

Horsepower to Drive a Pump

Definitions

To work with "horsepower," we need a solid understanding of what it is. Therefore, this section will start out with an explanation of terminology.

In everyday conversation, the terms "energy" and "power" are often used interchangeably. In technical work, they have specific, different meanings.

Energy is capacity to do work. It can be stored, either briefly or for a long time, in several different forms. For example, electrical energy can be stored in a battery, heat energy can be stored in a tank of hot water, and mechanical energy can be stored in a spinning flywheel.

Various methods are used to measure energy, either how much of it is stored somewhere or how much of it was used to do some work. Here are examples of units of measurement for different forms of energy:

- kWh (kilowatt-hours) for electrical energy
- Btu (British thermal units) for heat energy
- ft-lb (foot-pounds) for mechanical energy

There are other units of measure for energy; the above are just examples.

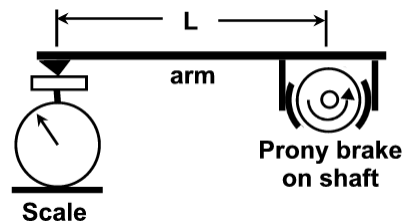
Power is the rate at which energy "flows." It is the rate that energy is consumed to do work. Various methods are used to measure the rate (power) from each type of energy. Here are examples:

- kW (kilowatts) for electrical energy
- Btu/hr (Btu per hour) for heat energy
- hp (horsepower) for mechanical energy

There are other units of measure for power; the above are just examples. Horsepower is a term that specifies an energy flow of a certain number of ft-lb per minute. Specifically, 1 hp = 33,000 ft-lb/min.

Brake horsepower is the amount of power being delivered by a rotating shaft that is driving a load. It is the horsepower actually delivered by the shaft of an electric motor, an engine, or any other source.

The name of the term comes from the traditional way it is measured: a friction brake called a prony brake is clamped around the shaft. The prony brake works much like an automotive drum brake. The brake is fitted with a projecting radial torque arm of specified length (L in the diagram). With the shaft rotating, the brake is tightened and the force at the end of the torque arm and the shaft rpm are measured.



The force at the end of the torque arm times the length (L) of the arm is the torque being developed:

$$\text{lb - ft of torque} = (\text{lb of force}) \times (\text{length L in ft})$$

The torque and the speed of rotation of the shaft tell us the horsepower being delivered by the device turning the shaft, because horsepower can be defined as:

$$\text{hp} = (\text{lb-ft of torque}) \times \text{rpm} \times 0.00019$$

Or, the same expression can also be written as:

$$\text{hp} = \frac{(\text{lb-ft of torque}) \times \text{rpm}}{5252}$$

Here's an example: suppose a two foot torque arm is clamped onto a shaft. We find with a tachometer that the shaft is rotating at 1725 rpm, and our scale tells us that 7.5 lb of force is produced at the end of the torque arm. The torque = 7.5 lb x 2 ft = 15 lb-ft. Therefore, hp = 15 lb-ft x 1725 rpm x 0.00019 = 4.9 hp.

Note — The order of the "pounds" and the "feet" used to express torque is a source of perpetual quibbling. Some contend that torque values should be labeled "lb-ft," while others maintain that the correct label is "ft-lb." The laws of mathematics require that in either case, "lb-ft" or "ft-lb," the numerical value is the same; so, which label is used has no effect on the numerical value.

Brake horsepower always has the same meaning no matter what is turning the shaft, be it a human being working a treadmill, a gas turbine engine, an electric motor, a windmill, or a gasoline engine.

Shaft horsepower is another name for brake horsepower.

Hydraulic horsepower is horsepower that is transmitted by a pressurized flow of water. In a manner similar to the way brake horsepower can be determined by measuring torque and speed, hydraulic horsepower can be determined by measuring pressure and flow:

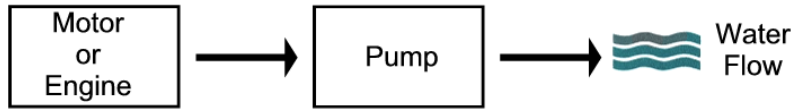
$$\text{hydraulic hp} = \frac{\text{psi} \times \text{gpm}}{1714}$$

Pump Horsepower

A pressure washer serves us by adding power to a flow of water:

- Mechanical power
- Heat power, if it is a hot water washer.

