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LIGHTING WITH ALCOHOL AND KEROSENE.

By

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Division of Agricultural Chemistry and Soils.

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UNIVERSITY FARM,
ST. PAUL, MINN.

UNIVERSITY OF MINNESOTA

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UNIVERSITY FARM, ST. PAUL, MINN.,
July 6th, 1911.

A. F. Woods,

Director of the Experiment Station.

Dear Sir:

I transmit herewith a report on an investigation conducted by Mr. R. M. West during 1910, to determine the relative lighting values of alcohol and kerosene. Aside from its use for strictly technical industrial purposes, denatured alcohol, in those countries where most used, is used to a greater extent for lighting than for either fuel or power purposes. Owing to the lack of complete data regarding the relative lighting value of kerosene and alcohol, it was deemed advisable to conduct the above investigation.

I would respectfully recommend that this report be published as a bulletin of this Division and Station.

Yours very truly,

RALPH HOAGLAND.

Approved: A. F. WOODS, Dean and Director.

LIGHTING WITH ALCOHOL AND KEROSENE

INTRODUCTION.

The source and quality of artificial light are factors in home economy which should be carefully considered. In Minnesota, artificial light is required as early as five o'clock in the afternoon in mid-winter, and at least by half-past eight o'clock in summer. Hence, an average daily period of three hours is a conservative estimate of the time during which artificial light must be used in the home.

Outside of those cities which are equipped with illuminating gas or electrical plants, kerosene is the fuel used almost universally for lighting. An ordinary round-wick kerosene lamp will burn about a quarter of a pound of oil an hour. On this basis the average daily consumption would be three-quarters of a pound, or two hundred and seventy-four pounds for the year. This is equivalent to forty-three gallons annually for one lamp. Assuming the cost of kerosene to average eleven cents a gallon, and the use of two lights as reasonable, a total of but nine dollars and fifty cents is expended for fuel. This average sum is a small one, but in many homes it is far exceeded. In any case, however, where the old style kerosene lamp is used, the most important fact for consideration is not the size of the sum expended, but that, large or small, it is spent for a light poor in quality, inefficient and uneconomical.

To be efficient, a light must serve the purpose for which it is intended. Artificial light is required to prolong the day, and consequently that light which most nearly resembles diffused daylight is the most efficient. The strongest light obtainable is not necessarily the best; nor is the obtaining of the most light for the least money economical when it involves the production of more light than is necessary, or light of such quality as would tend to strain or injure the eye. Fuels used for lighting must yield harmless products on combustion; the atmosphere of the room should be vitiated as little as possible, and the light must be safe as well as easy to manipulate.

All forms of light are obtained by heating some substance to incandescence, that is, to the point at which some of the energy imparted in the form of heat is given off as light. The quality of the light depends upon the character of the incandescent material, as well as on the temperature to which it is heated. This calls for the consideration of two factors; the fuel, or source of heat, and the incandescent body.

Fuels for lighting may be divided into three classes, as follows:—

Class I.—Such fuels as—

1. Acetylene.
2. Tallow.
3. Vegetable oils.

The illumination from the combustion of these fuels is due to the heating of small particles of free carbon, which are obtained by decomposition on burning.

Class II.—Such fuels as—

1. Water gas.
2. Hydrogen.
3. Alcohol.

These fuels are poor in carbon, completely and easily oxidized; and, unless modified by the addition of some of the oils of Class I, burn with a non-luminous flame. They may also be burned in contact with some non-inflammable substance which readily emits light on heating.

Class III.—Such fuels as—

1. Gasoline.
2. Kerosene.
3. Coal gas.

These fuels might belong to either Class I or Class II, depending upon the form of lamp in which they are burned. They resemble the fuels of Class I, in that they are high in carbon, which is readily freed on ignition. On the other hand they resemble the fuels of Class II, since they may be completely oxidized, and made to give a non-luminous flame by the admixture of sufficient air.[1]

Any of these fuels may be fairly compared with others of the same class, while all are comparable with those of Class III. It is only recently, however, that certain improvements in lamps have placed kerosene in Class III, and made it in any degree comparable with alcohol and the other fuels of Class II. It is only recently, too, in this country, that it has been in the least practical to consider alcohol as a fuel for light, since the high revenue tax (about two dollars a gallon), in addition to its high cost of production, has prohibited its use for such a purpose.

INDUSTRIAL ALCOHOL.

January 1st, 1907, a law became effective which permitted the manufacture and sale of alcohol free from excise, subject to certain restrictions and rulings of the Department of Internal Revenue. The most

(1) Electricity, though not a fuel, might be considered as belonging to Class II, since its value for lighting lies in its ability to heat to incandescence bodies of high resistance, which are sufficiently refractory in their nature to withstand rapid oxidation.

important of these restrictions are: first, all alcohol manufactured under this law must be so treated, or denatured, as to make it unfit for internal use; and second, all such alcohol must be manufactured, denatured and sold under strict government supervision. The enactment of this law was of economic importance: first, because of the large number of industries, the products of which at some time in the course of their manufacture are dependent upon the use of alcohol;[1] and second, because it opened the field to a new fuel as a possible competitor with petroleum products in the production of light, heat, and power. The use of alcohol in many of the industries is already established, irrespective of the cost, because of the lack of a suitable substitute. A decrease to one-fifth of its former price is, nevertheless, of immense importance to those industries and increases the possibility that alcohol may be used in the manufacture of still other products.

We are particularly interested in the effect of this reduction in cost upon the use of alcohol as a fuel. How long it will be before alcohol becomes an active competitor with such fuels as gasoline and kerosene cannot be even estimated with any degree of accuracy. Viewed from the standpoint of cost per unit of light, it can be safely asserted that when the price of the petroleum products rises, or when the price of alcohol drops, so that a dollar's worth of alcohol will furnish as much light, or as much heat, or as much power, as a dollar's worth of any other fuel, alcohol will, without question, be able to command attention as one of the important fuels. Just as in the case of all other commodities, however, the price both of petroleum and alcohol, above the actual cost of manufacture, is governed largely by the ratio of the demand to the supply. The cost of the production of denatured alcohol lies largely in the value of the raw materials, which now command good prices for food.[2] On the one hand is petroleum, a natural deposit which cannot be replaced; on the other, a product of agriculture, which can be supplied, from year to year, from resources limited in their extent only by the care which is bestowed upon the soil. If it is true, as is

(1) A partial list of the industries directly affected would include the manufacture of such articles as furniture, pianos, toys, wood-finishing, decorating, watches, photographic supplies, chemical industries, dyes, collodion, whips, varnishes and lacquers, explosives, imitation leather, artificial silk, rubber, shellac, electrical industries, celluloid, and many pharmaceutical products which are not intended for internal use.

(2) At present the starch products of Minnesota, such as the grains and potatoes, are not cheap enough to permit of their conversion into industrial alcohol to be used for lighting, even if theoretical yields were to be obtained.

The conversion of cellulose into alcohol is expensive and has resulted only in small yields. The discovery, however, of a cheap and effective chemical or bio-chemical process, for the utilization of such products as straw and sawdust for alcohol, would be of immense importance; and experimental work along this line might be most profitable.

popularly supposed, that the value of petroleum products is artificially maintained, still it is very evident that eventually, and at a no very distant future, the petroleum supply will be largely diminished and the prices of petroleum products must rise. The discovery of new oil fields can only postpone this increase for a time. It requires, too, but a glance at the industries of today to show that the uses for these petroleum products are rapidly multiplying, and their consumption is steadily increasing, with presumably a diminishing supply.

It must not be assumed, however, that the price per unit of light is the only, or even the most important, consideration in the selection of a fuel for lighting. In Europe,[1] although the difference between the two is not as great as in this country, still the cost of alcohol is higher than that of petroleum, and the use of alcohol for lighting is gradually increasing. Without doubt it has many commendable qualities, as a liquid fuel, that kerosene does not have. In this country even before the removal of the excise, it was used in preference to kerosene for small heating appliances; and it is fair to assume that, before the price of alcohol actually reaches a figure at which it could favorably compare with petroleum products, it will become an active competitor as a fuel for lighting.

SCOPE OF THE EXPERIMENT.

The relation between alcohol and other fuels for lighting has already to a considerable degree been established. There remains to be determind, however, the exact relation which exists between alcohol and kerosene. Lighting literature is replete with comparisons of these two fuels, but in every instance the alcohol has been burned in a special alcohol burner, with incandescent mantle; and the kerosene in an old style flat-wick or "Rochester burner lamp."[2] The introduction of successful kerosene mantle lamps has materially changed the situation.

