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AN INVESTIGATION OF MOTOR GASOLINES

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AN INVESTIGATION OF MOTOR GASOLINES

INTRODUCTION

During the early days of the petroleum industry when crude oil was processed primarily for kerosene, gasoline was a waste product and was separated from the oil used in lamps because of its tendency to vaporize and cause the lamps to explode. Later it was found that this ability to vaporize at reasonably low temperatures made possible the development of an internal combustion engine which would operate economically and satisfactorily on gasoline.

In the early development of the automobile, the average owner was satisfied if the engine would run continuously and start without too much difficulty. Nearly all engines were provided with priming cups so that fuel could be poured directly into the engine cylinder for starting. The motorist who was rash enough to drive his car in cold weather frequently provided himself with a can of ether mixed with a volatile gasoline for this purpose. The accelerating energy required to start the car moving was provided by using a heavy engine flywheel, speeding up the engine, and letting the clutch in. The engines themselves had practically no accelerating ability. Fuel economy in miles per gallon was not discussed because the distances traveled were short and the speeds low. Quoting from the 1892 catalog of a car manufacturer: "Speeds: The cars have three speeds; a small speed, an intermediate speed and a high speed. The high speed is generally adjusted to eleven m.p.h."

From this small beginning, motor cars, highways, and fuels developed together until gasoline, no longer a by-product, became the most important constituent of crude oil. As the demand for gasoline increased, the manufacturers endeavored to increase the available supply by using more and more of the heavier and less volatile portions of the crude.

Later, the cracking process, whereby the heavy fractions of the petroleum are broken up into lighter fractions by intense heat, and the polymerization process—by means of which materials often too volatile to be handled satisfactorily as liquids are made to combine with each other to form gasoline—came into commercial use, and have more than doubled the quantity of gasoline obtained from a barrel of crude oil.

Meanwhile engine developments made demands for fuels that would operate in high compression motors without knocking. The increased use of automobiles in cold weather called for a fuel that would start at temperatures well below zero, while sustained high speeds over a hot desert country required fuels relatively free from low boiling fractions. The gasoline manufacturing processes have become complicated beyond the understanding of the layman and the requirements for successful performance in various types of engines operating under different climatic conditions are involved and necessitate special blending.

The development of fuels and engines has gone hand in hand for many years. The original highly volatile (commonly called high-test) gasoline of thirty years ago would not operate satisfactorily in a modern engine. At the present time, the science of producing fuels is so well developed that it is possible to predetermine the volatility and anti-knock characteristics that will give the best service in a definite type of motor in any part of the United States at any specified season of the year. Modern engines will now develop three to four times as much power as earlier engines having the same bore and stroke and number of cylinders. Modern gasoline, which is blended to give the proper characteristics, has contributed its share toward this improvement.

Commercial automotive gasolines are so nearly alike that there is very little difference in the performance of engines with different brands when the gasolines are compounded to give the same volatility and anti-knock characteristics. These properties constitute the principal difference in the various grades—"third grade," "regular," "premium"—of today's gasolines. The engine performance, fuel consumption, and power developed are influenced much more by the carburetor adjustment, the ignition timing, and the condition of the motor, than by a change from one standard brand of gasoline to another. This uniformity in fuel performance is due to the co-operative efforts of petroleum technologists, the United States Bureau of Standards, chemists, and automotive engineers. It is now possible to predict the performance of a gasoline in a certain type of motor, under known climatic conditions, from laboratory tests.

PURPOSE OF INVESTIGATION

"Third grade," "regular," and "premium" gasolines are sold in the Twin Cities by practically every service station. Certain qualities are presumed to be built into these gasolines by the manufacturers in order to suit them for different types of service. Some motors are designed to operate only with "premium" gasolines; a majority of the cars require "regular" gasolines; while others seem to give satisfaction to their owners burning "third grade" fuels. The kind of service for which the motor is being used, the condition of the motor, and the adjustment of the carburetor and ignition will have much to do with the ability of a motor to use the cheaper grades of fuel. A retarded ignition setting or an overrich mixture may enable the use of a lower grade of fuel, but the fuel consumption will increase accordingly. Whenever it is possible to operate economically with a gasoline that costs less to produce, the user should have the benefit of any saving made, and the refiner should and does provide a less expensive fuel for this purpose. More expensive fuels are necessary for high duty, high performance motors. There is ample justification for the marketing of several grades of gasoline, and the qualities built into each of them are of vital importance to the public.

Seasonal changes in volatility are especially important to the car owners in Minnesota, while the presence of undesirable sulfur, acid, or gummy compounds concerns all gasoline users. The United States Bureau of Mines has been conducting semiannual surveys of gasolines by securing samples of gasolines from representative cities throughout the United States. The sampling was started in 1915 but was discontinued during the depression because of lack of funds. These surveys are made on gasolines manufactured by major companies only and the last survey was made up from tests made in oil company laboratories and reported to the bureau under a co-operative agreement.

The present investigation was conducted as a contribution to the information available about gasolines marketed in the state of Minnesota. An analysis of the tests enables comparisons to be drawn between gasolines sold at standard and cut-rate prices, and between those sold as "premium," "regular," and "third grade." It reveals the actual seasonal changes in blending and shows the extent to which some gasolines deviate from accepted standards. The large number of samples tested should present a representative estimate of what the purchaser may expect to get in return for money expended for any certain classification of gasoline.

SAMPLING

In order to secure representative samples of the gasoline sold to the public, three quart bottles of each grade of various brands were purchased at service stations. Retailers doing a relatively good volume of business were selected so that the supply of gasoline would be of recent delivery, and subsequent purchases were made at the same stations. The bottles were stored in ice-cooled refrigerator boxes and were thoroly cleaned between purchases.

ENGINE FUEL REQUIREMENTS

The successful operation of a gasoline engine is affected by two principal properties of the fuel:

1. Volatility
2. Anti-knock quality—octane number

Other properties may be important for continued satisfactory operation, but without suitable volatility it may be impossible to start or run the engine at all, while severe detonation or fuel-knock will cause loss of power and economy or may actually force a shut-down after a few minutes' operation. Gasoline should be free from corrosive materials, dirt, and water, and should contain a minimum of sulfur and gum.

VOLATILITY

REQUIREMENTS FOR STARTING

In order to obtain an explosive mixture of air and gasoline, the proper amount of gasoline must be gasified and mixed with the air. Explosiveness is not dependent upon the total quantity of gasoline present but only upon the proportion of the air and gasoline vapor[1] in the mixture. Mixture ratios (by weight) from 8 parts of air to 1 part of gasoline vapor, up to 20 parts of air to 1 part of vapor, are usually explosive in the engine cylinders. Beyond these limits ignition and explosion are not dependable. With an excess of vapor it is commonly said that the engine is flooded. The presence of an excess quantity of liquid gasoline does not necessarily indicate that flooding is occurring, because at low temperatures only a small part of the liquid is vaporized. About 15 pounds of air is actually necessary to burn 1 pound of gasoline, and from 12 to 14 pounds of air per pound of gasoline is actually supplied by modern carburetors when the engine is operating normally.

Most engines can be started in cool weather when the temperatures in the intake system are so low that only 5 to 15 per cent of the fuel is vaporized. Carburetors are provided with a choke or priming device so that up to 20 times the normal quantity of gasoline may be drawn into the intake system for starting. In this way, an explosive mixture of vapor and air is obtained, altho a large excess of liquid fuel is wasted. The temperature at which 10 per cent of a fuel will be vaporized in the intake manifold is commonly considered to be the lowest temperature at which that fuel may be expected to start in the average automobile.

REQUIREMENTS DURING RUNNING

An internal combustion engine is a machine used to convert chemical energy into mechanical energy. The chemical energy is in the form of gasoline and oxygen; therefore, the power produced will depend upon the quantity of energy-producing materials that can be introduced into the engine. However, in order to produce the energy quickly and satisfactorily, it is necessary that the mixture in the engine cylinder at the time the ignition spark takes place, consist of air and completely vaporized fuel in the proper proportions. Proportioning the fuel and air is a function of the carburetor and does not depend in any way upon the volatility. The temperature of the mixture just before ignition should be sufficiently high to maintain the fuel in the vaporized state, but no higher. Air and gasoline vapor both expand when the temperature increases, and therefore less energy may be introduced into a cylinder of fixed size when the mixture is hot than when it is cold. The gasoline should be partially in the form of a mist in the intake manifold so that the heat

[1] Gasoline vapor is in the gaseous state and should not be confused with atomized gasoline which is composed of small droplets or mist.

given to the mixture by the hot cylinder walls, valves, and the hot gases left in the cylinder from the previous explosion are just sufficient to complete vaporization. Gasolines that are not volatile enough produce a mixture that includes many small droplets in the intake manifold and are not distributed as evenly to the various cylinders as the more volatile products. Incomplete combustion of improperly vaporized fuels also results in the formation of compounds that are harmful to the metals in the engine. Unvaporized gasoline also mixes with the oil on the cylinder walls and works its way down into the crankcase diluting the lubricating oil. Low cylinder wall temperatures frequently condense fuel already vaporized and are conducive to crankcase dilution.

No gasoline manufacturer can hope to produce a fuel with exactly the right volatility for a wide variation in operating conditions, but the gasolines can be made so that they will operate satisfactorily under the average conditions obtained in the average automobile.

VARIABLES AFFECTING VOLATILITY

The vaporization of gasoline is influenced by the following factors:

The time elapsing after mixing gasoline and air
The volume or air-space available for vapor
The atmospheric pressure
The quantity of fuel
The movement of the air
The temperature of the mixture

If gasoline were poured into a saucer and allowed to stand in a room for a period of time, it would gradually evaporate until the saucer became perfectly dry. If the gasoline were thrown into the air it would evaporate more quickly but not instantly: some of it would fall to the floor and remain there until sufficient time had passed to complete the evaporation. Time is therefore a necessary element in the evaporation of gasoline. If the saucer were placed under a small bell jar, the vaporization would proceed until the space in the bell jar became saturated with gasoline vapors, after which the quantity of liquid in the saucer would remain constant. The quantity of gasoline evaporated depends upon the space available for the vapor, which is the same as the volume of air present. If the air were partially exhausted under the bell jar, the gasoline would have vaporized much more rapidly. Since the time for evaporation in the engine is a small fraction of a second, the air pressure is important. A large quantity of gasoline in the saucer would increase the amount of vapor under the jar but the per cent of gasoline evaporated would be less.

If the saucer filled with gasoline were placed in front of an electric fan, the evaporation would take place much more rapidly because the vapor is removed as rapidly as it is formed. If the temperature of the air were increased, or if the saucer or the air were heated, vaporization would take place at a greatly accelerated rate. It may be seen that volatility varies widely with the conditions imposed.

The measurement of actual volatility is a very difficult and laborious task and should be performed under conditions approximating those occurring in the fuel system of the engine itself. There is a wide variation in the velocity of the air through the intake manifold in a practical engine and in the temperature of the intake system. When the throttle is nearly closed, the pressure in the system is low, sometimes only half the ordinary atmospheric pressure. The relative amount of air and fuel present varies with the carburetor adjustment and with the closing of the choke. The determination of the actual volatility of the fuel for all conditions occurring in the intake system is, therefore, almost an impossible task. However, it is possible by making a more simple test, the American Society for Testing Materials Distillation, to obtain some information about the volatility of a given fuel.

AMERICAN SOCIETY FOR TESTING MATERIALS DISTILLATION TEST

The A.S.T.M. Distillation Test is made by heating the fuel in a flask and passing the vapors through an ice-cooled tube condenser. The vapor temperatures in the flask when 5 per cent, 10 per cent, 20 per cent, etc., of the original quantity of fuel is collected in the receiver, form the distillation data.

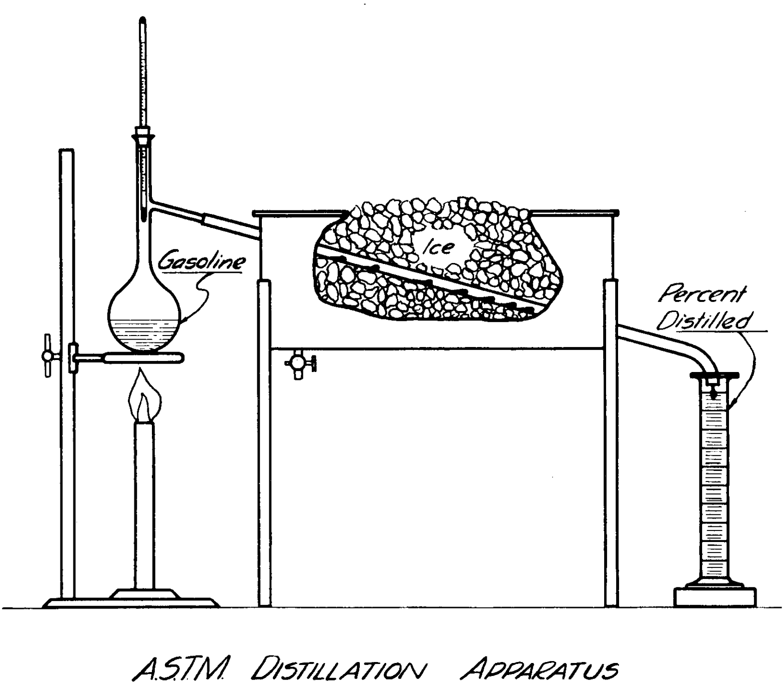


FIGURE. A.S.T.M. FLASK AND CONDENSER

Figure 1 shows the standard equipment used for this test with the standard shield around the burner and flask removed. The procedure, as standardized by the A.S.T.M., Method D-86-35, must be followed accurately if reproducible results are to be obtained and is too involved to be given completely here. As an example, the rate at which the heat is applied must be controlled to start the distillation not less than five nor more than ten minutes after the heat is applied, and thereafter the rate of flow must be not less than four nor more than five cubic centimeters per minute. Other requirements are equally as exacting, and the distillation test of an unknown gasoline generally requires one or more trial runs before a test can be completed in the approved manner.

The temperature of the vapor at which the first drop appears in the collector flask is called the initial boiling point, and the highest vapor temperature which is obtained while the flask is boiling dry, is called the end point. The total quantity collected in the receiver is called the recovery.

At the end point, the flask will still be filled with vaporized gasoline which condenses when the flask cools. This may then be poured out and measured and is called the residue.

The sum of the residue and recovery is always less than the original quantity of fuel because some of the very volatile vapors will diffuse into the air during the test. The distillation loss is the difference between the original sample of gasoline, (100 ml.) and the sum of the residue and the recovery.

The United States Bureau of Standards have developed elaborate equipment for determining the volatility of gasolines under conditions approximating those in engine intake systems. Tests of several hundred gasolines were made with this equipment and compared with A.S.T.M. distillation determinations for the same gasolines.[2] Empirical formulas were developed that permit a satisfactory calculation of volatility for various air to fuel ratios from the A.S.T.M. distillation curves for average gasolines. All distillation data are first corrected for distillation loss. This is done by adding the calculated loss to the amount of distilled gasoline collected in the receiver to obtain the total gasoline evaporated at the respective vapor temperatures.

These formulas may be found in publications of the Society of Automotive Engineers (15, 17, 112, 113).[3] Their discussion is beyond the scope of this bulletin. Typical applications show that a fuel which has an A.S.T.M. 90 per cent evaporated point of 380° F., would be completely vaporized in the engine cylinder with an air to fuel ratio of 12 to 1 at approximately 130 degrees above zero. Also that a gasoline with an A.S.T.M. 10 per cent evaporated point of 140° F., would be 5 per cent volatilized in the engine system at 20° F. below zero, if the choke

[2] The investigation of the U. S. Bureau of Standards covers a wide field. Only that portion of the work of immediate importance is mentioned here.

[3] Figures in parentheses refer to figures in the Bibliography, pages 39-45.

were set to draw in 15 times the normal amount of gasoline, thus giving a starting mixture of 20 to 1 at this low temperature. A completely closed choke will cause an engine to draw in up to 20 times the normal quantity of gasoline.

VAPOR LOCK

This term is used to denote the condition that exists when gasoline vaporizes in any part of the fuel system so as to interfere with the flow of liquid fuel. Vapor will form in the fuel line as soon as the vapor pressure of the fuel equals the pressure in the pipe. The vapors can leave the system only by passing through the carburetor, and since the carburetor nozzles are designed to handle liquid there is a shortage of fuel when gas passes through them and we say vapor lock has occurred. The engine may either stop entirely, or more frequently, it may simply lose power, slow down, run irregularly, etc. The fuel system generally is able to handle small amounts of vapor without difficulty but, as the temperature of the gasoline system increases, more vaporization takes place until the pipes contain so much vapor that the flow of gasoline is greatly diminished (29). Vapor lock may also be caused by high temperatures in the carburetor itself, so that the volatile constituents boil out of the carburetor bowl (23). These are just the materials that are desirable when starting the engine, and if boiling takes place immediately after the engine has been stopped, difficult starting may result. Vapor lock is frequently noticed by motorists when the engine is accelerated after idling. When the car is stopped, at a traffic sign for instance, the heat stored in the engine block, exhaust manifold, and water system is no longer dissipated into a rapidly moving air stream, and the temperature under the hood rises rapidly. Heat also flows directly from the engine through the metallic contact between the carburetor and the engine. As long as the engine is idling, sufficient fuel may be supplied, altho there is a considerable amount of gasoline vapor in the fuel lines, but when the throttle is opened the engine may stop entirely or accelerate very slowly.

Vapor lock may also occur at sustained high speeds, causing loss of power and speed. In cars using fuel pumps, the pressure produced by the pump in the carburetor feed lines tends to raise the initial boiling point of the gasoline so as to reduce the danger of vapor lock between the pump and the carburetor. On the suction side of the pump the reverse is true. It has been found that the fuel handling capacity of the pump remains practically constant after a certain engine speed has been reached so that the additional gasoline required for very high speeds is not delivered if a substantial quantity of vapor is formed in the line to the pump.

O. C. Bridgman of the U. S. Bureau of Standards has also developed empirical formulas for predicting the vapor locking tendencies of gasolines from the 10 per cent A.S.T.M. temperatures (19, 20), but the Reid vapor pressure test is more commonly used as a criterion.

REID VAPOR PRESSURE TEST (A.S.T.M. Designation D417-35T)

Figure 2 shows the arrangement of the equipment for this purpose. The lower cup, or base, contains 1/4 the volume of the upper tube. The lower cup filled with gasoline, is screwed into the upper tube and the apparatus immersed as far as the bottom of the pressure gage in water at exactly 100° F. After five minutes, the instrument is taken from the bath and shaken; immersed again for two minutes and again shaken; until the pressure recorded on the gage does not change with additional immersions. The final pressure obtained is called the Reid vapor pressure, after a correction has been made for the initial temperature of the air chamber.

Great care must be taken in filling the lower tube with the gasoline, so as to avoid the loss of volatile vapors during this process. In sampling gasoline from large containers, it is possible to submerge the gasoline chamber in the fuel and an accurate sample can be obtained. The tests reported here were made by chilling the gasoline and pouring it into the container. The results are, therefore, undoubtedly lower than would have been obtained if the gasoline had been sampled in the tank car. However, they represent rather accurately the vapor pressure of the gasoline as it is delivered to the consumer.

