5 Useful Work and Pump Efficiency

Useful work from a pump

The physicist James Watt is honored in the electrical community for the term 'watt'. He made various advancements and improvements to stationary boilers and steam engines. It is said that the first practical use of the steam engine was in raising (call it pumping) water out of the coalmines. Almost all mines would flood if the water were not pumped from the bilge, out of the mine. Before the steam engine, the miners used children and horses to lift and carry the bilge water.

James Watt developed the terms of energy, work, and power. He defined the following:

- Energy is the capacity to perform work. Example; I have the energy in my bicep muscle to lift a 100-pound weight.
- Work is a force multiplied over a distance. Example: If I lift a 5-pound weight one foot into the air, then I've performed 5 foot-pounds of work.
- Power is work performed within a certain specified time frame. Power is when I perform 5 foot-pounds of work within a second, or minute.

Many people confuse these terms, but they actually have precise definitions. If I should lift 10 pounds a distance of 10 feet, then I've performed 100-foot-pounds of work (10 pounds × 10 feet = 100). Before the steam engine, the most powerful force to perform work, or exert a force, was a horse.

James Watt, with actual tests, determined that a coal mine draft horse could lift 550 pounds, a distance of one foot, within a second. So, James Watt declared 550 foot-lbs/sec. to be one Horsepower. To this day, this has become the standard definition of a horsepower (1 HP =

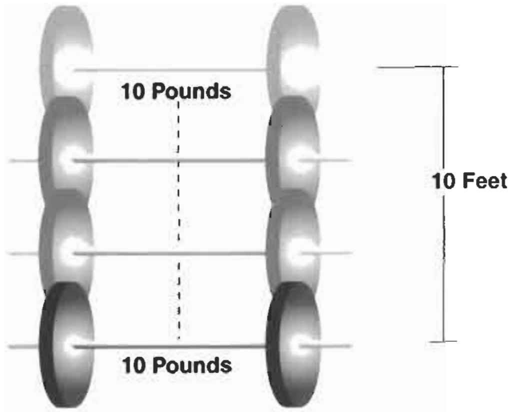

Figure 5-1

550 ft.-lbs./sec.). This is the reason that even today, all motors, whether steam, internal combustion engines, boilers, electric motors, gas turbines, and even jet and rocket engines are rated in Horsepower, and not Ostrich power or Iguana power.

We say that the motor generates horsepower (HP), and that the pump consumes brake horsepower (BHp). The difference between HP (output) and BHp (input) is what is lost in the power transmission; the bearings, shaft, and coupling between the motor and the pump.

We say that the useful work of the pump is called Water horsepower (WHp). It is demonstrated mathematically as:

$$\mathbf{WHp} = \frac{\mathbf{H \times Q \times sp.gr.}}{\mathbf{3960}}$$

Where: **H** = head in feet generated by the pump **Q** = flow recorded in gallons per minute **sp. gr.** = specific gravity
3960 = constant to convert BHp into gallons per minute

$$\mathbf{3960} = \frac{\textbf{Horsepower} \times \textbf{60 secs. / min.}}{\textbf{Weight of 1 gal. of water}}$$

$$\mathbf{3960} = \frac{\textbf{550 lbs. ft / secs.} \times \textbf{60 secs.}}{\textbf{8.333 lbs. / gal.}}$$

If the pump were 100% efficient, then the BHp would be equal to the WHp. However, the pump is not 100% efficient so the BHp = WHp × efficiency, and the formula is:

$$\mathbf{BHp} = \frac{\mathbf{H \times Q \times sp.gr.}}{\mathbf{3960 \times eff.}}$$

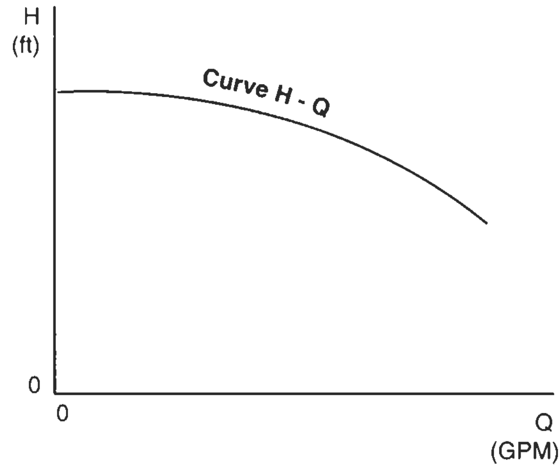

Figure 5-2

The graph (Figure 5–2) shows the useful work of a pump. Notice that the pump pumps a combination of head and flow. As a general rule, as flow increases, the head decreases.

