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SAMPLE



C H A P T E R 5

Principles of Engine Operation, Two- and Four-Stroke Engines

Learning Objectives

After studying this chapter, you will be able to:

- Explain simple engine operation.
- Explain why gasoline is atomized in the small engine.
- Describe four-stroke engine operation and explain the purpose of each stroke.
- Explain the concept of valve timing.
- Compare the lubrication system in a four-cycle engine to the system in a two-stroke engine.
- Describe two-stroke engine operation and explain the principles of two-cycle operation.
- List the advantages and disadvantages of two-stroke and four-stroke engines.

Key Terms

atomization
bottom dead center
compression ratio
compression stroke
exhaust stroke
four-stroke engine
intake stroke
internal combustion engine

power stroke
scavenge loss
stroke
top dead center
two-stroke engine
valve overlap

Principles of Engine Operation

A gasoline-fueled engine is a mechanism designed to transform the chemical energy of burning fuel into mechanical energy. In operation, it controls and applies this energy to mow lawns, cut trees, propel tractors, and perform many other laborsaving jobs.

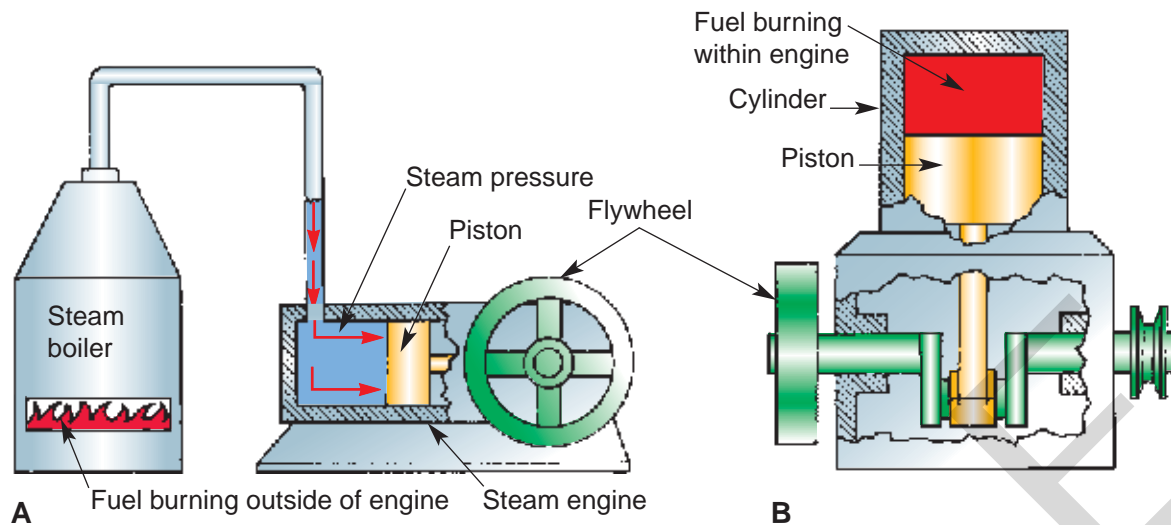
The small gasoline engine is called an *internal combustion engine* because an air/fuel mixture is ignited (fired) and burned inside the engine. See **Figure 5-1**.

For the engine to operate efficiently, the gasoline must be broken into small particles that will ignite

easily and burn quickly. In addition, the energy produced by the burning gasoline must be controlled in some way so it can perform useful work.

Gasoline Must Be Atomized

The more surface area of gasoline exposed to the air, the faster a given amount will burn. Gasoline placed in a container and ignited will produce a hot flame, yet it will not burn fast enough to produce the rapid release of heat necessary to run an engine. Even though a considerable quantity of fuel may be involved, a large flame will not necessarily result. See **Figure 5-2**.



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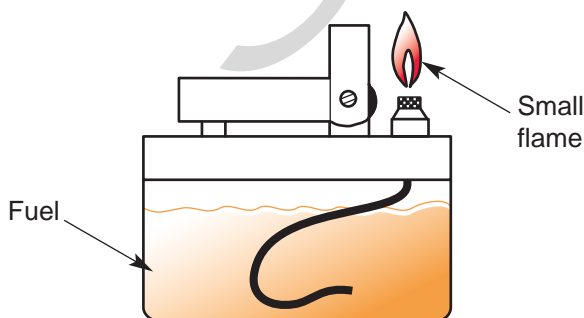
Figure 5-1. A—An external combustion engine burns fuel outside the engine. B—An internal combustion engine burns fuel within the engine.

Warning

Under no circumstances should experiments illustrated in this chapter be performed. Gasoline can be a very dangerous fuel and must be handled with caution. Illustrations and examples discussed here are meant to demonstrate how gasoline is prepared and used in an engine.

In **Figure 5-2**, the surface area of the wick in the lighter is small. Vapor from the surface of the liquid, combined with oxygen, is what burns readily. If the surface of the liquid is small, relatively little vapor will be given off to provide combustion. Since the liquid must change to vapor before it is burned, it would take considerable time to use up the fuel at this rate.

By placing the same amount of fuel in a shallow, wide container, more surface area will contact air,



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Figure 5-2. A small flame is produced, due to a small area of exposed fuel.

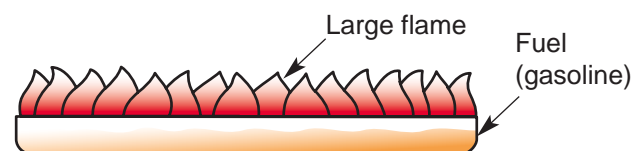
more vapor will be given off, and the fuel will burn more rapidly. See **Figure 5-3**.

To produce the rapid burning required in an engine, gasoline must be broken up into tiny droplets and mixed with air. This is called **atomization**.

Once the entire surface of each droplet of the air-fuel mixture is exposed to the surrounding air, a huge burning area becomes available. Given a spark, the entire amount of gasoline will flash into flame almost instantly. In effect, atomization causes a sudden release of heat energy. See **Figure 5-4**.