The job of the pressure washer pump is to convert mechanical power supplied by an electric motor or an engine to water power.



The amount of horsepower a pump adds to a stream of water is given by the hydraulic horsepower formula:

$$\text{hydraulic hp} = \frac{\text{psi} \times \text{gpm}}{1714}$$

This formula tells us for any particular psi and gpm how much horsepower must be put into the water by the pump. Like any human contrivance, a pump is not a perfect device. We must put more horsepower into the pump than we can get out of it, because some power is wasted inside the pump due to friction and other losses.

Therefore, pump calculations involve two horsepower numbers:

- The water horsepower desired at the pump outlet
- The mechanical (shaft) horsepower required at the pump shaft to obtain the desired water horsepower.

The ratio of the two horsepowers is called the *efficiency* of the pump:

$$\text{efficiency} = \frac{\text{horsepower output}}{\text{horsepower input}}$$

Pump efficiency may be expressed as a decimal (for example 0.85) or a percent (for example 85%). The formula for hydraulic (water) horsepower at the pump outlet can be modified to obtain the input horsepower required at the pump shaft:

$$\text{shaft hp} = \frac{\text{psi} \times \text{gpm}}{1714 \times (\text{pump efficiency})}$$

The efficiency of most pressure washer pumps is about 85%. If we use 0.85 for the pump efficiency in the above formula, it becomes this often-seen version:

$$\text{shaft hp} = \frac{\text{psi} \times \text{gpm}}{1460}$$

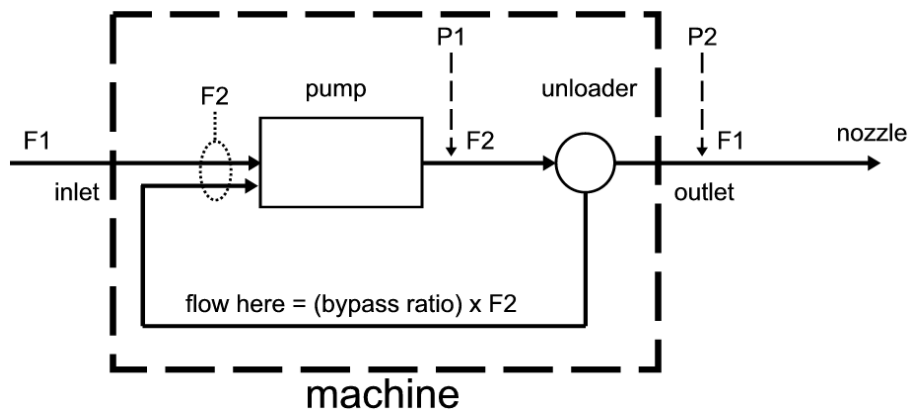
This formula is only an approximate, rule-of-thumb guideline. Any given pump is unlikely to have an efficiency of exactly 85%.

Applying the Pump Horsepower Formula

In addition to the fact that the efficiency of a specific pump is seldom precisely known, there is another factor that affects the accuracy of a pump horsepower calculation. That factor is the measurement of water flow, or more specifically, the point at which flow is measured.

Water flows into a machine, and of course the same amount of water flows out of the machine. So, does it really make a difference where the flow is measured? The answer is "yes," because it's common for the unloader to bypass a modest flow of water while the machine is spraying under full pressure.

A pressure washer involves multiple pressures and flows. The diagram below illustrates four pressures and flows.



F1 = flow into and out of the machine
 F2 = flow into and out of the pump
 P1 = pressure at the pump head
 P2 = pressure at machine outlet

The horsepower required at the pump shaft is

$$\text{shaft hp} = \frac{P1 \times F2}{1714 \times (\text{pump efficiency})}$$

The pump head pressure, P1, can usually be measured without great difficulty in any machine. Measurement of flow F2, however, can be difficult at best, and in many cases cannot be performed in any practical way. For machines using discrete plumbing components, F2 can be inferred by measuring the flow in the bypass line, but that works only for machine designs incorporating an accessible bypass line. In many machines, the unloader is integrated with the pump head, making measurement of F2 essentially impossible.

