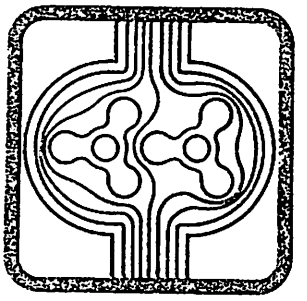
Unit Five

Chapter 36
FUELS



FUEL

Many fuels can be used to operate the internal combustion engine. These include methanol, benzol, alcohol, alcohol-gasoline blends, liquid petroleum gas, and the most popular fuel, gasoline. Gasoline is a hydrocarbon mixture in the form of a colourless liquid and is obtained from crude oil by a complicated distillation, fractionation, and cracking process.

36-1 FUEL MANUFACTURING PROCESSES

Fractionation. Fractionation, like distillation, depends upon the vaporization and subsequent condensing of a liquid and is used to separate liquids having different boiling points. The different boiling points of hydrocarbons such as gasoline, LPG and natural gas are shown in Fig. 36-2. The lighter hydrocarbons, such as those in the gasoline range, have quite low boiling points. The heavier elements of crude oil that are used in the manufacture of lubricating oils, etc., have higher boiling points.

The straight run gasoline that is obtained by the fractionation process is of insufficient quantity and of too low an antiknock quality to satisfy today's needs. Therefore, several other manufacturing processes are used to increase the quantity and quality of gasoline obtained from crude oil. These processes are thermal cracking, catalyst cracking, thermal reforming and catalytic reforming, and polymerization.

Thermal cracking. Thermal cracking is the process of breaking down the original structure of oil or breaking the molecules apart so that they can be re-formed in a different structure.

The thermal cracking process uses the oil

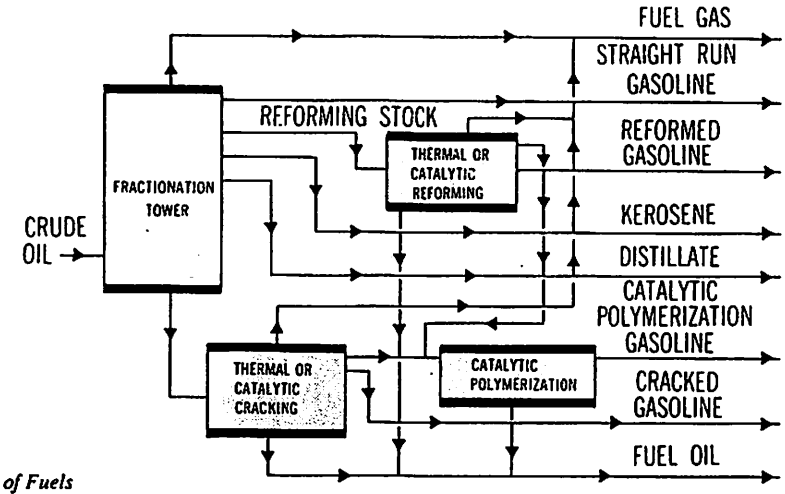


Fig. 36-1 Refining of Fuels

remaining from the distillation process and through the use of high temperatures and high pressures, it causes a series of chemical changes that result in the production of various petroleum products.

Catalytic cracking. Catalytic cracking uses a catalyst (a catalyst is a material that has the ability to cause a chemical change to take place without the catalyst being changed or consumed during the process) along with heat and pressure to break down and reform the molecular structure of the remaining oil from distillation.

Catalytic cracking produces gasoline with a higher octane rating than that produced by thermal cracking.

Thermal reforming. Thermal reforming is a process similar to thermal cracking but it is used to rearrange the molecular structure of straight run gasoline, thereby improving its antiknock qualities.

Catalytic reforming. Catalytic reforming uses a catalyst to rearrange the molecular structure of straight cut gasoline to improve its antiknock qualities.

Polymerization. Polymerization produces gasoline from the large quantities of gases created during the cracking and re-forming operations. The process uses heat and pressure or a catalyst to create the reaction necessary to produce the liquid fuel.

36-2 GASOLINE

Gasoline is a blend of various types and proportions of the fuels obtained by the different manufacturing processes. Fuel chemists prepare the best product for all-around performance by compounding many types of gasoline. The compounds are changed to meet the temperature conditions found during the different seasons of the year and to match temperature conditions in various regions of the country.

Several characteristics are considered in the compounding procedure, among which are volatility, antiknock value, and freedom from harmful chemicals and gum formations.