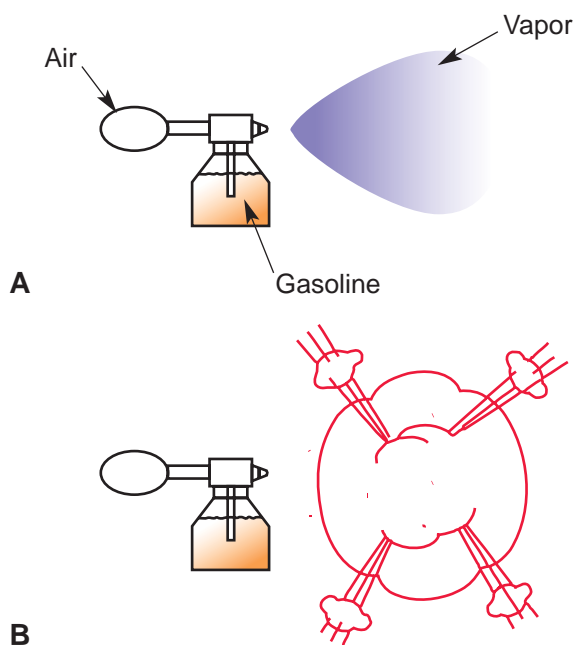
Combustion Force Must Be Contained

To perform useful work, the force caused by the rapidly burning gas must be contained and controlled. To illustrate this point, imagine that a metal lid is suspended on a string and held several inches above the ground. If a mixture of gasoline and air (atomized) were sprayed under it and ignited, the lid would be raised a short distance by the force of the combustion. See **Figure 5-5**.



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Figure 5-3. A large flame is produced by a large area of exposed fuel.



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Figure 5-4. A—When atomized fuel is exposed to the surrounding air, a large burning area is available. B—When the atomized fuel is ignited, it will flash into flame almost instantly.

The reason the lid hardly moved is that the combustion force was not confined and directed toward the lid. Instead, the force was exerted in all directions, and much of the force was lost. If the air-fuel mixture is sprayed inside a metal container with a lid, the full force of combustion will be directed against the lid when the mixture is ignited. This will blow the lid high into the air. See **Figure 5-6**.

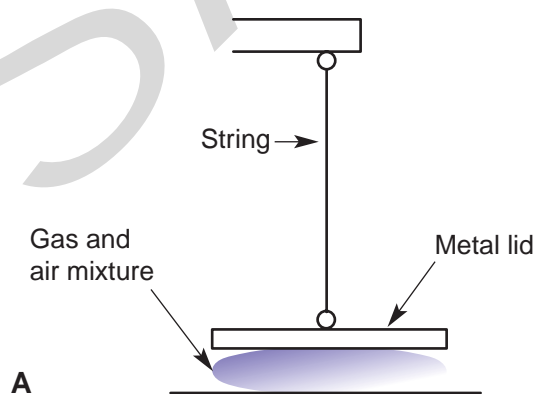
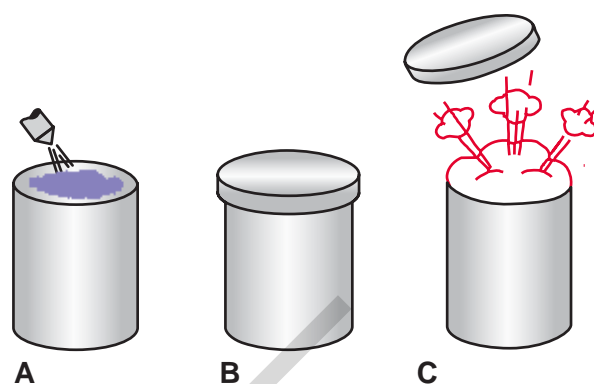


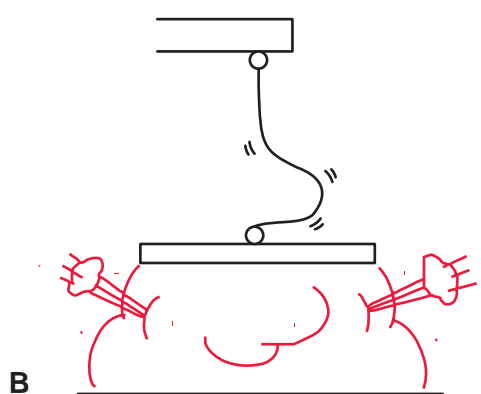
Figure 5-5. A—Atomized fuel is sprayed under a metal lid. B—When the fuel is ignited, the lid moves a short distance.



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Figure 5-6. A—Mixture of fuel and air is sprayed into a container. B—A lid is placed on top. C—The full force of combustion is directed toward the base of the lid when the mixture is ignited, and the lid is driven high into the air.

Even though the burning air-fuel mixture is confined by the container, once the lid starts to lift, a large amount of the force escapes to the sides. To eliminate this loss, a long, cylindrical container may be used with the lid having a close, sliding fit. See **Figure 5-6**. With the fuel mixture slightly compressed in the bottom of the container by the weight of the lid, the fuel will burn and direct most of the pressure against the lid as it travels up through the container. When the lid reaches the top, it will be traveling at a high rate of speed. The expansion of the gas will be nearly complete and little force will be lost, even after the lid clears the container.



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Constructing an Elementary Engine

An elementary engine can be formed by attaching a crankshaft and a connecting rod to the setup illustrated in **Figure 5-7**. The lid will serve as a piston and the container will act as a cylinder. See **Figure 5-8**. When the air-fuel mixture in the cylinder is ignited, it will drive the piston upward, causing the crankshaft to turn.

Although it is crude, this elementary engine illustrates the operating principles of a modern gasoline engine. Study the names of the various parts shown in **Figure 5-8**. Become acquainted with the parts and their application to engine design.

There are many shortcomings in the engine pictured in **Figure 5-8**. These are addressed in the following questions:

- How will a fresh air-fuel charge be admitted to the cylinder?
- How will the charge be ignited?
- What holds the various parts in alignment?
- How will the engine be cooled and lubricated?
- What will *time* the firing of the air-fuel mixture so that the piston will push on the crankshaft when the journal is in the correct position?
- How will the burned charge be removed (exhausted) from the cylinder?
- What will keep the crankshaft rotating after the charge is fired, and until another charge can be admitted and fired?

