Pump Selection and Sizing
(ENGINEERING DESIGN GUIDELINE)

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These design guidelines are believed to be as accurate as possible, but are very general and not specific to specific design cases. They were designed for engineers to do preliminary designs and process specification sheets. The final design must always be guaranteed for the service selected by the manufacturing vendor, but these guidelines will greatly reduce the amount of up front engineering hours that are required to develop the final design. The guidelines are a training tool for young engineers or a resource for engineers with experience.

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INTRODUCTION

Scope

This design guideline assists engineers and operations personnel to understand the selection and sizing of pumps. A pump is one of the most important pieces of mechanical equipment that is present in industrial processes. A pump moves liquid from one area to another by increasing the pressure of the liquid above the amount needed to overcome the combined effects of friction, gravity and system operating pressures.

There are two types of pump which are generally used in industrial processes: positive displacement pump and centrifugal. It is important to choose the suitable type of pump based on process requirement and fluid process properties. The functions and types of pump are explained in detail under the General Design Guideline section.

The theory section covers the selection method of the pump based on their application and engineering calculations for the sizing of the pump. When sizing the pump, the understanding of concept of cavitation is very important. Cavitation is an abnormal condition that can result in loss of production, equipment damage and worst of all, personnel injury. To prevent pumps from having this problem, the correct design should be followed by applied the correct theory when carrying out the activities of pump sizing and selection.

In the application section of this guideline, four case studies are shown and discussed in detail, highlighting the way to apply the theory for the calculation. Generally used theory, such as Bernoulli’s theory, is used as the basic of calculation because it is applicable for various conditions. This theory is applied in calculation of the NPSH of the pumps, which is shown in detail in this section. The case studies will help the engineer do the selection and sizing for the pumps base on their own plant system.

Example Calculation Spreadsheets is attached in the end of this guideline. This Example Calculation Spreadsheets is made based on case studies in the application section to make the reader easier to learn.
INTRODUCTION

General Design Consideration

Type of Pump

The selection of type and construction of a pump is very important to meet the process specification and proper application. Knowledge of the variety of pumps in the market should be review. It is mentioned before, that there are two general types of pump in today’s industry: positive displacement and centrifugal (dynamic) pumps.

Positive Displacement Pumps

Positive displacement (PD) pumps work by allowing a fluid to flow into some enclosed cavity from a low-pressure source, trapping the fluid, and then forcing it out into a high-pressure receiver by decreasing the volume of the cavity. Some examples of PD pumps are: fuel and oil pump in most automobiles, the pumps on most hydraulic systems, and the heart of most animals.

Some general types of the positive displacement pumps are as below:

a) Reciprocating Pump

Reciprocating pumps create and displace a volume of liquid, their "displacement volumes", by action of a reciprocating element. Liquid discharge pressure is limited only by strength of structural parts. A pressure relief valve and a discharge check valve are normally required for reciprocating pumps.

Reciprocating pumps can be further classified into three types of pump as below,

i) Piston Pumps
ii) Packed Plunger Pumps
iii) Diaphragm Pumps
b) Rotary Pump

Rotary pumps function with close clearances such that a fixed volume of liquid is displaced with each revolution of the internal element. Rotary pumps include:

i) Gear Pump  
ii) Lobe Pump  
iii) Vane Pump  
iv) Screw Pump

All those pumps above have the similar working principles: pumping the liquid with the help of rotating elements. The difference lies on the rotating elements; they could be gear, lobe, vane, or screw.

Centrifugal Pumps

Centrifugal pumps are dynamic pumps. A centrifugal pump raises the pressure of the liquid by giving it a high kinetic energy and then converts it into pressure energy before the fluid exits the pump. It normally consists of an impeller (a wheel with blades), and some form of housing with a central inlet and a peripheral outlet. The impeller is mounted on a rotating shaft and enclosed in a stationary casing. Casings are generally of two types: volute and circular. The impeller design and the shape of the casing determine how liquid is accelerated though the pump.
Some general types of the centrifugal pumps are as below:

a) Overhung pump

A pump with the impeller(s) cantilevered from its bearing assemblies is classified as an overhung pump.

![Figure 1: Foot mounted overhung pump](image1)

![Figure 2: Centerline mounted overhung pump](image2)

b) Between bearings pump

A pump with the impeller(s) located between the bearings is classified as a between bearings pump. The pump may be single-stage (one impeller), two-stage, or multistage. It can be axially (horizontally) split or radially split.