(1) The **Yahrbuch des Vereins des Spiritus-Fabrikanten in Deutschland** for 1910 (pp 382-3), reports the retail price of ninety per cent denatured alcohol, which corresponds in strength to the completely denatured alcohol of this country, as averaging thirty cents per gallon for the last nine years. The highest price was forty cents in 1904-5 and the lowest was twenty-five cents, in 1901-3.

The present prices for the two fuels, as quoted by Dr. Delbruck, Director of the Institute für Garungsgewerbe, are

Denatured alcohol (ninety per cent)................28 cents
Kerosene ....17 to 19 cents

The prices of kerosene are maintained by a tariff amounting to about five cents per gallon. This is imposed for the express purpose of encouraging the denatured alcohol industry.

(2) Since completing this work, Bulletin 103, of the Pennsylvania State College, has been received. This shows a comparison of alcohol, gasoline, kerosene and acetylene for lighting purposes. Although the plan of the investigation was somewhat different from this one, the comparison of alcohol with kerosene, both being burned in mantle lamps, gives essentially the same results as shown here.

The experimental work outlined in this report was begun in order to obtain data for a comparison of alcohol with kerosene under these altered conditions. As the investigation progressed, it seemed advisable to consider many of the factors, of secondary importance, which are of influence on lighting. The report also includes a brief comparison of alcohol with other illuminants, taken from the results of investigations which had furnished enough data for a fair comparison.

In this experiment it was planned to work only with portable lamps such as would be used in the home—primarily because it is in lamps of this type that kerosene is used almost exclusively. The general plan of the experimental work was as follows:—

First—Five portable lamps were selected for comparison, including both the mantle and wick types, as well as one lamp intended especially for alcohol.

Second—When possible, both alcohol and kerosene were burned in the same lamp, with the same mantle, and the comparison of the two fuels was made under as nearly identical conditions as possible. This was done in order to obviate the influence of the difference in mantles, and the differing effect of the construction of the lamps upon the light emitted.

Third—The candle power of each lamp was taken at varying degrees of intensity. Although the efficiency of a lamp is usually highest at its maximum intensity, it is not necessarily economical to use more light than the amount required.

Fourth—The amount of light obtained per pound of fuel, as well as the number of light units per dollar at the price paid for the two fuels, was calculated from the experimental results, and from these values comparisons of the two fuels were made.

Fifth—Secondary considerations involved in these comparisons were factors affecting—

1. Safety.
2. Health.
3. Eye sight.
4. Cleanliness.
5. Cost of maintenance in addition to fuel consumed.
6. Original cost of the lamp.
7. Manipulation.

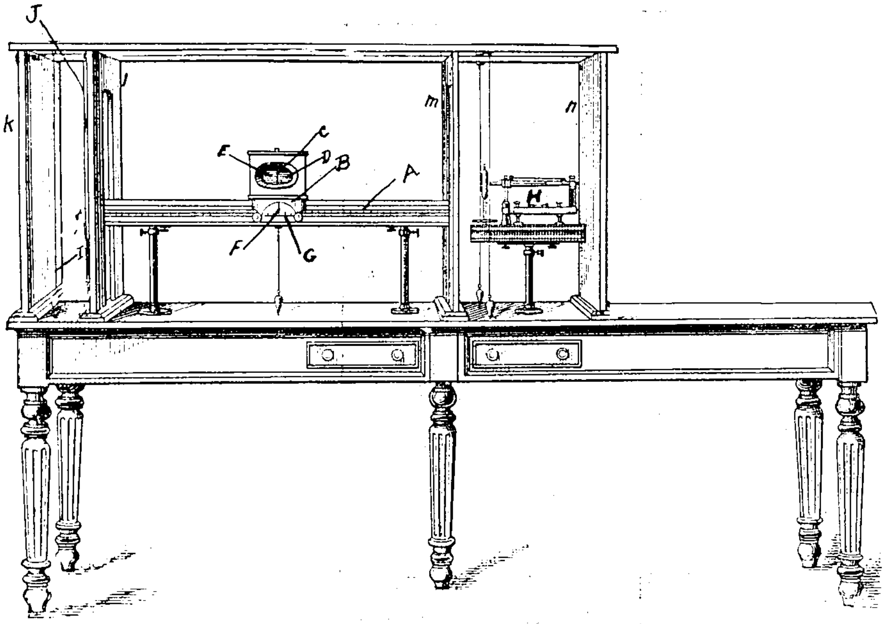
PRINCIPLES OF LIGHT MEASUREMENT.

In the measurement of light, just as in the measurement of other forms of both energy and matter, the unit is arbitrary. The unit of light measurement is the amount of light emitted by the burning of a standard candle. The specifications and methods of manufacture of this candle are fixed by law in England, and by ordinance in many of the cities of this country, in order to control the light furnished by public service corporations. The standard candle is made from spermaceti, three-fourths of an inch in diameter and one-sixth of a pound in weight. Definite specifications control the weaving of the wick, its material, size, number of strands, and twists per inch. Furthermore the size and quality of the wick must be such that exactly 120 grains per hour will be consumed. The light obtained from such a candle is called one candle of light, or is said to have an intensity of one candle power. There are several other working standards for the measurement of light, which have been adopted both for investigative purposes and for the legal regulation of light. While primarily based upon the candle light, they do not all refer to the standard English candle; hence confusion is often likely to result in comparing the reports of different investigators. In this experimental work, the English spermaceti candle was used; and throughout this report all light measurements of other investigators have been calculated to the same unit, in order to make them comparable.

Light measurement consists in comparing the light to be measured with that from the standard candle, or with some other light whose intensity is known in terms of the standard candle. The technique of light measurement depends primarily upon two principles: first, lights of equal intensities will cast equally heavy shadows at points equidistant from their sources; and second, the intensity of a light at any point varies inversely as the square of the distance from its source. To illustrate: if of two lights, of equal intensity, one is placed half as far from the eye as the other, the nearer light will appear, not twice as bright as the farther, but four times as bright. Inversely, if of two lights one is three times as far from the eye as the other, and the two lights appear to be equally bright, the farther light will be found to be nine times as intense as the nearer. These facts are just as important for consideration in the practical lighting of a room or a desk as they are for light measurement. It is plain, then, in view of these two principles, that for a comparison of two lights it is only necessary to move them toward or away from some object until the shadows which are cast are of the same intensity. The value of one light may then be readily calculated in terms of the other, after measuring the distances between the source of each light and the object utilized for casting the shadows. If one of these lights is a standard candle, the intensity of the other can be determined directly in candle power. In practice, the lights are usually made stationary, and the object is moved back and forth between the two until the shadows cast by both lights are equal. The source of error in such a comparison lies in the difficulty experienced in determining at what point the two shadows are of equal intensity. This difficulty is increased when the two lights are of different colors. For eliminating this difficulty, several kinds of apparatus for light measurement, known as photometers, have been devised.

DESCRIPTION OF THE APPARATUS.

The photometer used in the experimental part of this investigation is know as the "open bar photometer," and is the form ordinarily used for gas light measurement.

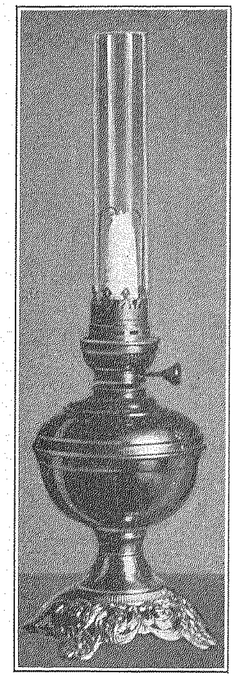


Suggs-Letheby Photometer.

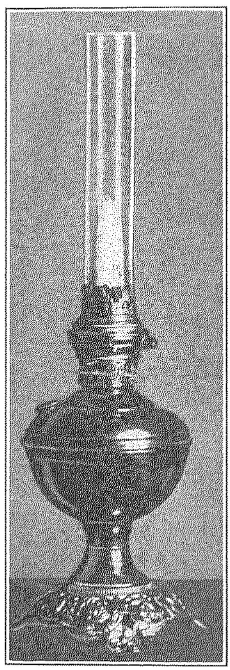
This instrument consists essentially of a graduated bar (A) on which a carriage (B) may be moved back and forth until the shadow of the figure on the diaphragm (C) is reflected with equal intensity in each of the mirrors (D) and (E). When this is effected the pointer (F) indicates on the scale (G) the relation between the two lights which are being compared. The balance (H) holds the standard candles, which are tested as to their rate of burning for each determination. The lamp to be tested is placed at the other end of the bar (A) so that the center of the flame comes between the two plumb-lines (I and J), which mark its position. The screens (k, l, m, n) are to prevent any reflected light from interfering with the test.