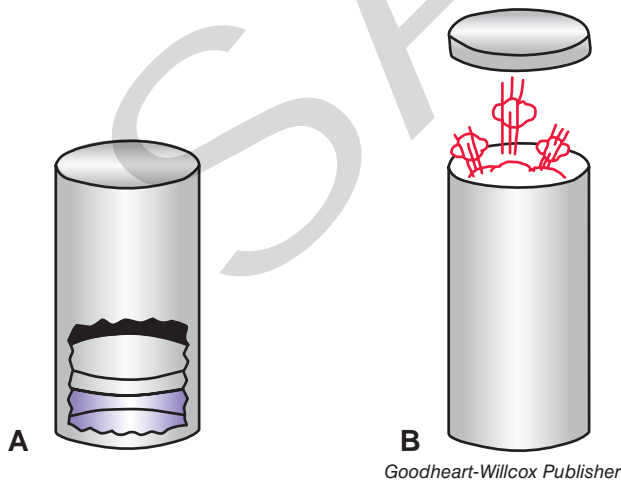
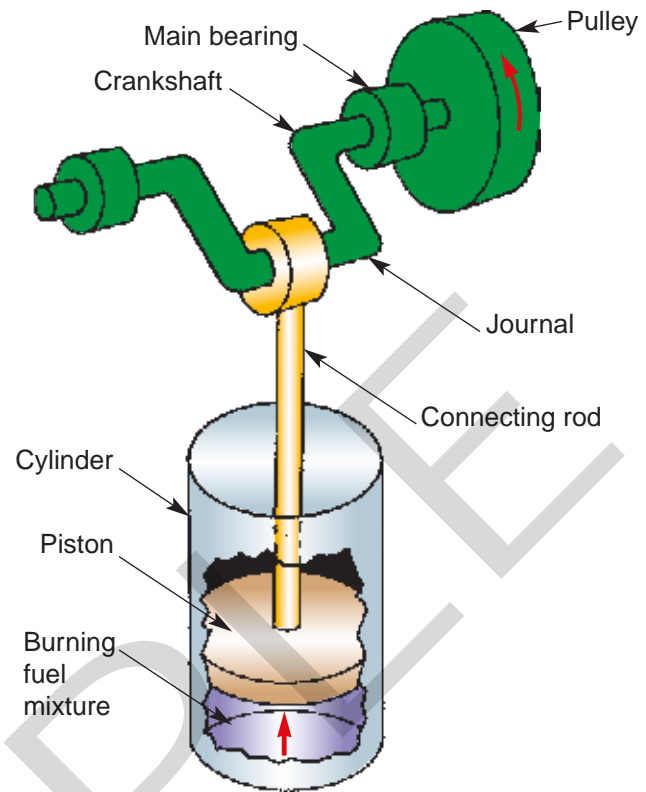


Figure 5-7. A—The lid is placed in a long container. B—Most of the energy of the burning fuel is absorbed by the lid, imparting greater speed to the lid when combustion occurs.



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Figure 5-8. The principles of operation illustrated here are the same as those used in a modern gasoline engine. Note how the burning fuel mixture forces the lid (piston) upward to turn crankshaft and pulley.

The previous questions can be categorized into five basic areas:

1. *Mechanical* (engine design and construction)
2. *Fuel metering* (mixing gasoline and air, and admitting it to the cylinder)
3. *Ignition* (firing the fuel charge)
4. *Cooling* (heat dissipation)
5. *Lubrication* (oiling of moving parts)

For purposes of this chapter, we will assume that the gasoline and air are being mixed correctly, the fuel charge is being fired at the right time, and the engine is properly cooled and lubricated. Each of these areas will be covered in detail in later chapters.

Simple Engine in Operation

In its simplest form, an engine consists of a ported cylinder, piston, connecting rod, and crankshaft. See **Figure 5-9**. The piston is a close fit inside the cylinder, yet it is free to slide on the lubricated

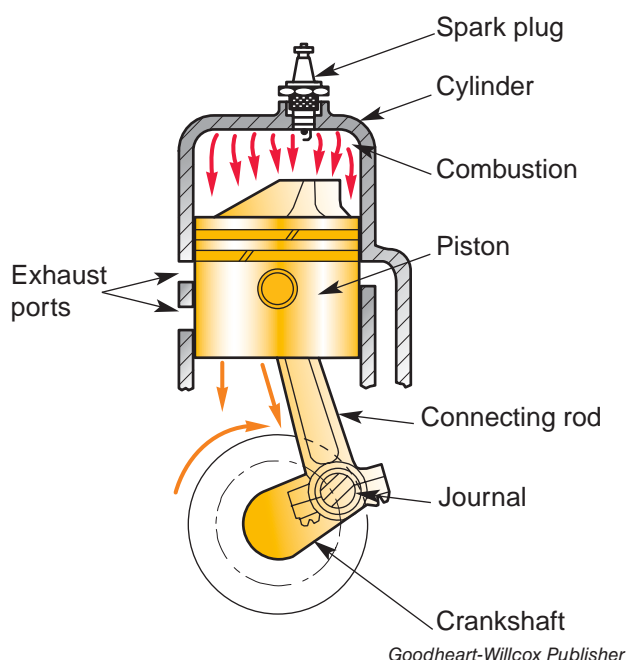


Figure 5-9. Combustion forces the piston down to rotate the crankshaft.

walls of the cylinder. One end of the connecting rod is attached to the piston; the other end is fastened to an offset journal, or crankpin, on the crankshaft. As the piston moves up and down, the connecting rod forces the journal to follow a circular path, rotating the crankshaft.

When the engine is cranked, gasoline is atomized and mixed with air. This mixture is forced through an intake port and into the cylinder, where it is compressed by the piston on the upstroke and ignited by an electrical spark.

Burning rapidly, the heated gases trapped within the cylinder (combustion chamber) expand and apply pressure to the walls of the cylinder and to the top of the piston. This pressure drives the piston downward, causing the crankshaft to turn. This downward movement of the piston is called the power stroke.

