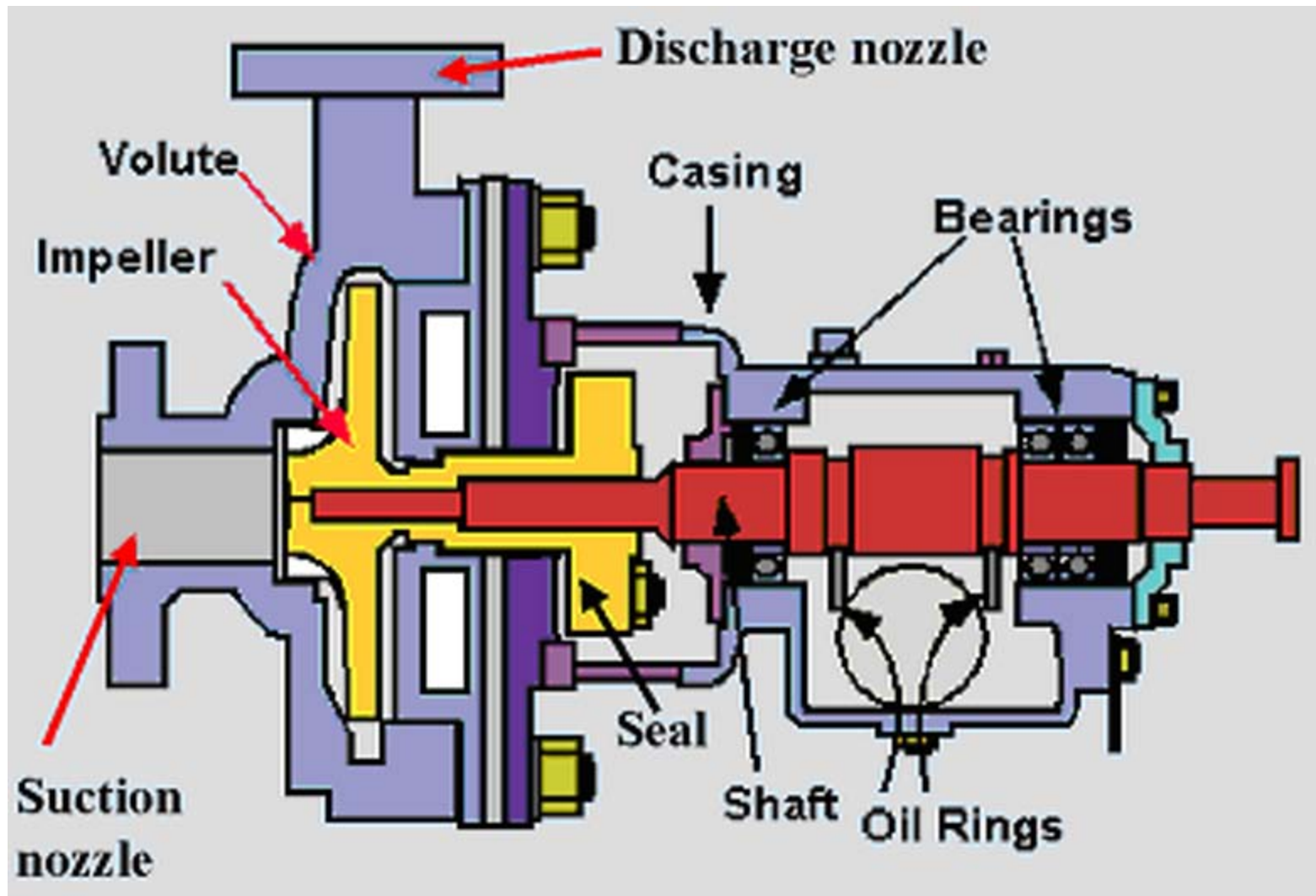


**TB-2009-003**

# **Pump Selection Guide**

**basic differences between pump types and pump laws**

# Pump Basic Parts



Centrifugal Pump Shown

# Basic Terms

**Discharge Nozzle:** Where the fluid exits the pump

**Suction Nozzle:** Where the fluid enters the pump

**Impeller:** The rotating blades that create the pressure differential which causes the fluid to flow (for centrifugal pumps).