Strictly speaking, this test should be made at the temperatures at which the fuels will be used, but since this is impractical, the choice of 100° F. was made. The temperatures in the fuel lines of automobiles, however, has been found to rise as much as 75° F. above that of the air and it is estimated that the actual fuel line temperature in the majority of cars, at the point most sensitive to vapor lock, is about 35° F. above atmospheric (26, 27). In warm weather this would frequently result in fuel line temperatures of 125° to 140° F. Two gasolines having the same vapor pressure at 100° F. may have quite different pressures at 125°, and the volumes of gasoline vapor released may be quite different. Boyd (13) states that three gasolines whose vapor pressures at 100° F.

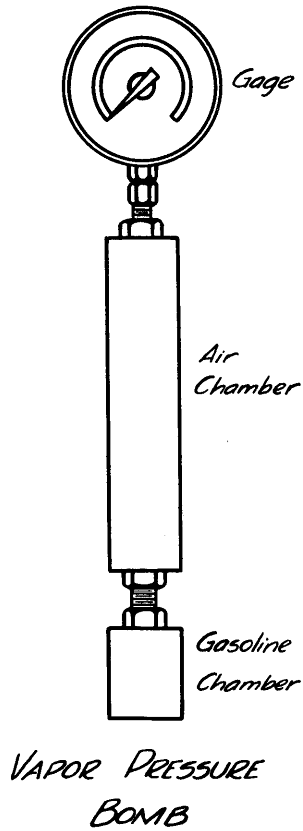


FIGURE 2. REID VAPOR PRESSURE APPARATUS

were 12 pounds per square inch produced volumes of vapor per volume original liquid, at 120° F. as follows:

No. 1	18 volumes
No. 2	22 volumes
No. 3	50 volumes

Since interference with the flow of fuel is dependent upon the volume of vapor released, it is evident that these three gasolines would have quite different vapor locking tendencies at 120° F.

The above data indicate that the allowable vapor pressures must be set at a conservative figure to insure suitable performance of gasoline in warm weather. Authorities differ on the maxima allowable but the following values are probably not far out of line:

Temperature of Atmosphere	Highest Reid Vapor Pressure
95° to 100° F.	8 lb. per sq. in.
80° to 85° F.	10 lb. per sq. in.
65° to 75° F.	12 lb. per sq. in.

It is evident that it is very important to have gasoline with the proper volatility for all conditions. Volatile material that is lost at the carburetor or through the vent in the gasoline tank constitutes the best anti-knock portion of the fuel. It may also account for low mileage since the engine does not receive all of the gasoline put in the fuel tank. The volatilized gasoline which has boiled out of the tank or carburetor is also a very definite fire hazard, and more than one gasoline fire has occurred under the hood of the engine because of the gasoline vapor trapped there.

The refiner or blender is confronted with the problem of providing an easy starting fuel with minimum vapor losses or hazards.

ANTI-KNOCK QUALITY

DETONATION

Every operator of a modern motor car has at some time or other noticed a very sharp metallic knock that occurs in the motor, generally when the engine is warm and is being operated with full throttle at a slow or moderate speed. It is common knowledge that the knock is much more severe with high compression motors. The names, carbon-knock or preignition, sometimes applied, are misnomers and undoubtedly arose from the fact that carbon deposits in the engine serve to aggravate the knock and that preignition, or the early ignition of the fuel charge, frequently occurs as a result of incandescent carbon deposits in the engine cylinder. Scientific investigation has determined the cause of this knock and the technical name that has come more and more into popular use is "detonation." It is particularly noticeable in the smooth, quiet-running modern automobile because the noise can be heard distinctly above that of the engine. In industrial engines and those used for trucking, the sound of detonation is not so easily distinguished, and motors are frequently operated under severely detonating conditions. When this is done, spark plugs may be ruined, the sides of the piston may be burned until the rings are melted in the grooves, cracks may be produced in the piston head, and occasionally bearings destroyed. Engines become very hot when allowed to detonate, carbon deposits are increased, power is lost, and overheating occurs. Occasionally, the detonation becomes so severe that operation is impossible. Engine failure has been particularly noticeable when aircraft engines, intended for operation with a high grade gasoline, have been driven with an inferior grade of fuel (70). Cases have been known where the engine ceased to operate every time it had been run at cruising throttle for a period of five to ten minutes.

Much progress has been made in the manufacture of fuels and in engine design to reduce the tendency to knock to a minimum. It has been very difficult to investigate this phenomenon because of the great speed of the reactions in the combustion chamber of an engine. Studies made by means of high-speed rotating films and moving pictures taken at the enormous rate of 4,000 exposures per second, show that flame in the combustion chamber of an engine travels from the spark plug progressively across the combustion chamber (138). The time involved in traveling across the combustion chamber may be as little as 1/500 of a second.

It has been shown by investigators in Germany, England, and the United States, that so long as the flame travels progressively across the combustion chamber, detonation does not occur. The process by which the flame moves is roughly illustrated in Figure 3.

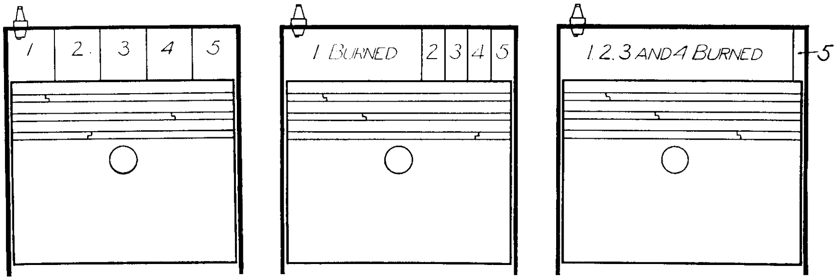


FIGURE 3. FLAME TRAVEL

Here the combustion chamber has been divided into five zones. When the fuel and oxygen in Zone 1 have combined, the temperature is increased and the unburned fuel in Zones 2, 3, 4, and 5 is pushed ahead of the expanding burned material, toward the far end of the combustion chamber. When the fuel in the first four zones has been burned, the fuel and air that originally comprised the fifth zone is compressed into a tiny space at the far side of the combustion chamber. The temperature of the unburned portion has been increased tremendously during this process and if it has become hot enough, the entire quantity of fuel left may burn instantaneously. When this occurs, the energy in one fifth of the original quantity of fuel is released with such tremendous speed that pressures far in excess of the normal explosion pressure in the engine are produced. To produce these enormous pressures, it is necessary only that the temperature of the last part of the charge to burn shall have exceeded its self-ignition temperature. The quantity of fuel which burns in this manner determines the intensity of the pressure wave thus created. Severe pressure waves of this nature strike the cylinder head or piston head violently enough to produce a sound resembling a hard, sharp blow from a hammer.

EFFECT OF COMPRESSION RATIO

Increased compression ratios are responsible for the major part of the improvement in economy and increase in power and performance of the modern motor. The compression ratio of an internal combustion engine is the ratio between the volume above the piston when it is at the bottom of its stroke and the volume above the piston when it is at the top of its stroke. In this definition it is assumed that the engine is a vertical one with the cylinder above the crankshaft. The compression ratio is readily increased by changing the cylinder head to one with a smaller volume above the piston; when it is increased, the temperature in the engine cylinder at the end of compression is correspondingly higher, and this results in higher combustion chamber temperatures throughout, and a greater tendency to knock. Also, the quantity of exhaust gas left in the cylinder at the time the new charge enters, is reduced because the clearance space is smaller. The entire cylinder, therefore, is more completely filled with gasoline vapor and air, and higher explosion temperatures with greater tendency to detonate follow.

When the mechanism of combustion during detonation is understood, it is possible to explain how developments in engines and fuels enable the use of high-duty, high-compression motors that produce exceptional power with excellent fuel economy.

Two principal factors enter into the elimination of detonation:

1. Changes in the fuel characteristics
2. Construction of combustion chambers

FUEL CHARACTERISTICS

Fuels that have high self-ignition temperatures in the combustion chamber resist detonation. Self-ignition temperature or thermal stability appears to be definitely related to the construction of the molecules making up the fuel. Fuels made by straight distillation from certain crude oils are more stable than others and gasoline made by the cracking process has a higher ignition temperature than straight-run gasoline distilled from the same crude. Reactions may take place in the fuel during compression by the piston or the advancing flame front so that the ignition temperature of the last part of the charge to burn is considerably lower than that of the original gasoline.

Many materials may be added to gasoline to increase its anti-knock value. In general the quantity required makes the cost prohibitive. Some very effective compounds have other objections, such as odor, tendency to foul the spark plugs, etc. The most effective and, at the same time, least harmful compound is tetra-ethyl-lead. The accepted theory regarding the action of this material is too complicated to be completely explained here. It is perhaps sufficient to say that the lead oxides produced by the combustion of this material are known as oxygen carriers. They are able to change back and forth from one form to another, alternately taking up and giving off oxygen; the exchange of this oxygen within the burning material serves to suppress the violent burning that occurs with detonation.

Many theories have been advanced and are well supported by experimental evidence as to the effects upon detonation of dissociation, cracking, formation of peroxides, presence of nuclear droplets, radiation, turbulence, and stratification of air flow in the combustion chamber. They cannot be discussed here but may be considered as contributors in one way or another to the auto-ignition of the last part of the charge to burn.

CONSTRUCTION OF COMBUSTION CHAMBERS

Any construction that will increase the rate of heat transfer from the last part of the charge to burn is advantageous. Rapid external cooling of this part of the charge during compression by the flame front may prevent auto-ignition or decrease the proportion of fuel that detonates. Features of construction may involve:

- Improved cooling water circulation
- The use of metals having high heat conductivity; e.g. aluminum and copper alloys
- Increasing the cold surface to volume ratio of that part of the combustion chamber where the last part of the fuel burns

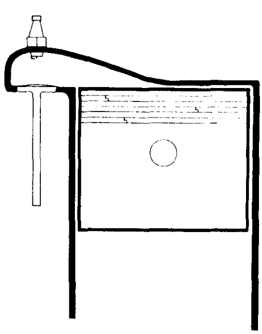


FIGURE 4. RICARDO COMBUSTION CHAMBER DESIGN

Most engines with the exception of some valve-in-head designs are patterned after a design by Ricardo. The principle of this design is illustrated in Figure 4. As the flame travels from the spark plug at the left, the last part of the charge to burn is compressed in the thin wafer-like space at the extreme right where heat is effectively extracted by the large water-cooled area of the cylinder head above it.

OPERATING FACTORS

Many operating factors are well known and their influence is easily explained. Cooler jacket water carries away more heat, therefore, engines seldom detonate until they are brought up to operating temperature. In warm weather, the air entering the engine cylinder, as well as the jacket water, is apt to be warmer and detonation is more severe.

Advancing the ignition timing has a tendency to increase the knock. Normally, when the end of combustion occurs, the piston has started on its downward movement, and the gases are being cooled with great rapidity by expansion, but when the spark is advanced, expansion may not have started, or compression by the piston may still be taking place, when the end of the combustion period is reached. As the throttle is closed, the quantity of exhaust gases carried over from the previous explosion is increased very greatly, so that detonation rarely occurs with a partially closed throttle.

An overrich mixture reduces detonation largely because rich mixtures burn slowly and more time is available to remove the heat from the last part of the fuel to burn, also the piston is moving down and removing the heat by expansion. Very lean mixtures will also reduce detonation but mixture ratios lean enough to do this would not perform satisfactorily in the engine.

TESTING FOR ANTI-KNOCK QUALITIES

It may be seen from the above explanation, that the tendency of a fuel to detonate in different types of engines and under different operating conditions will vary greatly. Therefore, it has been most difficult to develop methods for evaluating the anti-detonating qualities of fuels (73, 77, 95, 115). The Cooperative Fuel Research Committee, composed of representatives of the Society of Automotive Engineers, the Bureau of Standards, the American Society for Testing Materials, petroleum technologists, and automobile manufacturers, have been conducting tests to compare laboratory determinations with the actual operation of the fuels in a great many makes of automobiles on the road (126). The present laboratory method, which is approved by this committee, is known as the C.F.R. Motor Method (A.S.T.M. Designation D357-36T). The special engine, designed and approved by the committee, was used in the running of fuels covered in this survey. It is a single-cylinder engine constructed so that the compression ratio can be changed while the engine is running and so arranged that the jacket temperature, engine speed, throttle opening, intake air temperature, ignition advance, and mixture ratio, may be accurately controlled. (See Figure 5.)

Briefly, the method of test consists of burning the fuel to be tested in an engine and comparing the intensity of the knock with that of a standard fuel which has been calibrated against a mixture of heptane and iso-octane (2-2-4 trimethylpentane). The octane mentioned here has excellent anti-knock characteristics and is assigned a value of 100; heptane has very poor anti-knock characteristics and is assigned a value of 0. A gasoline which has the same anti-knock characteristics as a mixture of 50 per cent octane and 50 per cent heptane is said to have an octane rating of 50. If it matched a mixture of 70 parts of octane and 30 parts of heptane, it would be said to have an octane number of 70. A great deal of care and experience is required in making tests for octane number, and the process is slow and involved. Engine conditions must be kept as follows:

Jacket temperature 210° F.
Inlet air temperature 300° F.
Engine r.p.m., 900
The mixture ratio for all the fuels must be adjusted to give maximum knock
The compression ratio is set to produce an intensity of knock that is approximately the same for all tests
The spark advance is set at 26 degrees before dead center for a compression ratio of 5 to 1 and automatically changes with changes in compression ratio

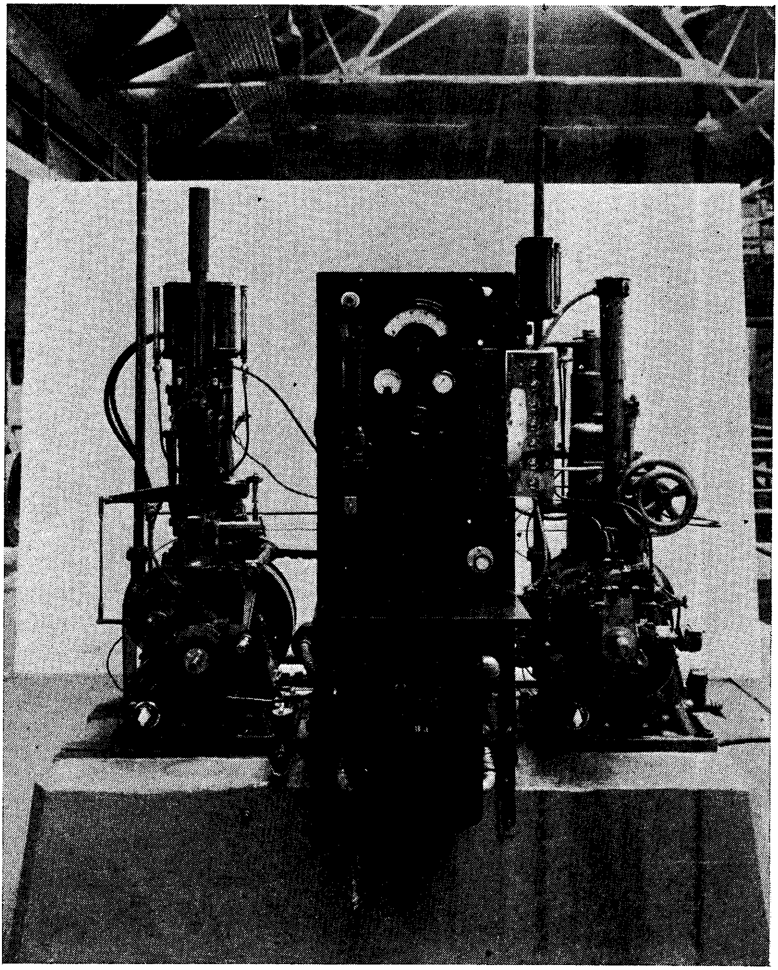


FIGURE 5. C.F.R. ENGINES

The petroleum industry is testing much of the gasoline with an air inlet temperature of 260° F. and a normal spark advance of 16 degrees at a compression ratio of 5 to 1. The above changes in technique result in an increase in the octane rating of some fuels. Service stations are now quoting octane numbers on tests made by this method which is designated as the L-3. It has not been approved by the Cooperative Fuel Research Committee, and specifications by the Federal Specifications Board and the A.S.T.M. do not recognize it. All octane numbers in this survey have been determined by the C.F.R. Motor (A.S.T.M.) Method.

CORROSION

When sulfur or other active materials are left in the gasoline after refining, either because they were not taken out in the refining process or because they were introduced during some of these processes, the brass, copper, or metallic alloys in the fuel system or in the carburetor may be attacked. This results in an accumulation of sediment or dirt in the fuel pipes, which may clog the fine nozzles in the carburetor or the nozzles themselves may be corroded or eroded so as to change their operating characteristics.

A simple and effective method for testing such materials is to immerse a polished copper strip in the gasoline for three hours at a temperature of 122° F. (A.S.T.M. D-130-30). If the copper strip is discolored at the end of this time, the corrosion test is said to be positive and the gasoline is not considered suitable for use in the fuel system.

SULFUR CONTENT

Sulfur may exist in noncorrosive compounds in the gasoline, but when these or other sulfur compounds are burned in the engine, sulfur dioxide (SO_2) or sulfur trioxide (SO_3) is formed. If these compounds leave the engine through the exhaust, no harm occurs. A certain proportion of the products of combustion, generally less than one per cent, leak past the piston rings into the crankcase. Here again, if the SO_2 and SO_3 gases can be discharged through the crankcase breather, or ventilator, before they have been cooled, no harmful results will be evident. If, however, some of these products do cool, and combine with the water or steam formed by the burning of the hydrogen[4] in the fuel, sulfurous or sulfuric acids are formed, which attack metal parts very actively. This results in pitted areas on the highly polished piston pins, brass bushings, or other steel or brass parts exposed to the crankcase fumes. Parts that are not rinsed by the flow of the force-feeding lubricating oil seem to be attacked most readily. Therefore, it is very desirable

[4] One and one-third pounds of water are formed by the combustion of one pound of gasoline.

that the quantity of sulfur in the gasoline be kept at a minimum. The standards specifications call for a maximum of 0.10 per cent.

Tests for sulfur in this investigation were made by the lamp method (A.S.T.M. D-90-34T) which consists of burning a certain quantity of fuel in a small lamp, absorbing the SO_2 and SO_3 by drawing the products of combustion through a soda solution and testing this solution for absorbed sulfurous and sulfuric acid.

GUM

When gasolines are manufactured by the cracking process and are allowed to stand for some time after manufacture, certain gums or resins are frequently formed. Immediately upon formation, they go into solution in the gasoline and do not make their presence known until the gasoline is evaporated in the intake system. As the gasoline is evaporated around the carburetor nozzle, in the intake manifold, or around the intake valve, the gum is left behind as a deposit in the intake system. This sometimes results in the sticking of the intake valves and interference with moving parts, such as the throttle or auxiliary air valves. Occasionally, sufficient gum has been deposited to partially clog the intake system and in very severe cases, it has caused gumming and sticking of the pistons and rings.

Two types of tests for gum in gasoline are commonly used: one such test is used to determine the stability of the gasoline or its tendency to form gum upon standing; the other to determine the amount of gum already in solution in the gasoline at the time the test is made (21). The latter test (A.S.T.M. D-381-36) was selected because gum is not formed during engine operation and only that already in solution in the gasoline can affect the engine deposits.