As the piston and connecting rod push the crankshaft journal downward, the pressure of the burned gases is released through an exhaust port. Meanwhile, a fresh air-fuel charge enters the cylinder and momentum pushes the crankshaft journal past the bottom of its travel, carrying it into the upstroke on another operating cycle.

Two- and Four-Stroke Engines

A basic design feature that aids in small engine identification is the number of piston strokes required to complete one operating cycle. A four-stroke engine, for example, requires four strokes per cycle; a two-stroke engine requires two.

A *stroke* of the piston is its movement in the cylinder from one end of its travel to the other. When the piston is at the bottom of its travel, it is said to be at **bottom dead center** (BDC). When it is at the top of its stroke, it is at **top dead center** (TDC). Each stroke of the piston, then, is either toward the rotating crankshaft or away from it. Each stroke is identified by the job it performs (intake, exhaust, etc.).

Four-Stroke Engine

In a *four-stroke engine* (called a *four-cycle engine*), four strokes are needed to complete the operating cycle. The four strokes are as follows:

- intake stroke
- compression stroke
- power stroke
- exhaust stroke

Two strokes occur during each revolution of the crankshaft. Therefore, a four-stroke cycle requires two revolutions of the crankshaft to complete one operating cycle. **Figure 5-10** illustrates each of the four strokes taking place in proper sequence.

Note

Four-stroke engines use intake and exhaust valves to control the flow of gases into and out of the combustion chamber.

Intake Stroke

Figure 5-10A shows the piston traveling downward in the cylinder on the *intake stroke*. As the piston moves down, the volume of space above it is increased. This creates a partial vacuum that draws the air-fuel mixture through the intake valve port and into the cylinder.

With the intake valve open during the intake stroke, atmospheric pressure outside the engine forces air through the carburetor. This gives a

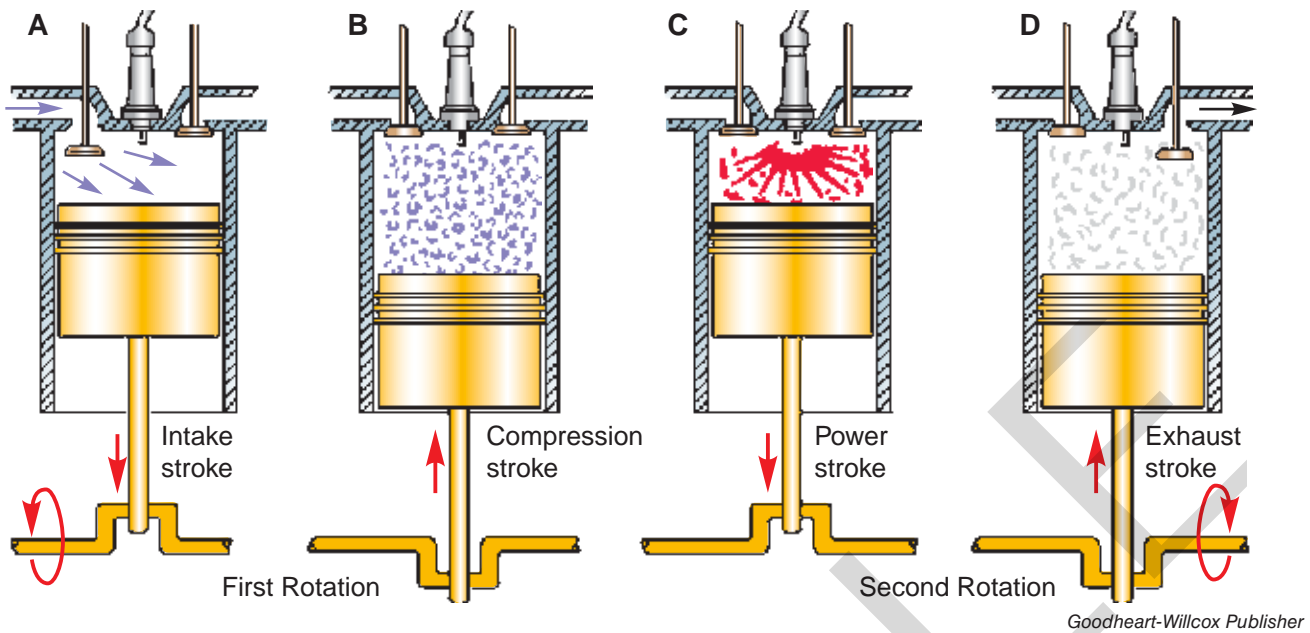


Figure 5-10. Sequence of events in a four-stroke engine, requiring two revolutions of the crankshaft and one power stroke out of four.

large boost to the air-fuel induction process. With nature balancing unequal pressures in this manner, it follows that the larger the diameter of the cylinder and the longer the stroke of the piston, the greater the volume of air entering the cylinder on the intake stroke.

Bear in mind that the intake valve performs several key functions. These key functions are as follows:

1. It must open at the correct instant to permit intake of air-fuel mixture.
2. It must close at the correct time and seal during compression.
3. Its shape must be streamlined, so the flow of gases into the combustion chamber will not be obstructed.

The intake valves do not get as hot as the exhaust valves. The incoming air-fuel mixture tends to cool the intake valve during operation.

Compression Stroke

The *compression stroke* occurs as the piston moves upward in the cylinder. See **Figure 5-10B**. During this stroke, the valves are tightly closed.

As the piston moves upward, the air-fuel mixture is compressed into a smaller space. This increases the force of combustion for two reasons:

1. When atoms that make up tiny molecules of air and fuel are squeezed closer together, heat energy is created. Each molecule of fuel is heated very close to its flash point (point at which fuel will ignite spontaneously). When combustion does occur, it is practically instantaneous and complete for the entire air-fuel mixture.
2. The force of combustion is increased because tightly packed molecules are highly activated and are striving to move apart. This energy, combined with expanding energy of combustion, provides tremendous force against the piston.

Note

It is possible to run an engine on uncompressed mixtures, but power loss produces a very inefficient engine.

Power Stroke

During the *power stroke*, both valves remain in the closed position. See **Figure 5-10C**. As the piston compresses the charge and reaches the top of the cylinder, an electrical spark jumps the gap

between the electrodes of the spark plug. This ignites the air-fuel mixture, and the force of combustion (rapid expansion of burning gases) pushes the piston downward.