Example:

Given: Pressure or Head required = 100 feet at 200 gpm. What is the water horsepower required for this pump? Assume a sp. gr. of 1.0

$$\mathrm{WHp} = \frac{H \times Q}{3960} = \frac{100\text{ ft.} \times 200\text{ gpm}}{3960} = 5.05\text{ HP}$$

If the specific gravity at pumping temperature were not equal to 1.0, then the water horsepower would be adjusted by the specific gravity.

$$\mathrm{WHp} = \frac{H \times Q \times \text{sp.gr.}}{3960}$$

Flow determination

Flow is the number of gallons per minute that the pump will discharge.

- Any pump will generate more flow as the discharge pressure is reduced.
- Equally, the pump will generate less flow as the discharge head or pressure requirements are increased. Obviously, both flow and head should be known before selecting a centrifugal pump.

AUTHOR'S NOTE

It is not practical to declare the flow without the accompanying head requirements. For this reason, when someone asks for the pump specifications, they need to know the flow in gallons per minute and the head in feet.

- The available areas in the impeller, and the available area in the volute determine the flow, gpm. There are two critical areas in the impeller, the exit area and the entrance area. For the volute casing, the most important area is the 'cutwater'. All fluid must pass this point.
- Head or pressure is developed in the pump; when the impeller imparts rotational energy to the liquid (increasing the liquid's velocity), and then the volute converts this energy (by decreasing the velocity) into pressure.
- The relationship between the 'exit area' of the impeller, and the 'cutwater area' of the volute, generally determine the flow of the pump.

See the illustration below (Figure 5–3):

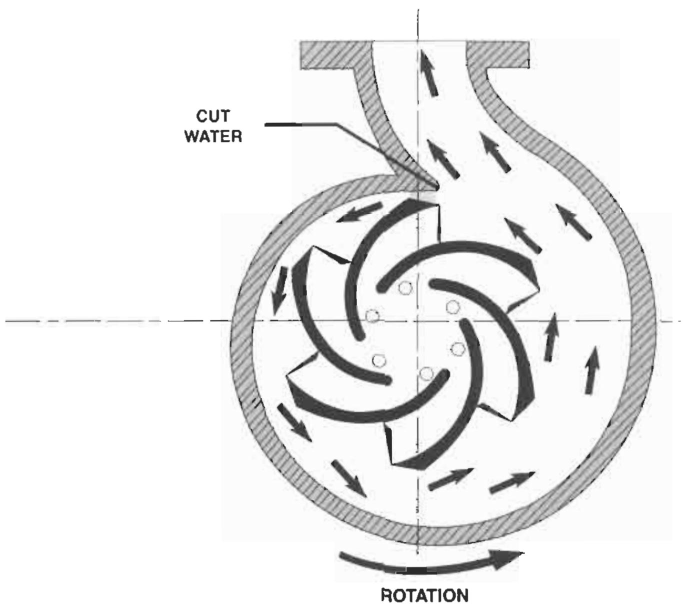

Figure 5–3

Pump efficiency

Numerous factors affect the pump's efficiency. The impeller is one of the most important efficiency factors.

Affecting the impeller's behavior are:

1. The impeller velocity.
2. The impeller diameter.
3. The number of blades on the impeller.
4. The diameter of the eye of the impeller.
5. The thickness of the impeller.
6. The pitch (angle) of the blades.

