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PHYSICAL AND CHEMICAL PROPERTIES OF GASOLINES  
SOLD THROUGHOUT THE UNITED STATES DURING  
THE CALENDAR YEAR 1915

BY

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# PHYSICAL AND CHEMICAL PROPERTIES OF GASOLINES SOLD THROUGHOUT THE UNITED STATES DURING THE CALENDAR YEAR 1915.

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By W. F. RITTMAN, W. A. JACOBS, and E. W. DEAN.

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## INTRODUCTION.

The Bureau of Mines, in the course of its petroleum investigations, has noted the dearth of published information regarding the physical and chemical properties of different varieties of gasoline generally marketed. Such information is of great importance both to producers and consumers, and for this reason it was deemed advisable to conduct an investigation to determine the properties of gasoline sold throughout the United States during 1915. The results of this investigation are reported in this paper.

## DEFINITION OF GASOLINE.

Gasoline has been defined in one of the standard dictionaries as "a highly volatile mixture of fluid hydrocarbons, obtained from petroleum; also by distillation of bituminous coal." The present work might well have been suggested by an attempt to make this definition more nearly complete and up-to-date. The definition is fairly adequate with regard to the source of gasoline, needing only to be extended so that it includes products extracted from natural gas by processes of compression or washing. The definition of the properties of gasoline is both comprehensive and indefinite. "Highly volatile" has no exact meaning when interpreted in degrees of temperature for boiling point or millimeters of mercury for vapor pressure. Also, the definition given does not indicate the uses of gasoline.

For the purposes of this report it is not necessary to discuss the sources and origin of gasoline, nor is there much interest at present in any use but one, which is as fuel for internal-combustion engines. The matter of chief importance is the definition of properties, which, as superficial consideration shows, introduce so many complications that a few words or even a few sentences are not adequate.

**NEED OF INFORMATION REGARDING PROPERTIES OF GASOLINE.**

Gasoline is now of such great commercial importance that adequate information regarding its physical and chemical properties should be furnished the public. The testing of gasoline for these properties is by no means novel or original, but in the past it seems to have been limited to refinery laboratories, and the refiners have not deemed it desirable to publish the information that they possess. Detailed descriptions of the properties of products have not, apparently, appealed to them as good advertising literature. To the authors' knowledge no advertisement has ever stated, for example, that a gasoline had an "iodine number" less than 6 or that 80 per cent of the gasoline would distill between temperature limits of 50° and 125° C., nor has any attempt been made to educate the public with regard to the advantages and disadvantages of low iodine numbers and narrow ranges of volatility. The common variety of advertisement usually states that the wise user gets more power out of the brand of gasoline sold by the advertiser, or that carbon troubles are eliminated, or that it "puts life in the motor," and so on.

Automobile users sometimes try to keep a check on the number of miles their cars will run on given quantities of gasoline, and they also note relative ease of starting and freedom from carbon deposition in the cylinders of the motor. The specific gravity and odor are properties commonly considered in judging the commercial value of a gasoline and a drying test is sometimes performed to determine whether the gasoline is admixed with kerosene.

**SCOPE AND LIMITATIONS OF THE PRESENT REPORT.**

The object of the investigation described herein has been to serve the public impartially in an educational way and not to emphasize the advantages or disadvantages of any variety of gasoline. The data obtained show the properties of a number of products, which were representative of commercial conditions throughout the country during the calendar year 1915. The analyses in themselves are of considerable importance and are of use in showing how similar tests may be generally applied and interpretation made to fit the specific needs of producers and consumers.

A specific example will illustrate the method with which this information has been obtained and presented. In the past gasoline has been generally obtained from crude petroleum by "straight distillation" processes. At present one of the important products in the market is the so-called blended casing-head gasoline. That product as finally put forth represents nearly 10 per cent of the total output and has served admirably to aid in preventing shortages in the market. This paper has not attempted to show that the char-

acteristic properties of a blended casing-head gasoline make it superior or inferior to a "straight" refinery product. The results do show, however, what these properties are and indicate how they may be determined.

A few tests of power development were made in connection with this study. These tests were necessarily of limited scope, and showed chiefly that the gasolines used did not differ widely in this respect, and that variations relate more to the ease with which the gasoline can be utilized rather than to the amount of power that can be developed under favorable conditions.

The bulk of the results given in this report go to show that there are possibilities of wide variation in the properties of gasolines and that a product bearing this name can not be defined as exactly as might be expected. However, by noting certain properties or relations between properties, it is possible to discover with some accuracy the source, method of production, and possible utility of the products examined.

## **STATUS OF GASOLINE MARKET IN FIRST FEW MONTHS OF 1916.**

### **UNSETTLED MARKET CONDITIONS.**

Recently (up to about August, 1916) there was a threatened shortage in the gasoline market and for a time prices soared in a manner to alarm consumers and arouse producers to great activity. There has resulted an increased production of crude oil in the Mid-Continent fields, and in addition refining methods have been so changed that gasolines of higher "end point" have been put out. This means that gasolines of the newer type contain considerable percentages of constituents that were formerly sold in the burning-oil fractions. Some of the samples collected during the present investigation show this tendency, but it is not universal and in studying the data this fact must be kept in mind. As the present is a transition period, no attempt has been made to study in detail the properties of the products recently put out. Such a study will be made at a later date when refinery practice has again become more uniform. For the purpose of this report a large number of samples were collected in the late spring of 1916. These were tested and their specific gravities were determined, with the view of obtaining indications as to the magnitude of the possible transition and also to show the average grade of the product being marketed.

### **TYPES OF GASOLINE SOLD IN THE MARKET.**

In considering the commercial types of gasoline, consideration must be given chiefly to methods of refining and production. The differences existing may be roughly divided as follows: (1) Varia-

tions due to grading according to specific gravity; (2) variations due to the source of the original crude oil, as the eastern fields, the Mid-Continent fields, and California; and (3) variations due to processes of production, as "straight" refinery products, blended casing-head gasoline, and gasoline produced by cracking processes.

Variations due to specific gravity need little discussion. It has been the accepted practice in the East for refiners to put out several grades of gasoline and naphtha, these products being differentiated according to their specific gravities. The highest-priced grade, called "76°" gasoline, is as light as is practicable to use, dangers in handling and evaporation losses being considered. Such gasoline really has a specific gravity of 73° to 74° B., the 76° figure being a trade rating which is not attained in actual practice. The other and cheaper grades of gasoline are sometimes rated according to gravity and are sometimes classed as "auto" or "motor" gasoline. Grading according to specific gravity was of some significance in the past, but now means nothing unless information is at hand regarding several other details. Of these the source of the crude oil from which the gasoline was produced is important. Gasoline from the Mid-Continent and western fields is more volatile for a given specific gravity than that produced from eastern crudes. Another factor of even greater importance than source is the method of production. Recently there has come on the market a product that is known as casing-head gasoline and is produced from certain varieties of natural gas by compression and condensation, or by washing with heavy oils and subsequently distilling the gasoline from the saturated wash oil. "Straight" casing-head gasoline is much more volatile than the ordinary refinery product and must be treated with some care both in handling and storage. It is not usually kept long in its original condition but is generally marketed in the form of a blend with heavy naphtha or light kerosene. Such a blended gasoline may be of any gravity desired by the producer, but it is naturally different in composition and properties from the straight refinery product it may chance to resemble superficially. This is due to the fact that the blend is generally composed of hydrocarbons both lighter and heavier than those found in the "straight" refinery product.

Still another possibility of variation is that due to the presence on the market of large quantities of what is termed cracked gasoline, made by the thermal decomposition, under pressure, of heavier hydrocarbons. These "cracked" gasolines always contain considerable percentages of unsaturated constituents, and may in some cases require that they be used under engine conditions different from those favorable for straight refinery products. Unsaturated compounds have certain characteristic chemical properties. Of these the



ones of importance in the present connection are the powers of reaction with sulphuric acid and with iodine. The latter property, iodine absorption, is of use in the laboratory determination of degree of unsaturation.

## METHODS BY WHICH THE INVESTIGATION WAS CONDUCTED.

### OBTAINING SAMPLES.

In collecting samples the use of a uniform method of sampling was impracticable because of the necessity of obtaining gasolines representative of all the important general markets of the country. The method of sampling that seemed most desirable was to purchase directly from retailers and thus obtain gasoline identical with what the average consumer could obtain. In the Pittsburgh and San Francisco districts this method was adopted, representatives of the bureau making actual purchases from filling stations. Gasolines from the other fields were obtained direct from refiners, whose kindness is heartily appreciated. The investigation showed that the characteristic differences among samples of gasoline are so great as to make the changes due to storage and transfer from containers relatively unimportant.

In addition the authors were able to make specific gravity tests of a large number of samples collected in the East and in the Middle West. These were obtained in the late spring of 1916 and indicated the tendency on the part of refiners to put out heavy gasolines.

### SPECIFIC GRAVITY TESTS.

Specific gravity measurements were made by the displacement method, an ordinary Westphal balance equipped with a special small plummet being used. This plummet proved decidedly convenient for testing quantities of liquid as small as 6 to 8 c. c. It is used with ordinary weights according to the scheme outlined by Weiss.<sup>a</sup> Such a plummet may be constructed by anyone having elementary skill in the art of glass working. The method is as follows:

A piece of ordinary glass tubing of about 7 mm. outside diameter is sealed at one end with a short platinum wire melted into the glass where sealed. This tube is allowed to cool and about 9 to 10 grams of mercury placed in it, making a column about 35 to 40 mm. high. The tube is then cut off to within 20 mm. of the top of the mercury and sealed off with a blowpipe flame. The plummet when completed is about 55 to 60 mm. long and should have a weight of 10 to 12 grams.

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<sup>a</sup> Weiss, J. M., Specific gravity, its determination for tars, oils, and pitches. *Jour. Ind. and Eng. Chem.*, vol. 7, January, 1915, pp. 21-24.

Specific gravities were determined from ordinary weighings with a Westphal balance by calculation according to the formula given below:

$$\text{Specific gravity of oil} = \frac{c-a}{b-a}$$

$a$  = the weight required to balance plummet in air.

$b$  = the weight required to balance plummet in water.

$c$  = the weight required to balance plummet in oil.

It may be noted that although in tabulating the results Baumé equivalents for specific gravities are recorded, the use of the Baumé scale is most heartily deplored. A full discussion of the disadvantages of this system of measuring density would be both lengthy and useless, and attention is called only to the fact that in using Baumé degrees the particular system employed should be known and stated. At least three systems are known by the authors to have more or less acceptance for liquids lighter than water. The general relation between Baumé degrees and specific gravity is expressed as follows:

$$\text{Specific gravity} = \frac{\text{Modulus}}{(\text{Modulus} - 10) + \text{degrees Baumé}}$$

The modulus 140 is approved by the Bureau of Standards and was employed in the work described herein. The modulus 141.5 is that adopted by one of the large instrument makers of this country, and is perhaps the one most largely used by oil men.

It is to be hoped that oil men will abandon this unreliable and illogical system of measuring density and resort to the more definite and simple system of specific gravity measured in decimal units. Because of the various moduli employed it is recommended that in reporting in terms of degrees Baumé care be taken to specify the particular modulus used. If the modulus is unknown, it may be of help to specify the name of the maker of the instrument used. The need of this precaution has already begun to receive recognition, and a sample of fuel oil recently sent to the bureau was accompanied by the following statement: "Baumé gravity (Tagliabue's) at 60° F., 16.2°."

#### DISTILLATIONS.

In the distillation methods generally employed for the testing of gasoline a simple flask of the Engler type is used, and the results obtained are reasonably satisfactory for technical purposes, as all that is desired is a uniform basis of comparison for different samples. In the present experiments, however, it was thought desirable to obtain a greater degree of efficiency in fractionation, and therefore the

method employed was one that a recent series of experiments<sup>a</sup> proved to be most desirable for the examination of crude petroleum.