Description of Lamps.—The lamps which were used for this experiment were purchased at retail, without disclosing the purpose for which they were to be used, and presumably they represent the lamps which would be obtained by any purchaser.

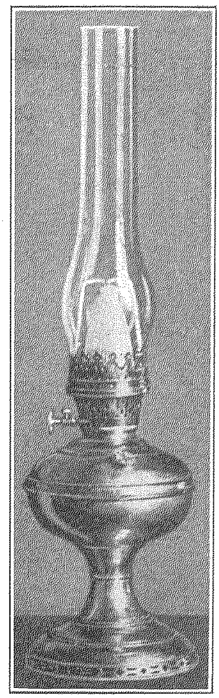
Lamp No. 1, intended for kerosene fuel, belongs to the mantle lamp type, with a wick feed. The wick has a beveled edge, which the manufacturers claim to be an aid in mixing the gas vapors with air. A flame-spreader is also used for this purpose. This lamp was found to burn satisfactorily with both oil and alcohol. The initial cost of the lamp was $4. Extra chimneys and extra mantles are sold at 25 cents each.



Lamp No. 1.



Lamp No. 2.

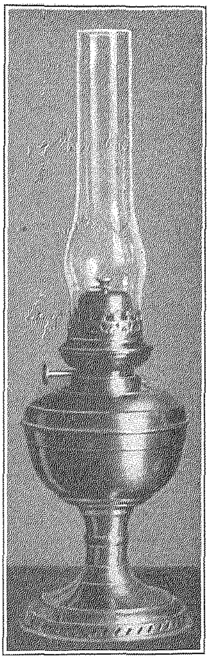


Lamp No. 3.

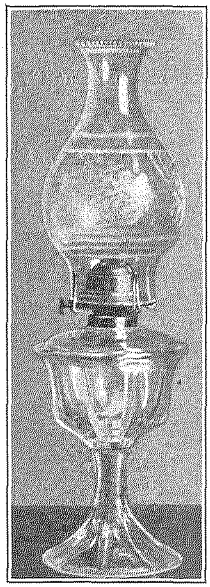
Lamp No. 2 is intended especially for alcohol, and is fitted with a gas generator and an incandescent mantle. This lamp must be primed before lighting. This is done by means of a spring pump conecting the generator with the lamp fount. After the lamp is lighted, the alcohol is conveyed to the generator by a wick. Attempts to burn kerosene in this lamp were unsuccessful. The prices of the lamp, extra mantles and chimneys are the same as those of No. 1.

Lamp No. 3 resembles lamp No. 1 very closely in the principle of its construction. It is furnished with a different style of flame-spreader, wick and chimney. The wick is larger in diameter, and the mantle is different in shape and much coarser in weave than in that furnished for lamp No. 1. Both alcohol and kerosene were burned successfully in this lamp. The original cost was $3. The prices for accessories are the

Lamp No. 4 is an ordinary round-wick kerosene lamp, with center draft supplied with a flame-spreader. This spreader was advertised to increase the size of the flame, and its intensity, without increasing the consumption. This lamp, of course, was not used with alcohol, as without a mantle a non-luminous flame would result. The lamp was the plainest style obtainable, and cost only $1.65. The price of more ornasame as in the case of the other two lamps.



Lamp No. 4.



Lamp No. 5.

mental founts is proportionally greater. Extra chimneys cost twenty-five cents, and wicks are three for ten cents.

Lamp No. 5 is an ordinary kerosene lamp, with a flat one-inch wick. This lamp cost fifty cents, chimney fifteen cents, and wicks were six for ten cents.

Fuels.—The alcohol used in these tests was completely denaturized and was bought at the rate of fifty-nine cents per gallon in five-gallon lots. The present retail price is sixty to seventy-five cents. This alcohol has a specific gravity of 0.837 at 60° F. corresponding to 6.958 pounds per gallon.

The kerosene used was slightly yellow in color. Its specific gravity is 0.846 at 60° F. corresponding to 7.033 pounds per gallon. The flash point of this oil as determined in an open tester was 144° C. with a fire point of 152° C. On distillation the oil began to boil at 160° C.; 63.5% distilled below 250° C. and 92.5% distilled below 300° C. This oil in five-gallon lots sold for 6.6 cents per gallon, and retails at from 9 to 11 cents.

PROCEDURE.

Details of Method.—The lamp to be tested was swung from an especially arranged balance, sensitive to 0.05 of a gram, in such a way that the plumb-lines of the photometer appeared through the center of the flame zone of the lamp. The lamp was then lighted, and allowed fifteen minutes in which to become heated before the test was started. In the meantime the standard candles were prepared and lighted. When the lamp had burned for the preliminary period, the height of the wick was adjusted as desired for the test, the beam of the balance was released, and enough weights added to nearly balance the lamp and its contents. In the course of half a minute or so the lamp would lose sufficient weight to be exactly counterpoised; and, as the pointer of the balance swung past the center, the exact time was recorded, as well as the weight of the lamp and its contents. The standardization of the candles was then commenced, and the lamp was compared with the standard. The tests were continued for three hours at a time. A series of readings were taken at the beginning of the first hour; in the middle of the second hour, and at the end of the third hour. Each series consisted of forty photometer readings, five direct and five reversed, for each of four different horizontal positions of the lamp.[1] The average of these one hundred and twenty readings was taken as the average candle power for the three-hour period. When the last of the readings had been taken, the beam of the balance was again released, and weights removed, until the lamp again slightly overbalanced the weight remaining. This weight was recorded; and, when the balance swung over, the time at which the pointer passed the center was again noted. The difference between the initial and final time gave the time required for the combustion of the amount of fuel represented by the loss in weight of the lamp. By calculating this loss in weight to volume, and multiplying the average candle power for any three-hour period by the number of hours for which one gallon of fuel will burn, the candle power hours per gallon were obtained. This calculation was made for each lamp, with both fuels when possible, and for several different

(1) Only the horizontal candle power of the lamp was determined.

heights of wick in addition to that height at which the maximum candle power was obtained. In no case was the wick moved during a three-hour test, except in the case of a few of the maximum candle power determinations; when it was necessary to regulate the lamp, from time to time, to prevent smoking. In the case of the mantle lamps series of tests were run in duplicate.

Discussion of Procedure.—After experimenting for a short time, it was very evident that the available candle power of a lamp depended upon several factors. A lamp which gave, during the first three-hour test, a gradually increasing candle power, gave during the second an almost constant candle power; and, during the third test, dropped from an average of 4.1 candle power for the first hour, to only 1.6 candle power for the third. An examination of the cause of this decrease showed the upper end of the wick to be so badly encrusted with carbonaceous matter as to prevent the free passage of the oil. Consequently it was found necessary to clean the wick before each determination, in order to have conditions in that respect uniform. It was further discovered that while, as a rule, the candle power increased during the three-hour period, with two successive tests this increase was proportionately less in the second than in the first, unless the lamp was filled equally before each test. When the fount was only half full, a very noticeable difference was evident, even in the course of a three-hour test. Although of minor importance, this point is of interest in view of the general practice of permitting a lamp to become nearly or quite empty before refilling.[1] Since the fouling of the wick and the decrease of oil supply made so decided a difference in the candle power, it seemed imperative that, in order to obtain results in any way comparable, a definite length of time for all of the tests should be decided upon. Three-hour tests were made, because this period was assumed to represent the average time that a single lamp would be required to burn for ordinary household use, and because it permitted of a sufficient combustion of fuel to make negligible any small error in recording the time of starting and stopping the test.

In the case of the flat-wick burner, it is plain that more light would be thrown out from the flat side of the wick than from the edge. Consequently, in taking the candle power from four different horizontal positions, a fair average of the light emitted from any side of the lamp was obtained. The same precaution was necessary in the case of the round wicks and the incandescent mantles; since it was impossible to have the wick exactly uniform at all points, and slight variations in the

(1) This same relation of the height of the oil in the fount to the candle power of the lamp was observed by Guiselin and Madoule. Jour. du Petiole, 1908, 2.

form of the mantles caused certain portions to glow more brightly than others.