Factors that affect the efficiency

1. Surface finish of internal surfaces – Efficiency increases from better surface finishes are mostly attributable to the specific speed Ns (discussed in Chapter 6) of the pump. Generally, the improvements in surface finishes are economically justifiable in pumps with low specific speeds.
2. Wear ring tolerance – Close tolerances on the wear rings have a tremendous effect on the pump's efficiency, particularly for pumps with a low specific speed (Ns < 1500).
3. Mechanical losses – Bearings, lip seals, mechanical seals, packings, etc., all consume energy and reduce the pump's efficiency. Small pumps (less than 15 HP) are particularly susceptible.
4. Impeller diameter – There will be an efficiency reduction with a reduction in the impeller diameter. For this reason, it's not recommended to reduce (trim) the impeller by more than 20%. For example, if a pump takes a full sized 10-inch impeller, don't trim the impeller to less than 8-inches diameter. This would be a 20% reduction.
5. Viscosity – Viscous liquids generally have a prejudicial effect on efficiency. As the viscosity of the fluid goes up, generally the efficiency of most pumps goes down. There are exceptions.
6. Size of solid particles – Low solids concentrations (less than 10% average) classified by size and material, generally exhibit no adverse affect to pump efficiency. However, the discharge configuration of the pump must be sufficiently large to prevent obstructions. For example, sanitary and wastewater pumps that handle high solids,

have 2 or 3 blades on a specially designed impeller with lower efficiency.

7. The type of pump – There are many types of pumps with configurations and characteristics for special services, such as sanitary, wastewater, and solids handling, etc., taking into account the Ns and design that perform their services effectively with a slightly less than optimum efficiency. In simple terms, special designs and services generally reduce efficiencies.

$$\text{Efficiency} = \frac{\text{Work Output}}{\text{Work Input}} = \text{Power Produced}$$

$$\text{Pump Efficiency} = \frac{\text{Water Horsepower}}{\text{Brake Horsepower}} = \frac{\text{WHp}}{\text{BHp}}$$

$$\text{Pump Efficiency} = \frac{H \times Q \times \text{sp. gr.}}{3960 \times \text{BHp}}$$

$$\text{Coupling Efficiency} = \frac{\text{Pump Horsepower}}{\text{Motor Horsepower}} = \frac{\text{BHp}}{\text{Hp}}$$

$$\text{Motor Efficiency} = \frac{\text{Motor Horsepower Output}}{\text{Energy / Power Input}} = \frac{\text{Hp}}{\text{KW}}$$

$$\text{BHp} = \frac{H \times Q \times \text{sp. gr.}}{3960 \times \text{eff.}}$$

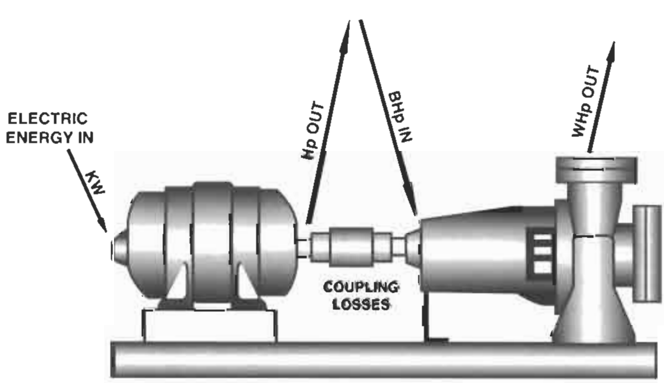

Figure 5-4

Calculating pump efficiency

Example

A system requires 2,500 gpm flow of brine (salt water with sp. gr. of 1.07) at 120 psi., 213 BHp required.

Calculate Head

$$\textbf{Head} = \frac{\text{psi} \times 2.31}{\text{sp. gr.}} = \frac{120 \text{ psi} \times 2.31}{1.07} = 259.06 \text{ Feet}$$

Calculate Efficiency:

$$\textbf{Efficiency} = \frac{H \times Q \times \text{sp. gr.}}{3960 \times \text{BHp.}} = \frac{259 \text{ ft.} \times 2500 \text{ gpm} \times 1.07 \text{ sp. gr.}}{3960 \times 213 \text{ BHp}} = 82\%$$

This pump is 82% Efficient.