Volatility. Volatility refers to the ease with which gasoline or other liquids vaporize. For example, since alcohol vaporizes at a lower temperature than water, it is said to be volatile. Gasoline is compounded of many kinds of hydrocarbons each having a different volatility. These hydrocarbons have boiling points ranging from approximately 40°C to 225°C. (See Fig. 36-2.) The volatility of gasoline affects the ease of starting,

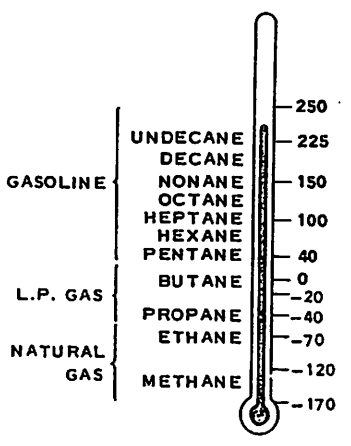


Fig. 36-2 Boiling Points of Hydrocarbons

length of warming-up period, and engine performance during normal operation.

For easy starting of a cold engine the gasoline must be highly volatile. Gasoline blended during the winter months is more volatile than that blended during the summer months. If the fuel is too volatile during the summer months, it vaporizes and forms a vapour lock or a vapour bubble in the fuel line or fuel pump. This bubble expands or contracts according to the pressure or vacuum produced by the fuel pump and therefore can prevent the delivery of the fuel to the carburetor fuel bowl.

During the warming-up period, a less volatile gasoline is required. For maximum power and economy of operation, fuel with a lower volatility but higher heat content is required. Therefore the volatility of the fuel must be such that the fuel will remain in liquid form until it reaches the air stream in the carburetor. Then it must vaporize quickly and mix uniformly with the correct proportions of air for the driving and temperature conditions.

Antiknock value. Various chemicals and manufacturing processes were employed by fuel chemists in developing higher octane gasolines that would permit the use of higher-compression engines. These chemicals and processes improved the gasoline by reducing the rate of flame travel during combustion that resulted in the prevention of excessive pressures which cause detonation or knocking.

When a substance burns, it is actually uniting in rapid chemical reaction with oxygen. The molecules of the substance and oxygen are set into very rapid motion which produces heat. If the molecules are confined, such as in the combustion chamber of an engine, they strike the sides of the chamber, producing pressure. The more rapid the movement, the greater the pressure.

Combustion takes place in three stages. These stages are called the *nucleus* or formation of flame, the *hatching-out,* and *propagation.*

The nucleus is a small ball of blue flame that develops around the spark-plug gap when the spark occurs. The nucleus grows slowly with very little increase in temperature or pressure. As the nucleus grows it begins to hatch out. During this stage the nucleus sends fingers of flame outward into the unburnt mixture. This creates a moderate increase in temperature and pressure. Finally, propagation takes place. During propagation a flame wall sweeps across the chamber, burning rapidly and creating great heat and pressure. As long as the fuel-air mixture burns evenly in these stages, maximum power without detonation will be produced. However, if during the third stage of combustion the combination of the heat of