The procedure employed was as follows: The distilling flask, having a bulb of 300 c.c. capacity and a column measuring 1 inch in internal diameter, 6.5 inches from bulb to outlet and 2 inches from outlet to top, was placed on a balance, and supported in an upright position by a cardboard box that contained a device for supporting the fractionating column and a quantity of aluminum beads. The flask and accessories were counterpoised and a 200-gram sample of gasoline weighed in. The supporting device was then inserted and beads enough poured in to form a compact column 5 inches high. The box, with the rest of the beads and the counterpoising weight, was set aside, so that at the end of the distillation the residue remaining in the flask could be determined.

The filled flask was then set up with an electric heater and a vertical condenser, the latter being a three-bulbed tube surrounded by a metal jacket containing cracked ice and water. The distilling flask was equipped with an accurate and sensitive thermometer. The distillates were collected in test tubes, the weights of which had been determined and marked on the glass.

The distillation was conducted at a uniform rate of about two drops a second, the tubes in which the distillates were collected being placed under the condenser in a vessel which contained cracked ice. The tubes and their contents were weighed immediately after the completion of each fraction, corked, and set aside in an ice bath for the determination of specific gravity.

After a distillation was completed the cooled flask was again placed upon the balance and the weight of the residue determined. The amount was added to the sum of the fractions and the result subtracted from the original weight of the charge, thus giving a measure of the loss incident to distillation. This procedure also furnished an excellent check upon errors of weighing and computing. If the loss was abnormally large, or if there was a gain instead of a loss, the presence of an error was immediately indicated.

The method of determining percentages by weight instead of by volume is not in common use among petroleum technologists in this country, and might be considered disadvantageous on account of the fact that commercial transactions in this country are conducted on the basis of volume. For scientific work, however, the advantage of working in terms of weight is considerable. In the first place, weight is more easily determined with proper accuracy than is volume, provided care is taken in weighing and marking tubes and equipping a balance with some convenient supporting device. In the second

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<sup>a</sup> Rittman, W. F., and Dean, E. W., The analytical distillation of petroleum: Bull. 125, Bureau of Mines, 1916, 79 pp.

place, the weight of any given quantity of liquid is constant and independent of temperature, whereas the volume varies with the temperature. Finally, weighing permits easy and accurate determination of the residue left in the flask.

As specific gravity determinations were made for all the cuts, it is a simple matter to recalculate the weight percentages into terms of volume in case a need arises for such information. For the purpose of this report it has not seemed necessary to make these recalculations.

It is to be noted that the method employed does not use the conventional "end point," but employs rather the measurement of residue left after a temperature limit is reached and the quantity of distillate in the flask is relatively small. This temperature limit is, however, approximately an end point, and may conveniently be considered such if a high degree of accuracy is not desired in making comparisons with the more general method.

#### EVAPORATION LOSSES.

Evaporation losses were determined by an empirical method which roughly paralleled conditions that cause losses in the commercial handling of petroleum products.

The procedure adopted was as follows: A 25-gram quantity of gasoline was placed in a tube made by cutting off the constricted top of an ordinary 2-ounce oil-sample bottle. This open-topped tube with its contents was placed in a bath at a temperature of 20° C. and kept here for an hour. Then the tube and contents were weighed and the percentage loss calculated.

Although the results by this method are without significance on an absolute basis, in that they do not even approximately show the probable amount of loss under commercial conditions, they serve well for comparing the various samples and show the relative possibilities of loss through evaporation.

#### DETERMINATION OF THE CONTENT OF UNSATURATED HYDROCARBONS.

##### SULPHONATION METHOD.

The sulphuric acid absorption method does not give satisfactory results when applied to "straight" refinery gasolines, the general result being merely a discoloration of the acid. On this account the test was made only with such samples as had iodine numbers sufficiently high to indicate the presence of cracked products.

The procedure adopted was simple, although neither rapid nor accurate. In a 50-c. c. tube, graduated in fifths of a cubic centimeter, there were placed 20 c. c. of the gasoline and 20 c. c. of ordinary sulphuric acid having a specific gravity of 1.84, indicating a

purity of 94 per cent. The two liquids were shaken together thoroughly and allowed to stand over night or until a clear-cut separation was obtained. The decrease in volume of gasoline was then read, the decrease being equivalent to the content of unsaturated compounds.

The method was undesirable in several ways, and experiments have been conducted more recently in the Bureau of Mines laboratory with a view to improving it. For the present it may be stated that the figures given in this report are of value only in showing roughly the percentage of the various products that might be removed by treatment with a sufficient quantity of sulphuric acid.

#### DETERMINATION OF IODINE NUMBERS.

A particularly satisfactory and sensitive method of differentiating gasolines with regard to their content of unsaturated hydrocarbons is the determination of iodine numbers. Iodine numbers, of course, represent only approximately the theoretical iodine absorption, as they are dependent on conditions of temperature and concentration and on the nature of the reaction. It is, therefore, necessary in giving iodine numbers to specify the conditions under which they were measured. For purposes of comparison, however, the determination of iodine numbers is of great advantage. The measurements can be made with ease and accuracy, and the differences for varying saturation percentages are great because the molecular weight of iodine is high and each unsaturated bond of the hydrocarbon absorbs two atoms.

In the work described in this report Hunt's modification of the method of Hanus was used. This is described in a recent paper by Smith and Tuttle.<sup>a</sup>

A 30-minute absorption period is recommended, and the quantities of oil and iodine should be so adjusted that at the end of the reaction 70 to 90 per cent of the iodine remains unabsorbed.

The procedure adopted may be outlined briefly as follows:

A quantity of gasoline, generally varying from 0.04 to 0.20 gram, was measured from a capillary pipette into an iodine absorption flask containing 10 c. c. of chloroform or carbon tetrachloride. Ten c. c. of Hanus solution, prepared by dissolving 13.2 grams of iodine and 3 c. c. of bromine in a liter of glacial acetic acid, was added, and the flask was stoppered and set aside in the dark for 30 minutes. At the end of this time 25 c. c. of 10 per cent potassium iodide solution was poured in and then 100 c. c. of distilled water was added. The excess of iodine was determined by titration with sodium thiosulphate solution, prepared by dissolving about 25 grams of sodium thiosul-

<sup>a</sup> Smith, W. H., and Tuttle, J. B., Iodine numbers of linseed and petroleum oils: Bureau of Standards Tech. Paper 37, 1914, pp. 1-17.

phate to the liter and standardizing against iodine liberated by a standard potassium dichromate solution.

The iodine number is the percentage by weight of iodine absorbed. It is calculated by the following procedure: The titre of an unknown is subtracted from that of a blank (Hanus solution and chloroform or carbon tetrachloride allowed to stand 30 minutes without any gasoline), and the difference in cubic centimeters of thiosulphate solution is multiplied by the weight of iodine equivalent to each cubic centimeter of the solution. The weight of iodine thus found is divided by the weight of gasoline taken and multiplied by 100, giving the iodine number.

#### DETERMINATION OF CALORIFIC VALUE.

The calorific value of a number of the gasolines was determined with a bomb calorimeter of the Dinsmore-Atwater type. The procedure employed was the same as that normally employed for determining the calorific value of oils, except that on account of the volatile character of gasoline it was necessary to adopt special precautions in weighing out the samples. The gasoline was placed in a gelatin capsule, the calorific value of which had been previously determined, and a correction made for the quantity of gelatin burned in the determination.

#### SULPHUR DETERMINATIONS.

The sulphur content of the gasoline was determined in a number of instances by precipitating the sulphur with barium chloride from the bomb liquors, and weighing as the sulphate. A correction was applied for the sulphur contained in the gelatin capsules.

#### ENGINE TESTS.

The engine tests run in connection with the present study were made possible through the kindness of Messrs. C. F. Kettering and J. H. Hunt, of the Dayton Engineering Laboratories Co., of Dayton, Ohio, who placed at the disposal of the Bureau of Mines their highly developed equipment, which is undoubtedly as accurate and reliable as any yet used. The results obtained show certain inaccuracies which were largely due to the inability of the bureau engineers to furnish samples of gasoline large enough to permit adequately long runs and the duplication of runs. The results, however, were adequate for the purposes of this report.

#### METHOD OF CONDUCTING TESTS.

Tests were made of the brake horsepower developed in an automobile engine when like amounts of gasoline were run through the carburetor. The conditions of operation were as follows:

The gasoline was tested by running an L-head, six-cylinder motor, with  $3\frac{1}{2}$  by 5 inch cylinders, on wide-open throttle at 1,000 revolutions per minute, the output being measured by means of a Sprague electric dynamometer.

The speed was measured by means of a Hopkins electric tachometer and did not vary over 1.5 per cent fast or slow during any run.

The outlet water from the cylinders was kept at a temperature of 140 to 150° F. (60 to 65.5° C.) during each run, the temperature being measured by an ordinary mercury thermometer set into an oil well at the bend in the outlet line.

The carburetor was adjusted to give the best engine torque obtainable when using the ordinary grade of gasoline sold in Dayton, Ohio. The adjustment was not changed thereafter during the series of runs.

A three-way valve was connected in the line at the carburetor, and after the engine had been running on ordinary gasoline long enough to bring the water to the proper temperature, the test gasoline was turned in. After the engine had run long enough to insure that the carburetor float chamber was filled with the test fuel, a run was made on 1 pound of this fuel, the beginning and end of the run being indicated by an electric bell controlled by the beam scale, and the time being taken with a stop watch.

The spark position was maintained constant during the run, being placed at the point that gave the best torque with the Dayton gasoline.

### RESULTS OF EXPERIMENTS.

The bulk of the data obtained is presented in Table 1. The variety of figures obtained has made it difficult to tabulate them in readily understood form, and it is impossible by mere inspection to note many of the points of interest and importance that have been brought out. It is deemed desirable, however, to present all results obtained, whether instructive or not, and on that account the condensed arrangement of Table 1 has been necessary. In a number of cases it will be found possible to follow the discussion of the text by running down individual columns of the table. Where this is not possible separate tables have been prepared, generally with the omission of figures which are not of significance. Also tables are given for the results of such tests as do not include the full list of products shown in Table 1, or which were conducted for samples of gasoline other than those listed in Table 1.

Whenever possible, curves have been plotted, generally for typical results only, as it was impracticable to prepare curves including all the results of each series of tests.

TABLE 2.—Gravities of typical samples of gasoline from the Eastern, Mid-Continent, and California fields.

Eastern samples.			Mid-Continent samples.			California samples.		
Sample No.	Specific gravity.	° B.	Sample No.	Specific gravity.	° B.	Sample No.	Specific gravity.	° B.
3	0.684	74.7	30	0.703	69.2	51	0.730	61.8
6	.090	72.9	39	.703	69.2	52	.727	62.6
11	.736	60.2						
2	.703	69.2	27	.733	61.0	47	.745	57.9
8	.706	68.3	31	.739	59.5	48	.749	56.9
1	.724	63.4						
4	.730	61.8						
15	.733	61.0						

TABLE 3.—Gravities of gasoline samples obtained in May, 1916.