The gasoline is placed in a small beaker which fits loosely in a metal cup surrounded by a bath which is kept at a temperature of about 325° F. At the same time, a blast of air at 305° to 320° F. is blown against the surface of the gasoline, so that the evaporation is very rapid. The weight of the original gasoline and of the gum left in the beaker after the gasoline has been evaporated by this method, serve to indicate the gum content of the gasoline. This test is known as that for preformed gum because it determines the gum that has already been formed, and does not indicate the gum that would be formed if the gasoline were kept in storage for some time. Gum is not found in gasoline immediately after manufacture and it does not accumulate in short periods of storage such as the time between fills of the fuel tank. Cracked gasolines allowed to stand over winter may develop serious quantities of gum. Gum inhibitors are added to the manufactured gasoline by most refiners in order to reduce the tendency to form gum during storage (61).

GRAVITY

Tests for gravity of the various gasolines used were made, not because they were of any particular significance to the user, but because the A.P.I. number is frequently quoted in the market reports and because it would give some indication of the average gravity of the gasolines being marketed today. The tests were made by the Westphal Balance. In this method, a small plummet is submerged in the gasoline and the gravity or weight of the gasoline displaced is compared with the weight of water displaced by the plummet. In this way, the specific gravity, which is the ratio of the weight of the gasoline to that of water at 60° F. was determined. The results were converted to A.P.I. (American Petroleum Institute) gravity, by means of the following formula:

$$\text{Degrees A.P.I.} = \frac{141.5}{\text{sp.gr. } 60/60^\circ \text{ F.}} - 131.5$$

The A.P.I. gravity is used by the petroleum industry and is expressed by a whole number, instead of the decimal specific gravity. The relation between A.P.I. gravity, and specific gravity and the corresponding weight per gallon are tabulated below. This table includes the A.P.I. numbers of most gasolines.

A.P.I. Gravity Number	Specific Gravity	Wt. per Gallon at 60° F. (Lbs.)
60	.7389	6.156
61	.7351	6.124
62	.7313	6.092
63	.7275	6.061
64	.7238	6.030
65	.7201	5.999
66	.7165	5.969
67	.7129	5.939
68	.7093	5.909
69	.7058	5.880
70	.7022	5.850
71	.6988	5.822
72	.6954	5.793
73	.6919	5.764
74	.6886	5.737
75	.6852	5.708

Gravity is used as an index for volatility in the manufacture of gasoline; for a known crude and a known process it affords a rapid method. There is so much difference in the gravity of gasolines made from the different crudes or made by straight distillation and by cracking, that it has little significance when applied to finished gasolines.

GASOLINE SPECIFICATIONS[5]

Specifications for the purchase of gasolines by the Federal Government, state agencies, and other large purchasers are generally based upon the tests enumerated above. The American Society for Testing Ma-

[5] Gasoline specifications data are collected in Table I.

TABLE I

GASOLINE SPECIFICATIONS*

Specifications	Season	Maximum Temperature Degrees Fahrenheit for Per Cent Evaporated 10	50	90	Maximum Residue Per Cent	Maximum Reid Vapor Pressure Lbs. per Sq. In.	Sulfur Per Cent	Minimum Octane Number	Gum Maximum Milligrams per 100 Milliliters
Federal Specifications Board VV-G-101a	Intermediate and summer	167	284	392	2	8 or 10‡	0.10	Not specified	Not specified
	Winter	149†	284	392	2	12	0.10	Not specified	Not specified
Federal Specifications Board W-M-571a	All seasons	149	257	356	2	10	0.10	65 or 75‡	Not specified
Minnesota State Highway Department	Winter	140	257	356	2	13	0.10	68	15
	Summer	158	257	356	2	8	0.10	68	15
A.S.T.M. Type A	Winter	140	284	392	2	13.5	Not specified	67 or 75§	7
	Intermediate	149	284	392	2	11.5	Not specified	67 or 75	7
	Summer	158	284	392	2	9.5	Not specified	67 or 75	7
A.S.T.M. Type B	Winter	140	257	356	2	13.5	Not specified	67 or 75§	7
	Intermediate	149	257	356	2	11.5	Not specified	67 or 75	7
	Summer	158	257	356	2	9.5	Not specified	67 or 75	7
A.S.T.M. Type C	Winter	167	284	392	2	13.5	Not specified	45§	7
	Intermediate	167	284	392	2	11.5	Not specified	45	7
	Summer	167	284	392	2	9.5	Not specified	45	7

* Negative corrosion test is required in all specifications.

† The government reserves the right to reject material during the months of December, January, February, and March, in those localities where the normal mean temperature during the month of January is less than 27° F., if when the thermometer reads 149° F. less than 10 per cent shall be evaporated.

‡ The government reserves the right to reject materials; (a) in those localities where the normal mean minimum temperature during the month of January is greater than 27° F. if the vapor pressure at 100° F. exceeds 10 pounds per square inch; (b) during the months June, July, August, and September if the vapor pressure exceeds 8 pounds per square inch. Departments purchasing gasoline for use in typical areas 23½° north latitude to 23½° south latitude require a vapor pressure not in excess of 8 pounds per square inch throughout the year.

§ "In all cases the octane number shall be agreed upon between the purchaser and the seller. In general, the following is applicable at the present time (1937): 75 octane number, minimum, corresponds to premium-priced gasolines; 67 octane number, minimum, corresponds to regular-priced gasolines; 45 octane number, minimum, corresponds to less than regular-priced gasoline."

terials published tentative specifications for gasoline in 1937. The maximum allowable temperature for 10 per cent evaporated and the maximum allowable Reid vapor pressure are generally changed with the season of the year. In Minnesota, the winter months are considered to be December, January, and February; the summer months July, August, and September; the remaining six months are classified as intermediate. The last part of June may be included in the summer season, and the first part of March in the winter season. Federal specifications VV-G-101a recognize the winter months in fixing the maximum Reid vapor pressure, but neglect any other seasonal change. Federal specifications VV-M-571a do not recognize seasonal changes but require a low 10 per cent point together with a very moderate Reid vapor pressure for the entire year. The effect of altitude on volatility and Reid vapor pressure is recognized in the following table taken from these specifications:

Alt. at Point of Delivery (Feet)	Distillation Range °F. Maximum Temperature for Per Cent Evaporated			Maximum Reid Pressure Lb. per Sq. In.
	10	50	90	
Sea level	149	257	356	10
2,000	153	261	361	
4,000	157	266	366	
5,000	....	......	...	8.5
6,000	160	270	370	
8,000	163	274	375	
10,000	....	....	....	7

Two specifications are written by the Federal Specifications Board and three by the A.S.T.M. in order to provide fuel for different types of service at a minimum cost. A motor operating continuously under heavy load or one running in a heated room does not require the volatility necessary for out-of-doors starting, and operation at varying speeds and loads; neither is there anything to be gained by operating a low compression motor with high-octane fuel. The manufacturing costs for fuels of low volatility and poor anti-knock qualities allows them to be sold at a minimum price and they should be used wherever they will give satisfactory service.

DATA AND RESULTS

Tests were made on 378 different gasolines.[6] The data on gasolines bought at any one time were separated according to the grade and the price paid. Averages were then taken. In Table II the averages for all gasolines bought at standard prices have been grouped according to seasons and grand averages for all gasolines bought in that season have been computed. Table III is a similar summary for all gasolines bought at cut-rate prices.

[6] The original data on each gasoline tested are available in mimeographed form. The brand is indicated by code. The names of manufacturers cannot be given.

TABLE II

SUMMARY BY GRADES AND BY SEASONS OF GASOLINE BOUGHT AT STANDARD PRICES

Date of Purchase	Cost per Gal. Cents	Distillation Range Degrees Fahrenheit: Initial Boiling Point	Per Cent Distilled and Per Cent Evaporated: 10		20	30	50		70	90		End Point	Residue Per Cent	Loss Per Cent	Reid Vapor Pressure Lbs. per Sq. In.	Octane Number A.S.T.M.	Sulfur Per Cent	Gum Mg. per 100 Ml.	Gravity A.P.I.
Premium grade—winter months—average for each purchase																			
Mar. 1937	21.1	92	132	_126_*	152	171	212	_207_*	260	329	_318_*	390	1.1	2.1	10.6	......	.035	3.9	66.6
Jan. 1938	21.9	100	138	_134_	156	172	205	_202_	251	319	_312_	381	1.5	1.4	10.6	76.9	.036	2.9	67.2
Mar. 1938	21.9	97	131	_127_	151	169	208	_204_	255	322	_313_	382	1.3	1.9	10.0	76.2	.062	2.0	66.2
Grand average	21.6	96	134	_129_	153	171	208	_204_	255	323	_314_	384	1.3	1.8	10.4	76.6	.044	2.9	66.7
Average deviation				7				22			28			0.6	0.8	2.6	.021	1.4	
Premium grade—intermediate months—average for each purchase																			
Apr. 1937	21.1	97	140	_136_	162	179	221	_217_	270	336	_328_	396	1.2	1.6	8.8	74.9	.042	5.5	66.2
May 1937	22.1	102	152	_148_	172	187	227	_225_	276	340	_334_	397	1.2	1.3	7.6	74.1	.040	4.7	63.2
Nov. 1937	21.8	107	145	_143_	165	185	226	_223_	272	337	_332_	394	1.5	1.1	8.8	76.8	.040	6.1	63.7
May 1938	22.2	103	141	_137_	162	180	214	_211_	257	322	_316_	380	1.4	1.4	9.4	75.7	.043	4.9	65.0
Grand average	21.8	102	145	_141_	165	183	222	_219_	269	334	_328_	392	1.3	1.4	8.7	75.4	.041	5.3	64.5
Average deviation				8				16			14			0.4	0.9	2.4	.017	3.5	
Premium grade—summer months—average for each purchase																			
June 1937	21.8	111	157	_155_	176	192	229	_227_	277	346	_341_	401	1.2	0.9	7.3	74.5	.042	7.6	62.2
Sept. 1937	22.1	119	165	_163_	183	202	236	_235_	275	335	_331_	389	1.3	0.8	6.0	75.0	.049	4.8	61.1
July 1938	22.2	113	155	_151_	176	193	230	_226_	274	336	_329_	382	1.3	1.8	7.1	76.3	.056	7.2	61.4
Grand average	22.0	114	159	_156_	178	196	232	_229_	275	339	_334_	391	1.3	1.2	6.8	75.3	.049	6.5	61.6
Average deviation				8				10			12			0.6	1.0	1.4	.017	4.8	
Regular grade—winter months—average for each purchase																			
Mar. 1937	19.3	92	136	_132_	161	176	222	_217_	274	346	_336_	398	1.0	2.1	10.9	69.0	.045	3.6	64.7
Jan. 1938	19.9	96	133	_128_	155	176	219	_213_	271	346	_334_	395	1.4	2.2	12.0	70.3	.044	1.8	66.0
Mar. 1938	19.9	94	131	_124_	154	175	221	_214_	273	348	_336_	395	1.5	2.3	11.1	70.2	.074	1.5	65.1
Grand average	19.7	94	133	_128_	157	176	221	_215_	273	347	_335_	396	1.3	2.2	11.3	69.8	.054	2.3	65.3
Average deviation				7				9			8			0.5	0.7	0.4	.025	1.3	
Regular grade—intermediate months—average for each purchase																			
Apr. 1937	19.3	93	138	_132_	159	177	220	_215_	275	348	_337_	402	1.2	2.3	8.7	69.1	.045	5.4	66.2
May 1937	20.2	99	151	_147_	173	191	234	_230_	285	347	_340_	401	1.1	1.4	7.9	69.0	.047	2.2	62.4
Nov. 1937	19.9	98	135	_131_	156	178	222	_217_	276	347	_337_	398	1.3	1.8	11.0	69.9	.043	1.6	64.8
May 1938	20.2	102	146	_142_	170	191	231	_227_	281	345	_338_	393	1.4	1.7	9.2	69.9	.057	1.4	62.7
Grand average	19.9	98	143	_138_	165	184	227	_222_	279	347	_338_	399	1.3	1.8	9.2	69.5	.048	2.7	64.0
Average deviation				9				11			8			0.5	1.2	0.7	.021	1.9	

* Italics are data for per cent evaporated.

TABLE II—*Continued*

SUMMARY BY GRADES AND BY SEASONS OF GASOLINE BOUGHT AT STANDARD PRICES

Date of Purchase	Cost per Gal. Cents	Distillation Range Degrees Fahrenheit: Initial Boiling Point	Per Cent Distilled and Per Cent Evaporated									End Point	Residue Per Cent	Loss Per Cent	Reid Vapor Pressure Lbs. per Sq. In.	Octane Number A.S.T.M.	Sulfur Per Cent	Gum Mg. per 100 Ml.	Gravity A.P.I.
			10		20	30	50		70	90									
Regular grade—summer months—average for each purchase																			
June 1937	20.0	110	160	*157**	181	199	243	*239**	290	351	*346**	401	1.2	1.3	7.7	68.1	.052	2.3	61.3
Sept. 1937	20.1	111	155	*152*	176	198	241	*239*	287	350	*344*	400	1.3	1.3	7.4	68.7	.051	1.5	61.4
July 1938	20.2	110	154	*146*	175	196	237	*232*	285	353	*342*	395	1.2	2.2	7.7	69.4	.071	2.1	61.5
Grand average	20.1	110	156	*152*	177	198	240	*237*	287	351	*344*	399	1.2	1.6	7.6	68.7	.058	2.0	61.4
Average deviation				8				8			7			0.7	0.5	0.8	.027	1.1	
Third grade—winter months—average for each purchase																			
Mar. 1937	17.5	104	160	*156*	187	211	253	*250*	297	360	*353*	409	1.1	1.4	7.4	53.3	.024	1.8	61.3
Jan. 1938	18.0	114	162	*159*	187	211	255	*252*	303	366	*362*	410	1.3	1.0	7.3	52.3	.034	1.7	61.1
Mar. 1938	16.2	105	153	*149*	182	205	248	*244*	297	363	*356*	405	1.3	1.6	7.9	53.3	.064	1.5	61.9
Grand average	17.2	108	158	*155*	185	209	252	*249*	299	363	*357*	408	1.2	1.3	7.5	53.0	.041	1.7	61.4
Average deviation				11				6			13			0.4	0.8	1.5	.024	0.6	
Third grade—intermediate months—average for each purchase																			
Apr. 1937	17.5	100	155	*151*	182	203	246	*243*	295	357	*352*	408	1.2	1.2	6.9	55.5	.024	3.9	64.0
May 1937	18.6	104	162	*158*	184	204	246	*243*	290	351	*346*	405	1.2	1.3	6.7	55.0	.033	2.7	61.7
Nov. 1937	17.8	113	166	*163*	189	210	255	*253*	304	367	*364*	412	1.3	0.8	7.1	53.0	.052	1.8	61.1
May 1938	17.6	109	160	*156*	185	208	249	*246*	299	367	*355*	406	1.3	1.4	7.7	53.3	.037	1.3	61.6
Grand average	17.9	107	161	*157*	185	206	249	*246*	297	361	*354*	408	1.2	1.2	7.1	54.2	.036	2.4	62.1
Average deviation				9				8			16			0.3	1.0	2.9	.024	1.5	
Third grade—summer months—average for each purchase																			
June 1937	18.5	111	164	*162*	188	208	255	*252*	307	368	*364*	417	1.1	1.1	7.4	52.1	.037	1.4	61.2
Sept. 1937	18.3	117	167	*164*	192	214	257	*255*	302	365	*361*	411	1.2	0.8	6.1	51.7	.040	2.2	60.7
July 1938	17.5	112	161	*155*	185	204	250	*246*	298	363	*356*	408	1.3	1.8	7.4	52.7	.046	1.1	61.5
Grand average	18.1	113	164	*160*	188	209	254	*251*	302	365	*360*	412	1.2	1.2	7.0	52.2	.041	1.6	61.1
Average deviation				6				6			12			0.7	0.8	1.4	.022	1.2	

* Italics are data for per cent evaporated.

TABLE III

SUMMARY BY GRADES AND BY SEASONS OF GASOLINES BOUGHT AT CUT-RATE PRICES

Date of Purchase	Cost per Gal. Cents	Distillation Range Degrees Fahrenheit: Initial Boiling Point	Per Cent Distilled and Per Cent Evaporated: 10		20	30	50		70	90		End Point	Residue Per Cent	Loss Per Cent	Reid Vapor Pressure Lbs. per Sq. In.	Octane Number A.S.T.M.	Sulfur Per Cent	Gum Mg. per 100 Ml.	Gravity A.P.I.
Premium grade—winter months—average for each purchase																			
Mar. 1937	18.4	89	134	*128**	155	176	219	*214**	271	344	*332**	399	1.1	2.6	11.6	66.0	.073	3.7	65.4
Jan. 1938	19.5	91	129	*120*	149	168	207	*200*	265	351	*333*	392	1.2	3.2	13.8	69.1	.049	1.4	66.4
Mar. 1938	19.2	89	128	*121*	150	171	206	*201*	256	328	*311*	384	1.4	3.0	12.8	71.5	.104	1.6	66.8
Grand average	19.0	90	130	*123*	151	172	211	*205*	264	341	*325*	392	1.2	2.9	12.7	68.9	.075	2.2	66.2
Average deviation				13				17			20			1.0	2.1	2.5	.037	1.2	
Premium grade—intermediate months—average for each purchase																			
Apr. 1937	18.2	83	129	*120*	152	171	217	*208*	272	360	*341*	401	1.2	3.5	11.8	68.0	.048	4.0	69.4
May 1937	20.1	90	132	*126*	152	172	219	*213*	277	349	*336*	395	1.0	2.5	10.9	63.9	.133	6.5	63.9
Nov. 1937	19.5	94	127	*122*	148	168	217	*208*	276	356	*347*	402	1.3	3.0	11.8	68.5	.063	3.8	65.1
May 1938	20.4	92	138	*132*	160	180	220	*190*	266	330	*320*	385	1.4	2.2	11.0	71.0	.086	2.4	64.6
Grand average	19.6	90	132	*125*	153	173	218	*205*	273	349	*336*	396	1.2	2.8	11.4	67.9	.083	4.2	65.8
Average deviation				13				22			12			1.0	1.8	2.7	.040	2.0	
Premium grade—summer months—average for each purchase																			
June 1937	19.8	103	150	*143*	165	183	230	*224*	289	363	*352*	406	1.1	2.3	9.6	66.1	.091	6.5	62.9
Sept. 1937	19.8	107	147	*144*	168	189	230	*227*	277	361	*354*	405	1.1	1.5	8.6	66.0	.106	5.6	60.0
July 1938	19.9	105	149	*145*	170	187	223	*219*	292	328	*321*	375	1.2	1.7	8.7	71.0	.090	3.7	63.9
Grand average	19.8	105	149	*144*	168	186	228	*223*	286	351	*342*	395	1.1	1.8	9.0	67.7	.096	5.3	62.3
Average deviation				6				14			16			0.6	1.0	3.2	.042	4.0	
Regular grade—winter months—average for each purchase																			
Mar. 1937	17.1	87	122	*114*	143	166	214	*230*	272	366	*336*	406	1.1	3.9	12.5	67.0	.097	3.5	66.0
Jan. 1938	18.0	90	125	*117*	146	164	207	*198*	265	351	*332*	393	1.2	3.3	14.0	67.5	.089	0.9	68.0
Mar. 1938	17.5	90	125	*116*	146	167	217	*208*	271	355	*334*	392	1.3	3.7	13.1	67.6	.124	0.9	66.0
Grand average	17.5	89	124	*116*	145	166	213	*212*	269	357	*334*	397	1.2	3.6	13.2	67.4	.103	1.8	66.7
Average deviation				16				26			12			1.5	2.9	2.3	.049	1.5	
Regular grade—intermediate months—average for each purchase																			
Apr. 1937	17.1	88	129	*122*	148	166	215	*208*	272	358	*342*	407	1.2	3.0	12.3	68.3	.100	5.5	70.2
May 1937	18.0	91	134	*126*	155	173	221	*213*	281	361	*345*	401	1.1	2.9	11.6	66.0	.105	2.6	65.0
Nov. 1937	18.0	92	131	*124*	151	173	224	*216*	285	362	*349*	401	1.3	2.8	12.3	62.2	.113	1.0	64.5
May 1938	18.9	94.4	134	*128*	156	180	228	*222*	284	356	*344*	394	1.3	2.5	11.2	67.6	.134	2.0	63.2
Grand average	18.0	91	132	*125*	153	173	222	*215*	281	359	*345*	401	1.2	2.8	11.9	67.0	.113	2.8	65.7
Average deviation				14				16			6			0.9	2.0	3.4	.051	1.9	

* Italics are data for per cent evaporated.