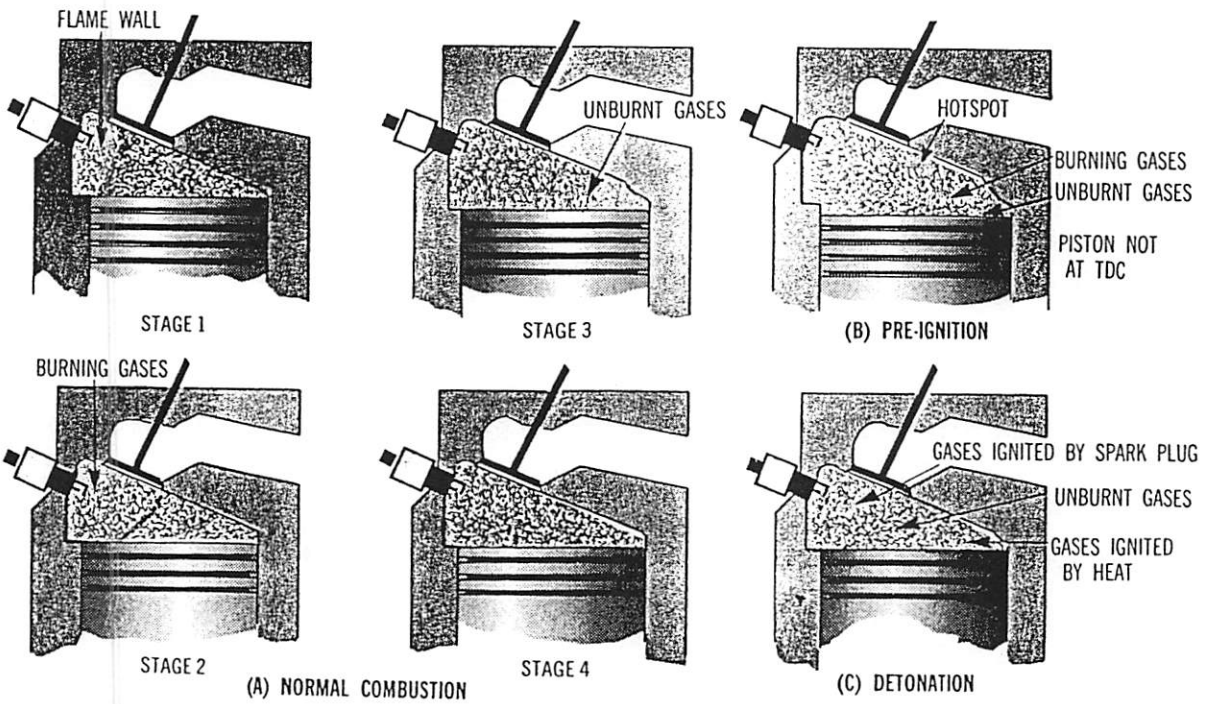


Fig. 36-3 Fuel Combustion Patterns

combustion plus the heat generated by the further compression of the unburnt fuel is sufficient to ignite the unburnt gases before the flame wall reaches them, detonation will occur.

Detonation. The knocking or pinging sound of detonation occurs when the temperature of the compressed gas reaches ignition temperature before the flame wall reaches the gas.

Detonation is harmful to an engine as it tends to damage the pistons, connecting-rod and main bearings, and the spark plugs. It results in the engine overheating, high fuel consumption, and loss of power.

Detonation knocks are usually regular in character and occur when the engine is being accelerated under heavy load or climbing a hill. It occurs when the accelerator is wide open and the engine is taking in a full charge of fuel-air mixture on the intake stroke. This increases the compression pressure and the heat of compression and can cause the fuel to ignite before the flame wall reaches the unburnt fuel.

Pre-ignition. Pre-ignition is an irregular knock that occurs when the fuel-air mixture is ignited by any means other than the spark at the spark plug. Ignition is usually caused by hot spots of carbon that form on the piston or combustion chamber or by an overheated exhaust valve or spark plug.

Pre-ignition is referred to as wild knocking and can occur any time after the intake valve has opened to admit a fresh charge of fuel-air mixture.

36-3 OCTANE RATING

In order to identify the antiknock qualities of gasoline, an octane rating system is used. This rating can be determined by two methods: the *motor method*, and the *research method*.

The motor method correlates better with the ratings of car-fuel combinations at high road speeds, while the research method correlates with ratings made in cars that knock at low road speeds. The research method is considered to be "mild," while the motor method is considered to be more severe. Most oil companies prefer the research method ratings since they consider them a better criterion of a gasoline's antiknock quality. The differences in the ratings given by the two tests is referred to as fuel sensitivity.

Fuel sensitivity is controlled by the fuel's chemical composition which is directly related to the type of crude used and the refining process to

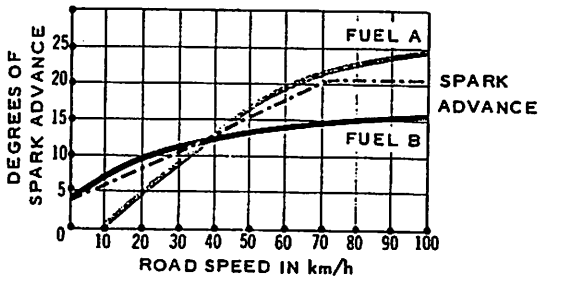


Fig. 36-4 Fuel Borderline Knock Curves

which it is subjected. Cracked gasolines are quite sensitive. A sensitivity range of 15 octane points is not uncommon, but the average range is between 6 and 8 octane points.

The octane rating of a fuel is determined by using a special test engine. This engine is especially designed so that the compression ratio can be varied while the engine is running. It is also equipped with a small diaphragm in the combustion chamber. This diaphragm actuates a bouncing pin to record electrically on a "knock meter" to determine the severity of the detonation.