Place where sample was obtained.	Specific gravity.	° B.	Place where sample was obtained.	Specific gravity.	° B.
Philadelphia, Pa.....	0.735	60.5	Chicago, Ill.....	0.741	58.9
Do.....	.735	60.5	Do.....	.747	57.4
Do.....	.730	61.8	Do.....	.739	59.4
Do.....	.737	60.0	Do.....	.752	56.0
Do.....	.733	61.0	Do.....	.737	60.0
Do.....	.732	61.2	Do.....	.746	57.6
Do.....	.734	60.8	East St. Louis, Ill.....	.748	57.1
Do.....	.718	65.1	Do.....	.736	60.2
Wheeling, W. Va.....	.710	67.2	Springfield, Ill.....	.748	57.1
Do.....	.719	64.8	Do.....	.738	59.7
Do.....	.729	62.1	Do.....	.744	58.1
Do.....	.724	63.4	Do.....	.747	57.4
Do.....	.721	64.2	Washington, D. C.....	.737	60.0
Do.....	.716	65.5	Do.....	.733	61.0
Do.....	.726	62.9	Do.....	.739	59.4
Louisville, Ky.....	.741	58.9	Do.....	.733	61.0
Do.....	.733	61.0	Do.....	.734	60.8
Do.....	.734	60.8	Do.....	.738	59.7
Do.....	.745	57.9	Do.....	.739	59.4
Do.....	.739	59.4	Baltimore, Md.....	.734	60.8
Covington, Ky.....	.740	59.1	Do.....	.734	60.8
Do.....	.734	60.8	Do.....	.729	62.1
Do.....	.745	57.9	Do.....	.731	61.5
Do.....	.738	59.7	Do.....	.738	59.7
Toledo, Ohio.....	.732	61.2	Do.....	.735	60.5
Do.....	.738	59.7	Do.....	.739	59.4
Do.....	.737	60.0	Do.....	.731	61.5
Do.....	.736	60.2	Do.....	.735	60.5
Do.....	.737	60.0	Do.....	.736	60.2
Cincinnati, Ohio.....	.741	58.9	Frederick, Md.....	.744	58.1
Do.....	.736	60.2	Do.....	.739	59.4
Do.....	.742	58.6	Do.....	.743	58.4
Do.....	.748	57.1	Do.....	.743	58.4
Do.....	.738	57.7	Do.....	.738	59.7
Springfield, Ohio.....	.722	64.0	Do.....	.733	61.0
Do.....	.743	58.4	Cumberland, Md.....	.733	61.0
Do.....	.747	57.4	Do.....	.734	60.8
Lafayette, Ind.....	a. 729	a. 62.1	Do.....	.723	63.7
Do.....	a. 744	a. 58.1	Do.....	.740	59.1
Muncie, Ind.....	.745	57.9	Do.....	.720	64.5
Do.....	.750	56.5	Hagerstown, Md.....	.721	64.2
South Bend, Ind.....	.745	57.9	Do.....	.719	64.8
Do.....	.749	56.8	Do.....	.730	61.8
Do.....	.745	57.9	Do.....	.735	60.5
Do.....	.739	59.4	Do.....	.728	62.4
Do.....	.742	58.6	Do.....	.723	63.7
Do.....	.749	56.8	Do.....	.739	59.4
New Albany, Ind.....	.742	58.6	Wilmington, Del.....	.728	62.4
Do.....	.750	56.5	Do.....	.736	60.2
Vincennes, Ind.....	.749	56.8	Do.....	.735	60.5
Do.....	.749	56.8	Do.....	.728	62.4
Do.....	.725	63.1	Do.....	.729	62.1
Danville, Ill.....	.749	56.8	Do.....	.733	61.0
Zanesville, Ohio.....	.740	59.1	Do.....	.735	60.5
Do.....	.715	65.8	Do.....	.727	62.6
Do.....	.740	59.1			

a Bottle cracked.



TABLE 1.—Results of specific gravity tests, distillations, evaporation-loss tests, and unsaturation tests of 52 samples of gasoline collected throughout the United States in the year 1915.

[In the table, data referring to gasolines from different refineries are indicated by spacing.]

Sample No.	Trade name.	State from which obtained.	Gravity.		Barometric pressure mm. of mercury.	Results of distillation in 5-inch column of aluminum beads at temperatures of—																												Evaporation loss, per cent.	Unsaturation test.		Total percentage distilled up to—									
			Specific gravity.	°B.		Up to 50° C.			50° to 75° C.			75° to 100° C.			100° to 125° C.			125° to 150° C.			150° to 175° C.			175° to 200° C.			Residue.				Iodine number.	Percentage absorbed in sulphuric acid.	50° C. (122° F.).		75° C. (167° F.).	100° C. (212° F.).	125° C. (257° F.).	150° C. (302° F.).	175° C. (347° F.).	200° C. (392° F.).						
						Per cent distilled.	Specific gravity.	°B.	Per cent distilled.	Specific gravity.	°B.	Per cent distilled.	Specific gravity.	°B.	Per cent distilled.	Specific gravity.	°B.	Per cent distilled.	Specific gravity.	°B.	Per cent distilled.	Specific gravity.	°B.	Per cent distilled.	Specific gravity.	°B.	Per cent distilled.	Specific gravity.	°B.	Per cent distilled.											Specific gravity.	°B.	Per cent distilled.	Specific gravity.	°B.	Distillation loss, per cent.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41						
1	Motor gasoline.....	Penn.....	0.724	63.4	738				2.2			31.6	0.709	67.5	41.7	0.727	62.6	18.9	0.742	58.7						5.2	0.764	53.3	0.4	0.8	4.6		0.0	2.2	33.8	75.5	94.4									
2	65° to 70° gasoline.....	do.....	.703	69.2	747	3.5	0.639	89.1	24.1	0.672	78.3	39.9	0.699	70.3	23.1	.727	62.6	8.5	.745	57.9						0.0			0.9	2.0	3.4		3.5	27.6	67.5	90.6	99.1									
3	74° to 79° gasoline.....	do.....	.684	74.7	749	14.5	.633	91.2	31.7	.666	80.2	32.1	.699	70.3	16.8	.727	62.6									4.5	.749	56.9	0.4	4.0	3.3		14.5	46.2	78.3	95.1										
4	Motor gasoline.....	do.....	.730	61.8	742	9.8	.624	94.4	4.8	.663	81.2	6.9	.703	69.2	18.2	.733	61.0	26.8	.752	56.2	21.3	0.767	52.5	11.0	0.785	48.3	0.0		1.2	2.4	7.9	1.0	9.8	14.6	21.5	39.7	66.5	87.8	98.8							
5	68° to 72° gasoline.....	do.....	.712	66.6	742	18.6	.624	94.4	8.5	.666	80.2	9.9	.703	69.2	14.5	.733	61.0	22.1	.752	56.2	15.1	.767	52.5	10.3		0.0		1.9	4.4	4.8		18.6	27.1	36.1	50.6	72.7	87.8	98.1								
6	74° to 76° gasoline.....	do.....	.690	72.9	742	30.5	.624	94.4	12.2	.666	80.2	12.3	.703	69.2	11.6	.733	61.0	12.8	.752	56.2	10.3	.767	52.5	8.1	.782	49.0	0.0		2.2	6.4	4.2		30.5	42.7	55.0	66.6	79.4	89.7	97.8							
7	Auto gasoline.....	do.....	.730	61.8	748	4.7	.630	92.2	9.3	.669	79.3	18.0	.712	66.6	26.6	.736	60.2	19.7	.758	54.7	14.6	.776	50.4			6.1	.795	46.1	1.0	1.6	14.9	2.6	4.7	14.0	32.0	58.6	78.3	92.9								
8	68° to 70° gasoline.....	do.....	.706	68.3	748	9.1	.636	90.1	23.0	.669	79.3	28.4	.709	67.5	22.7	.733	61.0	10.4	.755	55.4						5.2	.776	50.4	1.2	2.8	2.9		9.1	32.1	60.5	83.2	93.6									
9	73° to 76° gasoline.....	do.....	.687	73.8	747	18.9	.633	91.2	28.9	.669	79.3	30.4	.706	68.3	16.2	.730	61.8									4.6	.755	55.4	1.0	4.4	2.4		18.9	47.8	78.2	94.4										
10	86° gasoline.....	do.....	.666	80.2	741	42.2	.633	91.2	31.4	.669	79.3	15.9	.709	67.5												9.0	.742	58.7	1.5	6.4	2.0		42.2	73.6	89.5											
11	60° to 62° gasoline.....	do.....	.736	60.2	742				3.2	.669	79.3	13.6	.709	67.5	42.4	.733	61.0	27.6	.749	56.9	12.2	.764	53.3			0.0			1.0	0.8	5.9		0.0	3.2	16.8	59.2	86.8	99.0								
12	Motor gasoline.....	do.....	.736	60.2	739	1.2			3.2	.672	78.3	15.6	.712	66.6	39.0	.736	60.2	28.3	.752	56.2	12.0	.770	51.8			0.0			0.7	0.8	6.5		1.2	4.4	20.0	59.0	87.3	99.3								
13	68° to 70° gasoline.....	do.....	.718	65.0	747	3.5	.633	91.2	11.5	.669	79.3	24.2	.706	68.3	33.7	.730	61.8	18.6	.749	56.9	8.0	.767	52.5			0.0			0.5	1.2	4.1		3.5	15.0	39.2	72.9	91.5	99.5								
14	73° to 76° gasoline.....	do.....	.699	70.3	739	7.2	.636	90.1	25.8	.669	79.3	36.7	.709	67.5	21.5	.733	61.0									7.9	.755	55.4	0.9	2.8	3.4		7.2	33.0	69.7	91.7										
15	Motor gasoline.....	do.....	.733	61.0	755	7.9	.630	92.2	8.9	.675	77.4	16.4	.715	65.8	23.4	.739	59.5	21.9	.758	54.7	15.0	.776	50.4			5.9	.801	44.8	0.6	2.0	13.4	1.6	7.9	16.8	33.2	56.6	78.5	93.5								
16	68° to 70° gasoline.....	do.....	.706	68.3	738	16.7	.633	91.2	15.4	.672	78.3	20.9	.715	65.8	22.1	.739	59.5	13.1	.761	54.0						10.7	.785	48.3	1.1	3.6	3.2		16.7	32.1	53.0	75.1	88.2									
17	73° to 76° gasoline.....	do.....	.687	73.8	738	30.8	.630	92.2	18.3	.669	79.3	15.3	.712	66.6	13.7	.739	59.5	10.7	.758	54.7						10.0	.785	48.3	1.2	6.0	8.4	2.2	30.8	49.1	64.4	78.1	88.8									
18	Motor gasoline.....	do.....	.752	56.2	747	0.8			2.6	.681	75.6	15.4	.724	63.4	33.0	.745	57.9	26.7	.764	53.3	14.1	.779	49.7			6.5	.798	45.4	0.9	0.8	3.0		0.8	3.4	18.8	51.8	78.5	92.6								
19	Gasoline.....	do.....	.724	63.4	747	7.4	.633	91.2	12.6	.675	77.4	28.1	.721	64.2	26.1	.745	57.9	17.1	.764	53.3						7.8	.788	47.7	0.9	2.4	3.7		7.4	20.0	48.1	74.2	91.3									
20	62° naphtha.....	Ind.....	.733	61.0	736	5.4	.639	89.1	14.6	.678	76.5	25.4	.715	65.8	21.8	.739	59.5	15.7	.764	53.3	10.8	.779	49.7			4.5	.807	43.5	1.8	1.6	48.8	5.2	5.4	20.0	45.4	67.2	82.9	93.7								
21	72° naphtha.....	do.....	.693	72.0	748	17.1	.636	90.1	31.5	.675	77.4	34.8	.721	64.2	13.0	.742	58.7									2.5			1.1	3.2	8.5	2.0	17.1	48.6	83.4	96.4										
22	Gasoline.....	do.....	.745	57.9	753	4.6	.636	90.1	6.3	.678	76.5	13.5	.715	65.8	21.1	.739	59.5	26.3	.764	53.3	19.4	.779	49.7			7.5	.804	44.1	1.3	1.6	52.7	6.2	4.6	10.9	24.4	45.5	71.8	91.2								
23	do.....	La.....	.752	56.2	751				0.6			2.7	.715	65.8	25.1	.736	60.2	36.6	.752	56.2	25.2	.767	52.5	9.6	.788	47.7	0.0			0.2	0.8	10.5	2.0	0.0	0.6	3.3	28.4	65.0	90.2	99.8						
24	do.....	do.....	.736	60.2	753	2.6	.642	88.1	7.1	.678	76.5	23.9	.715	65.8	36.0	.742	58.7	20.4	.761	54.0						9.4	.782	49.0	0.6	1.2	44.7	3.1	2.6	9.7	33.6	69.6	90.0									
25	do.....	do.....	.718	65.0	739	4.2	.642	88.1	20.9	.678	76.5	31.1	.715	65.8	27.3	.739	59.5	11.4	.758	54.7						4.6	.779	49.7	0.5	2.0	18.3	2.6	4.2	25.1	56.2	83.5	94.9									
26	58° to 59° gasoline.....	Okla.....	.742	58.7	744				2.3			23.8	.721	64.2	42.4	.742	58.7	21.8	.761	54.0						8.5	.779	49.7	1.2	0.8	4.1		0.0	2.3	26.1	68.5	90.3									
27	60° to 61° gasoline.....	do.....	.733	61.0	749	1.1			5.1	.684	74.7	31.2	.715	65.8	37.7	.739	59.5	17.8	.758	54.7						6.1	.779	49.7	1.0	0.8	3.7		1.1	6.2	37.4	75.1	92.9									
28	66° to 68° gasoline.....	do.....	.709	67.5	746	6.9	.636	90.1	24.7	.675	77.4	37.2	.715	65.8	21.1	.739	59.5	7.4	.761	54.0						2.2			0.5	2.4	1.9		6.9	3.6	68.8	89.9	97.3									
29	60° to 61° gasoline.....	do.....	.733	61.0	746	3.8	.630	92.2	10.7	.678	76.5	22.6	.715	65.8	25.3	.739	59.5	18.4	.758	54.7	11.1	.779	49.7																							