The use of the incandescent mantle for illumination introduces, as the most important factor in the emission of light, the mantle itself. Consequently it appeared that a fair comparison of the two fuels could only be made by burning them in the same lamp and under the same mantle. This was done in the case of the mantle lamps. Furthermore, incandescent mantles often decrease rapidly in efficiency, particularly when first burned. This decrease depends largely on the materials used and the method of their manufacture. To compensate for consequent apparent errors in comparing the two fuels, check series were run with each lamp. Two different mantles were used. With one, the tests with kerosene were followed by those with alcohol; while with the second the two fuels were burned in the reverse order.[1]

Tests with the same lamp, but with different fuels, were carried on under as nearly as possible identical conditions with respect to the temperature and atmosphere; for the candle power of both standard candles and lamps is materially influenced by temperature, humidity and changes in the composition of the atmosphere.

The consumption and candle power of the fuel were determined, in each case, at several other intensities than the maximum at which the lamp would burn. This procedure seemed advisable, since, by charting the results, it would permit of a ready comparison, not only of the maximum candle power obtainable by each of the fuels, but also of their efficiency at any desired candle power. Furthermore such results would determine the relation existing between the rate of consumption and the candle power of the two fuels, and make it possible to ascertain at what candle power a lamp could be burned with the least proportionate consumption of fuel.

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(1) The change from kerosene to alcohol was affected by soaking the wick for some time in alcohol and finally by burning until a non-luminous flame was obtained. The wick was then cleaned and the test proceeded with. To change from alcohol to kerosene it was only necessary to allow the wick to dry over night, and soak in the oil until thoroughly wet.

RESULTS OF TESTS.

Series I, Lamp 1, Mantle 1—Kerosene.

Test No.	Time of Test Hrs., Min.	Total Consumption in Grams.	Consumption per Hour in Grams.	Average C. P.	C. P. H. per Gallon.	C. P. H. per Dollar Wholesale Price (1)	C. P. H. per Dollar Retail Price (2)
1	3 6	86	27.74	0.13	14.95	227.24	136.34
2	3 5-¼	94	30.45	0.49	51.34	730.37	468.22
3	2 55-½	100	34.19	1.46	136.23	2070.70	1242.42
4	2 57-¾	105	35.44	2.56	230.44	3502.69	2101.71
5	(Repeated)						
6	(Repeated)						
7	3 ½	116	38.56	7.44	615.52	9355.90	5613.54
8	3 6	113	36.45	3.53	308.95	4696.04	2817.62
9	2 38	101	38.35	6.12	509.09	7738.17	4642.90
10	2 55-½	117	40.00	7.90	630.05	9576.76	5746.06
11	3 4-¼	123	40.06	9.75	776.42	11801.58	7080.95
12	3 3-¼	128	41.91	13.68	1041.29	15827.61	9496.57
13	3 1-½	134	44.30	22.58	1626.01	24715.35	14829.21
14(3)	2 3-⅓	100	44.12	35.37	2557.43	38872.94	23323.76

Series II, Lamp 1, Mantle 2—Alcohol.

15	3 3	155	50.82	0.74	45.96	78.13	61.49
16	3 ⅔	162	53.82	1.14	66.85	113.65	89.44
17	2 59-½	175	58.50	3.35	180.73	307.24	241.80
18	2 58	186	62.70	5.52	277.85	472.35	371.74
19	2 59-½	203	67.86	13.03	606.01	1030.22	810.78
20	3 1	193	63.98	7.78	383.78	652.43	513.46
21	3 1-¾	217	71.64	15.21	670.08	1139.14	991.05
22	3 1-½	223	73.62	14.58	625.04	1062.57	836.24
23	3 0	194	64.67	9.48	462.65	786.51	684.26

Series III, Lamp 1, Mantle 2—Kerosene.

24	2 43-½	74	27.16	1.14	132.72	2017.34	1210.40
25	3 ½	96	31.91	6.75	274.81	10257.11	6154.27
26	(Repeated)						
27	2 44-¾	93	33.87	6.86	646.12	9821.02	5892.61
28	2 44-½	98	35.75	10.61	946.77	14390.90	8634.54
29	2 45	100	36.36	13.71	1202.87	18283.62	10970.17
30	2 57-¼	111	37.57	16.28	1382.35	21011.72	12607.03
31	2 59-¼	120	40.17	24.19	1921.05	29199.96	17519.98

Series IV, Lamp 1, Mantle 3—Kerosene.

32	2 57	96	32.54	1.08	105.88	1609.38	965.63
33	2 57	111	37.75	4.88	412.39	6268.33	3761.00
34	2 52-¼	117	40.75	9.46	740.58	11256.82	6754.09
35	2 52	120	41.86	15.99	1218.58	18522.26	11113.36
36	2 47-¾	122	43.64	20.50	1498.57	22778.26	13666.96

Series V, Lamp 1, Mantle 3—Alcohol.

37	2 34-¾	143	55.45	0.74	42.12	71.60	56.35
38	2 44	192	70.24	4.70	211.19	359.02	282.55
39	2 58	235	79.21	11.52	459.01	780.32	614.11

Series VI, Lamp 2, Mantle 1—Alcohol.

Test No.	Time of Test Hrs. Min.	Total Consumption in Grams.	Consumption per Hour in Grams.	Average C. P.	C. P. H. per Gallon.	C. P. H. per Dollar Wholesale Price (1)	C. P. H. per Dollar Retail Price (2)
40	2 56	235	80.11	36.30	1430.11	2431.19	1913.35
41	2 29	129	51.95	24.76	1504.24	2557.21	2012.52
42	3 1-¾	152	50.18	20.18	1269.22	2157.67	1698.09
43	2 51-¼	130	45.37	14.89	1035.79	1760.84	1385.78
44	2 52-¾	122	42.37	11.06	823.85	1400.55	1102.23
45	2 49-½	97	34.34	5.09	467.81	795.28	625.89
46	2 53	72	24.98	0.84	106.13	180.42	141.99
47	2 56-½	229	77.84	42.93	1740.64	2959.09	2328.80

Series VII, Lamp 2, Mantle 2—Alcohol.

48	2 51-¾	88	30.74	1.22	125.25	212.94	167.58
49	2 53	123	42.66	6.14	454.25	772.23	607.75
50	2 46	129	46.63	7.86	532.00	904.40	711.76
51	2 45	153	55.70	14.16	802.33	1363.96	1073.44
52	2 48-½	163	58.04	18.72	1017.96	1730.53	1361.93
53	(Repeated)						
54	2 49-¼	184	65.23	24.35	1178.15	2002.86	1576.25
55	2 50	222	78.35	35.41	1426.39	2424.86	1908.36
56	2 46-½	202	72.79	33.90	1469.87	2498.78	1966.44
57	2 40-¼	220	82.37	38.12	1460.61	2483.04	1954.15

Series VIII, Lamp 3, Mantle 1—Kerosene.

58	2 49-½	104	36.81	1.20	104.00	1580.80	948.48
59	2 53-¾	123	42.47	7.53	565.61	8597.27	5158.36
60	2 51-½	129	45.13	12.92	931.28	13881.86	8329.12
61	2 55-¼	142	49.19	25.53	1655.67	25164.97	15098.98
62	2 55-½	152	51.97	35.77	2195.71	33374.79	20024.87
63	(Repeated)						

Series IX[4], Lamp 3, Mantle 1—Alcohol.

64	1 49-½	124	67.95	1.75	81.28	138.18	108.75
65	1 46-¾	135	75.88	6.60	274.51	466.67	367.27
66	1 49-½	153	83.93	10.66	400.86	681.46	536.31
67	52-¼	82	94.16	15.86	531.60	903.72	711.23

Series X, Lamp 3, Mantle 2—Alcohol.

68	1 54	137	72.11	5.32	232.85	395.85	311.63
69	54	89	98.89	16.77	535.21	909.86	716.06
70	1 57-½	117	59.60	0.80	42.36	72.01	56.67
71	1 53-¾	152	79.48	10.21	405.33	689.23	542.42

Series XI, Lamp 3, Mantle 2—Kerosene.

72	2 58-½	105	35.29	1.05	94.92	1442.78	865.67
73	2 43	124	42.76	7.01	522.96	7949.30	4769.58
74	2 53-½	130	44.95	10.89	772.86	11747.47	7048.48
75	2 54-¼	133	45.79	17.40	1212.22	18425.74	11055.44
76	2 58-½	157	52.77	40.39	2441.70	37113.84	22268.30
77	2 54-¾	135	46.35	19.68	1354.52	20588.70	12353.22
78	2 55-¼	142	48.61	27.55	1808.02	27481.90	16489.14
79	2 55-½	160	54.70	52.94	3087.46	46929.39	28157.63

Series XII, Lamp 4, Kerosene.