The gasoline to be tested is used to operate the test engine and the results are recorded. Then the engine is operated on a mixture of special fuels. These fuels are iso-octane, a member of the gasoline family that has been given an octane rating of 100, and heptane, which can be obtained from crude oil or from the sap of the Jeffery pine tree, and has been given the octane rating of zero. The octane rating of the gasoline is determined by the amount of iso-octane in the iso-octane-heptane mixture that gives the same results as the gasoline being tested. In other words, if the iso-octane-heptane mixture requires 90% iso-octane and 10% heptane to match the performance of the gasoline tested, that gasoline would be given a 90 octane rating.

It should be noted that the tendency of a fuel to detonate varies in different engines and in similar engines operating under different conditions. For example: a rise of 10°C in air temperature increases the octane requirement by about three numbers. A 10% increase in humidity at 30°C reduces the octane requirements by one number, hence an engine does run somewhat better and quieter in wet weather. Engine combustion-chamber deposits increase the compression ratio and therefore increase the octane requirements of the fuel. Octane requirements can also be increased by advancing the spark timing or leaning the fuel-air ratio. The higher

the altitude in which the engine operates, the lower the octane requirements.

As a result of the variation in octane requirements, most gasolines are blended according to the seasons of the year and the altitudes of the location in which the fuel is to be used.

36-4 CHEMICAL CONTROL OF DETONATION

Detonation may be controlled by adding chemicals. These chemicals increase the reaction time of the fuel by breaking down into metals and oxides and thereby interfering with the normal combustion chemical reaction. This interference gives the flame wall time to reach all the fuel in the cylinder. Instead of the fuel exploding, normal combustion can take place.

For many years the most popular chemical used to control detonation was Tetraethyl lead (ethyl). Tetraethyl lead is a clear liquid composed of carbon, hydrogen, and lead.

To prevent lead deposits from forming in the combustion chamber, other compounds such as ethylene dibromide and ethylene dichloride were also added to change the lead compounds into a form which would vaporize and leave the cylinder with the exhaust gases.

Today we know this process leads to unhealthy concentrations of lead compounds in our air and as they are precipitated by rain and snow, eventually in our soil, rivers, and lakes. The solution was, in part at least, to remove lead from gasoline. Also, since the lead compounds in the exhaust gases destroyed the chemical action of the pellets in catalytic convertors, now used to convert another pollutant, nitrous oxides, into harmless byproducts, the development of unleaded gasolines was mandatory.

To control detonation in unleaded gasolines the compression ratios of engines had to be lowered, different blending procedures were used in the manufacture of gasoline, and some refineries began using new additives made from manganese compounds.

36-5 COMBUSTION-CHAMBER DESIGN AND DETONATION

The shape of the combustion chamber determines the turbulence, squish and quench effects of the fuel-air mixture in the cylinder.

Turbulence — is the name given to the swirling action of the fuel-air mixture as it enters the cylinder. It is produced by the design of the combustion chamber and is used to improve the mixing of the fuel-air mixture. The greater the turbulence of the fuel-air mixture entering the cylinder, the more uniform the mixture; therefore, the more uniform the combustion. Also, the greater the turbulence, the less time is required for the flame wall to ignite all the fuel in the cylinder.

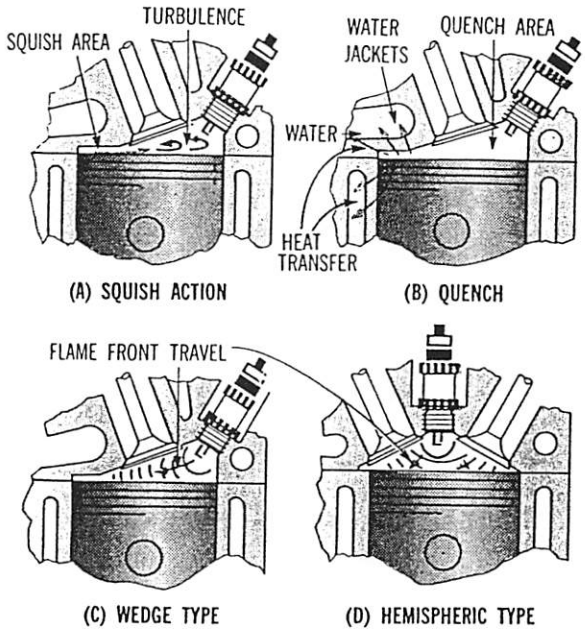


Fig. 36-5 Combustion Chamber Design and Detonation

Squish — refers to the manner in which the fuel-and-air mixture is pushed out of one area of the combustion chamber near the end of the compression stroke. The combustion chamber and piston head are designed so as to push the fuel-air mixture into the main area of the combustion chamber with great turbulence, thus promoting further mixing of the fuel-air mixture.