Actually, the full charge does not burn at once. The flame progresses outward from the spark plug, spreading combustion and providing even pressure over the piston face throughout the power stroke.

The entire fuel charge must ignite and expand in an incredibly short period of time. Most engines have the spark timed to ignite the fuel slightly before the piston reaches top dead center (TDC) of the compression stroke. This provides a little more time for the mixture to burn and accumulate its expanding force.

Basically, the amount of power produced by the power stroke depends on the volume of the air-fuel mixture in the cylinder and the compression ratio of the engine. The **compression ratio** is the proportionate difference between the volume of cylinder and combustion chamber at bottom dead center and the volume of cylinder and combustion chamber at top dead center. If the compression ratio is too high, the fuel may be heated to its flash point during the compression stroke and ignite too early.

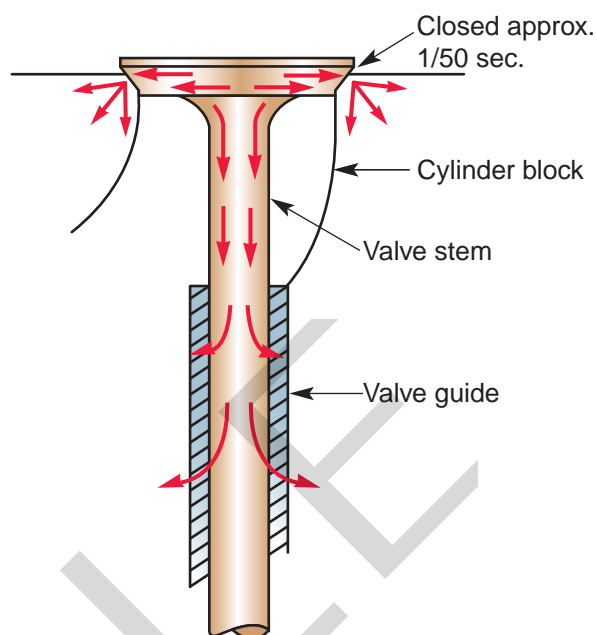
Exhaust Stroke

After the piston has completed the power stroke, the burned gases must be removed from the cylinder before introducing a fresh charge. This takes place during the **exhaust stroke**. The exhaust valve opens and the rising piston pushes the exhaust gases from the cylinder. See **Figure 5-10D**.

The exhaust valve has to function much like the intake valve. When closed, the valve must seal. When open, it must allow a streamlined flow of exhaust gases out through the port. The removal of gases from the cylinder is called **scavenging**.

The passageway that carries away exhaust gases is referred to as the exhaust manifold or exhaust port. The exhaust manifold must be designed for the smooth flow of gases.

The heat absorbed by the exhaust valve must be controlled or the valve will deteriorate rapidly. Some valve heat is carried away by conduction through the valve stem to the guide. However, the hottest part of the valve, the valve head, transfers heat through the valve seat to the cylinder block. See **Figure 5-11**.



Goodheart-Willcox Publisher

Figure 5-11. The exhaust valve must cool during an incredibly short period (1/50 sec. at 3600 rpm). Heat is conducted from the valve through the seat to the cylinder block. Some heat travels down the stem and to the valve guide.

Valve Timing

Valve timing is measured in degrees of crankshaft rotation. The point at which the valves open or close before or after the piston is at top dead center (TDC) or bottom dead center (BDC) varies with different engines.

Note

Engineers also specify the point at which the spark must occur. Chapter 9 of this text explores this in more detail.

Figure 5-12 shows one complete operating cycle of a four-stroke engine. Beginning at point A, the intake valve opens 10° before TDC and stays open through 235°. The exhaust valve closes 30° after TDC. **Valve overlap** occurs when both valves are open at the same time.

During the compression stroke, the intake valve closes and ignition occurs 30° before TDC. The power stroke continues through 120° past TDC. The exhaust valve opens 60° before BDC and stays open through 270°. During the last 40°, the intake valve is also open and the second cycle has begun.

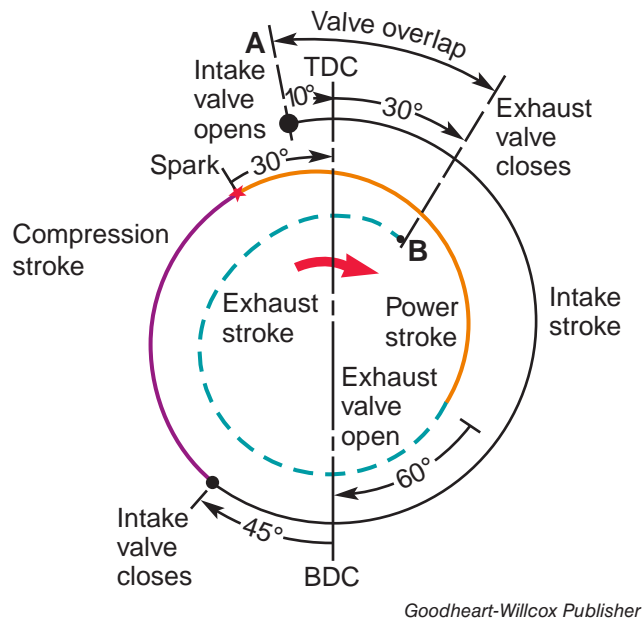


Figure 5-12. The four-stroke cycle diagram shows the exact number of degrees each valve is open or closed and the time spark ignition occurs. Note that both valves are open (overlap) through an arc of 40°, permitting exhausting gases to create a partial vacuum in the cylinder and help draw a mixture of fuel into the cylinder.

Lubrication

Lubrication of the four-stroke engine is provided by placing the correct quantity and grade of engine oil in the crankcase. Several methods are used to feed the oil to the correct locations. The two most common methods are the splash system and the pump system. Some engines employ one or the other; others use a combination of both.

The oil in a four-stroke engine must be drained periodically and replaced with clean oil. Also worth

noting, four-stroke engines must be operated in an upright position or the oil will flow away from the pump or splash finger, preventing lubrication.

