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Principles of Chemical Engineering

Pumps – Centrifugal vs. Positive Displacement

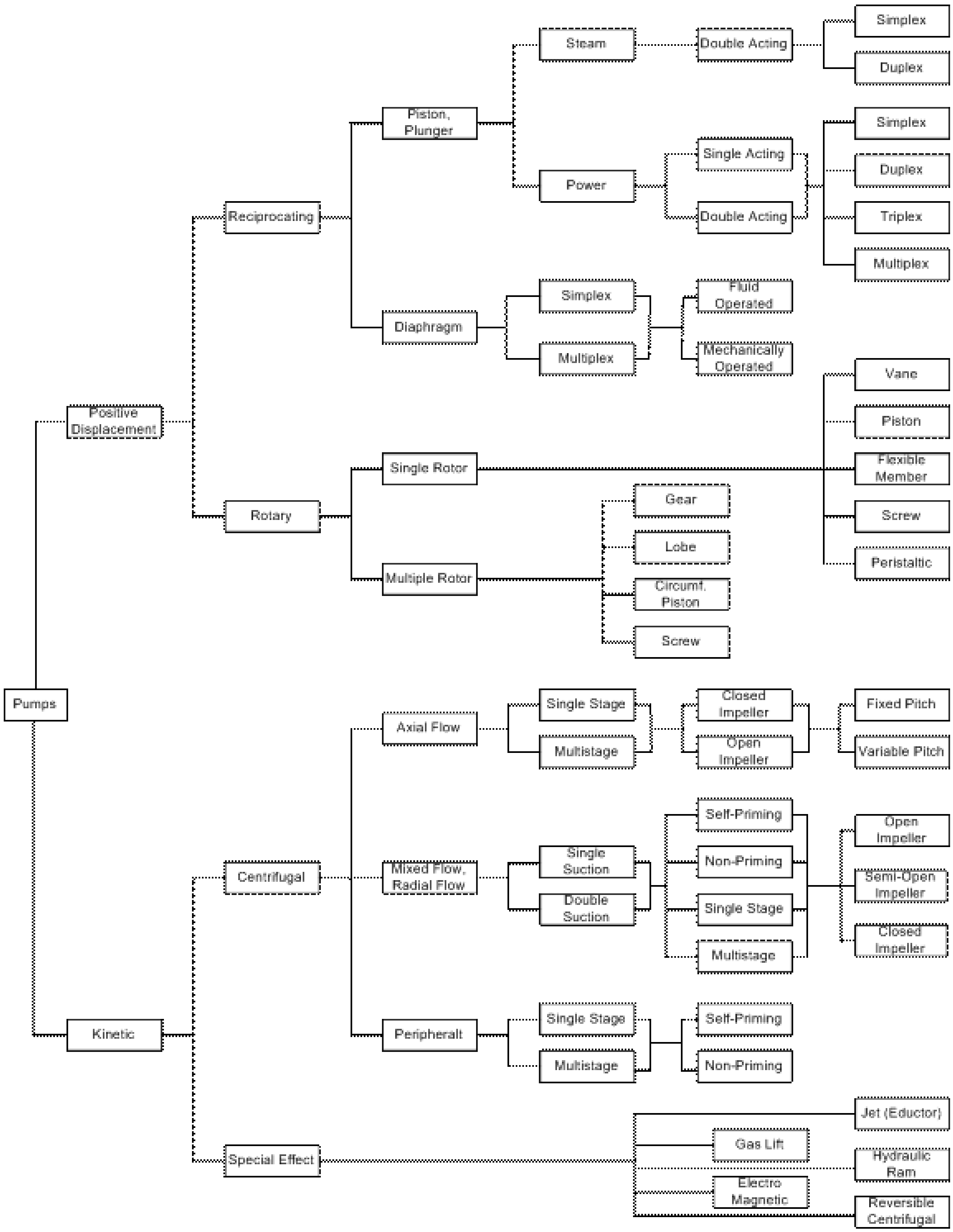
Two Categories – Kinetic (Centrifugal) and Positive Displacement

There are two main categories of pumps - kinetic and positive displacement. Almost all pumps fall into one of these two categories. The main difference between kinetic and positive displacement pumps lies in the method of fluid transfer. A kinetic pump imparts velocity energy to the fluid, which is converted to pressure energy upon exiting the pump casing. A positive displacement pump moves a fixed volume of fluid within the pump casing by applying a force to moveable boundaries containing the fluid volume.