TABLE III—*Continued*

SUMMARY BY GRADES AND BY SEASONS OF GASOLINES BOUGHT AT CUT-RATE PRICES

Date of Purchase	Cost per Gal. Cents	Distillation Range Degrees Fahrenheit: Initial Boiling Point	Per Cent Distilled and Per Cent Evaporated: 10		20	30	50		70	90		End Point	Residue Per Cent	Loss Per Cent	Reid Vapor Pressure Lbs. per Sq. In.	Octane Number A.S.T.M.	Sulfur Per Cent	Gum Mg. per 100 Ml.	Gravity A.P.I.
Regular grade—summer months—average for each purchase																			
June 1937	18.0	104	151	*148**	170	187	229	*226**	283	364	*356**	409	1.1	1.6	9.8	63.1	.104	2.0	62.0
Sept. 1937	18.0	103	141	*138*	162	184	232	*227*	288	368	*359*	408	1.1	1.8	9.3	65.3	.119	1.0	60.0
July 1938	18.4	101	142	*136*	164	186	236	*230*	291	362	*352*	401	1.2	2.2	9.7	66.4	.172	6.6	62.1
Grand average	18.1	103	145	*141*	165	186	232	*228*	287	365	*356*	406	1.1	1.9	9.6	64.9	.132	3.2	61.4
Average deviation			8				9			7				0.3	0.8	2.7	.050	2.3	
Third grade—winter months—average for each purchase																			
Mar. 1937	16.2	91	126	*120*	151	174	222	*215*	284	368	*354*	414	1.1	2.7	11.5	60.8	.059	4.0	66.2
Jan. 1938	17.0	95	129	*122*	152	173	219	*212*	276	356	*341*	398	1.3	2.8	12.6	60.4	.088	1.8	67.3
Mar. 1938	15.3	94	129	*122*	150	169	209	*203*	255	341	*323*	390	1.4	2.8	12.3	60.8	.079	2.3	68.1
Grand average	16.2	93	128	*121*	151	172	217	*210*	272	355	*339*	401	1.3	2.8	12.1	60.7	.075	2.7	67.2
Average deviation			16				26			20				1.4	2.8	6.5	.048	1.2	
Third grade—intermediate months—average for each purchase																			
Apr. 1937	16.5	93	141	*135*	168	186	234	*228*	292	367	*355*	416	1.2	2.5	9.5	57.0	.076	10.2	66.7
May 1937	17.1	95	144	*138*	167	189	236	*229*	297	367	*356*	409	1.1	2.3	10.1	55.0	.076	2.7	64.0
Nov. 1937	17.0	101	144	*141*	164	187	239	*234*	295	364	*357*	404	1.3	1.4	9.7	56.9	.100	0.8	63.6
May 1938	16.9	96	133	*129*	152	169	206	*202*	255	333	*322*	395	1.3	2.2	10.9	60.0	.092	2.4	69.1
Grand average	16.9	96	141	*136*	163	183	229	*223*	285	358	*348*	406	1.2	2.1	10.1	57.2	.086	4.0	65.9
Average deviation			14				17			15				0.8	1.8	4.9	.053	3.3	
Third grade—summer months—average for each purchase																			
June 1937	17.2	102	143	*137*	166	187	232	*226*	294	370	*358*	412	1.1	2.3	9.7	55.2	.068	3.6	64.4
Sept. 1937	16.9	107	148	*144*	167	188	236	*232*	295	370	*362*	413	1.2	1.7	8.1	58.9	.095	1.7	62.4
July 1938	16.9	101	146	*139*	169	188	237	*230*	295	358	*348*	398	1.2	2.6	10.0	60.6	.166	4.6	62.9
Grand average	17.0	103	146	*140*	167	188	235	*229*	295	366	*356*	408	1.2	2.2	9.3	58.2	.110	3.3	63.2
Average deviation			10				13			13				0.8	1.7	4.9	.070	3.8	

* Italics are data for per cent evaporated.

SEASONAL VARIATION

STANDARD PRICE GASOLINES

Table IV is arranged so that the seasonal variation in the three grades of gasoline may be readily observed. In the premium and regular grades the temperature for 10, 50, and 90 per cent evaporated and the Reid vapor pressure vary according to the season. The 10 per cent evaporated temperatures decrease as the season changes from summer to intermediate to winter months in order to provide the proper starting characteristics, while the vapor pressures decrease progressively from winter, to intermediate, to summer months so as to guard against vapor lock.

TABLE IV

AVERAGE SEASONAL CHANGES IN THREE GRADES OF GASOLINE BOUGHT AT STANDARD PRICES

	Distillation Range Degrees Fahrenheit								Reid Vapor Pressure Lbs. per Sq. In.	Octane Number A.S.T.M.
	Initial Boiling Point	Per Cent Distilled and Per Cent Evaporated 10		50		90		End Point		
Premium grade										
Winter months	96	134	*129**	208	*204**	323	*314**	384	10.4	76.6
Intermediate months	102	145	*141*	222	*219*	334	*328*	392	8.7	75.4
Summer months	114	159	*156*	232	*229*	339	*334*	391	6.8	75.3
Regular grade										
Winter months	94	133	*128*	221	*215*	347	*335*	396	11.3	69.8
Intermediate months	98	143	*138*	227	*222*	347	*338*	399	9.2	69.5
Summer months	110	156	*152*	240	*237*	351	*344*	399	7.6	68.7
Third grade										
Winter months	108	158	*155*	252	*249*	363	*357*	408	7.5	53.0
Intermediate months	107	161	*157*	249	*246*	361	*354*	408	7.1	54.2
Summer months	113	164	*160*	254	*251*	365	*360*	412	7.0	52.2

* Italics are data for per cent evaporated.

The temperatures for 50 and 90 per cent evaporated are progressively decreased as cooler weather approaches in keeping with the need of volatile fuels to reduce crankcase dilution and preserve economical operation. The average volatility data fall well within the seasonal requirements of A.S.T.M. Type B gasoline.

The third grade fuels do not show a definite seasonal trend in volatility. The data indicate compliance with the requirements of A.S.T.M. Type C fuel. There is no seasonal change in octane number for any of the above grades of fuel.

CUT-RATE GASOLINES

Table V is made up for cut-rate gasolines in the same manner as Table IV. All three grades show a general seasonal trend in volatility. In the premium grade gasolines, the temperatures for 50 per cent evaporated are the same for the summer and intermediate seasons, and there is a difference of only two degrees in the 10 per cent points Vapor pressures are definitely lower in the warmer months. The average volatilities in all three grades pass A.S.T.M. specifications for Type B fuel.

TABLE V

AVERAGE SEASONAL CHANGES IN THREE GRADES OF GASOLINE BOUGHT AT CUT-RATE PRICES

	Distillation Range Degrees Fahrenheit								Reid Vapor Pressure Lbs. per Sq. In.	Octane Number A.S.T.M.
	Initial Boiling Point	Per Cent Distilled and Per Cent Evaporated						End Point		
		10		50		90				
Premium grade										
Winter months	90	130	*123**	211	*205**	341	*325**	392	*12.7*	68.9
Intermediate months	90	132	*125*	218	*205*	349	*336*	396	11.4	67.9
Summer months	105	149	*144*	228	*223*	351	*342*	395	9.0	67.7
Regular grade										
Winter months	89	124	*116*	213	*212*	357	*334*	397	13.2	67.4
Intermediate months	91	132	*125*	222	*215*	359	*345*	401	11.9	67.0
Summer months	103	145	*141*	232	*228*	365	*356*	406	9.6	64.9
Third grade										
Winter months	93	128	*121*	217	*210*	355	*339*	401	12.1	60.7
Intermediate months	96	141	*136*	229	*223*	358	*348*	406	10.1	57.2
Summer months	103	146	*140*	235	*229*	366	*356*	408	9.3	58.2

* Italics are data for per cent evaporated.

EFFECT OF GRADE UPON QUALITY

The items in Tables VI and VII include those commonly written into fuel specifications and the relative qualities of fuels of various grades may be evaluated by them.

STANDARD PRICE GASOLINES

Table VI has been compiled for standard price gasolines. The 10 per cent evaporated temperatures indicate that the starting qualities of premium grade and regular grade fuels will be the same; the third grade will have poor starting characteristics in the winter and intermediate months. The 50 and 90 per cent temperatures indicate that premium grade is a more volatile fuel than the regular grade; the relatively small distillation range indicates a narrow "cut" in the manufacturing process—a conservative choice of material.

The average vapor pressure of premium grade gasoline is always less than that of the regular grade; the distillation loss is likewise less altho the premium grade is more volatile. These items reflect the choice of select blending materials for premium grade fuels.

Third grade fuels have low volatility and correspondingly low vapor pressures. No relation between grade and sulfur content is apparent. Premium grade gasolines seem to average higher in gum content; this may be due to a smaller demand and consequent longer storage at the

TABLE VI

THE EFFECT OF GRADE UPON THE AVERAGE QUALITIES OF GASOLINES BOUGHT AT STANDARD PRICES

	Cost per Gallon Cents	Distillation Range Degrees Fahrenheit Per Cent Evaporated			Total Distillation Range Initial Boiling Point to End Point Degrees Fahrenheit	Loss Per Cent	Reid Vapor Pressure Lbs. per Sq. In.	Octane Number A.S.T.M.	Sulfur Per Cent	Gum Mg. per 100 Ml.
		10	50	90						
Winter months										
Premium grade	21.6	129	204	314	288	1.8	10.4	76.6	.044	2.9
Regular grade	19.7	128	215	335	302	2.2	11.3	69.8	.054	2.3
Third grade	17.2	155	249	357	300	1.3	7.5	53.0	.041	1.7
Intermediate months										
Premium grade	21.8	141	219	328	290	1.4	8.7	75.4	.041	5.3
Regular grade	19.9	138	222	338	301	1.8	9.2	69.5	.048	2.7
Third grade	17.9	157	246	354	301	1.2	7.1	54.2	.036	2.4
Summer months										
Premium grade	22.0	156	229	334	277	1.2	6.8	75.3	.049	6.5
Regular grade	20.1	152	237	344	289	1.6	7.6	68.7	.058	2.0
Third grade	18.1	160	251	360	299	1.2	7.0	52.2	.041	1.6

service station together with the extensive use of cracked products in gasolines of high anti-knock rating.

There is a consistent difference in the octane numbers of the three grades. The octane numbers for the premium grade averages slightly above 75, for the regular grade between 68 and 70, and for the third grade about 53.

CUT-RATE GASOLINES

Table VII is prepared for cut-rate gasolines. The 10 per cent evaporated data indicate that the starting qualities of all three grades are about equal. The average for third grade—intermediate months—is the only exception. The temperatures for 50 and 90 per cent evaporated indicate a higher volatility for premium grade than for the others. The volatilities of regular grade and third grade gasolines, however, appear to be the same. The total distillation range is the same for regular grade and third grade fuels and is slightly greater than for premium grades. There is little difference between the vapor pressures of the three grades; the regular grade gasoline shows a slightly greater pressure for all seasons of the year. The octane numbers of the premium grade and regular grade gasolines are practically the same; the third grade anti-knock value is definitely lower. The sulfur content of premium grade fuels is somewhat lower than for the other two grades. There appears to be no relation between the preformed gum and the grade of gasoline.

EFFECT OF PRICE UPON QUALITY

Comparisons between the averages for the standard price and cut-rate gasolines are readily drawn from Table VIII.

All premium and regular grades of fuel pass the requirements for A.S.T.M. Type B gasoline. The average total distillation range is always less, Reid vapor pressure is consistently lower, and the sulfur content smaller for the standard priced fuels. This indicates a more conservative selection of materials. An examination of Tables II and III shows that the average deviations for the 10 per cent and 50 per cent points are higher for cut-rate gasolines, indicating less uniformity. The averages of the octane numbers of premium grade cut-rate gasolines do not meet A.S.T.M. requirements; with but one exception they average less than the standard price regular. The average octane numbers of the regular grade cut-rate and the standard price premium and regular grade fuels comply with the minimum A.S.T.M. requirement.

In the third grade class the cut-rate fuels average better than the standard price. Volatility is higher, anti-knock quality better, and distillation range slightly less. Altho the vapor pressure is high compared with the standard price material, it meets A.S.T.M. recommendations.

TABLE VII

THE EFFECT OF GRADE UPON THE AVERAGE QUALITIES OF GASOLINES BOUGHT AT CUT-RATE PRICES

	Cost per Gallon Cents	Distillation Range Degrees Fahrenheit — Per Cent Evaporated 10	50	90	Total Distillation Range Initial Boiling Point to End Point Degrees Fahrenheit	Loss Per Cent	Reid Vapor Pressure Lbs. per Sq. In.	Octane Number A.S.T.M.	Sulfur Per Cent	Gum Mg. per 100 Ml.
Winter months										
Premium grade	19.0	123	205	325	302	2.9	12.7	68.9	.075	2.2
Regular grade	17.5	116	212	334	308	3.6	13.2	67.4	.103	1.8
Third grade	16.2	121	210	339	308	2.8	12.1	60.7	.075	2.7
Intermediate months										
Premium grade	19.6	125	205	336	306	2.8	11.4	67.9	.083	4.2
Regular grade	18.0	125	215	345	310	2.8	11.9	67.0	.113	2.8
Third grade	16.9	136	223	348	310	2.1	10.1	57.2	.086	4.0
Summer months										
Premium grade	19.8	144	223	342	290	1.8	9.0	67.7	.096	5.3
Regular grade	18.1	141	228	356	303	1.9	9.6	64.9	.132	3.2
Third grade	17.0	140	229	356	305	2.2	9.3	58.2	.110	3.3

TABLE VIII

COMPARISON OF AVERAGE DATA ON GASOLINE BOUGHT AT STANDARD AND AT CUT-RATE PRICES

	Cost per Gallon Cents	Distillation Range Degrees Fahrenheit						Residue Per Cent	Loss Per Cent	Reid Vapor Pressure Lbs. per Sq. In.	Octane Number A.S.T.M.	Sulfur Per Cent	Gum Mg. per 100 Ml.
		Initial Boiling Point	Per Cent Evaporated			End Point	Total Range						
			10	50	90								
Premium grade—winter months													
Standard price	21.6	96	129	204	314	384	288	1.3	1.8	10.4	76.6	.044	2.9
Cut-rate price	19.0	90	123	205	325	392	302	1.2	2.9	12.7	68.9	.075	2.2
Premium grade—intermediate months													
Standard price	21.8	102	141	219	328	392	290	1.3	1.4	8.7	75.4	.041	5.3
Cut-rate price	19.6	90	125	205	336	396	306	1.2	2.8	11.4	67.9	.083	4.2
Premium grade—summer months													
Standard price	22.0	114	156	229	334	391	277	1.3	1.2	6.8	75.3	.049	6.5
Cut-rate price	19.8	105	144	223	342	395	290	1.1	1.8	9.0	67.7	.096	5.3
Regular grade—winter months													
Standard price	19.7	94	128	215	335	396	302	1.3	2.2	11.3	69.8	.054	2.3
Cut-rate price	17.5	89	116	212	334	397	308	1.2	3.6	13.2	67.4	.103	1.8
Regular grade—intermediate months													
Standard price	19.9	98	138	222	338	399	301	1.3	1.8	9.2	69.5	.048	2.7
Cut-rate price	18.0	91	125	215	345	401	310	1.2	2.8	11.9	67.0	.113	2.8
Regular grade—summer months													
Standard price	20.1	110	152	237	344	399	289	1.2	1.6	7.6	68.7	.058	2.0
Cut-rate price	18.1	103	141	228	356	406	303	1.1	1.9	9.6	64.9	.132	3.2
Third grade—winter months													
Standard price	17.2	108	155	249	357	408	300	1.2	1.3	7.5	53.0	.041	1.7
Cut-rate price	16.2	93	121	210	339	401	308	1.3	2.8	12.1	60.7	.075	2.7
Third grade—intermediate months													
Standard price	17.9	107	157	246	354	408	301	1.2	1.2	7.1	54.2	.036	2.4
Cut-rate price	16.9	96	136	223	348	406	310	1.2	2.1	10.1	57.2	.086	4.0
Third grade—summer months													
Standard price	18.1	113	160	251	360	412	299	1.2	1.2	7.0	52.2	.041	1.6
Cut-rate price	17.0	103	140	229	356	408	305	1.2	2.2	9.3	58.2	.110	3.3

67 OCTANE THIRD GRADE GASOLINES OF 1939

In the winter of 1938 a number of major oil companies announced a third grade gasoline with an octane number of 67. Samples of these gasolines were purchased in January, 1939, and were tested for octane number and distillation range. Table IX compares the distillation range and octane numbers of these gasolines with those purchased of the same companies in January, 1938.

TABLE IX

COMPARISON BETWEEN 67 OCTANE THIRD GRADE GASOLINES OF 1939 WITH THIRD GRADE GASOLINES OF 1938

Date of Purchase	Octane Number	Distillation Range Degrees Fahrenheit: Initial Boiling Point	Per Cent Distilled 10	Per Cent Distilled 50	Per Cent Distilled 90	End Point
Gasoline A						
Jan. 28, 1938	55.2	107	163	256	362	410
Jan. 29, 1939	67.0	100	140	238	344	416
Gasoline B						
Jan. 28, 1938	51.0	116	165	258	365	414
Jan. 24, 1939	66.6	96	137	250	374	419
Gasoline F						
Jan. 28, 1938	53.5	114	156	255	345	382
Jan. 24, 1939	65.8	94	135	232	349	395
Gasoline H						
Jan. 28, 1938	54	101	149	241	377	413
Jan. 24, 1939	65.9	95	130	223	364	409

The octane numbers have been improved and altho only one of the gasolines actually tested 67 octane number by the A.S.T.M. method, the others are so near that it is probable they would be rated as 67 octane number by the L-3 method. The lower end volatility has also been improved.

A HIGH SULFUR GASOLINE

Gasolines with good distillation characteristics and good anti-knock qualities but with high sulfur content are sometimes sold at low prices. A gasoline not covered in this survey was purchased in Minneapolis in the spring of 1938. It had good characteristics except that it was corrosive and had a high sulfur content. Purchasers of this gasoline would obtain good performance and would not be able to detect the corrosive materials without laboratory tests.