Test No.	Time of Test Hrs. Min.	Total Consumption in Grams.	Consumption per Hour in Grams.	Average C. P.	C. P. H. per Gallon.	C. P. H. per Dollar Wholesale Price (1)	Retail Price (2)
80	2 53–½	169	58.44	8.84	482.56	7334.91	4400.95
81(5)	2 23–¾	209	87.23	33.74	1233.91	18755.43	11253.26
82	2 53–½	219	75.73	18.99	799.95	12159.24	7295.54
83	2 50–¼	192	66.47	13.68	656.54	9979.41	5987.65
84	2 54–½	225	77.36	21.16	872.57	13263.06	7957.84

Series XIII, Lamp 5—Kerosene.

Test No.	Time of Test Hrs. Min.	Total Consumption in Grams.	Consumption per Hour in Grams.	Average C. P.	C. P. H. per Gallon.	C. P. H. per Dollar Wholesale Price (1)	Retail Price (2)
85	2 58	38	12.81	1.64	408.41	6207.83	3724.70
86	3 04–½	70	22.76	4.67	654.56	9949.31	5969.59
87	2 51	95	33.33	7.73	739.86	11245.87	6747.52

(1) The wholesale prices paid for the fuel used in this investigation were: alcohol, 59 cents per gallon and kerosene, 6.6 cents per gallon.

(2) The present retail prices are: denatured alcohol, 60 to 75 cents per gallon and kerosene, 9 to 11 cents. The high price was used for the calculation.

(3) Test No. 14 terminated at end of 2 hrs., 3⅓ min. on account of smoking.

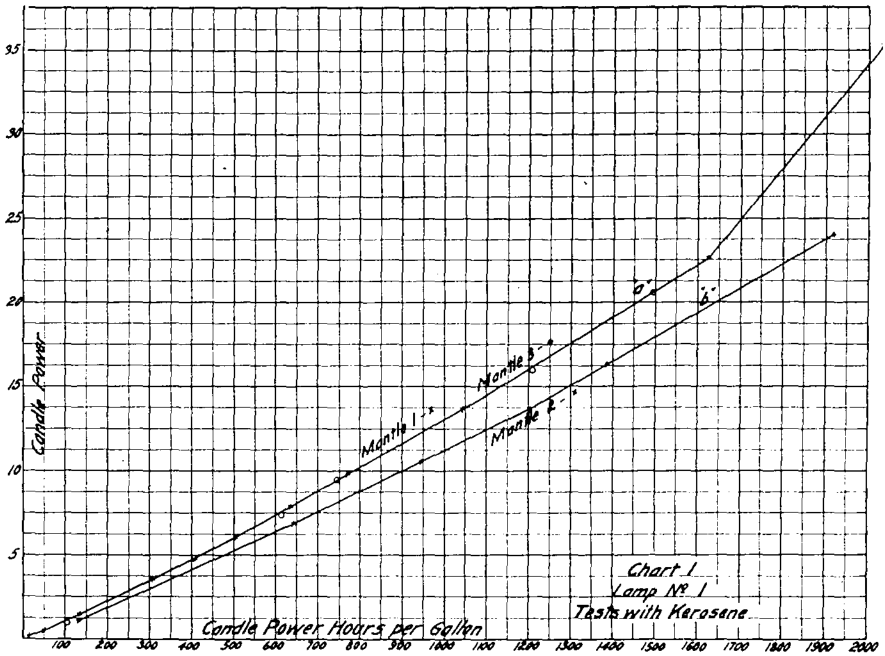
(4) The tests in this series and in Series X could not be run for three hours; at the end of the time indicated the burner became so hot that the alcohol burned in the base of the lamp and smoked the mantle.

(5) Test No. 81 was discontinued because of empty fount. The wick fouled very rapidly at maximum candle power and required constant attention to prevent smoking. At the end of the first hour the candle power fell off rapidly. It was impossible to burn this lamp at a lower candle power than 8.84 on account of the flame-spreader, which caused the lamp to smoke below the minimum as well as above the maximum.

DISCUSSION OF RESULTS.

Since the candle power readings could not conveniently be taken at any set degree of intensity it will be more practical to compare the results of these tests from a series of curves than from the tabulated readings. These curves represent the ratio of the candle power of the light to the candle power hours per gallon of fuel.

Chart 1 shows such a comparison of the results with kerosene, with each of the three mantles used on lamp No. 1. The two curves show that the candle power hours per gallon increase almost in direct proportion to the increased candle power. With mantle No. 1, as the candle power approached a maximum, the increase in efficiency was less rapid. The lights obtained from mantles Nos. 1 and 3 were very nearly the same, for a corresponding consumption of fuel. The curve is drawn through the points obtained by experiment with mantle 1. These points are indicated by X; while points on the curve for mantle 3 are shown by O. Mantle 2, although its maximum candle power was much lower than No. 1, showed almost as high a total number of candle power hours per gallon and a much higher comparative efficiency than either mantles 1 or 3. For example, at "a" a 20-candle power light shows 1460 candle power hours, while the same candle power in the case of mantle 2 at "b" would give an efficiency of 1650 candle power hours:

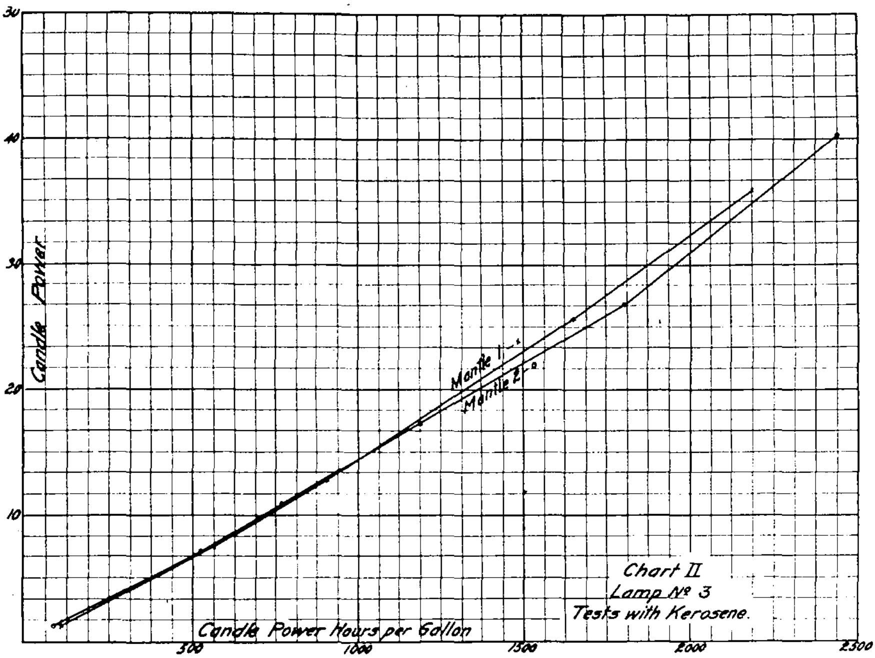


an increase of about 13 per cent. due to the mantle alone. The maximum candle power which could be obtained with any mantle was found to depend largely upon its regularity in shape. Depressions in the mantle tended to blacken, and consequently prevented the wick from being turned high enough to heat the entire mantle to the degree of incandescence that would otherwise be possible. As a consequence, in the use of two mantles with the same lamp and the same fuel, there appeared a greater variation in the maximum candle power obtainable than in the candle powers per gallon for any given intensity.

Chart No. II presents the curves obtained with lamp No. 3, using kerosene as fuel. The two mantles used in these tests resembled each other very closely in their efficiency. The maximum intensity, however, was greater by over seventeen candle power in the case of mantle No. 2.[1] The slight difference in efficiency, too, is in favor of this same mantle. Reference to Chart No. IV, Series IX and X, shows that the difference, although less in the case of alcohol, also gives mantle No. 2 the advantage. In fact, if it had been possible to obtain a slightly

(1) The maximum candle power, 52.94, is not shown on the chart. See table.