Note

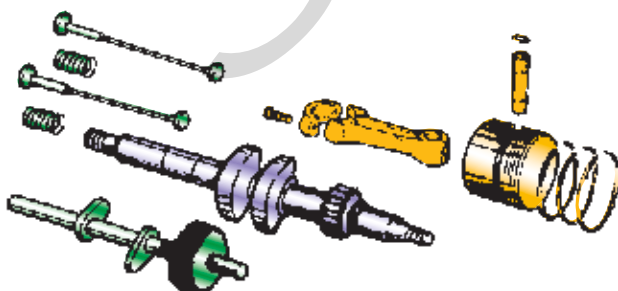
One manufacturer makes a four-stroke engine that does not rely on oil stored in the crankcase for lubrication. Instead, it runs on a mixture of gasoline and oil, which lubricates the internal engine parts. Engines of this design will be discussed in more detail in Chapter 11, Lubrication Systems.

Two-Stroke Engine

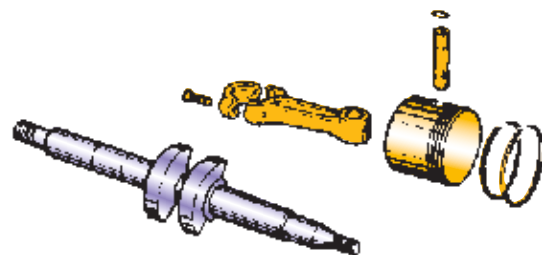
The *two-stroke engine* (commonly called *two-cycle engine*) performs the same cycle of events as the four-stroke engine. The main difference is that the intake, compression, power, and exhaust functions take place during only two strokes of the piston. The two strokes occur during each revolution of the crankshaft. Therefore, it takes only one revolution of the crankshaft to complete a two-stroke cycle.

A two-stroke engine has several advantages over a four-cycle unit. It is much simpler in design than the four-stroke engine because the conventional camshaft, valves, and tappets are unnecessary. See **Figure 5-13**.

Additionally, a two-stroke engine is smaller and lighter than a four-stroke engine of equivalent horsepower. Unlike the four-stroke engine, the two-stroke engine will get adequate lubrication even when operated at extreme angles. It receives its lubrication as fuel mixed with oil is passed through the engine.



Moving Parts—Four-Cycle Engine



Moving Parts—Two-Cycle Engine

Lawn-Boy Power Equipment, Gale Products

Figure 5-13. The number of moving parts in a four-stroke engine is greater than in a two-stroke engine. Other differences are listed in the chart at the end of this chapter.

Installing the correct mixture of fuel and oil is a critical factor in maintaining a two-stroke engine in good working condition. The prescribed type and grade of engine oil must be mixed with the fuel in proper proportion before being placed in the fuel tank.

In this way, there is clean oil continuously supplied to all moving parts while the engine is running. The oil eventually burns in the combustion chamber and is exhausted with other gases.

Two-stroke engines are popular in string trimmers, leaf blowers, and other high-rpm applications.

Principles of Two-Stroke Operation

The location of the ports in a two-stroke engine is essential to correct timing of the intake, transfer, and exhaust functions, **Figure 5-14**. The cutaway cylinder in **Figure 5-14A** shows the exhaust port at the highest point, the transfer port next, and the intake port at the lowest point. Some engines have more than one transfer port. See **Figure 5-14B**. **Figure 5-15** illustrates the principles of two-stroke engine operation.

Intake into the Crankcase

As the piston moves upward in the cylinder of a two-stroke engine, crankcase pressure drops and the intake port is exposed. Because atmospheric pressure is greater than the crankcase pressure, air rushes through the intake port and into the crankcase to equalize the pressures. See **Figure 5-15A**.

While passing through the carburetor, the intake air pulls a charge of fuel and oil along with it. This charge remains in the crankcase to lubricate ball and needle bearings until the piston opens the transfer port on the downstroke.

Ignition-Power

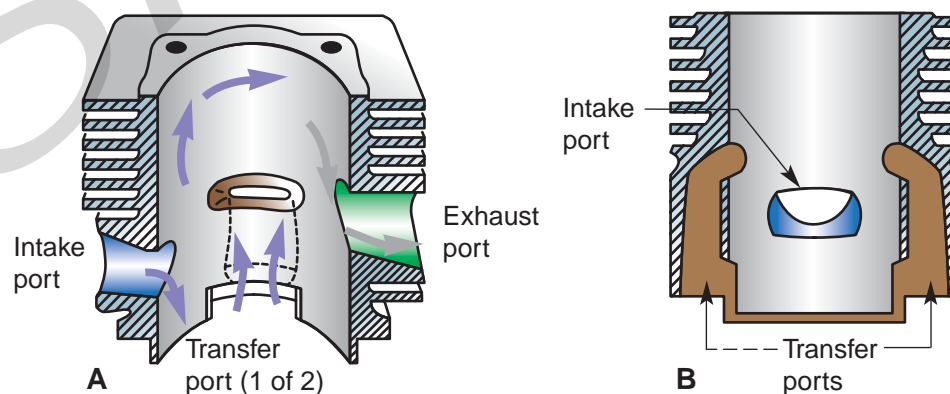
As the piston travels upward, it also compresses the air-fuel charge brought into the cylinder during the previous cycle to about one-tenth of its original volume. See **Figure 5-15A**. The spark is timed to ignite the air-fuel mixture when the piston approaches TDC. See **Figure 5-15B**.

On some small engines, spark occurs almost at TDC during starting, and then automatically advances so that it occurs earlier. This is done to get better efficiency from the force of combustion at higher speeds.

Peak combustion pressure is applied against the piston top immediately after TDC. Driving downward with maximum force, the piston transmits straight line motion through the connecting rod to create rotary motion of the crankshaft. See **Figure 5-15C**.