TABLE X

EXAMPLE OF HIGH SULFUR CONTENT AND CORROSIVENESS—INTERMEDIATE SEASON

	Cost per Gallon Cents	Distillation Range Degrees Fahrenheit: Per Cent Distilled 10	50	90	Octane Number A.S.T.M.	Sulfur Per Cent	Corrosion
Regular grade	18.9	140	239	358	67.7	.28	Positive
Third grade	15.7	144	236	358	65.4	.26	Positive

GRAPHICAL SUMMARY

In order to obtain a clearer picture of the seasonal changes in volatility the average temperatures for 10 and 90 per cent distilled for each purchase have been plotted against the dates of purchase in Plates I and II. The highest and lowest temperatures found are also plotted and the temperature ranges for standard price and cut-rate fuels indicated by suitable section lining.

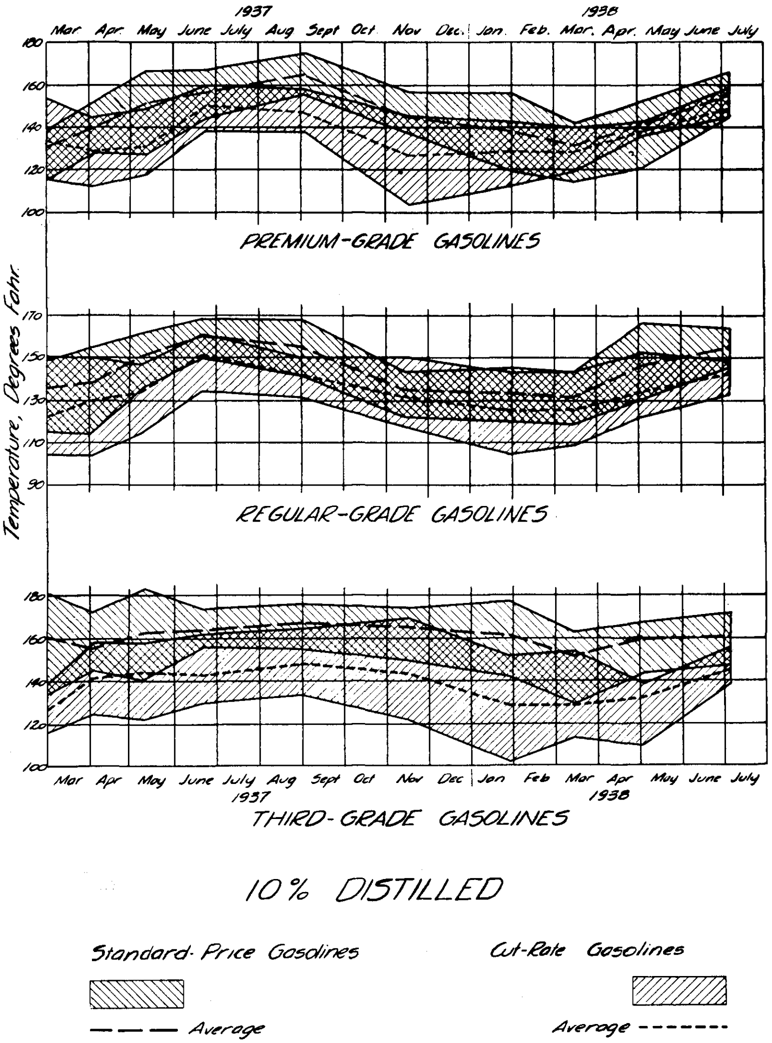
The average temperature lines for premium grade and regular grade gasolines follow the normal monthly climatic changes quite faithfully. The extreme temperatures lie farthest from the average for cut-rate gasolines except in the 90 per cent premium grade. Here one company selling at standard prices is responsible for 90 per cent points far below the others. The average monthly 90 per cent point is lower for cut-rate than for standard price fuels.

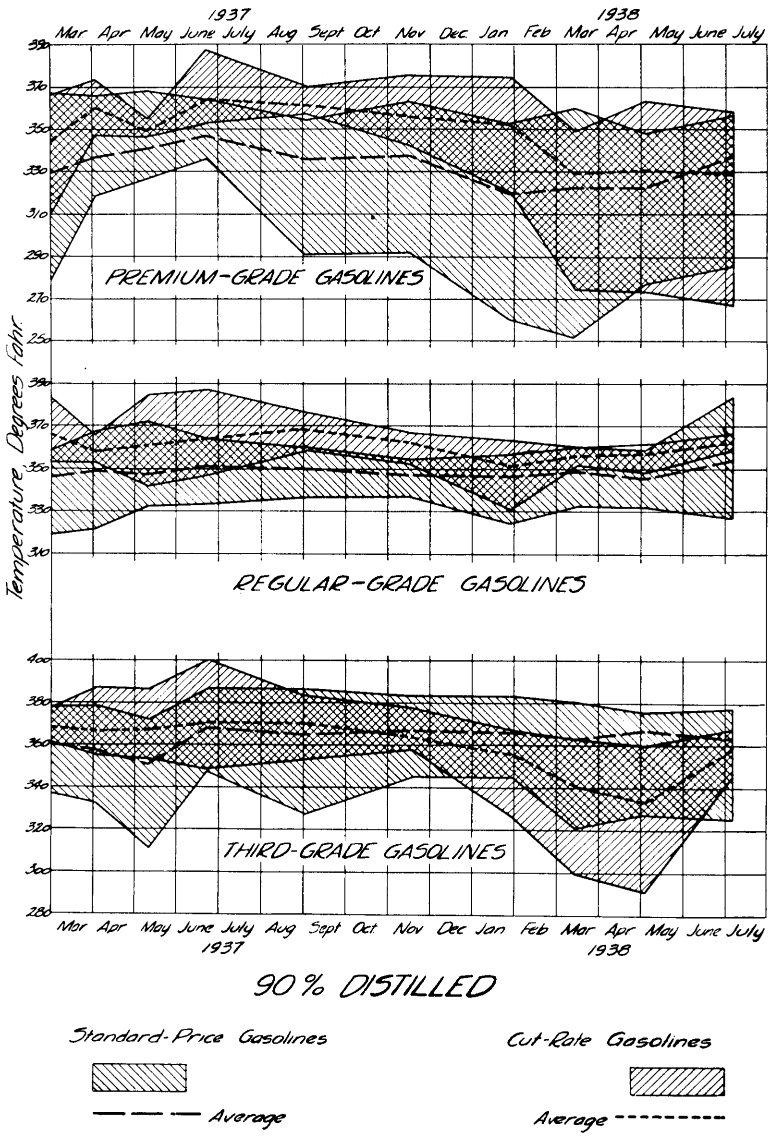
Higher distillation losses indicate higher evaporation loss in service. Plate III shows that the average distillation loss is always higher for cut-rate than for standard price material. Some very extreme values are noted for cut-rate gasoline.

Higher vapor pressures are to be expected with large distillation losses. Some Reid vapor pressures for individual gasolines are plotted on Plate IV. Two of the four cut-rate companies marketed gasolines with extremely high vapor pressures in November, 1937, and January and March, 1938. Some of these vapor pressures indicate high losses and dangerous fire hazards on mild days or for indoor operation.

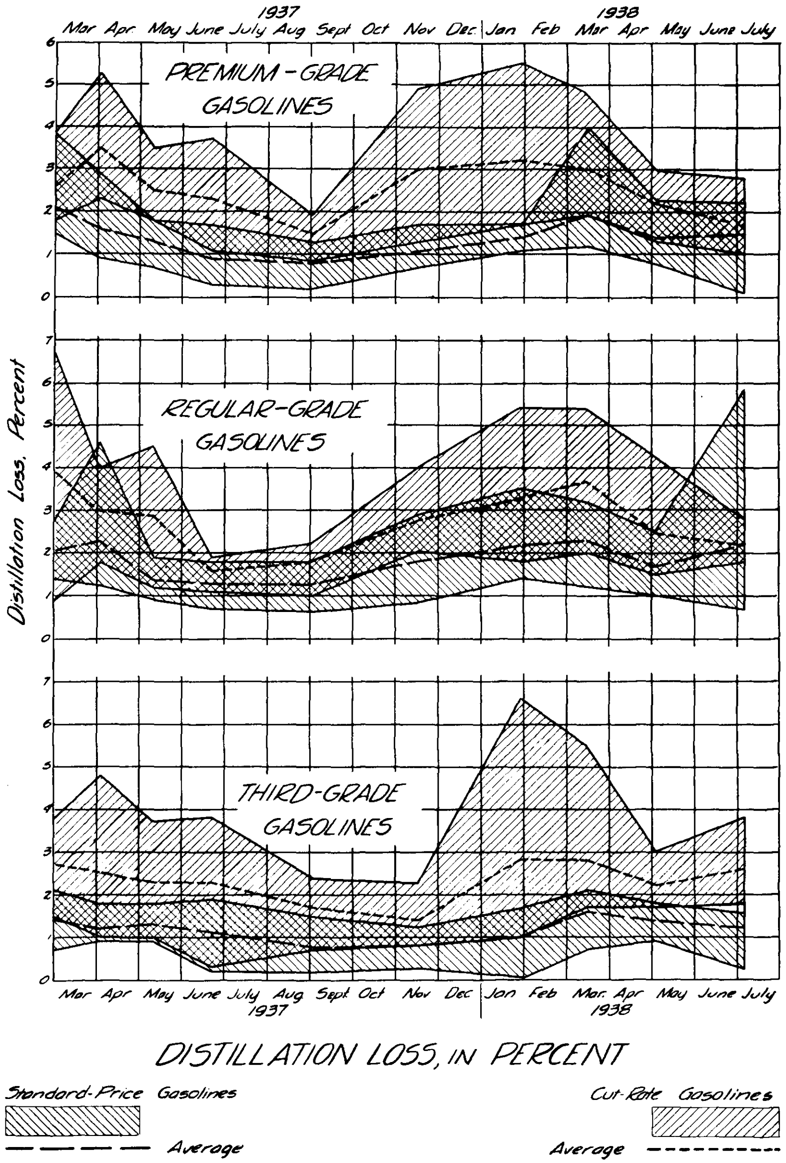
The A.S.T.M. specification states: "The technical data available do not afford an adequate basis for specifying maximum sulfur content. At the present time (1937), gasolines containing up to 0.25 per cent sulfur are marketed in the United States." The federal specifications have set an upper limit of 0.10 per cent.

Plate V shows that both the average and maximum sulfur content of cut-rate fuels is higher than for standard priced products. High sulfur content would be most apt to give trouble in cold weather. The premium grade cut-rate fuels show a decline in sulfur in the winter of 1937-38, but no other indication of reducing the sulfur content in cold months is apparent.

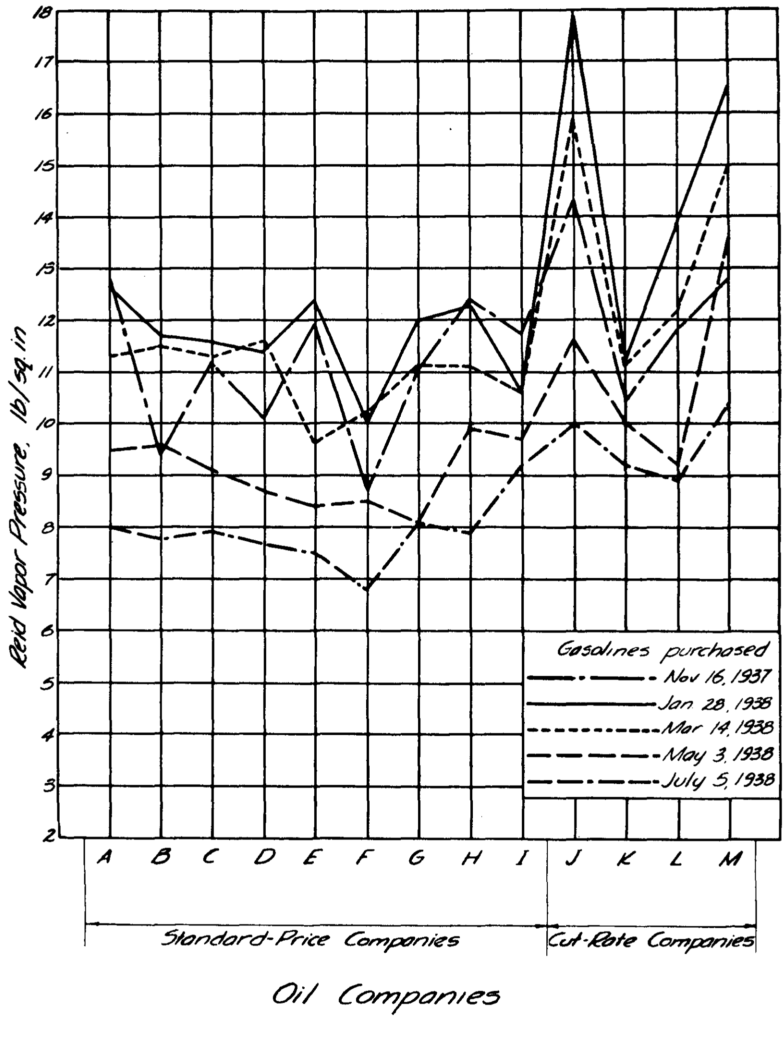

1937
1938
Mar. Apr. May June July Aug Sept Oct Nov Dec. Jan. Feb. Mar. Apr. May June July
180
160
140
120
100
PREMIUM-GRADE GASOLINES
Temperature, Degrees Fahr.
170
150
130
110
90
REGULAR-GRADE GASOLINES
180
160
140
120
100
Mar Apr May June July Aug Sept Oct Nov Dec Jan Feb Mar Apr May June July
1937
1938
THIRD-GRADE GASOLINES
10% DISTILLED
Standard-Price Gasolines
Cut-Rate Gasolines
Average
Average



90 % DISTILLED

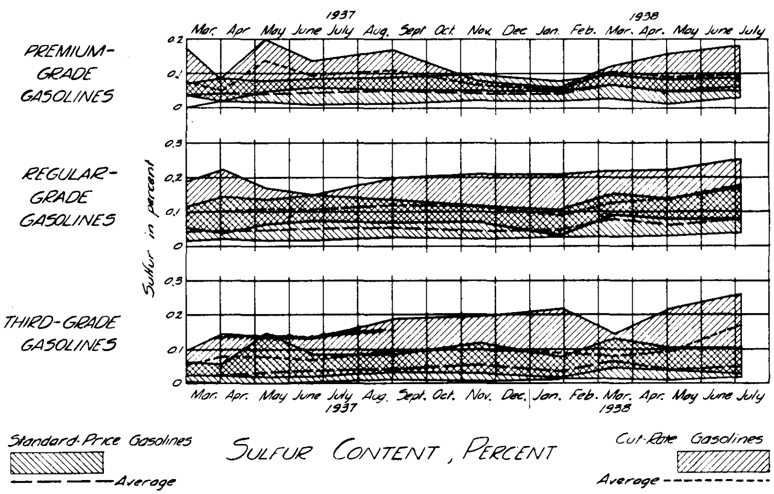


DISTILLATION LOSS, IN PERCENT



REID VAPOR PRESSURES OF REGULAR-GRADE GASOLINES

PLATE V



SULFUR CONTENT, PERCENT

CONCLUSIONS

Summaries must necessarily be reached by considering the averages of the test data. They do not apply to any individual concern in either of the price groups. Based upon the data obtained in this investigation, the following conclusions may be drawn:

1. All gasolines are blended according to the season of the year except the standard price third grade.

2. Premium grade gasolines have no advantages over regular so far as starting quality is concerned, but the upper range distillation temperatures are lower.

3. Third grade products have poor cold-weather starting qualities in the standard price group, but are likely to have good starting qualities when bought at cut-rate prices.

4. The average anti-knock qualities of standard price fuels vary with the grade in accordance with the A.S.T.M. specifications. Octane number constitutes the most noticeable difference between premium and regular grades of fuels.

5. The average anti-knock qualities of cut-rate products are approximately the same for premium and regular grades and are about equal to those of the regular grade standard price material. The third grade cut-rate gasoline is superior in this respect to the standard price product.

6. Cut-rate gasolines contain more sulfur and have a wider range of distillation temperatures than those sold at standard prices.

7. Enough volatile material has been included in some cut-rate fuels to produce excessive vapor pressures and a possible fire hazard.

8. In general, there is a greater change in quality with grade at standard prices than at cut-rate prices.

9. Standard price fuels are more conservatively blended and generally meet current specifications with a comfortable margin, while cut-rate materials may barely meet requirements.

10. The variation between the products manufactured by the various cut-rate companies is greater than for the standard price group.

Gasoline specifications are written for average conditions of operation in the average motor, and fuels complying with standard specifications are generally satisfactory in any current automobile. A fuel that does not measure up to current standards may be quite satisfactory under certain special driving conditions. One fuel may be suitable for city driving with frequent starting in cold weather; another may serve where long steady drives are made; still another may be satisfactory where heavy grades and hills are not encountered. It is sometimes possible to find a substandard fuel that appears to give as good service for the particular driving conditions imposed as the more expensive standard fuel. For good general all-round service with the motor tuned to best operation, fuels meeting standard specifications conservatively are the safest to use.

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Supplement

to

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University of Minnesota

An Investigation of Motor Gasolines

ORIGINAL TEST DATA ON INDIVIDUAL GASOLINES

Published by the University of Minnesota as a report on Official Project No. 665-71-3-69 conducted under the auspices of the Works Progress Administration.