TABLE 3.—Gravities of gasoline samples obtained in May, 1916—Continued.

Place where sample was obtained.	Specific gravity.	° B.	Place where sample was obtained.	Specific gravity.	° B.
Camden, N. J.....	0.740	59.1	Detroit, Mich.....	0.736	60.2
Do.....	.731	60.5	Do.....	.751	56.2
Do.....	.740	59.1	Do.....	.745	57.9
Do.....	.739	59.4	Do.....	.749	56.8
Do.....	.732	61.2	Do.....	.750	56.5
Do.....	.733	61.0	St. Louis, Mo.....	.740	59.1
Jersey City, N. J.....	.740	59.1	Do.....	.736	60.2
Do.....	.746	57.6	Do.....	.712	66.7
Do.....	.746	57.6	Do.....	.747	57.4
New York, N. Y.....	.734	60.8	Do.....	.737	60.0
Do.....	.742	58.6	Do.....	.723	63.7
Do.....	.734	60.8	Wichita, Kans.....	.747	57.4
Do.....	.736	60.2	Do.....	.738	59.7
Do.....	.725	63.1	Do.....	.742	58.6
Binghamton, N. Y.....	.729	62.1	Do.....	.742	58.6
Do.....	.729	62.1	Do.....	.749	56.8
Do.....	.731	61.5	Do.....	.748	57.1
Do.....	.732	61.2	Kansas City, Kans.....	.739	59.4
Do.....	.733	61.0	Do.....	.745	57.9
Buffalo, N. Y.....	.737	60.0	Do.....	.746	57.6
Do.....	.740	59.1	Do.....	.750	56.5
Do.....	.740	59.1			
Do.....	.734	60.8			
Do.....	.732	61.2			

TABLE 4.—Results of tests showing volatility ranges of typical "straight" refinery gasolines from Eastern, Mid-Continent, and California fields.

## EASTERN GASOLINE.

Sample No.	Commercial rating of gasoline (°B.).	Actual gravity as determined by test.		Percentage distilled at temperatures of—					
		Specific gravity.	°B.	Up to 50° C.	50° to 75° C.	75° to 100° C.	100° to 125° C.	125° to 150° C.	150° to 175° C.
12	(a).....	0.736	60.2	1.2	4.4	20.0	59.0	87.3	99.3
13	68° to 70°.....	.713	65.0	3.5	15.0	39.2	72.9	91.5	99.5
14	76°.....	.699	70.3	7.2	33.0	69.7	91.2	.....	.....

## MID-CONTINENT GASOLINE.

37	58° to 60°.....	0.745	57.9	1.7	7.4	21.2	50.9	79.4	93.6
33	60° to 62°.....	.727	62.6	3.3	14.6	41.4	68.2	87.3	96.4
39	63° to 70°.....	.703	69.2	8.6	34.4	70.4	91.2	.....	.....

## CALIFORNIA GASOLINE.

49	.....	0.749	56.9	3.0	12.6	51.1	81.9	94.3	.....
50	.....	.733	61.0	3.8	16.1	45.5	71.8	94.1	.....

(a) Rated as "motor" gasoline.

TABLE 5.—Results showing specific gravity and volatility ranges of blended casing-head and "straight" refinery gasolines from the eastern markets.

## BLENDED CASING-HEAD GASOLINE.

Sample No.	Commercial rating (°B.).	Actual gravity as determined by test.		Percentage distilled at temperatures of—					
		Specific gravity.	°B.	Up to 50° C.	50° to 75° C.	75° to 100° C.	100° to 125° C.	125° to 150° C.	150° to 175° C.
15	60° to 65°.....	0.733	61.0	7.9	16.8	33.2	56.6	78.5	93.5
16	68° to 70°.....	.706	68.3	16.7	32.1	53.0	75.1	88.2	.....
17	76°.....	.687	73.8	30.8	49.1	64.4	78.1	88.8	.....

## "STRAIGHT" REFINERY GASOLINE.

1	60° to 65°.....	0.724	63.4	0.0	2.2	33.8	75.5	94.4	.....
2	68° to 70°.....	.703	69.2	3.5	27.6	67.5	90.6	99.1	.....
3	74° to 76°.....	.684	74.7	14.5	46.2	78.3	95.1	.....	.....

TABLE 6.—Results showing iodine number and percentage absorbed by sulphuric acid of the gasolines that were higher in unsaturated compounds.

Sam- ple No.	State in which sam- ple was obtained.	Trade name of gasoline.	Iodine No.	Percent- age ab- sorbed by sul- phuric acid.
4	Pennsylvania.....	"Motor" gasoline.....	7.9	1.0
17	.....do.....	73° to 76° gasoline.....	8.4	2.2
21	Indiana.....	72° gasoline.....	8.5	2.0
23	Louisiana.....	Gasoline.....	10.5	2.0
15	Pennsylvania.....	"Motor" gasoline.....	13.4	1.6
7	.....do.....	"Auto" gasoline.....	14.9	2.6
25	Louisiana.....	Gasoline.....	18.3	2.6
44	Wyoming.....	.....do.....	43.8	3.6
24	Louisiana.....	.....do.....	44.7	3.1
20	Indiana.....	62° naphtha.....	48.8	5.2
22	.....do.....	Gasoline.....	52.7	6.2

TABLE 7.—Results showing calorific value, power developed in engine tests, specific gravity, and percentage of sulphur in various typical gasolines from Mid-Continent and Eastern fields.

Sam- ple No.	Field from which sample was obtained.	Process of manu- facture.	Gravity.		Calorific value of gasoline.		Power de- veloped, horse- power- hours per pound of gasoline.	Sulphur content, per cent.
			Specific gravity.	°B.	Calories per gram.	B. t. u. per pound.		
22	Mid-Continent..	Cracking plant..	0.745	57.9	11,165	20,097	1.345	0.02
26	.....do.....	"Straight" re- finery.	.742	58.7	11,174	20,113	1.403	.01
43	.....do.....	.....do.....	.733	61.0	11,180	20,124	1.350	.05
13	Eastern.....	.....do.....	.718	65.0	11,187	20,137	1.405	.04
19	Mid-Continent..	.....do.....	.724	63.4	11,215	20,187	1.395	.05
38	.....do.....	.....do.....	.727	62.6	11,221	20,198	1.396	.03
15	Eastern.....	Blended casing- head.	.733	61.0	11,230	20,214	1.376	.03
1	.....do.....	"Straight" re- finery.	.724	63.4	11,236	20,225	1.420	.03
34	Mid-Continent..	.....do.....	.715	65.8	11,250	20,250	1.365	.02
9	Eastern.....	.....do.....	.687	73.8	11,315	20,367	1.487	.02

TABLE 8.—Results showing gravities of fractions obtained by distillation from various types of gasoline.

## RANGE IN GRAVITY.

Kind of gasoline.	Specific gravity of fraction.						
	Up to 50° C.	50° to 75° C.	75° to 100° C.	100° to 125° C.	125° to 150° C.	150° to 175° C.	175° to 200° C.
Eastern "straight" refinery <i>a</i> .....	0.633 to 0.639	0.666 to 0.672	0.699 to 0.712	0.727 to 0.736	0.742 to 0.755	0.764 to 0.770	.....
Mid-Continent "straight" refinery <i>b</i> .....	.630 to .645	.672 to .696	.712 to .736	.736 to .761	.755 to .779	.773 to .779	0.788 to 0.795
California "straight" refinery <i>c</i> .....	.639 to .645	.678 to .693	.723 to .739	.752 to .764	.773 to .788	.....	.....
Blended casing head (eastern) <i>d</i> .....	.624 to .633	.663 to .675	.703 to .715	.733 to .739	.752 to .761	.767 to .776	.782 to .785
Cracked (Mid-Continent) <i>e</i> .....	.636 to .645	.675 to .684	.712 to .721	.736 to .749	.752 to .767	.767 to .785	.788 to .801

Kind of gasoline.	Gravity, in degrees Baumé, of fraction.						
	Up to 50° C.	50° to 75° C.	75° to 100° C.	100° to 125° C.	125° to 150° C.	150° to 175° C.	175° to 200° C.
Eastern "straight" refinery <i>a</i> .....	91.2 to 89.1	80.2 to 78.3	70.3 to 66.6	62.6 to 60.2	58.7 to 55.4	53.2 to 51.8	.....
Mid-Continent "straight" refinery <i>b</i> .....	92.2 to 87.1	78.3 to 71.1	66.6 to 60.2	60.2 to 54.0	55.4 to 49.7	51.1 to 49.7	47.7 to 46.1
California "straight" refinery <i>c</i> .....	89.1 to 87.1	76.5 to 72.0	63.6 to 59.4	56.2 to 53.2	51.1 to 47.7	.....	.....
Blended casing head (eastern) <i>d</i> .....	94.4 to 91.2	81.2 to 77.4	69.1 to 65.8	61.0 to 59.4	56.2 to 54.0	52.5 to 50.4	49.0 to 48.3
Cracked (Mid-Continent) <i>e</i> .....	90.1 to 87.1	77.4 to 74.7	66.6 to 64.1	60.2 to 56.9	56.2 to 52.5	52.5 to 48.3	47.7 to 44.8

*a* Samples 1 to 3, 8, 9, 11 to 14.*b* Samples 26 to 42.*c* Samples 45 to 52.*d* Samples 4 to 6, 15 to 17.*e* Samples 20 to 25, 44.

TABLE 8.—Results showing gravities of fractions obtained by distillation from various types of gasoline—Continued.  
AVERAGE GRAVITY.