**Pump Motor:** The unit that drives the impellers rotary motion or the mechanisms linear motion. Motors may be electric, gasoline / diesel or hydraulic and contain:

- Seals – to prevent leaking along rotating shaft
- Bearings – to reduce friction
- Casing - Mechanical structure that integrates the pump components and provides for mounting.

**Duty Cycle:** The operating time of work cycles of the pump in relation to resting time.

**Continuous Duty-** Operating times of an hour or more between load and rest.

**Intermittent Duty-** Operating times in increments such as 5 minutes, 10 minutes, 15 minutes, between load and rest.

**Efficiency:** The ratio of output shaft power to input power.

# Technical Terms

**Pump Types:** The type of pump that will operate most efficiently is determined by the application.

**Positive Displacement Pump:** A pump that causes fluid to move by trapping a fixed amount then forcing (displacing) the trapped volume through the discharge nozzle. Sub-categories of positive displacement pumps are classified according to the mechanism used to move the fluid.

**Rotodynamic Pump:** A pump that adds kinetic energy to the fluid by increasing the flow velocity thus increasing the pressure as the fluid exits the discharge nozzle. Sub-categories of Dynamic pumps are classified according to the method used to increase velocity.

**Positive Displacement versus Dynamic Pumps:** PDP tend to be more precise in the volume transferred however they can not operate in a closed valve condition without building up pressure which may cause damage to the downstream transport system. As they continue to displace liquid the pressure builds. DP's can operate against a closed valve with no pressure build up since they are unable to increase velocity in a closed position a fixed pressure is reached and held.

**Frequency/Hertz:** Indicates the rate of change of the direction of current for AC powered pumps. Expressed in Hz which is the number of cycles per second.

**Horsepower:** Measures the amount of work a motor can perform over time. A unit of hp is equal to 33,000 pounds lifted one foot in one minute or 746 watts=1 horsepower.

**Inertia:** A property of matter where a body offers resistance to any change in its state of rest or motion.

# Technical Terms

**Load:** The amount of torque required to drive an object. Once the reflected inertia is known, the torque can be calculated based on required acceleration time.

**Phase:** The number of alternating currents reaching their amplitudes within a 360 degree rotation. A standard AC motor is a polyphase 3-phase motor.

**RPM (Revolutions Per Minutes):** Indicates the speed of the motor in revolutions per minute.

**Speed Reducer:** Reduces speed of a load and increase the torque output through a series of gears. The gear ratio represents the construction of the gear and the torque multiplier. Useful for pumping thick fluids with smaller motors.

**Torque:** The turning force of a motor shaft commonly expressed in inch-pounds or inch-ounces.

**Starting Torque (Locked Rotor Torque):** The amount of torque a motor produces when full voltage is applied to get a motor up to speed.

**Full-Load Torque:** The amount of torque rating of a motor during a duty cycle.

**Pull-Out Torque:** The maximum torque available at the at full speed while applying full voltage. Once the motor is at full speed, the torque requirement is reduced (breakdown) to full load torque rating.

**Pull-Up Torque:** Can occur at locked rotor or during acceleration time to get up to continuous speed. Indicates lowest torque value as a motor gets up to speed.

**Watt:** Watt= Amps x Volts (Electricity Consumed= Current x Pressure)

**Voltage:** Is the amount of electrical pressure that moves an electrical charge (current).

# Types of Pump by Application

- Air Lift Pump
- Axial Flow Pump
- Bladder Pump
- Bicycle Pump
- Boiler Feedwater Pump
- Booster Pump
- Cantilever Pump
- Chemical Pump
- Circulator Pump
- Centrifugal Pump
- Condensate Pump
- Cryogenic Pump
- Diaphragm Pump
- Double-Diaphragm Pump
- DC Powered Pump
- Drum Pump
- Dosing Pump
- Dynamic Pump
- Explosion-Proof Pump
- Fire Pump
- Fuel Pump
- Fountain Pump
- Gear Pump
- Grinder Pump
- Hand Pump and Foot Pump
- Heat Pump
- Hydraulic Pump
- Injection Pump
- Jet Pump
- Laboratory Pump
- Lobe Pump
- Magnetic Drive Pump
- Marine Pump
- Metering Pump
- Momentum Transfer Pump
- Peristaltic Pump
- Piston Pump
- Plastic Pump
- Positive Displacement Pump
- Progressive Cavity Pump
- Rotary Pump
- Roundabout Play Pump
- Sampling Pump
- Sanitary Pump
- Screw Pump
- Sump Pump
- Star Pump
- Syringe Pump
- Sewage Pump
- Submersible Pump
- Trash Pump
- Turbine Pump
- Triplex Pump
- Turbo Pump
- Utility Pump
- Vacuum Pump
- Venturi Pump
- Vane Pump
- Water Pump
- Wastewater Pump
- Well Pump