![Figure 3: Radically split multistage-single & double casing.](image3)
c) Vertically suspended pump

A pump with the impeller(s) cantilevered vertically and the suction nozzle typically submerged is classified as a vertically suspended pump.

c) Seal-less pump

Seal-less pumps are special pumps which do not require shaft seals. Construction for seal-less pumps is driven by canned motors or magnetic couplings. It is normally used in process involve extremely hazardous fluid, where leakage cannot be tolerated.

d) Submersible pump

Submersible pumps are designed to prevent pump cavitation. The driver components inside are completely surrounded by the pumped fluid.

e) Horizontal self-priming pump

Horizontal self-priming pumps are designed to create a vacuum at the pump inlet. This enables the pump to “suck” fluid into its casing. The suction nozzle of the pump can therefore be located above the level of liquid being pumped.

Centrifugal pumps are used in more industrial applications than any other kind of pump. This is primarily because these pumps offer low initial and upkeep costs. Traditionally these pumps have been limited to low-pressure-head applications, but modern pump designs have overcome this problem unless very high pressures are required. The single-stage, horizontal, overhung, centrifugal pump is by far the most commonly type used in the chemical process industry.

Basically, pump selection is made on the flow rate and head requirement and with other process considerations, such as material of the construction pumps for the corrosive chemical service or for the fluid with presence solids in the stream.
Process Requirements Parameters

In designing the pump, the knowledge of the effect of parameters; such as pump capacity, NPSH, pumping maximum temperature, specific gravity, fluid viscosity, fluid solid content, and the other process requirements are very important. All of these parameters will affect the selection and design of the pump which will affect the performance of the pump in the process.

Pump capacity is a parameter plays an important role when selecting the pump. Capacity means the flow rate with which liquid is moved or pushed by the pump to the desired point in the process. It is commonly measured in either gallons per minute (gal/min) or cubic meters per hour (m³/hr). The capacity usually changes with the changes in operation of the process. A minimum required flow rate need to be specified, this is important to determining if a minimum flow bypass is required for the selected pump to avoid pump overheating and mechanical damage.

NPSH as a measure to prevent liquid vaporization or called cavitation of pump. Net Positive Suction Head (NPSH) is the total head at the suction flange of the pump less the vapor pressure converted to fluid column height of the liquid. The design engineer should always remember that pumps can pump only liquids, not vapors because when a liquid vaporizes its volume increases greatly. For example: 1ft³ of water it will vaporize to produce 1700ft³ of steam. This will cause the rise in temperature and pressure drop in the fluid and pump will stop functioning because it has not sufficient suction pressure present.

Pumping maximum temperatures is important in deciding pump construction style and pump cooling and mechanical seal requirements. The minimum operating temperature is to ensure that the material has adequate impact strength.

Specific gravity is parameter determines the pump head required to produce a desired pressure increase. For pumps with limited head capability such as centrifugal pumps, it affects pressure rise capability. Pump power requirements are also affected by specific gravity.

Viscosity is important in the selection of pump type and has a significant effect on centrifugal pump performance. Minimum values of viscosity are important in determining rotary pump (positive displacement pump) performance, while maximum viscosity is important in determining debits to centrifugal pump performance.
Fluid solid content will affect the pump design. It affected the aspects of the design for the flow characteristic, consideration design of erosion resistance, flow passage size, impeller style, peripheral speed, design features to disintegrate large particles, and shaft sealing design. This parameter has to be added in the data sheet for design.

Other process requirement such as flexibility for expansion should be consider as well. This is important for future capacity expansion; it helps to minimize the cost of expansion because to replace the pump will be a large sum of money. Working capacity of pump should always be design for more than 20% extra design capacity.
DEFINITION

**Bearing Housing** - The bearing housing encloses the bearings mounted on the shaft. The bearings keep the shaft or rotor in correct alignment with the stationary parts under the action of radial and transverse loads. The bearing house also includes an oil reservoir for lubrication, constant level of oil, jacket for cooling by circulating cooling water.

**Capacity** - Is the water handling capability of a pump commonly expressed as either gallon per minute (gal/min) or cubic meter per minute (m³/min).

**Cavitation** - Is the result of vapor bubbles imploding. This occurs when the amount of fluid flowing into the pump is restricted or blocked.

**Discharge Port** — Point where the discharge hose or pipe is connected to the pump.

**Datum Elevation** – It use as reference of the horizontal plane for which all the elevations and head are measured. The pumps standards normally specify the datum position relative to a pump part, eg. Centrifugal horizontal pump datum position is at the impeller shaft centerline.

**Dynamic Discharge Head** - The static discharge head plus the friction in the discharge line also referred to as Total Discharge Head.

**Dynamic Suction Head** - The static suction lift plus the friction in the suction line also referred to as Total Suction Head.