Kind of gasoline.	Specific gravity of fraction.						
	Up to 50° C.	50° to 75° C.	75° to 100° C.	100° to 125° C.	125° to 150° C.	150° to 175° C.	175° to 200° C.
Eastern "straight" refinery <i>a</i> .....	0.635	0.669	0.706	0.731	0.748	0.767	.....
Mid-Continent "straight" refinery <i>b</i> .....	.636	.680	.719	.742	.762	.777	0.791
California "straight" refinery <i>c</i> .....	.640	.686	.733	.759	.780	.....	.....
Blended casing head (eastern) <i>d</i> .....	.627	.668	.708	.736	.755	.769	.784
Cracked (Mid-Continent) <i>e</i> .....	.640	.678	.716	.741	.761	.778	.796

Kind of gasoline.	Gravity, in degrees Baumé, of fraction.						
	Up to 50° C.	50° to 75° C.	75° to 100° C.	100° to 125° C.	125° to 150° C.	150° to 175° C.	175° to 200° C.
Eastern straight refinery <i>a</i> .....	90.5	79.3	68.3	61.5	57.2	52.5	.....
Mid-Continent straight refinery <i>b</i> .....	90.1	75.9	64.7	58.7	53.7	50.2	47.0
California straight refinery <i>c</i> .....	88.7	74.1	61.0	54.4	49.5	.....	.....
Blended casing head (eastern) <i>d</i> .....	93.3	79.6	67.7	60.2	55.4	52.1	48.6
Cracked (Mid-Continent) <i>e</i> .....	88.7	76.5	65.5	58.9	54.0	49.9	45.9

*a* Samples 1 to 3, 8, 9, 11 to 14.

*b* Samples 26 to 42.

*c* Samples 45 to 52.

*d* Samples 4 to 6, 15 to 17.

*e* Samples 20 to 25, 44.

TABLE 9.—*Results showing relation between evaporation loss and percentage cut to 50° C., approximate relation between evaporation loss and cut to 75° C., and lack of relation between evaporation loss and specific gravity.*

## INDIVIDUAL SAMPLES.

Sample No.	Evaporation loss, per cent.	Specific gravity.	Per cent cut to 50° C.	Per cent cut to 75° C.	Sample No.	Evaporation loss, per cent.	Specific gravity.	Per cent cut to 50° C.	Per cent cut to 75° C.
32	0.4	0.752	0.0	0.7	48	1.6	0.749	3.0	11.4
1	0.8	.724	0.0	2.2	2	2.0	.703	3.5	27.6
11	0.8	.736	0.0	3.2	15	2.0	.733	7.9	16.8
12	0.8	.736	1.2	4.4	25	2.0	.718	4.2	25.1
18	0.8	.752	0.8	3.4	34	2.0	.715	5.2	31.2
23	0.8	.752	0.0	0.6					
26	0.8	.742	0.0	2.3	4	2.4	.730	9.8	14.6
27	0.8	.733	1.1	6.2	19	2.4	.724	7.4	20.0
33	0.8	.745	0.0	3.0	28	2.4	.709	6.9	31.6
37	0.8	.745	1.7	7.4	42	2.4	.712	8.6	27.6
40	0.8	.742	1.5	5.3	51	2.4	.730	8.7	24.1
43	0.8	.733	2.3	12.8					
					8	2.8	.706	9.1	32.1
13	1.2	.718	3.5	15.0	14	2.8	.699	7.2	33.0
24	1.2	.736	2.6	9.7	30	2.8	.703	12.1	36.4
29	1.2	.733	3.8	11.5	39	2.8	.703	8.6	34.4
31	1.2	.739	3.0	11.0					
36	1.2	.745	1.9	12.8	21	3.2	.693	17.1	48.6
38	1.2	.727	3.3	14.6	50	3.2	.733	3.8	16.1
41	1.2	.736	2.7	9.3	52	3.2	.727	14.3	28.2
44	1.2	.749	2.5	10.7					
46	1.2	.745	2.4	11.3	16	3.6	.706	16.7	32.1
47	1.2	.745	1.5	9.4					
49	1.2	.749	3.0	12.6	3	4.0	.684	14.5	46.2
7	1.6	.730	4.7	14.0	5	4.4	.712	18.6	27.1
20	1.6	.733	5.4	20.0	9	4.4	.687	18.9	47.8
22	1.6	.745	4.6	10.9					
35	1.6	.742	2.1	12.5	10	6.4	.666	42.2	73.6
45	1.6	.745	3.8	14.6	6	6.4	.690	30.5	42.7

## AVERAGES.

Evaporation loss.	Average specific gravity.	Average per cent cut to 50° C.	Average per cent cut to 75° C.
0.4	0.752	0.0	0.7
0.8	.740	0.8	4.6
1.2	.740	3.0	11.9
1.6	.741	3.9	13.5
2.0	.717	5.2	25.1
2.4	.721	8.3	27.4
2.8	.703	9.2	33.0
3.2	.717	15.7	38.4
3.6	.706	16.7	32.1
4.0	.684	14.5	46.2
4.4	.700	18.7	37.4
6.4	.678	36.3	58.1

## DISCUSSION OF RESULTS.

In order to discuss at length the results obtained, the data for each series of analytical tests are considered under separate heads, and subheads are employed to differentiate indications obtained in regard to source or method of manufacture of products. In addition, some space is given to a consideration of the relations between the properties indicated by the various series of tests.

The scheme of classification employed is shown below.

1. Discussion of individual properties.
  - (a) Specific gravity.
  - (b) Volatility or distillation range.
  - (c) Evaporation losses.
  - (d) Content of unsaturated compounds.
  - (e) Calorific value.
  - (f) Sulphur content.
  - (g) Power developed by engine tests.
2. Relations between properties.
  - (a) Volatility and specific gravity.
  - (b) Volatility and evaporation losses.

#### SPECIFIC GRAVITY.

Specific gravity is the property that is almost invariably measured in the commercial grading of gasolines. Most of the samples obtained have gravities between the limits of 55° and 75° B. (specific gravities of 0.758 to 0.684). One so-called "86°" product showed an actual gravity of 80° B. (0.666). It was not, however, a common market product.

In general the eastern gasolines are lightest, their gravities ranging between 60° and 75° B. (0.737 to 0.683). Products from the Mid-Continent fields fall mostly between the limits of 59° and 68° B. (0.741 to 0.707) and those from California between 57° and 63° B. (0.749 to 0.725). Typical specific-gravity values for products from the three fields are listed in Table 2. It is to be noted that there is a tendency in the eastern field to grade gasolines in three classes, in the Mid-Continent field in two classes, and in the West in one class.

In addition to the specific-gravity tests of the gasolines on the list represented in Table 1, tests were made of a large number of samples which were collected late in the spring of 1916; the results of these tests are shown in Table 3. The reader will note that these samples have gravities falling within narrow limits, those sold in the East being in general between 59° and 65° B. (about 0.740 to 0.720), and those from the middle West, between 57° and 61° B. (about 0.750 to 0.735).

Specific gravities of distillation cuts mean little or nothing in themselves and hence are discussed in connection with volatility relations. No conclusions of value may be drawn from a simple knowledge of the specific gravity of a gasoline, except that it seems that only the products from the eastern field are lighter than 70° B. Even this, however, is not a rule but a mere statement of probability, as there would be no difficulty in making light gasolines from products from either of the other fields, and especially from the Mid-Continent field.



**VOLATILITY OR DISTILLATION RANGE.**

The most important property in determining the utility and commercial value of a gasoline is that of volatility, indicated in the laboratory by the distillation range. Gasoline, like all petroleum products, is a complex mixture of a number of hydrocarbons, these varying in proportion and having different boiling points. Owing to this fact, the possibility of variation in the composition of products commercially classed as gasoline is practically infinite, and all that is possible in defining properties and constituents is to indicate limiting values. Thus, for example, we may say that a high-grade "straight" refinery Pennsylvania gasoline is made up of constituents of which 10 per cent boil below 50° C. and 85 per cent between the limits of 50° and 125° C. A blended casing-head gasoline of apparently the same commercial grade might have 30 per cent boiling below 50° C. and would contain a considerable proportion of constituents having boiling points ranging up to 200° C. Analyses furnishing information of this sort are useful for the study of the property of gasolines, but it should be definitely understood that they are not analyses for individual chemical compounds. Analyses for individual compounds are generally possible only through a relatively large amount of work and are of little practical value. The so-called ultimate analysis, for elements, is of course moderately simple, but furnishes information of small value, owing to the similarities regarding the relative proportions of hydrogen and carbon among the hydrocarbons found in petroleum.

Distillation methods necessarily involve mechanical factors which must necessarily be fixed in an empirical way. The results of a distillation are not of significance unless the method of procedure is stated. The general tendency is for apparent boiling points to be higher than actual ones, but this discrepancy is minimized by employing a method of maximum fractionating efficiency. Such is the Hempel method, which was employed in the present work.

**CLASSIFICATION OF GASOLINES.**

Gasolines at present on the market may be divided into groups and classes most conveniently by the following classification:

1. "Straight" refinery gasoline:
  - (a) From the eastern fields.
  - (b) From the Mid-Continent fields.
  - (c) From the western field.
2. Cracked gasoline (produced by cracking or synthetic processes).
3. Casing-head gasoline (produced from natural gas):
  - (a) Unblended (not marketed).
  - (b) Blended with various types of heavy naphtha.

Of the different types mentioned some can be detected by studying their range of volatility. Others must be differentiated by considering relations between the properties of volatility and specific gravity, and still others can be distinguished only by chemical tests.

#### VOLATILITY OF STRAIGHT REFINERY GASOLINES.

##### EASTERN GASOLINE.

A number of different grades of gasoline on the market are produced from eastern crudes by "straight" refinery methods. These are graded according to their gravity, the rating (in Baumé degrees) generally being a little higher than the figure that is obtained in the laboratory. The lower grades are often called "motor" or "auto" gasoline.

Three typical gasolines have been selected from the series and the results of the distillations are represented by the figures for samples 12, 13, and 14, in Table 4, and by the solid curves of figure 1. These three samples were selected because they were fairly representative of the products generally sold on the market and because they were known to be produced by "straight" refinery methods from Pennsylvania crude petroleum.

There are considerable differences of volatility among the different grades of products but the boiling points are largely less than 150° C. The heavier gasolines have smaller percentages boiling below 50° C. and larger proportions distilling above 125° C. than the lighter gasolines have.

##### MID-CONTINENT GASOLINE.

Gasolines from the Mid-Continent fields show similar variations in volatility. Typical samples are represented by Nos. 37, 38, and 39, in Table 4, and by the broken-line curves of figure 1. The differences in the curves are similar to those in the curves representing eastern products and the degrees of difference are much the same, except that there is a tendency to include in the heavier gasolines larger percentages of higher boiling constituents.

Attention must be called to the fact that the products from the Mid-Continent fields are more heterogeneous than the eastern gasolines and that the samples selected (Nos. 37, 38, and 39, from Kansas) are chosen because they seem to be about an average. Some of the other Mid-Continent gasolines are more like the eastern, still others are more like western gasolines.

##### CALIFORNIA GASOLINE.

In the California market only one grade is put out by the refineries as gasoline, the heavier naphthas being sold under the trade name of "engine distillate." Samples 49 and 50 (see Table 4 and the

dotted curves of figure 1) represent **two** typical California samples, one from the San Francisco district and the other from Los Angeles. The reader will note that the two samples do not show any striking or characteristic differences and also that the curves fall approximately halfway between the limiting curves of the eastern and Mid-Continent series.