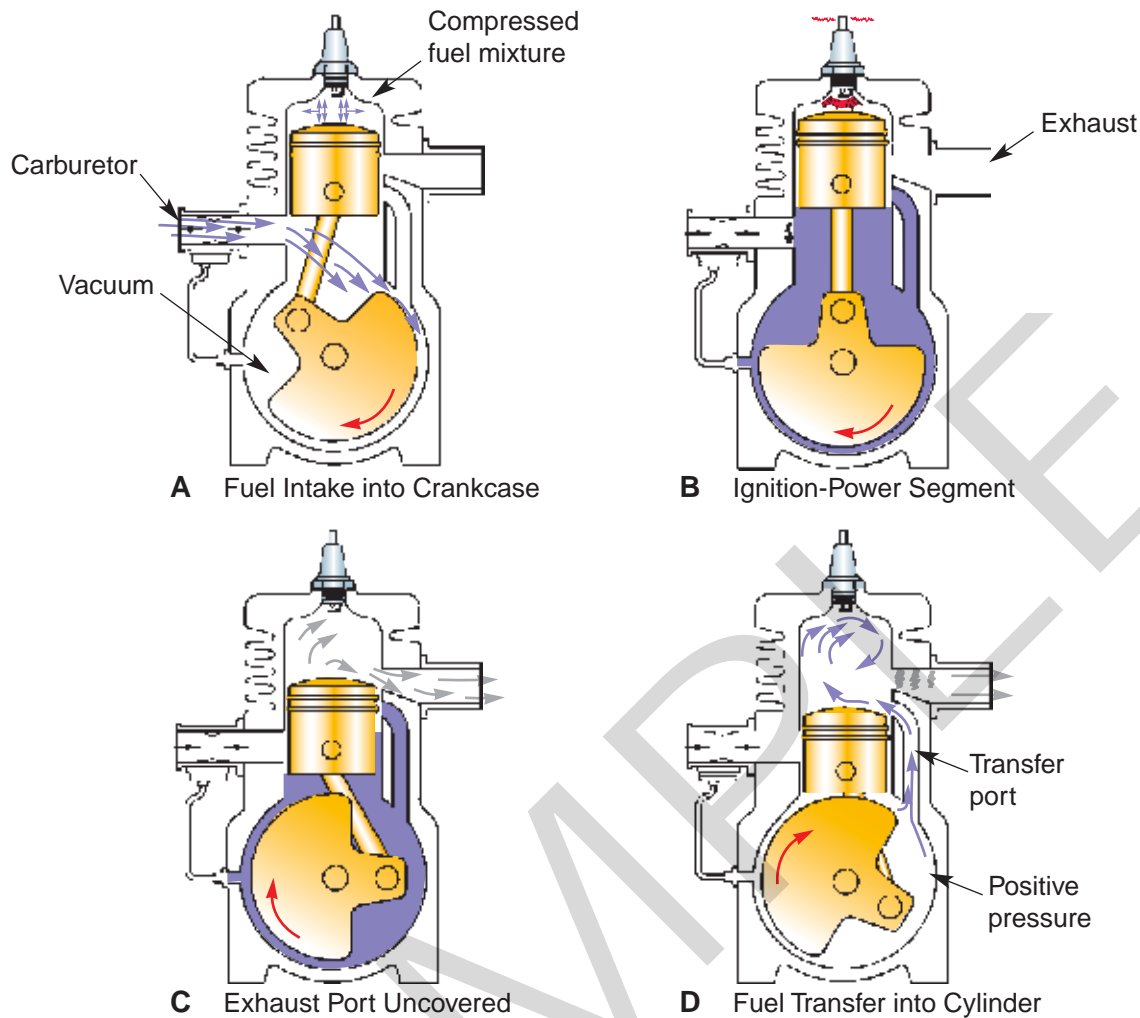
Exhaust

The exhaust phase of the two-stroke cycle is shown in **Figure 5-15C**. As the piston moves to expose the exhaust port, most of the burned gases are expelled. Complete exhausting of gases from the cylinder and combustion chamber takes place when the transfer ports are opened and the new air-fuel charge rushes in.



Kohler Co.

Figure 5-14. A cutaway cylinder block shows the location of the intake, exhaust, and transfer ports of a two-cycle engine. A—Due to the cutaway, only one of two transfer ports is shown. B—The section is revolved 90° to show both ports.



Rupp Industries, Inc.

Figure 5-15. These illustrations show the sequence of events that take place in a two-stroke engine. Compression and intake occur simultaneously, and then ignition occurs. Exhaust precedes the transfer of fuel during the lower portion of the power stroke. The piston functions as the only valve in the engine.

Fuel Transfer

Figure 5-15C and **Figure 5-15D** show the piston moving downward, compressing the air-fuel charge in the crankcase. When the piston travels far enough on the downstroke, the transfer port is opened and the compressed air-fuel charge rushes through the port and into the cylinder. The new charge cools the combustion area and pushes (scavenges) the remaining exhaust gases out of the cylinder. This completes one cycle of operation.

Scavenge Loss

In a conventional two-stroke engine, a significant portion of the air-fuel charge (in some cases, over 25%) flows out through the open exhaust port as it

pushes the exhaust gases from the cylinder. This occurrence is called *scavenge loss*. Scavenge loss results in increased hydrocarbon emissions and reduced fuel economy.

Stratified Scavenge Engine

To reduce two-cycle engine emissions and increase fuel economy, manufacturers have designed a two-cycle engine that effectively eliminates scavenge loss of the air-fuel charge. This engine, called a stratified scavenge engine, uses an extra intake port and a specially shaped piston to introduce a small amount of fresh air into the transfer port ahead of the air-fuel charge. When the transfer port is uncovered during the fuel transfer

phase of two-cycle operation, the fresh air flows into the cylinder before the air-fuel charge, pushing the spent exhaust gases from the cylinder. This prevents the unburned fuel in the air-fuel charge from escaping through the exhaust port.

Four-Stroke Engine vs. Two-Stroke Engine

The advantages and disadvantages of any engine are directly related to the purpose for which the engine is intended. It cannot be said that one type of engine is better than another without considering every aspect of its application.

The chart in **Figure 5-16** lists the differences between two- and four-stroke engines.