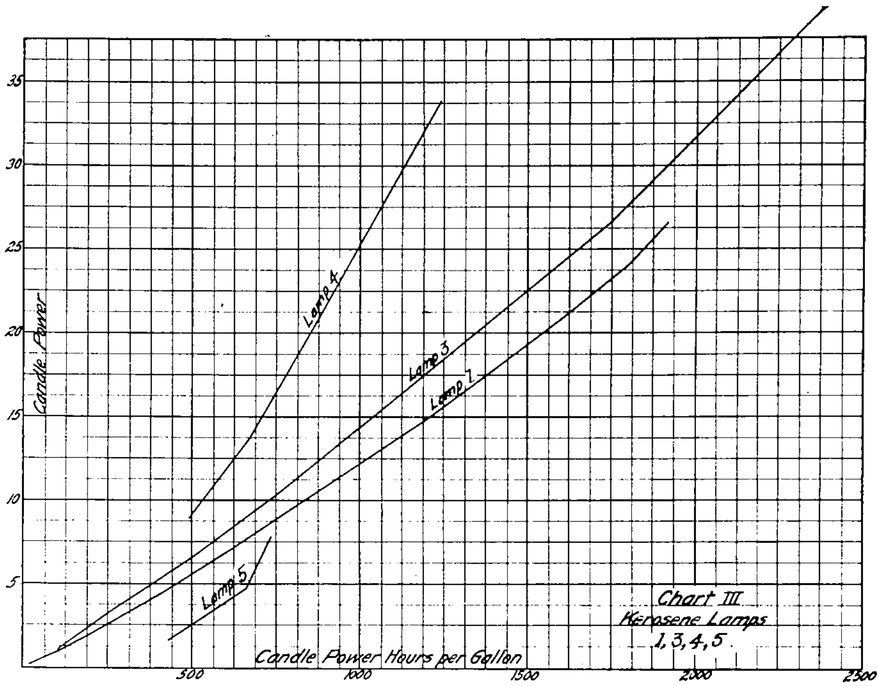
higher candle power with mantle No. 1, using kerosene, and thus extending the curve in the same general direction to the intersection of the curve for mantle No. 2 on Chart II, we should have the relation



expressed between the efficiency of the two mantles with kerosene almost identical with that shown in the case of alcohol with these same mantles.

Chart No. III shows the results obtained in Series XII and XIII, with the kerosene lamps Nos. 4 and 5 equipped with wick burners. The high minimum candle power in the case of lamp No. 4 was caused by the action of the flame-spreader, which caused smoking if the wick was turned too low. These two curves emphasize, more forcibly than the others, the fact that a definite lighting efficiency cannot fairly be ascribed to any fuel, irrespective of the lamp in which that fuel is burned. A comparison of the light obtained in the wick lamp and in the mantle lamp is also shown on this chart. There is no doubt, from the comparison of the four curves, that although the ordinary flat wick burner (lamp No. 5) has the highest efficiency, the maximum candle power is too low to make it an economical lamp for most purposes. Its efficiency, too, is relatively much less with increasing intensity. Of the other three lamps, the round wick, center-draft burner (lamp No. 4) is lowest in efficiency, while of the two mantle lamps, lamp 3 at its maximum, has a higher efficiency than lamp 1; although, candle power for candle power, lamp 1 produces the greatest number of candle power hours per gallon.

Chart No. IV shows the results obtained with each of the three



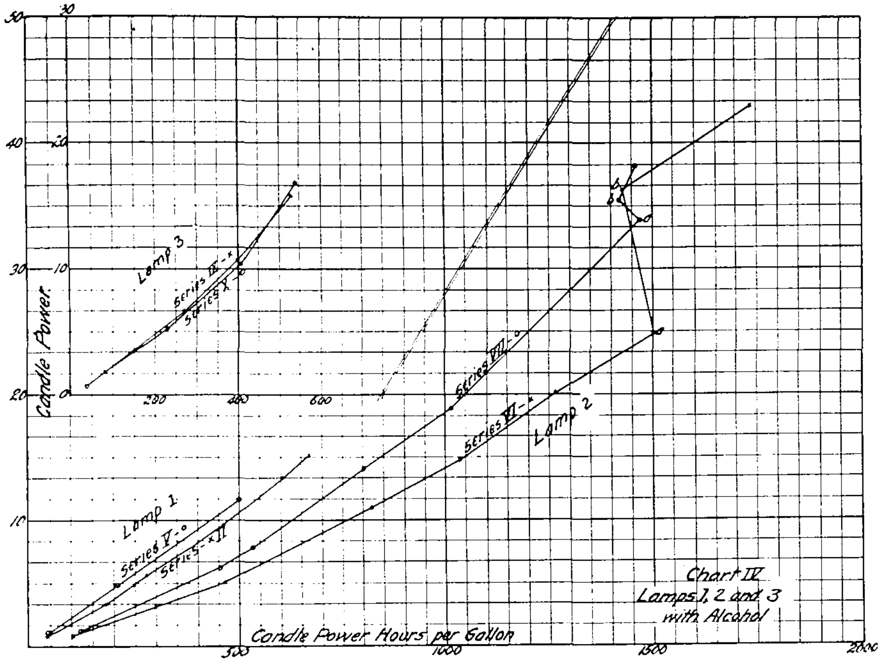
lamps in which alcohol was burned.[1] As is evident (Series VI and VII), the lamp which was designed for alcohol shows the highest efficiency for any given candle power, beside furnishing the highest maximum candle power. A peculiar coincidence to be noted is the marked loss in efficiency from "a" to "b" on each of the curves drawn for this lamp. This may be due to a faulty air-supply at this point. Series II, V, IX and X, representing the results of burning alcohol in the kerosene lamps, resemble each other very closely both in efficiency and in the maximum candle power obtainable.

The curves on Charts V and VI represent the means of the curves for the two mantles of lamps 1 and 3, respectively, in which both fuels were burned. These show, in both instances, not only a much higher candle power in the case of the kerosene, but a much higher efficiency for equal candle power as well. It is evident from these results that a

(1) To avoid confusion the curves for lamp No. 3 (Series IX and X), are set above the others, since several points on these two curves would coincide with those of lamp No. 1 (Series II and V).

fair basis for the comparison of these two fuels is a difficult matter to decided upon.

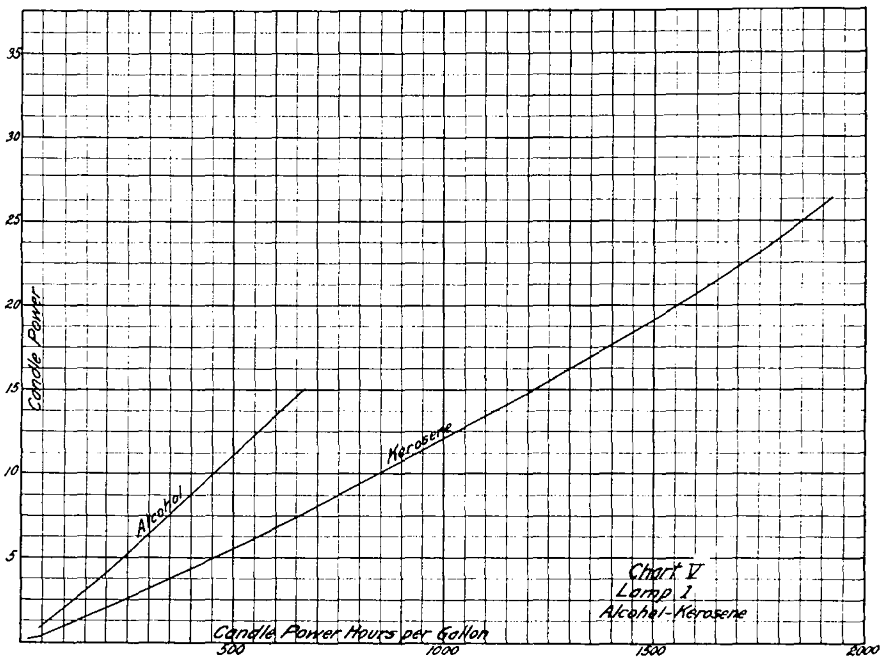
The two prime factors in light production (heat and incandescent body) are modified in their effect on each other by the details of the



lamp construction. With mantle lamps the degree of incandescence is affected by the materials, construction, and method of manufacture of the mantle, as well as by the heat imparted to it by the combustion of the fuel. The effective heat, too, is dependent largely on the pressure at which the fuel is fed and the amount of air supplied for combustion. A mantle must be symmetrical, and to be of maximum efficiency must be adapted in shape to the burner on which it is to be used. Otherwise it is heated unevenly, and portions of the mantle may fail to become incandescent. The texture of the mantle affects the area of the light-emitting surface. Consequently, in comparing two mantles, the number of threads per square inch, as well as the size of the thread, must be considered. Too close a weave results in poor circulation, and a decrease in the light given out, due to the retention of the products of combustion within the mantle, and a consequent decreasing rate of combustion of fuel. As an example of the effect of the composition of the impregnating solution used in the manufacture of mantles on their light-emitting power, V. B. Lewes[1] states that a solution of thoria alone