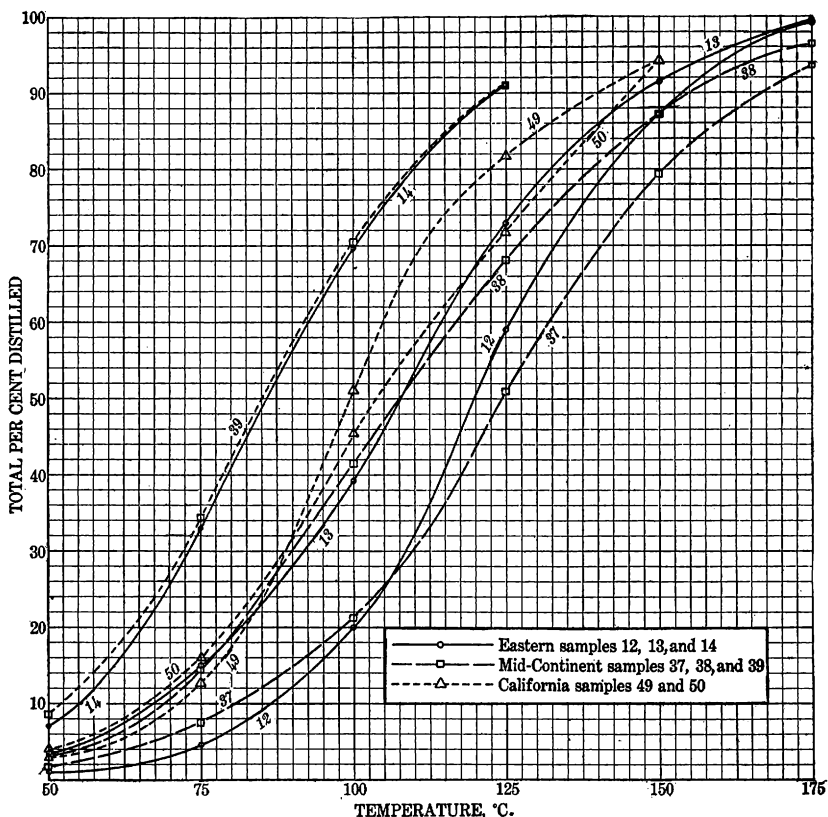


FIGURE 1.—Volatility ranges of typical "straight" refinery gasolines from Eastern, Mid-Continent, and California fields. Note similarity between products from Eastern and Mid-Continent fields as regards variation; also that California gasolines have a volatility range approximately midway between Eastern and Mid-Continent gasolines.

Figure 1 shows rather clearly that it is not possible by studying the property of volatility alone to distinguish the gasolines from the three fields. It is, however, important to note the normal ranges of volatility of gasolines produced by straight refinery methods.

#### VOLATILITY OF CRACKED GASOLINE.

It is impossible to draw any definite conclusions regarding the distillation ranges and volatility limits of cracked gasolines. A num-

ber of the samples collected show unquestionable evidence of having been produced by cracking processes but it is also certain that they are not "straight" cracked products but rather ones which have been blended with ordinary refinery products. No attempt has been made, therefore, to draw conclusions regarding the volatility of products of this class, except to note that the cracked gasolines on the market do not show any distinguishing features during the process of distillation.

#### VOLATILITY OF CASING-HEAD GASOLINE.

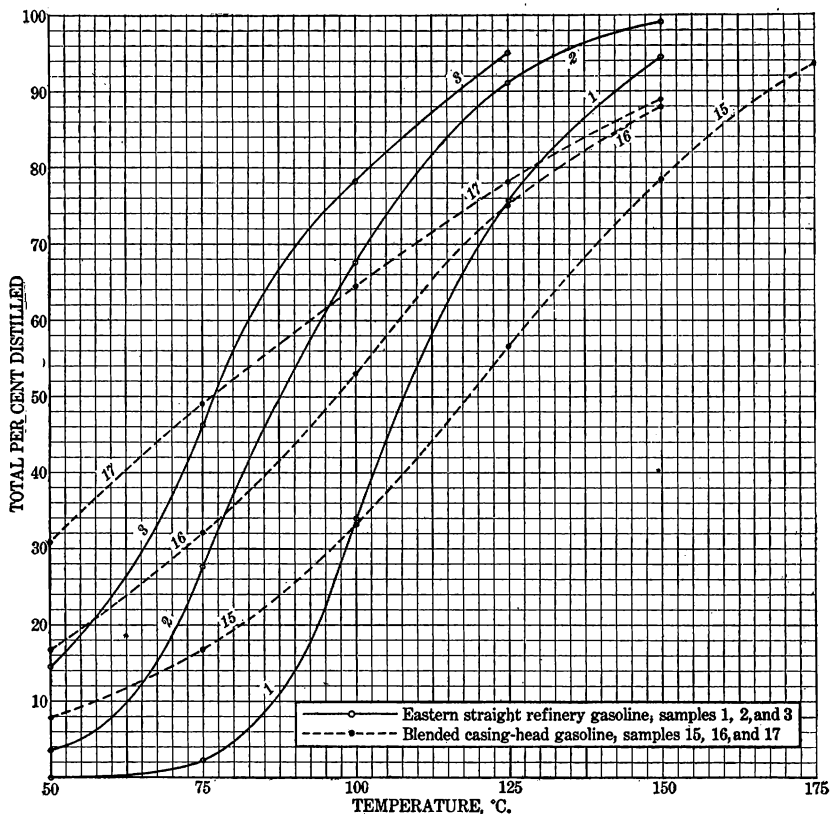
An important factor in the market is the so-called casing-head gasoline, which is extracted from natural gas by compression or scrubbing. It consists of hydrocarbons of low boiling points and when unmixed with other products is extremely volatile. This product must be stored and handled with care in order to avoid evaporation losses. Casing-head gasoline is rarely or never used "straight," being generally mixed with enough heavy naphtha to bring it to the proper specific gravity. The tendency to evaporate is incidentally reduced but still remains greater than that of a straight refinery product of approximately the same specific gravity.

Blended casing-head gasoline is an important factor in present market conditions and is not necessarily inferior to "straight" refinery gasoline. Although the tendency to evaporate is great there is an advantage in the fact that blended gasolines undoubtedly "start" with great ease in an engine. In addition it is claimed, with what seems perfectly sound logic, that the heterogeneous character of this gasoline slows down the velocity of combustion and results in maximum pressure being developed with a gradual push on the engine piston rather than with a sharp explosion. This results in the development of maximum power with a minimum of strain from high pressures. No data are at hand to support the claims generally made by producers of blended casing-head gasolines, but the contentions stated seem reasonable in theory.

It is possible by means of a distillation to distinguish blended casing-head gasolines from ordinary refinery products because the volatility range of the former has more or less definite general characteristics. This point is illustrated by results for typical gasolines, as shown in Table 5. Three blended products (Nos. 15, 16, and 17) are represented and three "straight" refinery products (Nos. 1, 2, and 3). The latter are not the three represented in Table 4 but are ones that show specific gravities more nearly approaching those at which they were rated. The samples selected for Table 4 (Nos. 12, 13, and 14) are more clearly representative of the products as they actually reach the consumer after having been handled by middlemen

and retailers. Samples 1, 2, and 3 (Table 5) have larger percentages of lower boiling constituents and the contrast with the blended gasolines is less striking than would have been the case if the more "weathered" sample had been chosen.

An examination of the figures in Table 5 and of the curves in figure 2 shows the clear-cut differences between the two types of gasoline. The blended casing-head products have larger percentages dis-



FIGURES 2.—Volatility ranges of gasolines. The flatter slope of the dotted curves shows that the content of both low and high boiling constituents is greater in the blended gasoline.

tilling below 50° C., but have longer distillation ranges. This tends to make the slope of the temperature-percentage curves for these gasolines flatter than those of the straight refinery products. However, it is unnecessary to plot a curve in order to detect a blended casing-head product, as the numerical results show plainly the characteristic features. Any gasoline having an unusually large distillation cut below 50° C. and with considerable percentages distilling within the temperature ranges of 150° to 175° C. and 175° to 200° C. may be classed as one of these blended products. An inspection of

the figures in Table 1 reveals the fact that samples 3, 4, and 5 are also blends and that they show the characteristics of this class even more clearly than do those represented in Table 5 and figure 2.

#### EVAPORATION LOSSES.

The results for evaporation losses shown in column 32 of Table 1 and in Table 9 are without significance on an absolute basis, as they show only the relative probabilities of shrinkage. The variations are proportionately great, ranging between 0.8 per cent and 6 per cent. The average figure for the entire series is 2.13 per cent.

#### CONTENT OF UNSATURATED HYDROCARBONS.

##### IODINE NUMBERS.

The content of unsaturated compounds of each sample in the list shown in Table 1 was studied by the convenient and accurate iodine absorption method. The iodine numbers (see Table 1, column 33, and Table 6) represent the percentage by weight of iodine absorbed by unsaturated hydrocarbons and show considerable variations for different gasolines. A relatively large content of unsaturated hydrocarbons indicates that the gasoline under examination is a so-called cracked product, either pure or mixed with gasoline of another variety.

The iodine numbers of the uncracked gasolines varied between 0.6 and 6.5. California gasolines showed the lowest iodine numbers, all uncracked samples from that field ranging between 0.6 and 1.5. The Mid-Continent gasolines ranged mostly between 2.0 and 4.0. The gasolines from the eastern fields showed the highest numbers, several values between the limits of 4 and 5 being discovered, and two gasolines, known to be straight refinery products in the manufacture of which no cracking process was used, iodine numbers of 5.9 and 6.5 were measured.

The iodine numbers of cracked gasolines vary between wide limits, probably on account of the fact that these cracked products are generally put on the market in the form of a blend with some gasoline that is more highly saturated. No attempt was made to determine the low limit of unsaturation which would show a product to be a blend with a cracked gasoline. It seems probable, however, that a gasoline having an iodine number of 8 or higher contains cracked products, and if the number is higher than 10 the indication is practically certain. The heavy naphthas used in producing blended casing-head gasoline are often unsaturated and in the case of several of the samples tested it is reasonable to assume that the producer may not have known that he was turning out a gasoline having a high degree of unsaturation.

The gasolines examined may be divided into three classes—(1) uncracked gasolines, (2) gasolines having small percentages of cracked products, introduced by blending, and (3) ordinary marketable cracked gasolines. In this report these classes have been differentiated as follows: Class 1, gasolines with iodine numbers of 6.5 or less; class 2, those with iodine numbers between 6.5 and 20.0, and class 3, those with iodine numbers between 20 and 60.

The character of gasolines having the iodine numbers of class 1 has been discussed. The gasolines of class 2 were apparently those in which the cracked constituents were in the minority. These products were either of the blended casing-head type or else they came from refineries putting out a moderately small proportion of cracked product. Those of the third class were the normal product of refineries specializing in the cracking process.

#### SULPHURIC ACID ABSORPTION.

All the gasolines of classes 2 and 3 were tested for their content of unsaturated compounds by the sulphuric acid absorption method. The percentages absorbed varied from 1 per cent for the products of class 2 up to 3 to 6 per cent for those of class 3.

The figures for iodine numbers and percentages of absorption of by sulphuric acid of gasolines of classes 2, 3, and 4 are collected in Table 6.

The sulphuric-acid tests were made rather roughly, and it is not assumed that the method is highly accurate. More satisfactory results could perhaps be obtained through the use of different apparatus, as mechanical shaking and centrifugal separation would undoubtedly give results more closely approximating the actual degree of unsaturation. It appears, however, that the sulphuric acid values do not follow in exactly the same order as the iodine numbers. The difference may be due to experimental error, but not necessarily, as the two methods measure different properties. Sulphuric acid absorbs each and every hydrocarbon molecule containing an unsaturated linkage. The absorption is no greater if the molecules contain two or more bonds than if they contain one. The iodine numbers indicate the number of actual unsaturated linkages.