Winter Season — Purchased March 1, 1937

Retailer	Cost per Gal. Cents	Initial Boiling Point	Distillation Range °F. Per Cent Distilled and Per Cent Evaporated 10	10	20	30	50	50	70	90	90	End Point	Residue Per Cent	Loss Per Cent	Reid Vapor Pressure Lb per Sq in.	Octane Number A.S.T.M.	Sulfur Per Cent	Corrosion	Gum mg per 100 ml.	Gravity A.P.I.
Premium Grade																				
A	21.1	89	120	115*	145	168	223	217*	278	349	339*	397	1.0	2.0	10.3		.043		3.2	64.0
B	21.1	94	133	131	148	165	210	207	255	323	317	388	1.0	1.7	10.7	78.0	.038		3.0	68.0
C	21.1	90	138	131	164	183	222	215	283	343	326	415	1.3	2.5	10.3		.014			64.0
D	21.1	89	138	127	162	186	234	225	276	340	324	376	1.2	3.8	11.4		.068		5.0	63.5
E	21.1	96	116	115	122	128	147	145	182	278	260	395	1.1	1.5	10.7		.070		2.0	76.0
G	21.1	92	138	131	166	194	247	241	302	367	359f	397	1.0	2.0	11.2		.028		8.0f	61.5
H	21.1	92	140	134	166	186	232	227	283	347	339	398	1.0	2.0	10.4	78.0	.023		Oil	63.5
I	21.1	97	130	127	146	157	180	177	218	286	279	356	1.0	1.5	9.6		.000		2.0	72.5
J	18.1	82	115	106	132	148	186	178	238	346	321	412	1.1	3.9	14.6f		.045		3.0	70.0
K	19.1	97	138	135	160	176	210	206	250	310	301	370	1.1	1.8	10.4		.031		4.0	69.0
L	19.2	85	130	125	160	192	243	239	304	366	350f	409	1.1	1.9	11.4		.041		4.0	62.0
M	17.3	94	152	145f	170	190	239	232	293	356	344	406	1.1	2.7	10.0	66.0f	.176			60.5
Regular Grade																				
A	19.1	88	115	112	140	164	217	210	265	348	337	391	1.0	2.2	11.4	69.0	.043		3.0	66.0
B	19.1	93	143	138	169	185	230	225	280	345	335	390	1.0	2.0	11.0	69.0	.036		4.0	63.5
C	19.1	89	130	125	160	177	215	211	280	350	339	412	1.0	2.2	10.0	70.0	.024			65.5
D	19.1	86	140	140	166	182	224	218	264	319	308	375	1.0	2.8	11.7	68.0	.119		6.0	62.0
E	19.1	92	126	122	144	162	202	198	257	357	342	412	1.1	1.9	11.5	70.0	.047		3.0	68.0
G	19.1	95	148	139	176	189	237	230	291	358	346	392	0.9	2.6	11.0	70.0	.017		5.0	63.5
H	20.1	92	140	135	164	172	227	223	280	348	341	418	1.1	1.4	10.3	70.0	.035		Oil	64.5
I	19.8	98	148	142f	169	180	223	218	274	347	336	391	1.1	2.1	10.0	70.0	.036		0.8	65.0
J	17.1	84	105	93	123	142	187	270f	252	384	316	413	1.3	6.7	16.4	66.0	.078		4.0	71.5
K	17.1	84	120	113	148	176	232	224	283	356	341	393	1.0	3.2	10.7	70.0	.053		5.0	65.0
L	18.1	84	112	103	130	152	196	185	261	371	338	414	1.1	4.9	14.8f	67.0	.068		4.0	70.0
M	16.1	97	151	149f	170	194	242	239	292	353	349	406	1.1	0.9	8.0	65.0f	.189		1.2	59.5
Third Grade																				
A	17.6	101	150	145	185	212	255	252	287	358	351	420	1.0	1.4	7.0	54.5	.009		3.0	60.5
B	18.1	108	177	172f	201	222	256	253	301	361	357	408	1.1	1.3	6.8	52.0	.014		3.0	61.0
C	17.6	95	133	130	162	192	249	245	304	378	369	427	1.1	1.7	8.8	54.0	.009		1.0	63.0
D	17.6	100	152	147	179	204	248	243	290	350	340	391	0.9	2.1	8.3	56.6	.063		1.0	61.5
E	18.2	115	167	165	190	212	260	258	311	375	371	420	1.3	0.7	6.0	51.0	.029		1.0	60.5
G	16.1	106	181	177f	206	223	251	249	288	337	332	386	1.0	1.5	7.5	52.0	.021		61.5	
J	16.1	86	116	107	135	154	198	188	265	377	353	428	1.2	3.8	15.0f	69.0	.088		5.0	69.5
K	16.1	96	138	130	170	196	245	238	311	370	361	398	1.2	2.8	9.0	47.5	.029		3.0	64.0
L	16.3	86	117	111	140	158	200	193	265	361	345	417	1.2	2.6	14.0f	66.0	.094		4.0	68.0
N	16.4	95	132	130	160	190	244	240	296	364	358	412	1.0	1.5	7.9		.024		4.0	63.5

* Italics represent the per cent evaporated.
f Fail to pass A.S.T.M. specifications

TABLE III

Intermediate Season — Purchased April 2, 1937

Retailer	Cost Per Gal. Cents	Initial Boiling Point	Distillation Range °F. Per Cent Distilled and Per Cent Evaporated 10		20	30	50		70	90		End Point	Residue Per Cent	Loss Per Cent	Reid Vapor Pressure Lb. per Sq in.	Octane Number A.S.T.M.	Sulfur Per Cent	Corrosion	Gum mg. Per 100 ml.	Gravity A.P.I.
Premium Grade																				
A	21.1	94	128	124*	150	171	222	217*	272	344	333*	401	1.2	1.7	9.9	72.0f	.037		4.0	65.5
B	21.1	95	139	135	160	178	212	210	253	325	315	395	1.2	1.3	8.8		.031		6.0	
C	21.1	97	140	135	165	187	232	228	287	332	324	418	1.5	1.5	8.6	77.0	.022		Oil	63.0
D	21.1	86	132	123	160	184	228	222	273	337	323	377	1.1	2.9	10.4	74.0	.080		6.0	64.0
E	21.1	102	129	127	141	153	185	183	236	335	324	391	1.0	1.4	8.6		.087		3.0	75.5
F	21.1	102	152	148	174	183	220	217	270	329	323	402	1.1	1.4	6.9	72.0f	.043		Oil	65.5
G	21.1	94	150	145	172	191	245	240	302	366	360f	395	1.4	1.6	9.1	74.0	.032		10.0f	61.0
H	21.1	92	142	136	168	182	230	225	283	337	331	406	1.2	1.8	9.4	75.0	.016		Oil	63.5
I	21.1	108	152	150f	169	183	212	211	253	318	315	379	1.2	0.9	7.2	80.0	.031		4.0	71.5
J	18.1	83	114	106	132	148	185	178	234	360	332	424	1.4	3.6	14.7f		.019		3.0	68.0
K	19.1	95	145	139	163	182	228	223	278	347	337	385	1.0	2.3	10.1	69.0f	.050		4.0	69.0
L	19.2	84	112	101	138	160	217	201	288	373	347	396	1.2	5.3	13.8f		.045		5.0	72.5
M	17.3	92	145	135	175	193	237	231	290	360	349	399	1.2	2.8	8.7	67.0f	.080		4.0	68.0
Regular Grade																				
A	19.1	93	132	127	155	175	229	224	280	348	340	394	1.1	1.9	10.3	69.0	.026		2.0	64.0
B	19.1	85	114	105	132	148	184	176	239	367	331	424	1.4	4.6	8.0	69.0	.038		3.0	69.5
C	19.1	91	136	133	162	181	228	223	282	356	349	414	1.2	1.6	9.4	70.0	.030		Oil	64.5
D	19.1	89	133	127	149	174	220	214	266	332	322	374	1.2	2.3	9.6	69.0	.148		8.0	63.5
E	19.1	99	138	136	158	166	210	206	272	363	354	407	1.2	1.2	7.5	70.0	.048		2.0	68.0
F	19.1	98	154	146	168	183	225	218	278	321	311	399	1.2	2.8	7.3		.028		Oil	67.5
G	19.1	93	146	137	176	193	234	226	295	364	352	399	1.0	2.7	9.0	70.0	.022		12.0f	65.0
H	20.1	91	139	134	161	182	225	221	285	350	344	421	1.3	1.9	9.3	70.0	.031		Oil	64.5
I	19.8	100	151	146	172	189	227	223	279	333	326	388	1.2	2.0	8.3	70.0	.034		Oil	69.5
J	17.1	83	119	111	140	159	200	193	257	360	340	422	1.4	3.1	14.0f	62.0f	.084		7.0	
K	17.1	96	143	135	163	185	232	225	284	353	340	401	1.1	3.0	9.4	70.0	.056		Oil	69.5
L	18.1	80	104	98	120	140	180	171	247	354	329	401	1.0	4.0	17.9f	73.0	.039		4.0	76.5
M	16.1	93	150	145	171	182	248	244	301	366	358f	406	1.3	1.8	7.9		.220		Oil	64.5
Third Grade																				
A	17.6	100	163	159	189	208	249	246	296	358	352	421	1.2	1.3	6.8	56.0	.033		2.0	61.0
B	18.1	100	153	148	180	206	258	253	310	379	371	413	1.2	1.8	6.8	46.0	.002		1.0	67.5
C	17.6	95	144	140	166	186	243	239	300	375	366	423	1.4	1.2	8.0	54.0	.023		1.0	63.5
D	17.6	98	148	145	181	206	247	245	288	346	341	392	1.1	0.9	7.2		.056		5.0	
E	18.2	108	172	168f	195	213	257	255	310	374	370	419	1.2	1.0	5.8	50.0	.026		8.0f	61.5
F	17.6	102	156	152	180	197	231	228	282	337	333	402	0.9	1.5	7.5	57.0	.023		8.0f	66.5
G	16.1	101	152	147	184	205	235	234	276	332	328	386	1.2	1.0	5.9	70.0	.008		2.0	
J	16.1	85	126	119	148	166	207	201	268	355	343	429	1.3	2.7	12.4f	60.0	.109		10.0f	72.0
K	16.1	99	157	153	190	200	251	246	311	366	351	402	1.2	1.7	7.1	50.0	.025		7.0	68.0
L	16.3	89	124	114	147	171	234	220	297	387	363	418	1.2	4.8	11.6f	61.0	.142		11.0f	68.0
N	17.6	100	158	155	186	208	245	243	292	359	353	416	1.2	1.0	6.9	57.0	.029		13.0f	59.0

*Italics represent the per cent evaporated
f Fail to pass A.S.T.M. specifications

TABLE IV

Intermediate Season — Purchased May 10-13, 1937

Retailer	Cost per Gal. Cents	Initial Boiling Point	Distillation Range °F. Per Cent Distilled and Per Cent Evaporated. 10	10	20	30	50	50	70	90	90	End Point	Residue Per Cent	Loss Per Cent	Reid Vapor Pressure Lb per Sq in.	Octane Number A.S.T.M.	Sulfur Per Cent	Corrosion	Gum mg per 100 ml	Gravity A.P.I.
Premium Grade																				
A	22.1	97	144	141*	166	178	225	223*	275	338	333*	397	1.1	0.9	8.0	68.0	.036		4.0	63.0
B	22.1	99	143	138	163	177	220	216	272	356	346	395	1.1	1.7	8.0	78.0	.030		8.0f	65.5
C	22.1	102	152	149	174	189	236	233	288	330	327	419	1.4	1.0	7.5	73.0	.022		Oil	62.0
D	22.0	101	160	154f	183	199	231	227	274	336	329	387	1.2	1.5	7.4	74.0	.078		3.5	62.5
E	22.1	101	127	125	139	147	178	174	231	329	318	388	1.1	1.8	8.8	76.0	.063		5.0	69.0
F	22.1	104	148	146	166	186	228	225	276	340	334	394	1.1	1.3	7.1	74.0	.047		Oil	63.0
G	22.1	110	167	164f	190	206	255	253	310	368	365f	403	1.1	0.8	5.7	72.0	.034		Oil	59.0
H	22.1	98	159	153	182	202	241	238	288	326	319	404	1.2	1.8	8.2	74.0	.016		Oil	62.5
I	22.1	107	165	163f	184	198	233	232	273	334	331	385	1.2	0.7	7.6	78.0	.031		3.1	62.5
J	20.1	90	128	115	146	160	201	192	262	348	329	399	1.0	3.5	12.4f	66.0	.129		0.4	63.0
K	20.1	86	134	128	160	178	221	216	275	346	336	385	1.0	2.0	9.9	70.0	.047		5.5	66.0
L	20.1	88	118	114	139	162	215	207	282	346	333	404	1.0	2.9	11.8f	56.0	.194		10.0f	66.0
M	20.1	97	149	145	165	189	241	236	290	355	347	392	1.1	1.8	9.4	63.5	.163		10.0f	60.5
Regular Grade																				
A	20.1	100	154	149	179	202	246	241	290	346	340	395	1.1	1.6	6.9	68.6	.038		1.0	60.5
B	20.1	99	156	148	184	195	237	233	288	351	341	391	1.1	1.9	7.8	69.0	.036		3.0	61.0
C	20.1	98	148	146	168	187	235	231	290	343	337	418	1.2	1.7	7.6	69.0	.028		Oil	63.0
D	20.1	98	150	147	167	187	223	221	271	332	328	382	1.1	0.9	8.6	68.0	.136		6.0	62.0
E	20.1	99	136	134	155	168	210	208	271	355	350	403	1.2	0.9	7.0	70.0	.039		1.0	64.5
F	20.1	99	147	144	174	192	235	232	283	338	335	401	1.1	1.3	8.1	69.0	.042		Oil	63.0
G	20.1	103	161	157f	182	205	250	245	307	372	361f	407	1.0	1.6	8.5	69.0	.015		2.0	61.0
H	21.1	97	145	140	166	182	236	233	289	351	345	418	1.1	1.4	8.3	69.0	.058		Oil	63.0
I	20.1	102	158	154f	180	198	233	230	279	333	327	394	1.1	1.6	8.6	70.0	.034		0.5	64.0
J	18.1	90	129	118	153	171	212	202	291	385	361f	423	1.2	4.5	12.5f	60.0	.115		2.0	64.0
K	18.1	93	144	137	168	182	222	218	270	342	332	387	1.2	1.2	10.5	70.0	.062		0.4	65.5
L	18.6	85	115	104	135	155	214	203	275	361	342	398	1.1	3.9	13.5f	66.0	.168		5.0	68.0
M	17.2	95	147	143	165	185	235	230	287	355	344	396	1.0	2.0	9.8	68.0	.077		3.0	62.5
Third Grade																				
A	18.6	101	171	167	195	215	251	249	293	355	350	418	1.2	1.0	6.5	55.0	.024		4.0	61.0
B	19.1	101	160	156	179	200	255	251	307	373	369	417	1.2	1.1	7.6	51.0	.024		3.0	62.0
C	18.8	97	146	142	166	193	245	240	300	371	364	422	1.3	1.7	8.8	53.0	.016		1.0	63.5
D	18.6	95	141	137	161	182	225	220	272	333	325	377	1.2	1.8	8.2	67.0	.147		4.0	62.0
E	18.6	103	162	157	190	213	259	255	307	370	364	421	1.2	1.5	5.7	52.0	.015		3.0	61.5
F	18.6	126	183	181f	202	214	235	234	263	311	308	377	1.0	0.9	3.1	51.0	.003		0.9	61.0
G	17.6	103	169	166	192	210	251	249	291	347	343	402	1.0	1.0	6.7	56.0	.000		3.0	61.0
J	17.1	88	122	113	147	178	220	211	298	387	371	424	1.2	3.7	12.9f	58.0	.124		5.0	66.5
K	17.1	98	156	152	180	193	236	231	288	353	345	395	1.2	1.8	9.1	48.0	.025		2.4	65.5
L	17.1	94	140	132	156	182	228	221	280	353	338	401	1.0	2.6	11.0	62.0	.136		3.0	62.5
N	17.1	100	158	155	187	204	255	252	324	374	371	417	1.2	1.0	7.6	53.0	.018		0.4	61.5

* Italics represent the per cent evaporated.

f Fail to pass A.S.T.M. Specifications.

T A B L E V

Summer Season

Purchased June 21, 1937

Retailer	Cost per Gal. Cents	Initial Boiling Point	Distillation Range °F. Per Cent Distilled and Per Cent Evaporated. 10		20	30	50		70	90		End Point	Residue Per Cent	Loss Per Cent	Reid Vapor Pressure Lb per Sq. in.	Octane Number A.S.T.M.	Sulfur Per Cent	Corrosion	Gum mg per 100 ml.	Gravity A.P.I.
Premium	**Grade**																			
A	22.1	107	164	160*f	186	196	229	227*	278	339	335*	396	1.0	0.8	7.9	73.4f	.027		6.7	62.0
B	21.6	106	150	146	164	177	218	214	274	356	344	407	1.3	1.7	8.1	75.0	.082		8.7f	62.5
C	22.1	115	165	163f	178	188	218	216	246	336	329	389	1.3	1.0	7.0	77.2	.009		Oil	64.0
D	22.1	108	155	153	179	193	233	230	280	336	332	391	1.2	0.8	7.8	74.2	.07		4.8	61.5
E	22.1	113	153	151	169	181	215	213	279	364	360f	425	1.4	0.6	6.6	75.1	.036		8.3f	63.0
F	20.1	120	167	165f	187	202	240	239	282	345	343	400	1.7	0.3	6.3	71.0f	.059		Oil	61.0
G	22.1	113	154	152	170	188	229	227	282	353	348	403	1.1	0.9	6.7	74.9	.032		6.2	62.5
H	22.1	101	144	139	168	194	244	239	293	352	346	409	1.2	1.5	8.5	73.2f	.021		17.7f	62.0
I	22.1	116	164	161f	183	206	239	237	279	336	333	393	1.0	0.9	6.6	76.3	.045		1.1	61.5
J	19.1	99	138	130	153	170	216	207	292	387	368f	429	1.0	3.7	11.5f	60.0f	.131		0.9	63.5
K	20.1	104	149	142	166	187	227	221	281	353	343	392	1.2	2.2	9.2	70.8	.067		17.8f	64.5
L	20.1	100	152	144	161	179	232	225	291	354	346	403	1.1	2.4	9.9f	65.1f	.110		5.9	62.0
M	20.1	110	160	157	181	197	244	241	292	358	353	402	1.2	1.1	7.7	68.4f	.056		1.5	61.5
Regular	**Grade**																			
A	20.1	112	166	162f	190	208	249	245	291	350	343	400	1.0	1.5	8.0	68.5	.046		2.1	60.0
B	19.6	111	160	156	179	196	245	240	291	350	342	395	1.2	1.8	7.7	68.6	.045		1.1	61.0
C	20.1	113	168	164f	186	202	248	244	297	360	355	417	1.2	1.3	8.6	67.0	.035		Oil	61.0
D	20.1	107	150	147	166	187	231	229	281	333	329	380	1.1	0.9	8.0	66.3	.146		4.1	60.5
E	20.1	111	153	151	175	193	232	230	281	355	351	406	1.3	0.7	6.8	68.7	.071		2.8	62.5
F	20.1	107	162	157	182	195	240	236	289	347	339	397	1.5	1.7	8.2	68.1	.045		Oil	62.5
G	20.1	109	163	159f	186	203	251	247	301	364	358f	408	1.3	1.6	7.5	67.3	.030		4.4	61.0
H	20.1	108	157	154	180	205	248	246	297	359	355	405	1.1	0.7	7.3	69.3	.016		1.4	61.0
I	20.1	112	163	160f	185	202	240	238	285	345	340	399	1.2	1.1	7.2	69.4	.036		0.3	62.0
J	18.1	96	134	131	156	172	220	216	283	387	378f	436	1.0	1.7	12.3f	59.7f	.118		1.9	63.5
K	18.1	112	159	157	173	190	228	226	271	347	341	395	1.2	1.1	8.4	67.6	.072		3.6	63.5
L	18.6	100	151	146	168	186	228	224	287	364	355	405	1.1	1.9	10.6f	65.0f	.085		1.0	61.0
M	17.2	108	161	157	182	200	239	236	292	358	350	399	1.1	1.6	8.1	60.0f	.142		1.4	60.0
Third Grade																				
A	18.6	109	170	166	193	212	256	254	298	358	353	421	0.9	1.1	8.3	55.0	.008		0.4	60.5
B	18.1	107	163	156	187	213	275	267	342	387	383	422	1.2	1.8	8.4	48.9	.043		2.6	60.5
C	18.6	105	156	153	176	189	243	239	300	373	366	429	1.2	1.9	9.2	54.0	.028		1.9	63.0
D	18.6	112	168	167	194	210	249	248	291	348	346	398	1.0	0.2	7.4	53.5	.085		1.4	61.0
E	18.6	114	159	157	188	208	258	255	312	378	372	424	1.2	1.2	6.5	50.7	.021		2.1	61.0
F	18.6	118	167	166	186	208	252	251	305	359	358	398	1.1	0.4	5.5	52.2	.009		0.6	61.0
G	17.1	116	174	172f	198	216	248	247	295	365	362	421	1.3	0.7	6.8	51.1	.022		0.7	62.0
H	18.6	108	160	155	184	209	260	255	313	380	372	421	1.0	1.7	7.1	51.5	.078		1.6	61.0
J	17.1	99	130	121	159	182	225	215	306	400	381	431	1.2	3.8	12.2f	55.0	.126		1.3	65.5
K	17.1	103	147	140	169	190	228	223	271	348	332	391	1.1	2.6	8.6	48.0	.020		1.1	66.5
L	17.1	95	133	127	153	168	220	214	288	357	345	403	1.1	2.4	11.1f	64.6	.102		4.9	64.5
N	17.4	112	162	161	185	208	255	254	311	374	373	425	1.0	0.3	6.9	53.2	.025		7.1f	61.0

* Italics represent the per cent evaporated.

f Fail to pass A.S.T.M. specifications.