Quench — refers to the cooling of the unburnt fuel-air mixture in the combustion chamber. It helps to prevent the mixture from igniting because of the high temperatures in the combustion chamber before the mixture can be ignited by the flame wall. The squish area of the combustion chamber is also the quench area. These areas are very close to the water jackets; they are relatively cool and extract heat from the unburnt mixture and, as a result, reduce the tendency for detonation to occur.

Spark plug location — determines the distance

the flame wall must travel in order to ignite all of the fuel-air mixture. In a hemispheric-type combustion chamber the spark plug is located near the centre of the dome. After ignition the flame wall can travel in all directions with an increasing circular pattern. With this design the flame wall travels a short distance and there are no distant pockets of the fuel-air mixture to detonate. Therefore, no squish or quench areas are required and little if any turbulence is produced.

When the spark plug is located to one side of the combustion chamber, as in the wedge shaped combustion chamber, the flame wall must travel across the diameter of the combustion chamber. Squish and quench areas are required along with turbulence in order to have complete combustion without detonation.

Heat of compression — is increased as the compression ratio increases. Therefore, detonation can occur if the compression ratio is high enough so that the combined temperatures of the heat of compression and the heat of combustion will ignite the fuel-air mixture ahead of the flame wall.

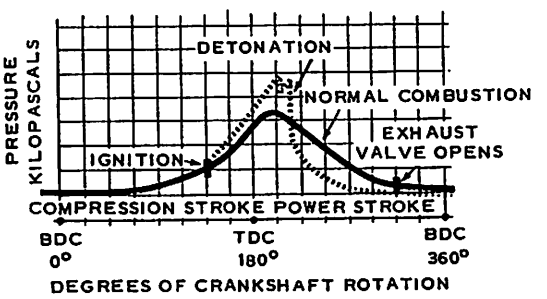


Fig. 36-6 Typical Pressure Curve of Normal Combustion and Detonation

36-6 FUEL ADDITIVES

Gasoline often contains additives or chemicals to improve its operating qualities. Tetraethyl lead is the most popular compound added to gasoline to improve the octane rating. Dyes are added to identify the different grades of gasoline. Metal deactivators are added to prevent the gasoline from reacting with certain metals. Phosphorus compounds are added to prevent metallic deposits from the gasoline combining with combustion-chamber deposits to form a composition that retains heat and could cause pre-ignition. Anti-oxidant inhibitors are added to prevent the formation of resins and gum. Anti-icing chemicals are added to prevent carburetor icing.

36-7 DIESEL FUEL

The type of fuels available for use in diesel engines varies from the volatile type of jet engine fuels, to kerosene, and to heavier furnace oils. The properties of the diesel fuels depend upon the nature of the crude used and the type of refining process. Diesel fuels are produced with a boiling range of between 150°C and 400°C.

Diesel fuels are graded as D1, D2, and D4. A D1 fuel is one that has a range from kerosene to intermediate distillates and has a low boiling point. A D2 fuel is heavier and has a higher boiling point; D4 fuel is even heavier and has higher boiling points. D2 and D4 fuels contain more impurities.

While refining removes the impurities and produces higher grade fuels, it also lowers the heat value of the fuel. Therefore, a given quantity of high-grade fuel will produce slightly less power than an equal amount of low-grade fuel.

Cetane rating. Gasolines are classified by octane ratings; diesel fuels are classified by cetane ratings. This rating system classifies diesel fuel according to the time lag or delay between the time the fuel is injected into the combustion chamber and the time it is ignited by the heat of compression. The shorter the time lag, the more volatile the fuel, and the higher the cetane rating. The longer the lag, the lower the rating. Most engines require fuels with a cetane rating of between 30 to 60. For starting engines in cold weather, fuels with ratings of 85 to 95 are frequently used.

36-8 OTHER FUELS

Liquid petroleum gas. Liquid petroleum gas (LPG or propane) is a mixture of gaseous petroleum compounds, such as butane and propane, which are surplus material in the oil fields. LPG is a very volatile fuel with a boiling point of −40°C. It has an excellent octane rating of approximately 96, in a dry gas, and does not create carbon in the engine. LPG engines are easily started in cold weather and have less objectionable exhaust odours.

For storage and transportation, LPG is compressed and cooled to a liquid state. Approximately 1250 L of gas are compressed into 5 L of liquid and stored in strong tanks.

