practice, where the oil is introduced into an atmosphere of blue water-gas and the latter acts as a protection against excessive decomposition of the oil, with the result that little lampblack is formed.

With the idea that this protective atmosphere might be produced by air or inert gases introduced into the generator during the making period, certain tests were made both in San Jose and Santa Barbara in order to determine the generator efficiency and capacity with various amounts of inerts. In general it may be said that the tests were not very conclusive but were of sufficient interest to be reported. The capacity of the generators was considerably increased, but the total production in B.t.u. remained about the same. It is of course recognized that any procedure that will increase the specific gravity of the gas will increase the cost of distribution, and for this reason the increase in the efficiency of manufacture must be quite evident before the adoption of such a method is justified.

TESTS AT SAN JOSE.

The tests at the San Jose plant consisted of adding a measured quantity of air to the generator. In the first tests the air was added at the rate of approximately 1000 cubic feet per minute, extending practically over the entire making period, and was introduced, under three pounds pressure, into the combustion or superheating chamber and the making chamber of the primary shell. As near as could be estimated, the air was injected equally into the heat and make chambers, simultaneously.

During preliminary trials, due to the large amount of additional heat made available, the B.t.u. dropped rapidly, and at 5 p.m. the first day the city gas at plant showed 470 B.t.u., and on the uptown calorimeter, at 5.30 p. m., the gas was 500 B.t.u. Calorimeter tests, just before the introduction of the air, showed that 538 B.t.u. gas was being made. Some complaints were made of "no" or "poor" pressures.

In the next day's operations the heat oil was reduced from 22 gallons to 18 gallons per run, the same amount of make oil (90 gallons in primary) being used. It was then found that the make chamber rapidly lost its heat, due to the absorption of the heat by the air admitted; the use of the air in the make chamber was abandoned, and the entire volume of air was injected into the upper chamber only. By the contact of this air with the checkers, the air was sufficiently heated to maintain good combustion with the hydrogen formed in the make chamber.

The use of the steam plus the air in the combustion or superheating chamber was discontinued almost immediately. It was found that the intimate contact and mixing of the hot steam with air resulted in a water vapor or fog, which very rapidly cooled down the checkers and prevented the proper dissociation of the make oil.

The limit of 90 gallons of make oil in the primary was increased, first to 120 gallons and then to 150 gallons, as the condition of the generator toward the end of the 90-gallon period warranted a much larger (and perhaps longer) unit make.

Summary of Tests in San Jose to Determine Effect of Adding Air to Generators.

	Test number					
	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
B.t.u. of gas made	500	557	510	450	510	560
M cubic feet of gas made	26.6	25.6	23.5	24.1	28.4	21.8
Cubic feet air per minute	1,052	0	1,093	1,122	895	0
Cubic feet air per run	6,652	0	5,465	5,610	7,831	0
Air admitted	Total run	0	1st half	2d half	Total run	0
Oil						
Make oil per minute (gallons)	20.6	18.75	20.0	20.0	20.6	25.0
Make oil per run (gallons)	180.0	190.0	140.0	140.0	180.0	150.0
Oil admitted to	Primary and secondary shell	Primary and secondary shell	Primary only	Primary only	Primary only	Top primary Bottom primary
Steam *Making period*						
Pounds per run	515.0	445.3	535.6	461.8	609.5	445.7
Pounds per M cubic feet gas	19.3	17.4	22.8	19.2	21.5	20.4
Gas Analyses						
CO_2	3.5	1.7	4.6	4.6	4.6	2.9
C_nH_{2n}	5.8	2.7	5.2	3.1	5.5	3.5
O_2	0.1	0.2	0.2	0.2	0.1	0.1
CO	6.2	7.2	6.9	8.8	6.3	8.5
CH_4	24.9	27.6	23.7	21.0	24.6	28.5
H_2	38.2	58.8	40.2	40.8	34.8	53.1
N_2	21.3	1.8	19.2	21.5	24.1	3.4
Commercial Efficiency						
$\frac{\text{B.t.u. gas}}{\text{B.t.u. make oil}}$ (per cent)	50.0	51.1	58.1	52.6	54.8	55.3

Note: Efficiency calculated on make oil only on account of heat oil used to heat both shells, whereas in tests Nos 3, 4, and 5 make oil used in primary shell only.