[illegible]

TABLE VI

Summer Season | Purchased September 15, 1937

Retailer	Cost Per Gal. Cents	Initial Boiling Point	Distillation Range °F. Per Cent Distilled and Per Cent Evaporated. 10	10	20	30	50	50	70	90	90	End Point	Residue Per Cent	Loss Per Cent	Reid Vapor Pressure Lb per Sq in.	Octane Number A.S.T.M.	Sulfur Per Cent	Corrosion	Gum mg per 100 ml.	Gravity A.P.I.
Premium Grade																				
A	22.1	120	172	169*f	192	214	248	246*	286	342	337*	390	1.2	0.9	6.0	73.7f	.036	Neg.	1.6	59.5
B	22.1	115	170	167f	184	209	252	249	295	350	347	399	1.1	1.0	7.0	76.3	.053	Neg.	2.1	59.5
C	22.1	124	175	172f	192	208	235	233	272	354	345	409	1.2	1.3	6.0	77.2	.057	Neg.	Oil	60.5
D	22.1	113	155	154	178	200	238	237	278	337	335	392	1.3	0.2	7.7	74.7	.086	Neg.	3.2	60.5
E	22.1	134	175	174f	193	208	240	239	276	336	335	402	1.4	0.2	3.2	74.0	.045	Neg.	4.5	59.0
F	22.1	123	164	162f	184	204	241	239	282	339	335	388	1.7	0.8	5.1	72.0f	.047	Neg.	Oil	60.5
G	22.1	120	156	154	168	180	206	204	242	318	311	381	1.2	1.2	5.2	78.0	.012	Neg.	3.2	66.0
H	22.1	112	155	152	174	196	244	241	290	351	348	404	1.6	0.9	6.3	74.0	.067	Neg.	16.8f	61.0
I	22.1	111	166	165f	180	196	224	223	252	291	288	340	1.0	1.0	7.3	75.3	.041	Neg.	2.4	63.8
J	19.1	109	138	136	153	166	190	188	233	370	360f	425	1.2	1.7	9.9f	65.1f	.150	Neg.	1.6	54.5
K	20.1	109	148	147	170	193	238	237	287	360	357f	399	1.0	0.8	7.6	68.6f	.067	Neg.	1.6	63.0
L	20.1	100	142	138	170	194	243	238	295	357	350	393	1.1	1.9	9.0	63.3f	.165	Neg.	15.0f	61.0
M	20.1	109	158	154	179	204	248	245	294	359	351	401	1.0	1.5	8.0	69.0f	.043	Neg.	4.2	60.5
Regular Grade																				
A	20.1	105	147	141	177	203	244	241	286	350	342	397	1.3	1.7	7.7	68.0	.036	Neg.	1.2	61.0
B	20.1	111	163	151f	180	204	248	245	292	350	346	398	1.1	1.1	6.4	68.7	.030	Neg.	0.7	59.5
C	20.1	116	167	164f	180	205	252	249	300	359	353	408	1.4	1.6	7.0	68.4	.038	Neg.	Oil	60.5
D	20.1	112	161	159f	176	190	232	230	276	336	333	394	1.3	0.6	7.1	68.2	.134	Neg.	2.8	59.5
E	20.1	107	140	139	156	174	212	210	262	343	338	397	1.2	0.8	8.5	69.0	.059	Neg.	2.7	65.5
F	20.1	108	148	144	170	194	242	239	288	352	346	400	1.7	1.2	7.3	68.8	.054	Neg.	Oil	61.5
G	20.1	108	146	141	171	195	239	235	283	350	340	400	1.2	1.8	9.2	69.8	.040	Neg.	1.0	63.5
H	20.1	114	157	156	181	205	251	250	299	360	358f	406	1.2	0.7	7.0	68.4	.028	Neg.	0.8	60.5
I	20.1	117	168	163f	194	216	252	249	293	350	341	400	1.1	1.6	6.5	68.8	.044	Neg.	1.0	61.0
J	18.1	103	131	128	150	165	197	193	259	377	364f	426	1.3	2.0	9.4	63.1f	.118	Neg.	1.0	57.5
K	18.1	108	150	148	174	194	237	235	288	360	356	401	1.1	1.0	9.1	70.3	.065	Neg.	0.2	62.5
L	18.6	98	137	134	158	185	249	242	306	359	352	394	1.0	2.0	9.8f	65.7f	.094	Neg.	1.3	61.5
M	17.2	102	146	142	165	191	245	239	301	375	365 f	411	1.0	2.2	9.0	62.3f	.198	Neg.	1.7	60.5
Third Grade																				
A	18.6	112	171	168f	195	218	257	255	297	358	353	419	1.2	1.0	6.8	56.0	.042	Neg.	0.2	60.0
B	18.1	121	170	169f	196	219	265	264	312	378	376	425	1.2	0.3	5.3	50.0	.023	Neg.	2.2	59.5
C	18.6	118	164	158	196	221	272	268	325	387	382	424	1.1	1.5	6.5	49.5	.020	Neg.	1.0	59.5
D	18.6	116	171	169f	195	218	256	254	298	355	351	404	1.2	0.8	6.6	52.2	.089	Neg.	0.2	60.0
E	18.6	116	162	160	176	198	237	235	292	366	362	416	1.3	0.7	6.2	53.0	.048	Neg.	0.6	62.5
F	18.6	120	176	175f	199	217	250	249	283	327	326	369	1.1	0.3	5.4	51.2	.013	Neg.	0.4	61.0
G	17.1	111	155	151	184	209	257	254	303	368	364	407	1.3	1.0	6.3	50.5	.045	Neg.	12.0f	63.0
H	18.6	121	167	166	192	213	260	259	308	377	375	422	1.3	0.2	6.0	51.6	.038	Neg.	0.7	60.5
J	15.9	100	134	130	148	166	209	203	281	383	369	425	1.2	2.4	9.9f	60.8	.124	Neg.	1.7	61.0
K	17.1	112	153	152	178	203	252	250	306	369	367	414	1.2	0.7	6.1	58.0	.034	Neg.	0.1	62.0
L	17.1	101	140	136	158	178	231	225	289	353	346	389	1.1	1.9	10.0f	62.0	.187	Neg.	1.3	65.0
N	17.4	114	165	158	183	204	253	248	304	374	366	422	1.1	1.8	6.5	54.6	.034	Neg.	3.8	61.5

* Italics represent the per cent evaporated.

f Fail to pass A.S.T.M. specifications.

[illegible]

TABLE VII

Intermediate Season

Purchased November 16, 1937

Retailer	Cost Per Gal. Cents	Initial Boiling Point	Distillation Range °F. Per Cent Distilled and Per Cent Evaporated.									End Point	Residue Per Cent	Loss Per Cent	Reid Vapor Pressure Lb per Sq in.	Octane Number A.S.T.M.	Sulfur Per Cent	Corrosion	Gum mg per 100 ml.	Gravity A.P.I.
			10		20	30	50		70	90										
Premium Grade																				
A	21.8	106	148	145*	175	202	243	239*	280	339	333*	393	1.2	1.3	8.4	75.4	.038	Neg.	2.7	61.5
B	21.8	108	154	151f	174	196	239	237	284	344	342	395	1.3	0.7	7.9	78.0	.034	Neg.	0.7	60.5
C	21.9	107	145	143	168	190	239	236	286	350	345	408	1.8	1.0	8.7	79.0	.022	Neg.	Oil	61.5
D	21.8	112	157	154f	182	204	242	239	284	351	343	424	3.0f	1.0	8.1	74.0	.045	Neg.	Oil	60.5
E	21.9	112	140	139	152	166	194	192	242	332	327	392	1.2	0.8	8.0	76.0	.053	Neg.	4.5	67.0
F	22.0	99	136	132	154	170	200	197	240	311	301	368	1.3	1.7	11.6f	78.5	.020	Neg.	Oil	69.0
G	21.8	102	136	134	156	177	233	230	298	363	359f	404	1.2	1.0	9.8	76.4	.023	Neg.	3.4	63.5
H	21.8	106	155	151f	172	190	242	239	295	354	349	400	1.5	1.2	8.5	76.0	.099	Neg.	24.7	61.0
I	21.8	107	136	135	153	166	200	198	237	292	288	362	1.2	0.8	8.0	78.0	.031	Neg.	0.8	68.5
J	19.1	86	103	96	119	136	177	166	240	373	341	408	1.3	4.9	14.3f	68.0f		Neg.	4.7	67.5
K	19.8	105	145	141	159	192	235	231	284	358	349	395	1.3	1.7	8.4	69.1f	.075	Neg.	2.5	63.5
L	19.3	89	120	111	142	161	219	203	296	375	354	409	1.2	4.3	14.3f	68.0f	.045	Neg.	6.0	66.5
M	19.8	98	140	138	160	183	235	231	283	349	343	394	1.3	1.3	10.3	69.1f	.071	Pos.	2.2	63.0
Regular Grade																				
A	19.8	91	128	122	146	168	217	209	276	348	331	398	1.3	2.9	12.8f	68.6	.050	Neg.	1.6	66.0
B	19.8	104	140	138	164	188	235	232	281	342	337	395	1.4	1.0	9.4	69.9	.032	Neg.	0.1	62.0
C	19.9	102	133	130	157	176	228	224	282	352	345	402	1.5	1.5	11.0	69.6	.030	Neg.	Oil	64.5
D	19.8	101	138	131	163	188	228	222	274	336	324	391	1.4	2.4	10.1	68.0	.115	Neg.	1.9	61.5
E	19.9	94	122	119	138	156	196	190	258	350	334	399	1.2	2.1	11.9f	70.3	.043	Neg.	1.8	68.5
F	20.1	98	138	133	152	175	214	207	278	354	339	399	1.4	2.4	12.4	70.5	.020	Neg.	Oil	66.0
G	19.8	94	136	131	156	175	212	209	274	348	340	400	1.2	1.4	11.8f	70.0	.026	Neg.	0.6	66.0
H	19.8	98	143	138	166	185	226	223	274	353	344	402	1.3	1.6	11.2	69.5	.025	Neg.	1.0	65.0
I	19.8	104	140	138	164	188	238	236	286	344	341	397	1.2	0.8	8.7	73.0	.045	Neg.	4.4	64.0
J	17.8	91	117	110	137	159	208	197	278	367	347	396	1.2	4.0	12.8f	60.8f	.098	Neg.	0.6	65.5
K	17.8	92	136	130	158	183	230	224	287	367	356	402	1.2	2.3	11.7f	72.0	.070	Neg.	1.9	64.5
L	18.3	86	120	113	135	157	216	207	284	361	348	400	1.2	2.7	14.3f	68.3	.080	Neg.	0.6	66.5
M	18.2	99	150	144	172	192	241	236	291	352	344	404	1.4	2.0	10.4	63.6f	.206	Neg.	Oil	60.5
Third Grade																				
A	17.8	111	166	163	193	217	257	255	295	358	353	418	1.3	1.2	7.1	56.5	.120	Pos.	0.5	60.5
B	17.8	122	167	166	193	217	262	261	310	373	371	423	1.3	0.2	5.8	51.4	.026	Neg.	0.6	59.5
C	17.9	118	174	172f	198	218	269	267	322	384	381	420	1.4	0.6	5.7	50.4	.062	Neg.	1.4	59.0
D	17.8	104	174	170f	198	214	250	248	293	350	345	398	1.4	0.9	6.8	54.0	.073	Pos.	5.3	60.5
E	17.9	112	152	151	169	186	224	223	275	364	360	412	1.3	0.8	7.7	54.0	.061	Neg.	1.7	64.5
F	18.6	110	166	161	190	214	251	248	297	346	342	379	1.1	1.2	8.9	54.2	.010	Neg.	1.3	63.0
G	16.8	107	151	147	176	208	268	264	325	384	380	423	1.3	1.0	8.4	50.3	.027	Neg.	1.9	61.5
H	17.8	121	175	173f	199	209	257	255	312	379	376	424	1.3	0.5	6.1	52.9	.035	Neg.	1.4	60.0
J	16.8	95	138	133	151	177	234	227	293	362	351	399	1.2	2.2	11.7f	57.2	.101	Neg.	0.5	66.0
K	16.7	113	170	168f	194	215	262	259	322	378	376	405	1.5	0.8	6.4	48.0	.030	Neg.	0.2	61.0
L	16.8	91	122	120	144	168	227	221	288	360	351	399	1.2	1.9	12.2f	63.5	.128	Neg.	2.0	66.0
M	16.3	98	138	133	162	187	239	234	290	358	351	404	1.2	0.9	9.3	62.0	.194	Neg.	1.2	60.5
N	18.0	109	152	149	171	188	231	228	281	364	358	412	1.3	1.1	8.9	54.0	.047	Neg.	0.2	64.5

* Italics represent the per cent evaporated.
f Fail to pass A.S.T.M. specifications.

TABLE VIII

Winter Season — Purchased January 28, 1938

Retailer	Cost Per Gal. Cents	Initial Boiling Point	Distillation Range °F. Per Cent Distilled and Per Cent Evaporated.									End Point	Residue Per Cent	Loss Per Cent	Reid Vapor Pressure Lb per Sq in.	Octane Number A.S.T.M.	Sulfur Per Cent	Corrosion	Gum mg Per 100 ml.	Gravity A.P.I.
			10		20	30	50		70	90										
Premium Grade																				
A	21.9	94	132	128*	153	170	211	208*	266	335	329*	386	1.4	1.2	11.7	74.0	.037	Neg.	1.5	66.5
B	21.9	98	146	140	172	193	228	224	280	348	336	398	1.3	1.9	10.9	77.9	.027	Neg.	1.5	63.0
C	21.9	100	150	145f	169	192	233	229	282	346	338	400	2.1f	1.3	9.9	76.9	.025	Neg.	Oil	62.5
D	21.9	105	156	152f	180	196	234	229	282	347	340	400	1.4	1.4	9.6	73.0f	.079	Neg.	6.1	61.0
E	21.9	100	119	118	126	132	150	149	186	267	259	370	1.4	1.1	10.4	79.0	.058	Neg.	4.4	76.0
F	22.0	96	132	130	148	163	194	192	226	289	284	364	1.7	1.1	12.2	78.1	.019	Neg.	Oil	71.0
G	21.9	105	133	131	150	166	198	195	246	330	321	386	1.1	1.9	9.6	77.1	.023	Neg.	1.3	67.5
H	21.9	98	142	137	168	187	223	218	286	353	344	400	1.5	1.9	11.2	75.3	.032	Neg.	Oil	65.0
I	21.9	103	128	126	140	152	175	174	209	260	255	328	1.4	1.2	10.1	81.2	.023	Neg.	2.6	72.0
J	19.1	85	112	107	127	144	178	172	225	320	301	375	1.1	3.0	15.6f	66.6f	.042	Neg.	0.2	70.5
K	19.8	99	143	138	166	186	215	213	270	357	346	398	1.2	1.7	11.7	70.8f	.046	Neg.	3.8	66.0
L	19.3	85	122	104	146	168	210	197	284	374	345	398	1.2	5.5	16.4f	69.9f	.056	Neg.	0.4	67.5
M	19.8	94	138	132	158	174	226	217	283	352	340	396	1.2	2.6	11.7	69.1f	.052	Neg.	1.4	61.5
Regular Grade																				
A	19.9	90	120	112	141	164	216	207	272	350	329	397	1.3	3.5	12.7	71.0	.053	Neg.	1.7	67.0
B	19.9	97	132	130	155	180	223	222	278	349	337	398	1.3	2.0	11.7	69.9	.028	Neg.	0.5	64.0
C	19.9	95	138	133	161	181	224	219	277	346	339	402	1.5	1.8	12.0	70.0	.029	Neg.	Oil	66.0
D	19.9	98	140	130	164	188	228	220	275	341	325	386	1.4	3.5	11.4	70.0	.102	Neg.	0.8	63.0
E	19.9	96	124	122	139	154	189	186	233	324	314	385	1.4	1.4	12.4	70.8	.033	Neg.	2.0	70.5
F	19.9	93	136	129	158	178	219	213	274	348	336	395	1.7	2.5	12.3	70.4	.042	Neg.	Oil	66.0
G	19.9	92	126	121	148	167	210	202	260	351	337	396	1.3	2.3	13.9f		.027	Neg.	1.2	68.5
H	19.9	102	135	132	156	178	226	221	283	356	347	402	1.4	1.7	11.6	69.8	.025	Neg.	1.6	65.5
I	19.9	102	145	140	169	190	232	229	284	350	342	397	1.3	1.4	10.0	70.9	.053	Neg.	4.6	63.5
J	17.8	83	114	101	130	141	178	167	243	330	300	368	1.2	5.4	16.5f	66.0	.023	Neg.	0.3	72.5
K	17.8	95	139	134	160	180	217	214	262	355	342	398	1.2	1.8	10.6	70.0	.054	Neg.	2.2	66.5
L	18.3	80	104	96	123	143	186	173	261	363	336	398	1.2	4.0	17.9f	70.7	.075	Neg.	0.2	71.5
M	18.2	101	143	137	169	194	245	239	295	358	349	406	1.3	2.2	11.2	63.2f	.203	Pos.	Oil	60.5
Third Grade																				
A	17.9	107	163	158	194	220	256	253	300	362	353	410	1.3	1.7	8.0	55.2	.024	Neg.	1.3	60.5
B	17.9	116	165	161	188	214	258	255	308	374	369	419	1.4	1.2	6.9	51.0	.027	Neg.	1.3	60.5
C	17.9	131	178	177f	200	222	266	265	320	381	380	419	1.4	0.0	4.9	50.0	.012	Neg.	3.5	59.0
D	17.9	116	175	172f	201	218	252	250	291	348	344	400	1.4	0.8	7.8	52.0	.076	Neg.	1.6	61.0
E	17.9	105	143	142	164	186	232	231	291	368	365	415	1.2	0.9	7.5	53.0	.046	Neg.	1.3	63.5
F	18.6	114	156	153	183	210	255	252	296	345	341	382	1.2	1.0	7.5	53.5	.017	Pos.	0.8	62.0
G	17.9	106	153	150	178	205	262	259	317	384	380	426	1.3	1.1	8.6	51.2	.035	Neg.	2.0	61.5
J	16.8	82	102	95	122	138	181	172	238	327	305	371	1.4	4.0	17.7f	63.6	.015	Neg.	1.5	75.0
K	16.7	103	152	151	172	192	228	226	281	357	352	402	1.3	1.0	9.4	48.7	.022	Neg.	0.7	66.0
L	16.8	83	117	93	142	164	210	193	275	365	328	391	1.2	6.6	16.3f	67.5	.156	Neg.	2.6	70.5
M	16.8	101	135	132	162	190	243	240	295	364	358	410	1.2	1.1	10.5	62.0	.218	Pos.	2.9	60.5
N	17.9	105	137	134	160	183	235	231	290	367	360	413	1.4	1.4	9.1		.029	Neg.	1.5	64.5

* Italics represent the per cent evaporated.
f Fail to pass A.S.T.M. specifications.