It would appear that simply removing the unloader would allow easy measurement of F2. Aside from safety concerns, there are two problems with removing the unloader:

1. Many machines use an integral pump-unloader, making removal not feasible;
2. The unloader circuit and all items downstream of the pump determine the load on the pump. To remove the unloader can significantly change the pump operating point and required horsepower.

Therefore, flow measurements are usually made on the water stream flowing into or out of the machine, with the resulting calculation as follows:

$$\text{shaft hp} = \frac{P1 \times F1}{1714 \times (\text{pump efficiency})}$$

How much error does that introduce? The ratio of horsepower determined from water flow through the machine to horsepower determined from water flow through the pump itself can be found by dividing one formula by the other. The result is

$$\frac{\text{hp determined from flow through machine}}{\text{hp determined from flow through pump}} = \frac{F1}{F2}$$

The flows F1 and F2 differ by the amount of the unloader bypass flow. Thus, the horsepower determined from flow through the machine will be in error by the same percentage as the unloader bypass ratio, yielding a result slightly smaller than the correct pump shaft horsepower. For example, an often-quoted rule-of-thumb allows 5% bypass, making the horsepower determined from flow through the machine 95% of the correct horsepower.

It is unfortunate to approximate the pump flow by measuring the machine flow. However, the alternative of measuring true pump flow is often unduly burdensome, as it may require test fixtures highly specialized to each machine model, possibly including machining of special fixtures and adapters.

Additional Factor: The Pump Power Train

All of the discussion up to this point results in a calculation of horsepower that must be supplied to the drive shaft of a pressure washer pump. That power is transmitted from its source, an electric motor or an engine, to the pump in one of four ways: direct drive, "gear belt" (notched pulley), V belt, or gearbox.

Almost no power is lost in a direct drive. However, the other three power train setups each lose a small amount of power between the input end (at the power source) and the output end (at the pump). The Cleaning Equipment Trade Association performance standard uses these efficiency values:

- Gear belt, 0.98
- V belt, 0.97
- Gearbox (helical), 0.96

When the driver efficiency is added to the horsepower formula, the formula becomes:

$$\text{hp input to power train} = \frac{\text{psi} \times \text{gpm}}{1714 \times (\text{pump efficiency}) \times (\text{power train efficiency})}$$

Additional Factor: Engine Ratings

An electric motor is rated according to the horsepower it can deliver through its shaft at full rated load. For example, a 5 hp pressure washer motor can continuously deliver 5 hp through its shaft, and even more for brief intervals. Assuming that the motor's environment is not extreme, the only thing likely to degrade its output is excessive variation in electrical supply.

The power obtainable from a combustion engine is subject to many more variables, such as user maintenance, fuel quality, altitude, temperature, and relative humidity. Consequently, an engine driving a pressure washer cannot deliver the horsepower that is marked on it. For gasoline engines, the "engine horsepower" must be greater than the horsepower at the input to the pump drive train by multipliers such as these:

- 1.3 to 1.5 for overhead valve engines
- 1.8 to 2.0 for side valve engines

The exact multiplier for a particular engine is determined by the characteristics of that engine.

When the engine multiplier is added to the horsepower formula, the formula becomes:

$$\text{engine or motor hp} = \frac{\text{psi} \times \text{gpm} \times K}{1714 \times (\text{pump efficiency}) \times (\text{power train efficiency})}$$

where typical values are:

pump efficiency = 0.85 nominal

power train efficiency = 0.96 to 1.0, depending on type

K = 1.0 for an electric motor

1.3 to 1.5 for an overhead valve engine

1.8 to 2.0 for a side valve engine

Additional Factor: Instrumentation

The horsepower calculations require measurements of pressure and flow. Even if the instruments used for the measurements have been properly calibrated, they are subject to specified limits of error. The measurement errors can add together in a cumulative way and significantly affect the result.

The Bottom Line

Many factors combine to render approximate the results of efforts to determine the horsepower required to drive a pump. Conservative choice of components can compensate for uncertainties, but it's important to understand the factors involved.