# Types of Pump by Technology

## 1 Positive displacement pumps

### 1.1 Rotary-type pumps

#### 1.1.1 Gear pump

#### 1.1.2 Progressing cavity pump

#### 1.1.3 Roots-type pumps

#### 1.1.4 Peristaltic pump

### 1.2 Reciprocating-type pumps

#### 1.2.1 Compressed-air-powered double-diaphragm pumps

## 2 Rotodynamic pumps

### 2.1 Centrifugal pump

#### 2.1.1 Radial flow pumps

#### 2.1.2 Axial flow pumps

#### 2.1.3 Mixed flow pumps

### 2.2 Eductor-jet pump

Of these Centrifugal type pumps are the most common

# Pump Sizing Formulas

## Pump Affinity Laws

### *Volume Capacity*

*The volume capacity of a centrifugal pump can be expressed like*

$$q_1 / q_2 = (n_1 / n_2)(d_1 / d_2) \quad (1)$$

*where*

*q = volume flow capacity (m<sup>3</sup>/s, gpm, cfm, ..)*

*n = wheel velocity - revolution per minute - (rpm)*

*d = wheel diameter*

### *Head or Pressure*

*The head or pressure of a centrifugal pump can be expressed like*

$$dp_1 / dp_2 = (n_1 / n_2)^2 (d_1 / d_2)^2 \quad (2)$$

*where*

*dp = head or pressure (m, ft, Pa, psi, ..)*

# Pump Sizing Formulas

## **Power**

The power consumption of a centrifugal pump can be expressed as

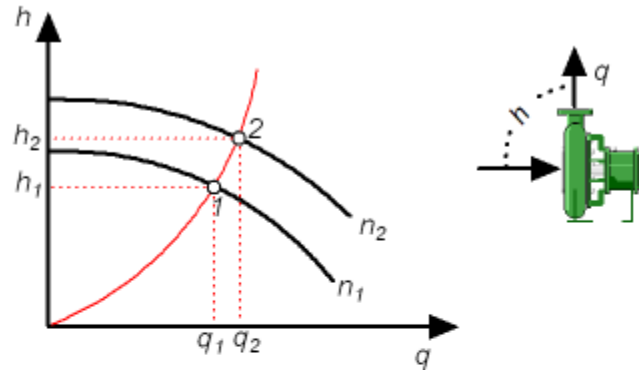
$$P_1 / P_2 = (n_1 / n_2)^3 (d_1 / d_2)^3 \quad (3)$$

where

$P$  = power (W, bhp, ..)

# Pump Sizing Formulas

## Changing the Wheel Velocity



If the **wheel diameter is constant** - change in pump wheel velocity can simplify the affinity laws to

### Volume Capacity

$$q_1 / q_2 = (n_1 / n_2) \quad (1a)$$

### Head or Pressure

$$dp_1 / dp_2 = (n_1 / n_2)^2 \quad (2a)$$

### Power

$$P_1 / P_2 = (n_1 / n_2)^3 \quad (3a)$$

# Pump Sizing Formulas

## Example: Pump Laws

A cooling water pump is operating at a speed of 1800 rpm. Its flow rate is 400 gpm at a head of 48 ft. The power of the pump is 45 kW. Determine the pump flow rate, head, and power requirements if the pump speed is increased to 3600 rpm.