[illegible]

T A B L E   IX

Winter Season — Purchased March 14, 1938

Retailer	Cost Per Gal. Cents	Initial Boiling Point	Distillation Range °F. Per Cent Distilled and Per Cent Evaporated. 10	10	20	30	50	50	70	90	90	End Point	Residue Per Cent	Loss Per Cent	Reid Vapor Pressure Lb per Sq in.	Octane Number A.S.T.M.	Sulfur Per Cent	Corrosion	Gum mg Per 100 ml.	Gravity A.P.I.
Premium Grade																				
A	21.9	91	121	118*	144	166	214	209*	273	337	329*	396	1.3	1.7	11.3	72.7f	.077	Neg.	2.3	65.0
B	21.9	93	130	126	158	182	229	225	275	338	332	398	1.4	1.2	11.1	80.0	.079	Neg.	1.7	63.0
C	21.9	101	139	136	164	186	235	231	288	349	343	404	1.9	1.4	9.0	76.7	.062	Neg.	Oil	62.0
D	21.9	93	141	134	165	188	229	222	277	349	335	391	1.3	3.2	10.6	74.5	.095	Neg.	3.4	61.5
E	21.9	97	114	112	120	126	142	141	178	252	244	366	1.0	1.2	10.7	79.5	.064	Neg.	2.4	76.0
F	21.9	108	142	140	164	185	227	225	273	332	328	386	1.4	0.9	7.8	66.0f	.028	Neg.	Oil	64.0
G	21.9	99	133	131	150	160	187	184	227	315	303	370	1.3	1.7	8.1	78.5	.047	Neg.	1.6	69.0
H	21.9	89	128	117	150	174	229	216	289	360	341	404	1.4	4.0	11.3	76.7	.063	Neg.	Oil	64.5
I	21.9	99	131	128	146	156	182	179	214	264	258	321	1.0	1.4	9.9	81.1	.041	Neg.	0.9	70.5
J	17.9	84	120	111	144	165	204	195	250	346	321	403	1.4	4.8	15.3f	72.5f	.120	Neg.	2.3	66.0
K	19.8	93	134	130	152	171	197	194	226	274	266	356	1.4	2.2	11.5	77.3	.067	Neg.	0.8	70.5
L	19.3	85	118	109	139	159	197	191	267	348	322	388	1.3	3.2	14.6f	67.0f	.110	Neg.	1.3	68.5
M	19.8	95	139	134	166	188	226	223	280	342	335	388	1.4	1.9	10.0	69.5f	.120	Neg.	1.9	62.5
Regular Grade																				
A	19.9	95	133	126	161	186	234	226	286	354	339	396	1.4	2.9	11.3	69.6	.081	Neg.	0.9	63.0
B	19.9	95	133	128	154	176	225	219	277	346	335	395	1.3	2.1	11.5	70.0	.077	Neg.	1.3	64.5
C	19.9	93	123	118	146	171	227	219	283	362	354	409	1.6	2.3	11.1	70.0	.064	Neg.	Oil	65.0
D	19.9	91	125	117	153	179	228	221	271	339	325	385	1.5	3.0	11.6	70.0	.150	Neg.	3.0	62.5
E	19.9	99	126	124	141	156	192	189	237	331	323	395	1.3	1.2	9.6	71.5	.043	Neg.	1.5	68.5
F	19.9	98	142	135	166	184	218	214	269	332	322	384	1.9	2.1	11.1	70.0	.022	Neg.	Oil	66.5
G	19.9	88	118	108	141	159	204	197	268	357	339	399	1.4	3.2	12.3	71.0	.068	Neg.	0.6	68.0
H	19.9	92	138	131	162	179	228	220	286	359	347	400	1.4	2.4	10.9	70.0	.073	Neg.	1.9	65.0
I	19.9	93	136	131	162	183	228	224	280	349	339	394	1.4	1.9	10.2	70.0	.086	Neg.	1.5	63.0
J	16.8	84	122	107	144	166	213	200	268	360	327	394	1.3	5.4	15.0f	69.3	.095	Neg.	Oil	67.5
K	16.8	98	143	136	159	177	229	222	278	351	338	386	1.2	2.8	10.6	69.8	.088	Neg.	0.8	65.5
L	18.3	83	108	100	128	147	192	180	246	352	324	387	1.3	4.6	15.9f	68.0	.098	Neg.	1.0	71.0
M	18.2	94	128	121	152	179	234	228	291	356	349	401	1.5	2.0	11.1	63.5f	.214	Neg.	Oil	62.0
Third Grade																				
A	16.3	111	164	158	191	216	252	249	296	357	351	407	1.3	1.5	8.0	56.0	.065	Neg.	0.7	60.0
B	16.9	108	156	152	185	209	255	252	307	375	367	419	1.4	1.6	6.6	51.1	.087	Neg.	1.8	60.5
C	16.3	98	130	126	160	186	239	234	297	371	363	414	1.4	1.7	8.8	54.0	.059	Pos.	1.6	63.5
D	16.3	108	155	151	187	212	250	246	293	353	346	397	1.3	1.7	7.7	54.0	.130	Neg.	1.8	61.0
E	16.3	109	161	159	186	208	246	244	296	369	366	411	1.4	0.7	7.7	53.0	.042	Neg.	1.7	62.5
F	16.3	105	164	161	196	209	243	241	276	321	317	363	1.3	1.2	6.9	52.0	.014	Neg.	1.2	62.5
G	15.3	101	147	140	178	204	256	250	313	381	370	419	1.3	2.1	8.4	52.0	.063	Neg.	1.0	62.0
H	16.3	101	149	142	176	193	241	235	298	377	367	413	1.4	2.0	9.3	54.0	.050	Neg.	2.1	63.0
J	15.3	82	116	104	136	158	201	188	257	346	314	380	1.4	5.5	15.6f	64.0	.046	Neg.	2.7	70.5
K	15.3	104	155	151	181	200	235	232	270	355	340	394	1.4	1.7	9.9	50.0	.057	Neg.	0.9	66.0
L	13.9	93	114	112	125	135	162	159	201	299	284	382	1.3	1.7	12.8	65.5	.073	Neg.	1.0	74.5
M	16.8	96	130	123	157	183	239	232	292	362	355	402	1.4	2.5	11.0	64.0	.141	Pos.	4.7	61.5

* Italics represent the per cent evaporated.
f Fail to pass A.S.T.M. specifications.

TABLE X

Intermediate Season — Purchased May 3-10, 1938

Retailer	Cost Per Gal. Cents	Initial Boiling Point	Distillation Range °F. Per Cent Distilled and Per Cent Evaporated. 10		20	30	50		70	90		End Point	Residue Per Cent	Loss Per Cent	Reid Vapor Pressure Lb per Sq in.	Octane Number A.S.T.M.	Sulfur Per Cent	Corrosion	Gum mg per 100 ml.	Gravity A.P.I.
Premium Grade																				
A	22.2	98	142	138*	164	188	226	223*	273	342	333*	395	1.3	1.6	9.5	71.1	.037	Neg.	1.7	64.0
B	22.1	98	146	137	174	192	232	227	275	334	323	389	1.2	2.2	10.0	77.5	.031	Neg.	0.8	62.0
C	22.2	109	151	146	177	197	236	232	284	348	340	406	1.8	1.6	8.3	76.2	.033	Neg.	Oil	61.5
D	22.2	102	140	137	170	193	233	229	274	337	332	385	1.3	1.4	9.5	71.4	.080	Neg.	18.3f	61.5
E	22.2	100	120	119	128	136	150	159	205	302	294	381	1.1	0.9	10.5	78.0	.080	Neg.	2.1	72.5
F	22.1	108	140	136	161	176	210	207	255	316	311	384	1.5	1.4	9.4	72.0	.038	Neg.	Oil	66.5
G	22.1	110	141	137	153	166	191	189	225	308	300	368	1.2	1.4	8.3	78.3	.009	Neg.	1.5	68.5
H	22.2	102	145	143	175	196	232	230	288	335	333	386	1.9	0.8	9.8	77.2	.044	Neg.	Oil	63.0
I	22.2	100	140	138	157	174	204	203	237	277	274	322	1.2	1.1	9.3	80.0	.039	Neg.	5.0	65.5
J	18.9	75	137	130	161	183	225	119	270	338	324	400	1.3	2.9	12.4f	69.6	.151	Neg.	3.5	63.5
K	22.2	94	142	137	160	173	199	196	227	273	263	344	1.7	2.2	11.6f	78.0	.045	Neg.	2.0	70.0
L	20.2	98	136	130	159	177	226	218	290	363	352	397	1.1	2.4	11.1	68.0	.077	Neg.	1.1	63.0
M	20.2	99	136	130	161	185	231	227	278	347	340	398	1.3	1.3	9.0	68.6	.070	Neg.	3.0	62.0
Regular																				
A	20.2	99	138	134	167	194	238	235	285	346	341	398	1.2	1.4	9.5	69.8	.048	Neg.	2.6	62.0
B	20.1	102	152	146	169	191	236	232	282	343	335	395	1.3	1.8	9.6	70.0	.045	Neg.	0.6	61.5
C	20.2	103	140	137	167	190	239	235	290	357	349	403	1.5	1.2	8.1	69.5	.027	Neg.	Oil	62.5
D	20.2	97	130	126	154	179	223	218	269	334	322	382	1.3	2.5	10.2	68.0	.133	Neg.	0.7	62.5
E	20.2	104	137	133	155	169	210	202	265	350	340	391	1.1	2.3	8.4	70.9	.068	Neg.	2.0	64.5
F	20.1	97	151	147	175	196	228	225	284	331	329	387	1.9	1.3	9.9	71.3	.050	Neg.	Oil	64.0
G	20.1	101	150	145	174	193	231	227	280	349	340	398	1.2	1.8	9.2	70.0	.041	Neg.	0.4	63.5
H	20.2	103	149	146	177	198	239	237	294	358	354	402	1.5	1.0	9.1	69.7	.041	Neg.	2.5	62.0
I	20.1	109	166	161f	190	205	237	234	281	337	332	384	1.4	1.4	8.5	70.0	.059	Neg.	0.7	62.0
J	18.2	86	122	112	145	167	213	203	268	361	339	400	1.2	4.3	13.6f	69.2	.156	Neg.	5.0	65.5
K	20.2	100	152	146	178	200	238	235	290	354	348	387	1.6	1.6	9.7	69.4	.076	Pos.	0.6	63.0
L	18.7	90	122	118	142	167	223	215	288	360	348	391	1.3	2.4	11.6f	68.0	.085	Neg.	0.5	64.0
M	18.4	101	138	134	161	186	237	233	288	348	342	400	1.1	1.5	10.0	63.7f	.219	Neg.	Oil	60.5
Third Grade																				
A	17.9	105	162	155	197	222	253	250	292	350	341	410	1.3	1.8	7.4	56.0	.042	Neg.	2.0	60.5
B	17.9	108	148	144	177	205	255	251	309	376	368	418	1.2	1.5	6.9	52.0	.039	Neg.	1.5	61.5
C	17.9	108	144	142	170	195	244	241	304	367	364	417	1.4	0.9	8.9	53.4	.025	Neg.	2.7	62.5
D	17.9	108	167	162	186	209	247	244	288	343	337	396	1.3	1.4	7.9	52.9	.101	Neg.	1.4	60.5
E	17.4	108	166	162	186	207	253	249	308	375	369	416	1.3	1.6	7.8	55.3	.033	Neg.	0.3	61.0
F	16.9	120	163	161	185	206	244	242	281	327	324	372	1.2	0.9	6.2	52.0	.024	Neg.	1.4	62.5
G	16.9	107	168	163	192	214	249	245	306	375	369	410	1.3	1.7	8.5	52.0	.025	Neg.	0.5	62.0
H	17.9	106	160	157	184	201	248	246	306	371	367	411	1.2	1.0	7.9	53.1	.010	Neg.	0.8	62.0
J	16.9	94	138	131	160	182	215	208	265	342	327	411	1.2	3.0	11.9f	59.3	.054	Neg.	5.1	68.0
K	16.9	103	144	139	167	185	229	225	281	360	351	396	1.4	1.8	9.7	49.3	.035	Neg.	0.7	66.0
L	16.9	91	110	109	118	124	144	142	183	290	275	377	1.3	1.7	12.3f	67.6	.068	Neg.	1.6	76.0
M	16.9	96	140	137	163	186	237	231	290	340	333	394	1.1	2.2	9.7	64.0	.211	Neg.	2.4	66.5

* Italics represent the per cent evaporated.
f Fail to pass A.S.T.M. specifications.

TABLE XI

Summer Season | Purchased July 5, 1938

Retailer	Cost Per Gal. Cents	Initial Boiling Point	Distillation Range °F. Per Cent Distilled and Per Cent Evaporated. 10		20	30	50		70	90		End Point	Residue Per Cent	Loss Per Cent	Reid Vapor Pressure Lb per Sq in.	Octane Number A.S.T.M.	Sulfur Per Cent	Corrosion	Gum mg per 100 ml.	Gravity A.P.I.
Premium Grade																				
A	22.2	110	152	150*	178	198	239	236*	279	340	335*	392	1.1	1.2	7.2	75.0	.052	Neg.	2.9	60.5
B	22.2	112	158	154	180	200	241	236	287	345	336	393	1.2	2.2	7.3	77.5	.028	Neg.	5.7	60.0
C	22.2	116	149	147	171	188	228	225	278	350	345	391	1.1	1.1	7.4	75.5	.061	Neg.	3.4	63.0
D	22.2	113	157	156	176	193	233	231	276	340	335	390	1.3	1.0	7.4	76.5	.075	Neg.	2.8	60.5
E	22.2	127	165	154f	183	200	237	236	284	356	355	406	1.3	0.1	3.2	74.5	.083	Neg.	23.1f	57.0
F	22.3	105	154	139	176	192	232	220	286	342	320	370	1.3	5.4	8.6	76.0	.071	Neg.	Oil	62.5
G	22.2	110	144	140	162	176	209	204	249	332	318	380	1.4	2.0	7.5	77.6	.034	Neg.	6.1	65.0
H	22.2	109	157	153	180	198	231	228	284	339	334	400	2.0	1.2	8.3	76.0	.042	Neg.	28.8f	62.0
I	22.1	117	158	153	179	195	220	218	247	285	279	318	0.9	2.1	7.1	78.0	.060	Neg.	6.7	62.5
J	18.9	100	144	140	171	184	227	221	383	358	350	403	1.1	1.8	9.4	70.0f	.174	Neg.	5.2	60.5
K	20.2	106	145	139	164	179	197	193	227	267	258	330	1.2	2.8	10.0f	78.0	.046	Neg.	3.1	59.5
L	20.2	107	148	145	166	193	238	234	287	346	340	382	1.3	1.2	7.9	70.0f	.073	Pos.	2.8	63.5
M	20.2	107	158	156	181	191	230	228	272	341	336	386	1.3	1.0	7.5	68.0f	.069	Neg.	Oil	62.0
Regular Grade																				
A	20.2	106	160	152	189	214	256	252	293	348	340	394	1.2	2.2	8.0	69.0	.091	Neg.	2.2	59.0
B	20.2	110	164	158	182	200	239	236	285	348	339	394	1.2	1.8	7.8	70.0	.038	Pos.	1.2	61.0
C	20.2	113	158	150	176	198	247	239	298	366	353	409	1.3	2.7	8.1	69.5	.034	Neg.	Oil	61.5
D	20.2	110	148	146	167	187	226	223	269	326	321	380	1.1	1.2	7.7	67.0	.156	Neg.	0.2	60.5
E	20.2	110	145	144	163	182	220	219	273	350	345	397	1.0	0.7	7.5	70.0	.068	Neg.	3.6	63.5
F	20.2	108	149	137	177	200	248	241	292	360	342	390	1.5	3.5	7.9	70.0	.053	Neg.	Oil	62.0
G	20.2	104	154	132	181	201	250	237	307	383	357f	401	1.2	5.8	7.9	70.5	.038	Neg.	1.3	61.0
H	20.2	112	147	145	168	186	228	226	275	347	343	397	1.1	0.9	7.9	69.0	.061	Neg.	1.8	62.5
I	20.1	117	156	153	174	192	222	219	269	346	339	392	1.2	1.1	6.8	70.0	.093	Neg.	4.3	62.5
J	18.2	100	145	141	168	186	228	223	288	365	357f	406	1.3	2.0	10.4f	67.0	.155	Pos.	8.1f	62.5
K	18.2	105	148	143	174	192	236	232	289	361	354	390	1.2	1.8	9.2	70.0	.072	Neg.	4.4	63.0
L	18.7	98	132	126	152	182	243	235	296	364	352	401	1.2	2.8	10.0f	64.0f	.215	Pos.	9.2f	62.5
M	18.4	100	142	136	164	183	236	230	290	358	347	407	1.2	2.1	9.2	64.5f	.246	Pos.	4.7	60.5
Third Grade																				
A	17.4	110	160	158	185	207	250	248	291	356	351	416	1.2	0.8	7.5	56.0	.024	Neg.	0.5	61.0
B	17.9	113	173	155	203	207	262	251	320	374	357	414	1.4	4.6	7.6	51.5	.029	Neg.	2.1	61.0
C	17.9	116	163	152	184	198	247	246	295	371	370	419	1.3	0.2	6.4	52.0	.048	Pos.	2.1	61.0
D	17.9	112	165	160	191	212	253	249	295	353	346	397	1.2	1.8	7.3	52.5	.103	Neg.	0.7	60.0
E	17.9	111	153	150	177	201	251	246	303	373	356	416	1.2	1.8	7.7	52.0	.091	Neg.	1.5	62.0
F	16.6	115	162	160	182	202	230	229	270	325	323	372	1.2	0.7	6.9	53.5	.018	Neg.	0.5	63.5
G	16.9	107	148	139	179	200	253	246	305	378	365	416	1.3	2.7	8.2	52.5	.032	Neg.	1.0	62.5
H	17.9	111	164	159	180	207	254	250	208	377	371	415	1.3	1.5	7.3	51.6	.026	Neg.	0.5	61.0
J	16.9	98	141	135	170	187	230	224	293	363	354	400	1.3	2.7	11.0f	63.5	.186	Pos.	9.5f	63.5
K	16.9	110	156	151	178	205	245	241	288	345	339	385	1.2	1.8	8.1	51.0	.026	Neg.	1.3	63.0
L	16.9	97	139	130	164	179	239	228	305	368	355	401	1.2	3.8	11.4f	62.5	.196	Neg.	23.1f	64.0
M	16.9	100	146	140	165	183	233	226	294	355	345	404	1.1	2.1	9.4	65.5	.256	Neg.	2.9	61.0

* Italics represent the per cent evaporated.

f Failure to pass A.S.T.M. specifications.