San Jose, September, 1921—Steam Gas and Oil.

(With and without inerts added.)

	Period of operations	
	23 days, inerts added	7 days, no inerts added
Gas		
Total gas made (M cubic feet)	27,539	8,536
Average B.t.u. (observed)	511	529
Gas made per run (cubic feet)	27,000	22,000
Gas made per operating hour (cubic feet)	108,000	90,000
Oil		
Heat oil per M cubic feet (gallons)	0.72	0.84
Make oil per M cubic feet (gallons)	6.80	6.83
Heat and make oil per M cubic feet (gallons)	7.52	7.67
Steam		
Blast and Heat Period		
Steam used per run (pounds)	113.7	149.6
Steam used per M cubic feet (pounds)	4.21	7.12
Making Period		
Steam used per run (pounds)	476.5	461.2
Steam used per M cubic feet (pounds)	17.65	22.00
Purging Period		
Steam used per run (pounds)	47.2	44.7
Steam used per M cubic feet (pounds)	1.75	2.13
Summary		
Total all steam per run (pounds)	637.4	655.5
Total all steam per M cubic feet (pounds)	23.61	31.25
Gas Analyses		
CO_2	3.4	2.4
C_nH_{2n}	5.2	3.4
O_2	0.2	0.2
CO	7.2	8.9
CH_4	24.4	24.8
H_2	42.6	55.6
N_2	17.0	4.7
Calculated B.t.u.	512	528
Specific gravity	.504	.379
Per cent non-combustible	20.6	7.3

In the discussion of the generator efficiencies, consideration should first be given to the increased capacity of the machine from approximately 90,000 cubic feet per hour to 108,000 cubic feet per hour, or 20 per cent; and, in terms of B.t.u., to about 16 per cent, using the September averages, with and without air. The ease of operation whereby this added capacity can immediately be reached is worthy, also, of special note.

Due to easily regulated oil supply (both heat and make), and proper control of the quantity of air admitted, the operating condition of the checker-brick was maintained, almost continuously, without variation in the cycle. This, together with the fact that no heavy carbon deposits interrupted the passage of the oil or gas, provided much less supervising of the daily operations. No smoke difficulties had to be overcome, as the machine came off in a cleaner manner.

On account of the granular condition of the lampblack from the crude gas, it was not so easily carried off with the wash water overflow, and a slightly heavier carbon deposit remained, requiring the washbox to be cleaned oftener.

The tar recovered in the primary scrubber was greater per thousand cubic feet of gas made, but remained in a more fluid condition. As no "carbon-tar" or pitch difficulties were met, the increased quantity to be removed was offset by the ease with which it was handled.

On account of the increased make per hour, the washer and scrubber water was proportionately increased in volume. No changes in the secondary or oil scrubbers were noted with the inerts and no apparent change in naphthalene percentages took place.

It is almost impossible to determine accurately the comparative labor expense in the two series, but it is estimated that the labor cost was practically the same per unit of gas made. The expense for electric energy for operating the high pressure exhauster used for air was negligible.

The gas distributed to the city mains during the period when air was added had an average specific gravity of .504 to .533. The gas without diluents averaged .380 to .400. This shows an increase in specific gravity of 30 to 33 per cent.

During the early part of September, when this series of tests began, several calls were received daily, assignable to "poor pressure" and insufficient gas. The consumers using gas in automatic and tank water-heaters appeared to be the majority requiring attention. All the larger gas installations in restaurants, candy kitchens, bakeries, etc., were canvassed, and the length of the gas flame on the burners was increased by closing the air shutters, thereby eliminating the principal difficulties found.

Pressure charts taken at various points disclosed a demand for a higher pressure, and as soon as this was increased about one inch, the complaints of "poor pressure" practically ceased.

Conclusions from San Jose tests.

The amount of heat oil required when air was introduced during the gas-making process was about 20 per cent less than when the same heating value gas was made in the regular way, but the percentage of make oil increased and there was no gain in the total oil efficiency by the use of air. The make per hour in cubic feet and in total B.t.u. was somewhat greater with the use of air.