Solution:

Flow rate

$$\begin{aligned} \dot{V}_2 &= \dot{V}_1 \left( \frac{n_2}{n_1} \right) \\ &= (400 \text{ gpm}) \left( \frac{3600 \text{ rpm}}{1800 \text{ rpm}} \right) \\ &= 800 \text{ gpm} \end{aligned}$$

Head

$$\begin{aligned} H_{h_2} &= H_p \left( \frac{n_2}{n_1} \right)^2 \\ &= 48 \text{ ft} \left( \frac{3600 \text{ rpm}}{1800 \text{ rpm}} \right)^2 \\ &= 192 \text{ ft} \end{aligned}$$

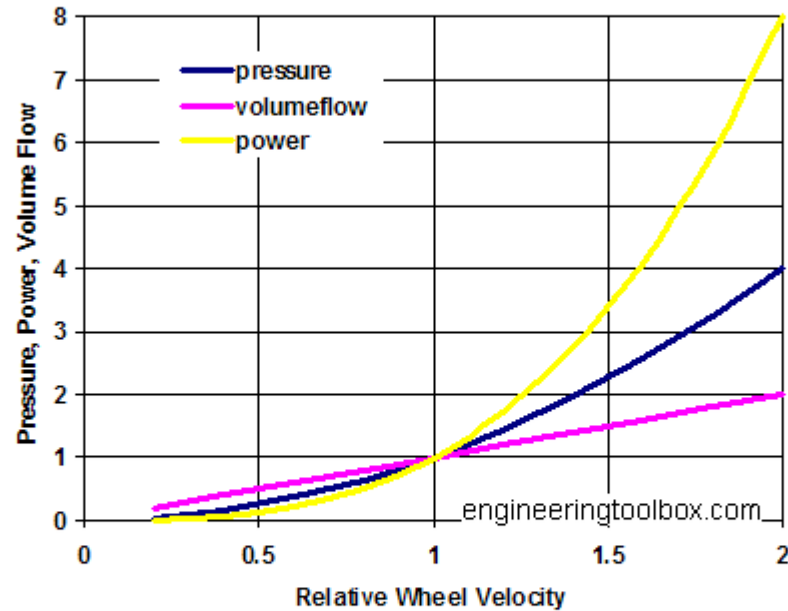
Power

$$\begin{aligned} P_2 &= P_1 \left( \frac{n_2}{n_1} \right)^3 \\ &= 45 \text{ kW} \left( \frac{3600 \text{ rpm}}{1800 \text{ rpm}} \right)^3 \\ &= 360 \text{ kW} \end{aligned}$$

# Pump Sizing Formulas

## Power

$$P_1 / P_2 = (n_1 / n_2)^3 \quad (3a)$$



**Note!** If the speed of a pump is increased with 10%

- the volume flow increases with 10%
- the head increases with 21%
- the power increases with 33 %

If we want to increase the volume flow capacity of an existing system with 10% we have to increase the power supply with 33%.

# Pump Sizing Formulas

## Common Physical Properties

### Physical Properties

<i>Property</i>	<i>Units</i>	<i>Water</i>	<i>Organic Liquids</i>	<i>Steam</i>	<i>Air</i>	<i>Organic Vapors</i>
Heat Capacity	KJ/kg 0C	4.2	1.0-2.5	2.0	1.0	2.0-4.0
	Btu/lb 0F	1.0	0.239-0.598	0.479	0.239	0.479-0.958
Density	kg/m <sup>3</sup>	1000	700-1500		1.29@STP (1 bar, 0°C)	
	lb/ft <sup>3</sup>	62.29	43.6-94.4		0.08@STP (14.696 psia and 60°F)	
Latent Heat	KJ/kg	1200-2100	200-1000			
	Btu/lb	516-903	86-430			
Thermal Cond.	W/m 0C	0.55-0.70	0.10-0.20	0.025-0.070	0.025-0.05	0.02-0.06
	Btu/h ft 0F	0.32-0.40	0.057-0.116	0.0144-0.040	0.014-0.029	0.116-0.35
Viscosity	cP	1.8 @ 0 0C	**See Below	0.01-0.03	0.02-0.05	0.01-0.03
		0.57 @ 50 0C				
		0.28 @ 100 0C				
		0.14 @ 200 0C				
Prandtl Number		1-15	10-1000	1.0	0.7	0.7-0.8

\*\* Viscosities of organic liquids vary widely with temperature

Liquid density varies with temperature by:

$$\rho_L \propto (T_c - T)^{0.3}$$

Gas density can be calculated by:

$$\rho_G = \frac{(MW)(P)}{ZRT}$$

Boiling Point of Water as a Function of Pressure:

$$T_{bp} (°C) = (\text{Pressure (MPa)} \times (1 \times 10^9))^{0.25}$$

# Pump Sizing Formulas

## Resistance through Pipes

A. Liquid lines should be sized for a velocity of  $(5+D/3)$  ft/s and a pressure drop of

2.0 psi/100 ft of pipe at pump discharges

At the pump suction, size for  $(1.3+D/6)$  ft/s and a pressure drop of 0.4 psi/100 ft of pipe