The present work does not permit the drawing of conclusions regarding the value and utility of the cracked products. This problem will probably never be fully settled until gasolines of the cracked variety have been thoroughly tried by a large number of users and under all sorts of working conditions. However, the lack of comment from men in regard to these products seems to indicate that they are giving satisfaction. The experiments reported herein have shown chiefly that cracked gasolines are on the market and that they

can be detected even in small proportion by simple and accurate chemical methods.

In this connection it may be noted that at least one other method is in use for detecting unsaturated compounds—namely, measuring under standard conditions the amount of heat resulting from the mixing of gasoline and acid.

#### **CALORIFIC VALUES.**

The calorific values of typical samples, which are given in Table 7, show a difference of only about 1.5 per cent between the highest and lowest values, and a general, though not universal, tendency for the calorific power (per unit weight) to increase as a gasoline becomes lighter.

#### **SULPHUR CONTENT.**

The sulphur content of all the gasolines, as shown in Table 7, is negligibly low, ranging between 0.01 and 0.05 per cent.

#### **POWER DEVELOPED BY ENGINE TESTS.**

A number of engine tests of typical gasolines were made with special care and accuracy. The probable error in all the results seems to have been less than 5 per cent and in most cases about 3. The results of the tests appear in Table 7. The amount of power developed by the different samples did not at the most differ more than 10 per cent. The average difference on either side of the mean was found by calculation to be only 2.1 per cent. From this it seems that the probable error of the experiments, although small on an absolute scale, was so large in relation to the differences that had to be measured that the limited data obtained do not permit the drawing of definite conclusions as to the chemical and physical properties that control these differences. The smallness of the variations is, however, definitely established and leads to the following important conclusion.

All gasolines can, under properly regulated engine conditions, be made to develop about the same amount of power. This result indicates that the claims made by many refiners for the superior power-producing qualities of their gasolines are largely without foundation. It does not necessarily follow that all gasolines are equally good, but it is certain that in some instances exaggerated claims are made for the number of miles obtainable from a gallon. The possible element of superiority undoubtedly lies in some products giving maximum efficiency over a wider range of engine conditions, such products consequently being more nearly "fool-proof" and "weather proof."

The important fact is, therefore, that if the user of gasoline takes suitable care of his engine he can get almost as good results out of a cheap gasoline as out of an expensive "high-test" product. It is



interesting to note that many owners of automobiles have already discovered that a "high-test" gasoline is not necessary and that they are able to get efficient service out of "homemade" blends of gasoline and kerosene. On the other hand, those who use engines not suitably constructed or find it undesirable or inconvenient to make the necessary adjustments may justly claim that high-test gasolines are worth the prices paid.

#### **RELATIONS BETWEEN SPECIFIC GRAVITY AND VOLATILITY.**

As was pointed out in previous pages, certain conclusions may be drawn regarding the source, method of production, and utility of a gasoline from a study of its volatility and specific gravity. It appears that by noting the relations of these properties to each other it is possible to obtain more extensive and more important information than that obtainable by the study of individual sets of properties. One of the most characteristic differences among petroleum products from different fields of this country occurs in the relation between specific gravity and boiling point. Eastern oils are of paraffin base and for a given boiling point have a relatively low specific gravity. California oils are of asphaltic base and show a higher specific gravity for the same boiling point. The Mid-Continent oils are of mixed paraffin and asphaltic base and show specific gravities varying between those characteristic of oils from the other two fields.

In studying the results obtained from the tests of the samples collected it is necessary to be cautious in drawing conclusions as to the source of the crude petroleum used in making a gasoline from the locality in which the sample was purchased. The facilities for transporting crude oil are so highly developed that the location of a refinery means little. Some of the large companies have pipe lines extending through several States, and they are able to distribute their crude oil almost at will. In general, however, it is safe to assume that gasoline purchased in California and in parts of the Mid-Continent area near the producing fields are derived from regional crude oils. In the East, however, this does not hold, as both crude oils and refined products are largely shipped there from fields where prices are lower. A number of the samples tested were, however, obtained from refineries in the Pittsburgh district which use Pennsylvania crude oil. These products were selected as being representative of the class derived from eastern crudes.

#### **RELATION OF VOLATILITY OF GASOLINE TO SPECIFIC GRAVITY OF ORIGINAL SAMPLE.**

Samples from the three fields may show similar distillation curves yet have specific gravities differing by several degrees Baumé. Thus,

on inspecting figure 1, which shows distillation curves of a number of typical gasolines from the three fields, the reader will note that three of the gasolines (samples 51, 38, and 13), one from each field, have volatility curves that are approximately the same. The California sample is evidently a little more volatile than either of the other two. The latter are nearly equal, their curves crossing with a slight angle at about the middle point. The specific gravities were as follows: Sample 51, from California, 0.733 (61.0° B.); sample 38, from Mid-Continent field, 0.727 (62.6° B.); sample 13, from Pennsylvania, 0.718 (65.0° B.).

Another pair of curves (for samples 39 and 12) show a Mid-Continent sample that is clearly a little more volatile than the Pennsylvania product having the adjacent curve. The gravities of these samples were as follows: Sample 39, from Mid-Continent field, 0.703 (69.2° B.); sample 12, from Pennsylvania, 0.699 (70.3° B.).

These comparisons are only qualitative as the volatility relations could not be put on an equal basis; and in any event the data are insufficient for use in drawing exact conclusions. It is evident, however, that for gasolines of the same volatility, the Mid-Continent products are heavier than the eastern and that the California products are heavier than either the Mid-Continent or eastern products.

#### RELATIONS AMONG SPECIFIC GRAVITIES OF DISTILLATION CUTS.

In addition to the valuable information obtainable by comparing the specific gravity of a sample with its volatility range, more or less definite conclusions can be drawn from the specific gravities of the various distillation cuts. Gravities of various cuts for representative samples from the three fields are shown in Table 8. The reader will note that the ranges of gravity of the different cuts overlap so that absolutely definite conclusions can not be drawn. There are, however, as shown by the figures of Table 8 and by the curves in figure 3, characteristic differences for average values which fix the probable source of a gasoline. The differences are of about the same general order as those indicated for specific gravities of original samples. For a given volatility an Oklahoma sample is, in terms of gravity, about 2.5° to 3.5° B. (0.010 to 0.014 specific gravity) heavier than an eastern gasoline and a California product is from 4° to 8° B. (0.017 to 0.032) heavier than those from the East. In making this summation, consideration has not been given to cuts up to 50° C., as these have no fixed lower limit.

These differences are greater than those indicated above, and are more reliable and accurate, as they represent a large number of determinations and also fixed conditions of volatility, which could

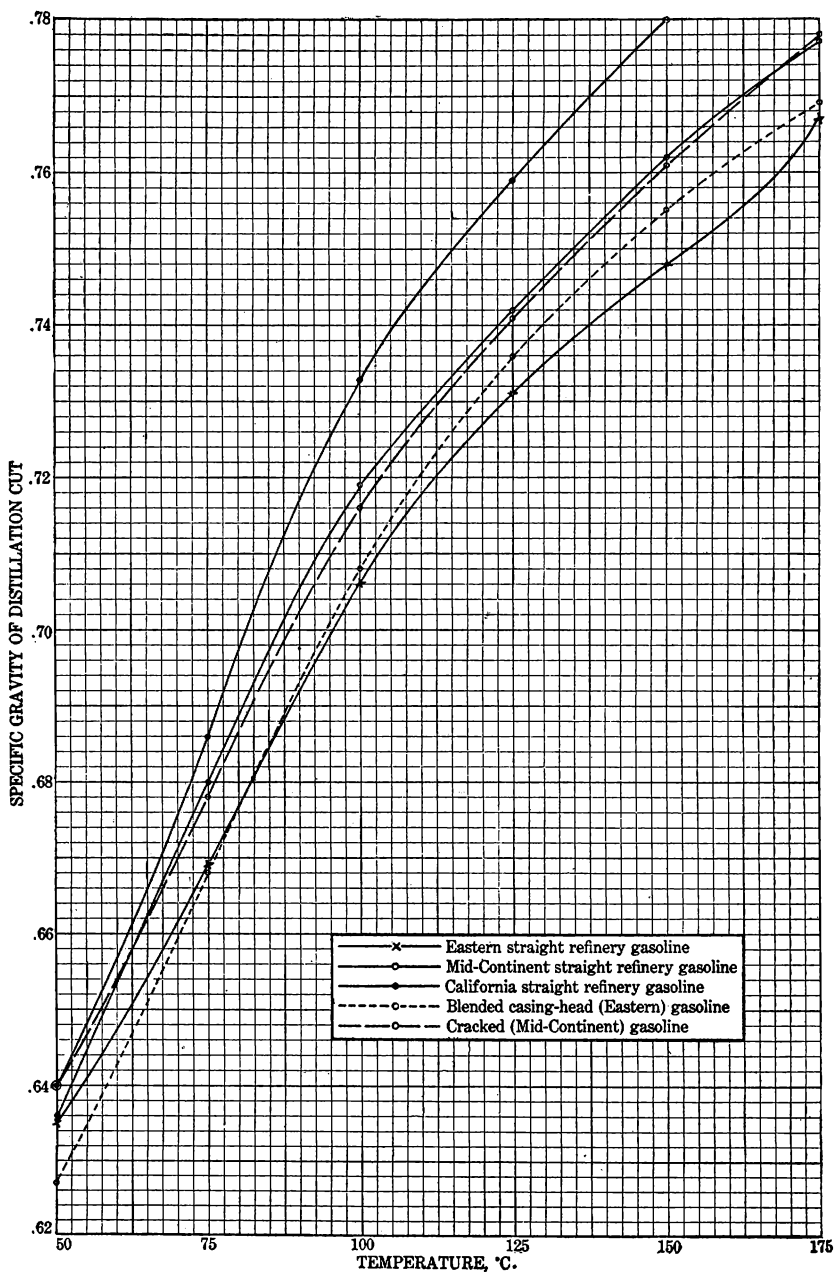


FIGURE 3.—Variations in average specific gravities of distillation cuts from "straight refining, blended casing-head, and cracked gasolines.

not be attained in the other case where it was necessary to depend upon the relations of single samples to illustrate the points in question.

The blended casing-head gasolines examined resembled the straight refinery products of the eastern field rather closely in volatility and specific-gravity relations. The cracked gasolines resembled the Mid-Continent products, possibly on account of their being derived from crude petroleum from that field. Figures for these types of gasoline are included in Table 8.

#### CONCLUSIONS REGARDING VOLATILITY-GRAVITY RELATIONS.

1. It seems that, by studying the volatility and specific-gravity relations of the original gasoline, or, better still, of the distillation cuts, one can determine the source of the product with a moderate degree of certainty. It is also possible, in the case of a product made by blending samples of different volatilities and different types, to ascertain this fact by noting the gravities of the distillation cuts. The lower cuts will show the specific-gravity and volatility relation characteristic of gasoline from one producing field—and the higher cuts, that of gasoline from some other field. The average gravities for distillation cuts of samples from the three fields are shown in Table 8.

2. For a given volatility a Mid-Continent gasoline is  $2.5^{\circ}$  to  $3.5^{\circ}$  B. (0.010 to 0.014 specific gravity) heavier than one derived from Pennsylvania crude, and a California gasoline is  $4^{\circ}$  to  $8^{\circ}$  B. (0.017 to 0.032) heavier than the eastern products.

3. The gasolines derived from natural gas (so-called casing-head products) showed specific-gravity and volatility relations similar to those of straight refinery products derived from eastern crudes. The heavy naphthas used in blending have, of course, the specific gravity characteristic of the field from which they were derived.