Characteristics	Four-Cycle Engine (equal hp) One Cylinder	Two-Cycle Engine (equal hp) One Cylinder
1. Number of major moving parts	Nine	Three
2. Power strokes	One every two revolutions of crankshaft	One every revolution of crankshaft
3. Running temperature	Cooler running	Hotter running
4. Overall engine size	Larger	Smaller
5. Engine weight	Heavier construction	Lighter in weight
6. Bore size equal hp	Larger	Smaller
7. Fuel and oil	No mixture required	Must be premixed
8. Fuel consumption	Fewer gallons per hour	More gallons per hour
9. Oil consumption	Oil recirculates and stays in engine	Oil is burned with fuel
10. Sound	Generally quiet	Louder in operation
11. Operation	Smoother	More erratic
12. Acceleration	Slower	Very quick
13. General maintenance	Greater	Less
14. Initial cost	Greater	Less
15. Versatility of operation	Limited slope operation (Receives less lubrication when tilted)	Lubrication not affected at any angle of operation
16. General operating efficiency (hp/wt. ratio)	Less efficient	More efficient
17. Pull starting	Two crankshaft rotations required to produce one ignition phase	One revolution produces an ignition phase
18. Flywheel	Requires heavier flywheel to carry engine through three nonpower strokes	Lighter flywheel

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Figure 5-16. This chart lists the differences between two-stroke and four-stroke engines.

Summary

- A gasoline-fueled engine is a mechanism designed to transform the chemical energy of burning fuel into mechanical energy.
- A gasoline engine is an internal combustion engine. In an internal combustion engine, gasoline is combined with air and burned inside the engine.
- The more surface area of gasoline exposed to the air, the faster a given amount will burn. To produce the rapid burning required in an engine, gasoline must be broken up into tiny droplets and mixed with air. This is called atomizing.
- The stroke of a piston is its movement in the cylinder from one end of its travel to the other.
- Four-stroke engines need four strokes to complete the operating cycle: intake, compression, power, and exhaust.
- Lubrication of four-stroke engines is generally provided by a splash system or a pump system.
- In a two-stroke engine, the intake, compression, power, and exhaust functions take place during two strokes of the piston.
- Two-stroke engines are typically smaller and lighter than four-stroke engines of equivalent horsepower.
- The two-stroke engine receives its lubrication as a fuel-oil mixture is passed through the engine. Therefore, it will receive adequate lubrication even when operated at extreme angles.

Review Questions

Answer the following questions using the information presented in this chapter.

Know and Understand

1. A gasoline-fueled engine changes ____ energy to ____ energy.
 - A. chemical, mechanical
 - B. chemical, electrical
 - C. mechanical, electrical
 - D. mechanical, chemical
2. *True or False?* In an internal combustion engine, gasoline is combined with air and burned inside the engine.
3. To perform useful work, combustion force must be _____.
 - A. contained
 - B. dispersed
 - C. quenched
 - D. atomized
4. The four strokes of a four-stroke engine in proper order are _____.
 - A. intake, compression, power, exhaust
 - B. intake, power, exhaust, compression
 - C. compression, exhaust, intake, power
 - D. exhaust, intake compression exhaust
5. Each of the following is a function of the intake valve except _____.
 - A. it must open at the correct moment to permit intake of the air-fuel mixture
 - B. it must close at the right time to seal during compression
 - C. it must be streamlined so the flow of gasses into the combustion chamber will not be obstructed
 - D. it must get hotter than the exhaust valve to burn off by-products of combustion
6. When the atoms that make up molecules of air and fuel are compressed, ____ energy is created.
 - A. electric
 - B. mechanical
 - C. heat
 - D. chemical
7. *True or False?* Because fuel is atomized, the entire air-fuel charge burns at once.
8. The removal of gases from the cylinder during the exhaust stroke is known as _____.
 - A. rushing
 - B. scavenging
 - C. quenching
 - D. atomizing
9. *True or False?* Valve timing is measured in degrees of crankshaft rotation.
10. The compression ratio must be limited in gasoline spark ignition engines, because _____.
 - A. there is no power advantage after compressing the fuel to a certain point
 - B. the engine becomes too difficult to start
 - C. mechanically it is not possible to increase the compression ratio
 - D. the heat of compression will ignite the air-fuel mixture too soon

11. The time during the four-stroke cycle when both valves are open is called _____.
 - A. second cycle
 - B. overlap
 - C. simultaneous sealing
 - D. None of the above.
12. *True or False?* All four-stroke engines use an oil pump to distribute the oil contained in the engine's crankcase to the proper locations throughout the engine.
13. *True or False?* Four-stroke engines do not require periodic oil changes.
14. In a two-stroke engine, it takes _____ revolution(s) of the crankshaft to complete an entire two-stroke cycle.
 - A. one
 - B. two
 - C. three
 - D. four
15. *True or False?* In a conventional two-stroke engine, a portion of the air-fuel charge flows out through the open exhaust port as exhaust gases are pushed from the cylinder.
16. Each of the following is an advantage of a two-stroke engine except _____.
 - A. it uses less fuel than a comparable four-stroke engine
 - B. it is simpler in design than a four-stroke engine
 - C. it is smaller and lighter than a four-stroke engine of equivalent horsepower
 - D. lubrication is not affected by the angle of operation

Analyze and Apply

17. Explain why gasoline is atomized before being burned in an engine.
18. Why is there a difference in temperature between the intake valve and the exhaust valve?
19. How does compression increase the force of combustion?

Critical Thinking

20. What types of engine performance problems are likely to occur if fuel is improperly atomized?
21. What are some of the characteristics of gasoline that make it an ideal fuel for small internal combustion engines?
22. Which implements and applications are better suited for the use of a four-stroke engine than a two-stroke engine?

Suggested Activities

1. Look up additional information about internal combustion engine development. Names to look up include Christian Huygens, Philip Lebon, Samuel Brown, William Barnett, Pierre Lenoir, Beau DeRochas, Dr. N. A. Otto, Atkinson, Gottlieb Daimler, Priestman and Hall, Herbert Akroyd Stuart, and Rudolph Diesel.
2. Begin a collection of engine repair and service manuals.
3. Make a bulletin board display that illustrates the principles of two- and four-stroke engines.



Piotr Wytrazek/Shutterstock.com

The rotating assembly, consisting of the crankshaft, connecting rod, and piston, is at the heart of the small gas engine.