\*\*D is pipe diameter in inches

B. Steam or gas lines can be sized for  $20D$  ft/s and pressure drops of 0.5 psi/100 ft of pipe

C. Limits on superheated, dry steam or gas line should be 61 m/s (200 ft/s) and a pressure drop of 0.1 bar/100 m or 0.5 psi/100 ft of pipe. Saturated steam lines should be limited to 37 m/s (120 ft/s) to avoid erosion.

D. For turbulent flow in commercial steel pipes, use the following:

$$\Delta P = M^{1.8} \mu^{0.2} / 20,000 D^{4.8} \rho$$

where :

$\Delta P$  = Frictional pressuredrop, psi/100equivalent feet of pipe

M = Mass flow, lb/hr

$\mu$  = viscosity, cP

$\rho$  = density, lb/ft<sup>3</sup>

D = Pipe inside diameter, in.

\*\*For smooth heat exchanger steel tubes, replace 20,000 with 23,000

# Pump Sizing Formulas

## Resistance through Pipes

E. For two phase flow, an estimate often used is Lockhart and Martinelli:

First, the pressure drops are calculated as if each phase exist alone in the pipe, then

$$X = \left( \frac{\Delta P_L}{\Delta P_G} \right)^{0.5}$$

now, the total pressure drop can be calculated by one of the following :

$$\Delta P_{\text{total}} = Y_L \Delta P_L \text{ or } Y_G \Delta P_G$$

where

$$Y_L = 4.6X^{-1.78} + 12.5X^{-0.68} + 0.65$$

$$Y_G = X^2 Y_L$$

# Pump Sizing Formulas

## Common Factors

A. Power estimates for pumping liquids:

$$kW=(1.67)[\text{Flow (m}^3/\text{min)}][\text{Pressure drop (bar)}]/\text{Efficiency}$$

$$\text{hp}=[\text{Flow (gpm)}][\text{Pressure drop (psi)}]/1714 (\text{Efficiency})$$

\*\*Efficiency expressed as a fraction in these relations

B.  $\text{NPSH}=(\text{pressure at impeller eye}-\text{vapor pressure})/(\text{density}*\text{gravitational constant})$

Common range is 1.2 to 6.1 m (4-20 ft) of liquid

C. An equation developed for efficiency based on the GPSA Engineering Data Book is:

$$\text{Efficiency} = 80-0.2855F+.000378FG-.000000238FG^2+.000539F^2-.000000639(F^2)G+.0000000004(F^2)(G^2)$$

where Efficiency is in fraction form, F is developed head in feet, G is flow in GPM

Ranges of applicability are F=50-300 ft and G=100-1000 GPM

Error documented at 3.5%

# Pump Sizing Formulas

## Common Factors

**D. Centrifugal pumps: Single stage for 0.057-18.9 m<sup>3</sup>/min (15-5000 GPM), 152 m (500 ft) maximum head; For flow of 0.076-41.6 m<sup>3</sup>/min (20-11,000 GPM) use multistage, 1675 m (5500 ft) maximum head; Efficiencies of 45% at 0.378 m<sup>3</sup>/min (100 GPM), 70% at 1.89 m<sup>3</sup>/min (500 GPM), 80% at 37.8 m<sup>3</sup>/min (10,000 GPM).**

**E. Axial pumps can be used for flows of 0.076-378 m<sup>3</sup>/min (20-100,000 GPM) Expect heads up to 12 m (40 ft) and efficiencies of about 65-85%**

**F. Rotary pumps can be used for flows of 0.00378-18.9 m<sup>3</sup>/min (1-5000 GPM) Expect heads up to 15,200 m (50,000 ft) and efficiencies of about 50-80%**

**G. Reciporating pumps can be used for 0.0378-37.8 m<sup>3</sup>/min (10-100,000 GPM) Expect heads up to 300,000 m (1,000,000 ft).**

**Efficiencies: 70% at 7.46 kW (10 hp), 85% at 37.3 kW (50 hp), and 90% at 373 kW (500 hp)**