Compressed natural gas (CNG). Methane, the principal compound of natural gas, has been

used as a satisfactory alternative fuel in internal-combustion engines. Unlike propane, natural gas is not easily converted to a liquid, so it must be stored as a gas. Relatively high pressures, up to 25 MPa (3600 psi), are needed to compress enough gas to make storage and use in vehicles practical.

Alcohol. Alcohol, a distillate of wood or grain, has a high octane rating and is sometimes blended with benzol to be used as a fuel for racing engines. Alcohol is also frequently used as an additive to gasoline to absorb the water which is formed in the fuel system because of condensation. The water causes corrosion of the metal parts or could freeze and block the passage of fuel. Water will not pass through the fuel filters of the pump and carburetor; instead it is collected there and eventually prevents the passage of gasoline. The alcohol additive absorbs the water, thus permitting it to pass through the filters, carburetor jets, and into the combustion chamber, where it is converted into steam and passes out through the exhaust system.

Benzol. Benzol is a hydrocarbon obtained from the refinement of coal tar. It is highly volatile and has a high octane rating. It may be blended with gasoline to increase the octane rating of the fuel or mixed with alcohol and used as a fuel for racing engines.

36-9 COMBUSTION AND HEAT

Combustion is the rapid combination of a fuel with oxygen to produce heat. When gasoline is used as the fuel, it is the combining or oxidation of the carbon and the hydrogen that produces the chemical change that results in heat. The chemical equation for the combustion of gasoline is:

$$C_8H_{18} + 12.5\,O_2 = 8CO_2 + 9H_2$$

When C_8H_{18} represents the chemical formula for gasoline, and 12.5 O_2 is the oxygen required to burn one part of gasoline, this produces 8 parts of carbon dioxide (CO_2) plus 9 parts of water (H_2O). For each gallon of gasoline burned, over a gallon of water is produced.

However, air is a mixture of approximately one part of oxygen and 3.5 parts of nitrogen; therefore, nitrogen must be considered as a part of combustion. Since it requires 12.5 parts of oxygen for combustion of one part of gasoline, combustion must also include 43.75 parts of nitrogen. Therefore, the chemical formula now reads:

$$C_8H_{18} + 12.5\,O_2 + 43.75N_2 = 8CO_2 + 9H_2O + 43.75N_2$$

The burning of the fuel in the combustion chamber is rarely complete. Not all of the carbon in the gasoline is converted into carbon dioxide. When there is a shortage of oxygen, free carbon and carbon monoxide are formed. Twice as much oxygen is required in the formation of carbon dioxide as in carbon monoxide. The more carbon monoxide an engine produces, the less power it produces. Therefore, an ample supply of oxygen is required for maximum power. The power produced from any fuel is determined by its heat value which is measured in joules per gram of fuel completely burned. Gasoline has a heat energy value of approximately 40 MJ/kg (approximately 20 500 BTU), diesel fuels a value of approximately 45 MJ/kg (approximately 23 000 BTU).

The temperatures produced in the combustion chamber vary widely. The compression ratio, the combustion-chamber design, the cooling system, the fuel-air ratio, and the amount of burnt gases left in the cylinder at the end of the exhaust stroke all affect combustion-chamber temperatures.

At the end of the compression stroke the temperature could rise to approximately 550°C in an engine with an 8:1 compression ratio. After ignition this temperature will rise rapidly to as high as 2200°C.

REVIEW QUESTIONS

1. What is fractionation?
2. What is the purpose of thermal cracking?
3. Describe the refining processes used to increase the antiknock qualities of fuels.
4. What is a catalyst?
5. Why is volatility an important characteristic of automotive fuels?
6. Describe the normal combustion pattern of gasoline.
7. Explain the difference between detonation and pre-ignition.
8. What is meant by the term "fuel sensitivity"?

9. Describe the motor method of establishing an antiknock rating of fuel.
10. Explain how tetraethyl lead controls detonation.
11. How does turbulence improve combustion?
12. Explain how quench reduces the possibility of detonation.
13. Name and state the purpose of three fuel additives.
14. List three reasons why an engine would require gasolines with different octane ratings.
15. What determines the grade of diesel fuel?
16. Why is the boiling point of diesel fuel important?
17. Why is a mixture of alcohol and benzol a good fuel for racing engines?
18. Describe the chemical reaction that takes place during the combustion of gasoline.
19. How is the heat value of gasoline measured?
20. Give three reasons why the combustion chamber temperatures vary widely.