(1) Jour. Gas Light. 104, 192.

gives practically no light. The addition of one per cent. of ceria gives a mantle of wonderfully high lighting efficiency; while, by increasing the proportion of ceria over two per cent, this efficiency rapidly decreases. After dipping, the mantles are put through a wringer, which



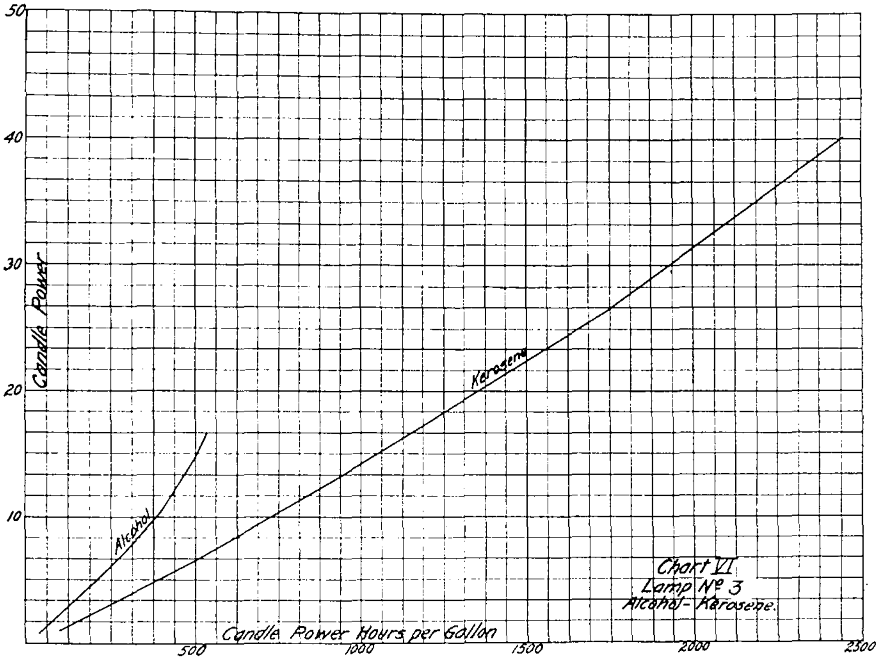
is adjusted to permit of the retention of the desired amount of impregnating solution. The amount of this solution retained has a very marked influence on the lighting value of the mantle, as well as on its life. The fabric used in the manufacture of the mantle is of hardly less importance. Thus, while a cheap cotton-fabric mantle will rapidly lose in efficiency during the first hundred hours it is burned, a mantle of ramie or China grass fabric may actually increase in efficiency.[1]

The air-supply also affects the heat produced, and consequently the lighting power of the fuel. An insufficient amount results in incomplete combustion and the vaporization of a portion of the fuel unburned. An excess of air, on the other hand, carries off a portion of the heat generated, thus decreasing the net heat available for the mantle. For complete combustion, kerosene requires much more air, pound for pound, than alcohol. Hence a lamp arranged to supply air for the combustion of kerosene furnishes more air than necessary for the

(1) Bohm, C. R. Chem. Ztg., 33, 447.

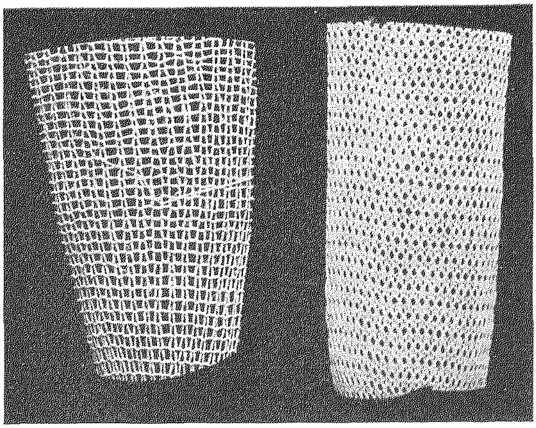
burning of alcohol. On the other hand a burner intended for alcohol would result in the incomplete combustion of the kerosene, and cause blackening of the mantle from the carbon which is not burned.

The pressure in a wick-fed lamp is caused principally by the draft



created through the chimney. In consequence, the height of the chimney is of very material influence on the amount of air supplied for combustion. Thus, while a kerosene lamp requires a very tall chimney, the alcohol will burn successfully with a much shorter one. In the case of lamps in which the fuel is supplied by gravity, this factor may, of course, be more easily controlled. To offset this apparent fallacy in the comparison of the two fuels, as burned in the same lamp, there is the fact that—while, pound for pound, alcohol will require only about half as much air as kerosene—under equivalent conditions, nearly twice as much alcohol as kerosene was burned in the same length of time. Since the efficiency of alcohol, burned in the special alcohol lamp, is comparatively much higher than that of the same fuel burned in the kerosene lamps, it would seem unfair to base a comparison solely on the results of the tests with those two lamps in which both fuels were successfully burned. A glance at the picture of the two mantles, however, will explain where a portion of this seeming discrepancy lies.

Mantle I shows the texture of the kerosene lamp No. 3, while II shows a mantle from the alcohol lamp. It is easy to see that much of the increase in comparative efficiency is due to the closer weave of the alcohol mantle, with a correspondingly greater light-emitting surface.



MANTLE I. MANTLE II.

Probably, however, to give a fair comparison of these two fuels, their true relative lighting values must be considered as being somewhere between that represented by the comparison of the two fuels burned in the same lamp, and that in which each fuel is burned in the lamp designed for its use.

In spite of the much higher efficiency of kerosene, per unit of cost, in other respects alcohol leads kerosene and is more desirable. Alcohol is a safer fuel for all purposes, since it is miscible with water, which may be used to extinguish an alcohol fire. The petroleum oil, on the other hand, floats on water and the use of water in case of fire serves only to spread the flames.

Since alcohol, pound for pound, requires less air than kerosene for burning, the products of combustion are less, as is the vitiation of the air in a closed room. For equal candle powers, however, the difference in this respect is much less, since a greater consumption of alcohol is required.

The character of these products of combustion should also be considered. If the combustion is complete in each case, water and carbon-dioxide will be the only products formed. If the supply of air is insufficient, however, the kerosene lamp will smoke, due to the liberation of carbon. The alcohol, on the other hand, if only partially burned, may form aldehyde, and even formaldehyde, from the wood alcohol used in denaturizing. The presence of these products in any amount should, of course, be guarded against; but there is little likelihood of their formation if the alcohol lamp is kept clean, and the free passage of the air unobstructed.