4. The cracked gasolines showed specific-gravity and volatility relations characteristic of Mid-Continent products. The gasolines tested were derived from petroleum products from this field. It remains to be proved whether the relations of specific gravity and volatility are fixed by the cracking process or whether they remained unchanged during it.

#### RELATIONS BETWEEN EVAPORATION LOSSES AND VOLATILITY.

The method employed for the measurement of evaporation losses was necessarily such that the results have little value on an absolute basis. That is, it is impossible to predict from the figures obtained what the probable shrinkage will be in the commercial handling of

gasolines of the types studied, even if conditions of storage, etc., are rather definitely fixed. The results do, however, show the relative probabilities of shrinkage, and differentiate the gasolines in a satisfactory manner. The experimental method employed was necessarily rather crude, but it has been possible to devise a system of averaging results which show sharply defined relations.

Obviously, of course, the percentage of loss by evaporation is regulated by the volatility of the sample, which is in turn a function of its content of low-boiling constituents. The results of the experiments have established this fact in a satisfactory manner. The data obtained have been used to show the average relation between the loss by evaporation and the percentages in the samples boiling up to the limits of 50° and 75° C.

The figures for evaporation losses have been collected in the order of their magnitude in the first part of Table 9. The nature of the figures and their small differences make evident the fact that they involve a proportionately large percentage error. It is also impossible to average these percentages for the purpose of reducing the probable error. On the other hand, however, the averaging of the values with which the percentage evaporation losses are compared seems perfectly feasible and has been adopted, yielding a relation which is fairly clear-cut and definite. In the second part of Table 9 are given the evaporation losses and the average figures for specific gravity and distillation cuts up to 50° and up to 75° C. of gasolines, showing the indicated loss. These results are plotted in figure 4. The curve showing the relation of the percentage losses to the magnitude of the percentage distilling up to 50° C. is consistent, though a trifle irregular. A similar curve for the total cut to 75° C. is a little less consistent and a little more irregular. A curve showing the relation between percentage evaporation loss and specific gravity of sample shows only a rough relation and is decidedly irregular. This curve clearly indicates that the influence of specific gravity on evaporation loss is accidental and exists only because in a general way light gasolines have large percentages of volatile constituents.

#### SUMMARY OF EXPERIMENTAL RESULTS.

1. Fifty-two samples of gasoline, of varieties sold throughout the United States during the year 1915, were collected and subjected to a comprehensive series of tests, and in addition about 150 samples were collected in the spring of 1916 and tested for specific gravity only.

2. Of these tests several yielded results that were more or less uniform and negative in value.

- (a) The calorific values per unit of weight for different samples showed a maximum variation of only about 1.5 per cent between the

highest and lowest value obtained. The results are accurate within about 0.2 per cent.

(b) The quantities of power developed under like engine conditions varied only about 10 per cent between extremes, the possible error being 3 to 5 per cent.

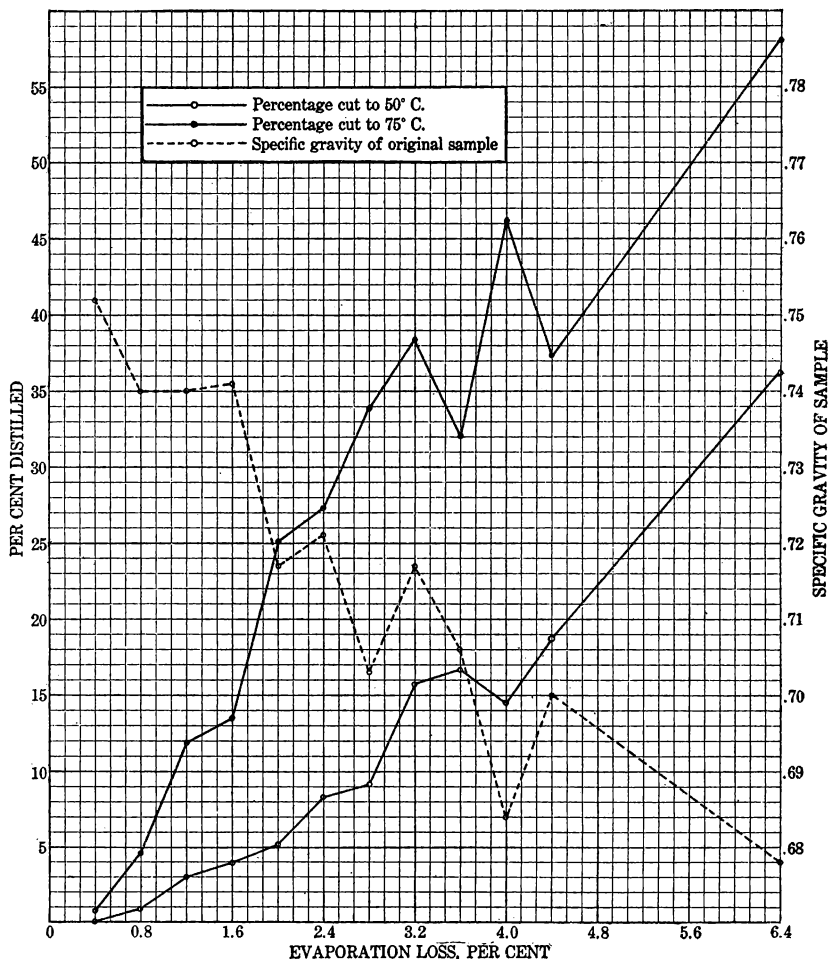


FIGURE 4.—Relation between evaporation loss and percentage cuts to 50° and 75° C., and to specific gravity of original gasoline. The evaporation losses and percentage cut to 50° C. show a consistent but irregular relation; for percentage cut to 75° C. the relation is less definite; in the curve for evaporation loss and specific gravity, only a rough and accidental relation is shown.

(c) The sulphur content of the gasolines was so small as to be negligible.

3. The volatility of the different gasolines, as indicated by the distillation range, varied widely. The normal market products have

boiling ranges with lower limits varying from below 50° up to about 75° C. The upper limits varied from 125° to about 175° C. There were, however, several exceptions to the above general rule. One special "86°" gasoline boiled almost entirely below 100° C. Some of the blended casing-head products contained products boiling up to 200° C. and higher.

No characteristic differences in volatility among products from the three fields were shown, except that in general eastern gasoline showed greater tendencies to vary than the Mid-Continent and the California gasolines. The volatility of the last was more nearly uniform than that of products from the other two fields. Cracked or synthetic gasolines showed no characteristic volatility properties. Blended casing-head gasolines were characterized by an abnormally large content of both low and high boiling constituents and were deficient in constituents boiling at intermediate points of the distillation range.

4. (a) Specific gravities of original samples varied over a wide range, falling between the limits of 75° and 55° B. (0.683 and 0.757 specific gravity) with one exception, the "86°" product, which is not generally sold on the market. Eastern gasolines have the largest range of gravity, varying between 75° and 60° B. (0.683 and 0.737 specific gravity), Mid-Continent products ranged between 68° and 58° B. (0.707 and 0.745) and California gasolines ranged between 63° and 55° B. (0.725 and 0.745).

(b) The specific gravities of the distillation cuts show clearly the differences in chemical nature of the hydrocarbons found in products from the three fields. For a given distillation range Mid-Continent products are in terms of specific gravity, 0.010 to 0.014 (about 2.5° to 3.5° B.) heavier than eastern gasolines, and California gasolines are 0.017 to 0.032 (about 4° to 8° B.) heavier than the eastern.

5. The gasolines varied widely in their content of unsaturated compound, a high content of unsaturated hydrocarbons being characteristic of cracked or synthetic gasolines. Uncracked gasolines of the series tested had iodine numbers varying from 1 to 6.5. Products with higher iodine numbers contained greater or less percentages of cracked gasoline. The ordinary product of this type, marketed as gasoline had iodine numbers ranging between 40 and 60. Products with numbers much lower, but still well above the 6.5 mark may have been blends containing only small percentages of gasoline made by cracking processes.

For uncracked gasolines the percentages of the various products with numbers much lower, but still well above the 6.5 mark absorbed by sulphuric acid, were negligible. Cracked gasolines showed losses varying from 1 to 6 per cent.

6. Relative evaporation losses seem to be approximately in direct proportion to the magnitude of the distillation cut up to 50° C.

7. By applying some or all of the tests employed it is possible to settle quite definitely the source, method of production, and probable utility of any sample of gasoline that may be examined.

### **SUGGESTED SPECIFICATIONS FOR PURCHASE AND SALE OF GASOLINE.**

In this investigation it was not found possible to include a comprehensive series of experiments showing how the physical and chemical properties of a gasoline control its action in an automobile engine. However, certain indications obtainable from the results given are of value in indicating how specifications may be drawn for the purchase and sale of gasoline. The following facts are of interest:

1. The two properties of a gasoline that tend to make its cost relatively high are (a) a narrow range of boiling point and (b) freedom from unsaturated constituents. These properties are possessed by the so-called "high test" gasolines, which have gravities of 70° to 74° B., and are obtained by "straight" distillation processes.

2. It is evident that the first factor of expense is one that can be efficiently minimized. The results of the engine tests made show that the "high test" gasolines were slightly, if at all, superior to the cheaper products as regards power development, and then only on a weight basis. As gasoline is sold by volume the actual rating runs the other way. The chief element of advantage seems to be that the "high test" gasolines yield maximum efficiency over a larger range of engine conditions. The newer designs in the way of engine construction have largely tended toward making possible the use of gasolines that are more difficult to vaporize. In any event, proper care and adjustment of an engine makes unnecessary the employment of a "high test" gasoline. It appears, therefore, that the user need not purchase the more expensive lighter grades if the engine is efficient in design and if the operator is moderately skillful and careful. Heavy gravity refinery gasolines and cracked gasolines, and blended casing-head products, are now being used in enormous quantities; and as far as can be judged from the absence of complaints regarding them, they are giving satisfactory results.

From the same indications it appears that a high degree of saturation is as unnecessary as narrow boiling range. There are on the market large quantities of cracked gasolines having iodine numbers up to 60, and the content of unsaturated compounds seems to cause the users no inconvenience. It is probable that by suitable adjustment of conditions, especially as regards setting the carburetor to



produce a "lean" mixture in the engine, products of even higher degree of unsaturation may be used. The present market products are apparently so refined and blended that their characteristic properties do not even attract attention.

A minor fact that deserves mention is the undesirability of attempting to use "motor" gasoline either as a cleaning fluid or as a drying solvent. This is shown by the high boiling points of some of the constituents in many of the gasolines tested.

To summarize the matter of gasoline specifications, it may be said that the conditions under which the gasoline is to be used should be considered and then requirements should be outlined for as cheap a motor fuel as can be consumed with approximate maximum efficiency. If engine conditions are adjusted to attain this condition, a cheap gasoline will yield as much or even more power than the lighter and more expensive "high-test" products. In addition the results indicate that both cracked and blended casing-head gasolines may be utilized to as great advantage as straight refinery products.

#### ACKNOWLEDGMENTS.

This investigation was instituted and conducted under the direction of W. A. Williams, chief petroleum technologist of the Bureau of Mines, to whom the authors wish to make particular acknowledgment of their indebtedness. Mr. Williams suggested the need of the present study and furnished advice and guidance with regard to both the actual work and the interpretation of results.

The kindness of the many refiners who cooperated with the bureau is heartily appreciated, and attention is called to the fact that they were both willing and anxious to aid in obtaining for users information regarding their products.

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Calorimetric and sulphur determinations were made by S. W. Dean, of the Pittsburgh petroleum laboratory of the Bureau of Mines.

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