**Endurance limit** – Is the stress below which the shaft will withstand an infinite number of stress reversals without failure. Since one stress reversal occurs for each revolution of the shaft, this means that ideally the shaft will never fail if the maximum bending stress in the shaft is less than the endurance limit of the shaft material.

**Friction Head** - The head required to overcome the resistance to flow in the pipe and fittings. It is dependent upon the size, condition and type of pipe, number and type of pipe fittings, flow rate, and nature of the liquid.

**Friction Loss** - Refers to reductions in flow due to turbulence as water passes through hoses, pipes, fittings and elbows.
Impeller — A disk with multiple vanes. It is attached to the pump engine or motor and is used to create the centrifugal force necessary for moving water through the pump casing.

Mechanical Seal — A common wear part that forms a seal between the pump and the engine or motor. Also prevents liquid from seeping into the engine or motor.

Net Positive Suction Head (NPSHa) - Is the total head at the suction flange of the pump less the vapor pressure converted to fluid column height of the liquid

Net Positive Suction Head Required (NPSHr) - NPSH in meters (feet) determined by Supplier testing, usually with water. NPSHR is measured at the suction flange and corrected to the datum elevation. NPSHR is the minimum NPSH at rated capacity required to prevent a head drop of more than 3% (first stage head in multistage pumps) due to cavitation within pump.

Pressure Head - Pressure Head must be considered when a pumping system either begins or terminates in a tank which is under some pressure other than atmospheric. The pressure in such a tank must first be converted to feet of liquid. Denoted as \( h_p \), pressure head refers to absolute pressure on the surface of the liquid reservoir supplying the pump suction, converted to feet of head. If the system is open, \( h_p \) equals atmospheric pressure head.

Static Suction Head - Head resulting from elevation of the liquid relative to the pump center line (datum). If the liquid level is above pump centerline (datum), \( h_S \) is positive. If the liquid level is below pump centerline (datum), \( h_S \) is negative. Negative \( h_S \) condition is commonly denoted as a “suction lift” condition

Static Discharge Head - It is the vertical distance in feet between the pump centerline and the point of free discharge or the surface of the liquid in the discharge tank.

Suction Port — Point where the suction hose or pipe is connected to the pump.

Vapor Pressure Head - Vapor pressure is the absolute pressure at which a liquid and its vapor co-exist in equilibrium at a given temperature. The vapor pressure of liquid can be obtained from vapor pressure tables. When the vapor pressure is converted to head, it is referred to as vapor pressure head, \( h_{vp} \). The value of \( h_{vp} \) of a liquid increases with the rising temperature and in effect, opposes the pressure on the liquid surface, the positive force that tends to cause liquid flow into the pump suction i.e. it...
reduces the suction pressure head. (Vapor pressure can be said as the external pressure required to prevent fluid from evaporate become vapor).

**Velocity Head** - Refers to the energy of a liquid as a result of its motion at some velocity ‘v’. It is the equivalent head in feet through which the water would have to fall to acquire the same velocity, or in other words, the head necessary to accelerate the water. The velocity head is usually insignificant and can be ignored in most high head systems. However, it can be a large factor and must be considered in low head systems.

**Viscosity** — is a mechanism of fluid resistance to flow of a liquid at a given temperature. High viscosity liquids such as motor oil are more resistant to flow than water.

\[
\text{Kinematics Viscosity (cSt)} = \frac{\text{Absolute Viscosity (cP)}}{\text{Specific Gravity}}
\]

**Volute** — A stationary housing inside the pump housing in which the impeller rotates. It is used to separate air and water.

**Total Head** - Pressure required in feet (meter) of head that the pump must produce. The head at the discharge pump flange minus the head at suction flange.

**NOMENCLATURE**

- **C**: Constant for pump geometry
- **D**: Diameter of impeller, in
- **g**: Acceleration due to gravity, 32.2 ft/s\(^2\) (9.81 m/s\(^2\))
- **H\(_c\)**: Total head developed from centrifugal pump, ft
- **H\(_d\)**: Discharge head, ft (m)
- **H\(_s\)**: Suction head, ft (m)
- **H\(_t\)**: Total head, ft (m)
- **h\(_a\)**: Acceleration for the reciprocating pump only for calculate the head losses due to pulsation in the flow, ft (m)
- **h\(_f\)**: Head produce from pressure loss in pipe, fitting, and entrainment, ft (m)
- **h\(_f(d)\)**: Head produce from pressure loss in pipe, fitting, and entrainment with depend the pipe diameter and type of flow from discharge to destination, ft (m)
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