An examination of the gas analyses shows an increase in illuminants. The saturated hydrocarbon (marsh gas) remained very constant, considering the proportion in which it was present.

Tests at Santa Barbara.

The experiment in Santa Barbara consisted of introducing a quantity of stack gas into the gas generator during the make period. The products of combustion were produced by the combustion of crude oil with about 100 per cent excess air in a small auxiliary generator. The original purpose of this experiment was to eliminate, if possible, the production of smoke at the end of the gas-making run. As far as the original purpose was concerned, the experiment was a failure, but the figures given below seem to show some interesting results, which may warrant further investigation.

	Regular operation (No inerts)	Experimental operation (Inerts introduced)
Days run	14	15
Total gas made	12,827,100	13,792,500
Gas making oil per M cubic feet	7.55	7.17
Heat oil per M cubic feet (gallons). (Includes oil used in auxiliary generator for inerts)	0.99	0.97
Total heat and make oil per M cubic feet (gallons)	8.54	8.14
Heat units per weighted sample taken at plant	534	527
B.t.u. in gas per gallon heat and make oil	62,529	64,742

By-Products Produced.

A one-day test on carbon production under the inert process made on November 15 is as follows:

Total gas made	735,100 cubic feet
Total wet carbon weighed out of pit	37,944 pounds
Average moisture from three samples	62 per cent
Dry carbon	14,419 pounds
Dry carbon produced per M cubic feet of gas made	19.6 pounds

Unfortunately it was impossible to get any weight or measurement of the tar produced for this day's run, but it can be stated from observation by the plant operators that the quantity of tar is materially greater than with the regular process for the same quality of gas, and the tar produced is in a much more liquid form.

Method of operation.

The cycles used under the regular operation and during the test with inerts were as follows:

	Regular operation	With inerts
	Minutes	Minutes
Dry blast	5	5
Generator heating	6	9
Gas making	20	28
Idle	2	2
Purge	3	3
Totals	36	47

During the make period under the inert process oil was burned in an auxiliary generator at an average rate of one-sixth gallon per minute, with air supplied under three pounds pressure at an average rate of 410 feet per minute as measured by an orifice meter. From this auxiliary generator the flue gas entered the top of the main generator just above the checker-brick at an average temperature of 1420° F. A sample of this gas, taken while air and oil were being introduced at the above rates, had the following composition:

CO_2	8.0%
O_2	9.2%
CO	0.4%
N_2	82.4%
Total	100.0%

Perhaps the most interesting result from the introduction of inerts and air in this manner was the increased capacity of the generator. An observation of 18 days using inerts gave an average rate of making of 66,100 cubic feet per hour. An observation of 27 days' result, under operation, gave an average rate of making of 55,300 cubic feet per hour—an increase of 19.6 per cent in favor of the inert process.

Quality of gas.

The comparative quality of the gas made with and without inerts added is best shown by two tabulated analyses of the different gases, as follows:

	No inerts	Inerts
CO_2	0.9	2.0
C_6H_6	0.7	0.8
C_nH_{2n}	2.9	4.8
O_2	0.9	0.5
CO	6.9	6.7
H_2	62.2	46.8
CH_4	22.4	23.2
N_2	3.1	15.2
B.t.u. calculated	524	515
B.t.u. observed	539	538
Specific gravity calculated	.375	.511

The important difference in the quality of the two gases is obvious from the above analyses.

Complaints.

Immediately after beginning the distribution of special gas containing inerts, the number of complaints received at the office was materially increased. The average number of complaints of every character received on 12 days with no inerts was 8.7, and the average number received per day for thirteen days with inerts added was 14.8. It should be stated, however, that the number of complaints was gradually reduced. It appeared that when the appliances were once adjusted no further complaints resulted. It is also noteworthy that there was a very substantial increase in the number of naphthalene complaints on the days when inerts were supplied, which is doubtless due to the fact that this heavier gas did not flow so freely past partial stoppages.

Conclusions.

The tests at the Santa Barbara plant show a considerable increase in generator capacity, a small reduction in oil, and an improvement in the tar. The company considers the results sufficiently encouraging to warrant further experiments along this line.

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