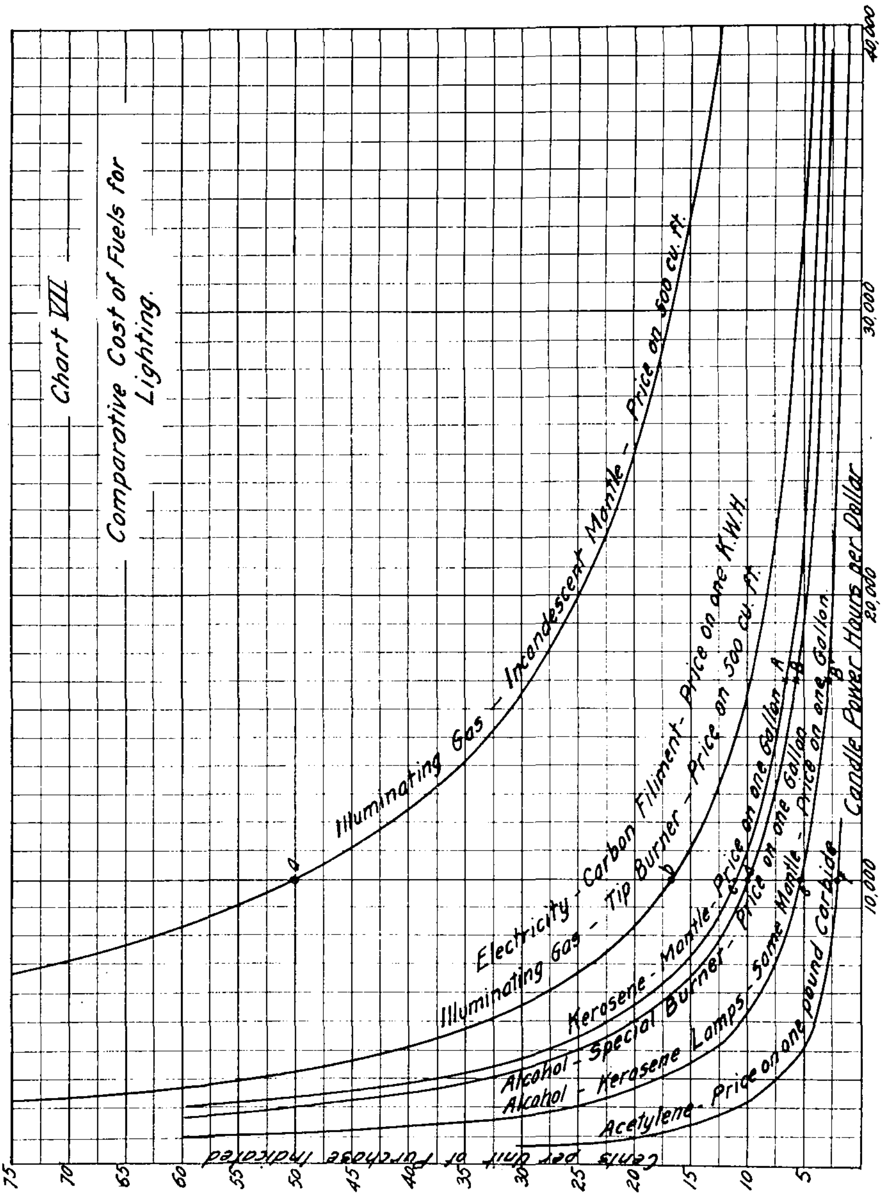
The character or quality of the light is as important as the quantity. In the case of the mantle lamp, the color of the light depends on the character of the mantles rather than on the fuel. Both alcohol and kerosene give good white lights. The best quality of light obtainable, of course, would be that which most nearly resembles daylight. The yellow light of the old-style kerosene lamp is acknowledged to be the worst of all forms of artificial lighting in this respect.

As to cleanliness, alcohol has the advantage. It evaporates readily; and, though the addition of pyridine for denaturizing gives a very unpleasant odor, the alcohol leaves no stain or grease-spot. In the use of alcohol, too, the wick is encrusted less, and the tendency of the mantles to blacken is obviated. The blackening of the mantles is one of the most troublesome features in the manipulation of the kerosene mantle lamps. At or near their maximum light, in particular, they require close attention to prevent their smoking. Burned at a normal height of wick, however, and if the manufacturer's directions are closely observed, and the wick is not turned too high when first lighted, no trouble should be experienced. Any irregularity in the mantle has a tendency to blacken, especially after having been used for some time. Consequently, cleanliness, trimming of the wick, and the general care of the lamp, require constant attention for good results.

The cost of maintenance, aside from the cost of the fuel, is about the same for all of the mantle lamps, although a lower burning temperature in the case of the alcohol lamp tends to result in a decreased consumption of the wick. The cost of the wick, however, is of less consideration than the loss of light resulting from its becoming encrusted with carbon. Greater care must be taken in the handling of portable mantle lamps, because of the very fragile mantles. With reasonable care, however, one mantle ought to serve for several months. It is very probable, in view of these facts, that alcohol will come into general use even before its price reaches that of kerosene.

In order to provide for fluctuation in prices of the various fuels, at different points throughout the state, Chart VII was arranged.

The curves on this chart show the number of candle power hours obtainable for one dollar, at any given market price, in the case of the common fuels. These curves are based on the lighting efficiency, not at the maximum candle power, but on the efficiency of a sixteen candle power light, which is ordinarily sufficient for reading within a horizontal radius of from five to six feet.[1] A comparison of the market price of any two fuels with the candle power hours per dollar, as shown



in this chart, will show at a glance the most economical fuel to be used.

(1) This low candle power was selected because the most efficient method of lighting is to have several sources of low intensity rather than one of high. Thus, five lamps of sixteen candle power will be a much more efficient means of lighting than one eighty candle power lamp.

Points on any curve, in the same vertical line, are points of equal candle power hours per dollar. The horizontal position of these points shows the price at which the corresponding fuel would have to sell in order that they might all be equally economical for lighting purposes. For instance, the point "a" indicates 10,000 candle power hours per dollar, with illuminating gas selling at 50 cents for 500 cubic feet, or $1 per 1,000 cubic feet. The point "b," directly beneath "a," shows the same number of candle power hours per dollar, in the case of either electricity or gas, with a tip burner; but, in order to obtain the same number of candle power hours per dollar, in the case of either electricity or gas, the gas would have to sell for 16½ cents per 500 cubic feet, while electricity would still be as cheap at 16½ cents per kilowatt hour. The point "c" shows that kerosene would still be comparatively economical at eleven cents per gallon, while alcohol would have to sell at some price between five and ten cents per gallon, as shown at "d" and "e." For acetylene to compete with these other fuels, calcium carbide would have to sell at two cents per pound. At 6½ cents, the price paid for kerosene for use in this investigation, as shown at A, a sixteen candle power light may be maintained, giving 17,000 candle power hours for one dollar. In order to give the same economy, alcohol, as shown directly below at B and B″ would have to sell at from 3 to 5½ cents per gallon, as compared with a present price of 59 cents.

In the same way, alcohol may be compared with the other fuels. The curves obtained with alcohol burned in the special alcohol burner, as well as that obtained by burning alcohol in the kerosene lamp, are shown. It is probable that neither of these are strictly comparable with the kerosene curve, as already explained, but that the true efficiency curve lies somewhere between the two. In any case, however, alcohol must sell at something below the price of kerosene in order to compete with it, if only the actual cost of the fuel is to be considered.

While the efficiency of these fuels is given for only sixteen candles of light, a glance at the other charts will show that, in the case of kerosene as well as alcohol, the efficiency is much higher when the lamp is burned at its maximum intensity. Although it would be possible to design a lamp with a lower maximum candle power, with possibly as high an efficiency as these lamps at their maximum, for many purposes more than sixteen candle power are necessary; and such limitation of the light would be undesirable.

CONCLUSIONS.

The comparison of these two fuels justifies the following general conclusions:

First—With all the lamps tested the greatest amount of light per unit of fuel is obtained at the maximum candle power which the light will give.

Second—Kerosene burned in the old-style lamp, without a mantle, gives a poor quality of light, and is an uneconomical and inefficient fuel.

Third—Mantle lamps for either fuel are efficient, and give a light of good quality, although somewhat greater care is necessary in their manipulation.

Fourth—A comparison of these two fuels, alcohol in a mantle lamp and kerosene in a wick burner, is greatly misleading. Such a comparison gives alcohol over double the lighting value of kerosene; while, with each fuel burned in the lamp best suited to its use, kerosene has the higher efficiency.

Fifth—When alcohol and kerosene are burned in the same lamp and under the same mantle, the lighting value of alcohol is approximately one-half that of kerosene. The two fuels under these conditions stand in nearly the same relation as regards their lighting values as they do in their heating values. This is to be expected, since within certain limits the incandescence of the mantle is proportional to the temperature to which it is heated.[1]

Sixth—The alcohol burned in the special alcohol burner (lamp 2) gives only a slightly lower efficiency than kerosene in the mantle lamps. While, as has been shown, a comparison in the case of two different lamps is of doubtful value, yet alcohol should be credited with the difference between the efficiencies obtained by burning that fuel in the special alcohol burner and in the kerosene mantle lamps, in so far as this difference is due to the texture of the mantle and not to its size or the character of the solution used for impregnating it. The use of kerosene in a mantle so closely woven has not as yet been found practical.

Seventh—It is unfair to ascribe a definite lighting power to any fuel, irrespective of the lamp in which it is burned. This is especially true of those fuels that in themselves supply only the heat factor and not the incandescent substance. New materials and new methods for the manufacture of incandescent mantles will undoubtedly be introduced. There will be further improvements in the lamps. Whatever these may be, with some slight modification, they probably will be made adaptable to either alcohol or kerosene. It is possible, too, that improvements in the

(1) It, of course, is not expected that the two fuels will ever be used interchangeably in the same lamp. The comparison in this experiment was in order that all of the conditions might be controlled, and the effectiveness of the two fuels in their relation to each other observed.

kerosene mantle lamp, allowing for a more complete admixture of air, will permit of this fuel being burned under a mantle of as fine a texture as that used for alcohol. Whether this be accomplished or not, it seems safe to predict that, while the absolute amount of light obtainable with any of these fuels may be materially increased, it is doubtful if their relative lighting values will be greatly affected.