Kinetic pumps can be further divided into two categories of pumps – centrifugal and special effect. Special effect pumps include jet pumps, reversible centrifugal, gas lift, electromagnetic and hydraulic ram. Special effect pumps are not commonly used relative to centrifugal pumps, so they will not be covered in this course.

Positive displacement pumps are also divided into two major pump categories – reciprocating and rotary. Reciprocating pumps transfer a volume of fluid by a crankshaft, eccentric cam or an alternating fluid pressure acting on a piston, plunger or a diaphragm in a reciprocating motion. Rotary pumps operate by transferring a volume of fluid in cavities located between rotating and stationary components inside the pump casing. The relative features of reciprocating and rotary pumps, as well as centrifugal pumps, will be covered in this course.

Figure 1 below shows the major pump categories and the types of pumps within each category.



Comparison Table – Centrifugal vs. Positive Displacement Pumps

Table 1 below outlines some of the main differences between centrifugal pumps, reciprocating pumps and rotary pumps. Note that “centrifugal”, “reciprocating” and “rotary” pumps are all relatively broad categories. The table below provides a comparison of features between these pump categories that generally holds true. However, there are exceptions. For example, reciprocating pumps generally require more space than centrifugal pumps for a given flow rate. But, there may be specific applications where a positive displacement pump requires less space relative to a centrifugal pump. Also, note that Table 1 lists typical maximum flow rates and heads. It is possible to build special pumps outside the upper bounds of the pressures and flow rates listed, but such pumps would be prohibitively expensive for most applications.

Parameter	**Centrifugal Pumps**	**Reciprocating Pumps**	**Rotary Pumps**
Optimum Flow and Pressure Applications	Medium/High Capacity, Low/Medium Pressure	Low Capacity, High Pressure	Low/Medium Capacity, Low/Medium Pressure
Maximum Flow Rate	100,000+ GPM	10,000+ GPM	10,000+ GPM
Low Flow Rate Capability	No	Yes	Yes
Maximum Pressure	6,000+ PSI	100,000+ PSI	4,000+ PSI
Requires Relief Valve	No	Yes	Yes
Smooth or Pulsating Flow	Smooth	Pulsating	Smooth
Variable or Constant Flow	Variable	Constant	Constant
Self-priming	No	Yes	Yes
Space Considerations	Requires Less Space	Requires More Space	Requires Less Space
Costs	Lower Initial Lower Maintenance Higher Power	Higher Initial Higher Maintenance Lower Power	Lower Initial Lower Maintenance Lower Power
Fluid Handling	Suitable for a wide range including clean, clear, non-abrasive fluids to fluids with abrasive, high-solid content Not suitable for high viscosity fluids Lower tolerance for entrained gases	Suitable for clean, clear, non-abrasive fluids. Specially-fitted pumps suitable for abrasive-slurry service. Suitable for high viscosity fluids Higher tolerance for entrained gases	Requires clean, clear, non-abrasive fluid due to close tolerances Optimum performance with high viscosity fluids Higher tolerance for entrained gases

Capacity

The wide variety of centrifugal pumps manufactured offer a relatively large range of available capacities. Radial-flow and mixed flow pumps are used for low to medium capacity applications. For high capacity applications, axial-flow pumps are capable of delivering flow rates in excess of 100,000 gpm. Centrifugal pumps are not stable at low flow rates, although there are special low-flow centrifugal pumps available that can deliver flow rates less than 10 gpm. However, for extreme low-flow applications (< 1 gpm), positive displacement pumps are a better selection.

Reciprocating and rotary pumps are capable of capacities ranging from low to medium, with flow rates peaking at 10,000+ gpm. In theory, reciprocating pumps can be manufactured to deliver more capacity, but they become prohibitively large and expensive at high flow rates. Both reciprocating and rotary pumps are capable of delivering product at extremely low flow rates (fractions of a gpm), making them particularly suitable for many chemical injection applications.

Pressure

Centrifugal pumps and rotary pumps are best suited for low to medium pressure applications. Reciprocating pumps are usually specified for high pressure service, with capabilities exceeding 100,000 psi. Multi-stage centrifugal pumps can deliver at pressures of 6,000+ psi and may be the most economical choice at this pressure in high capacity applications. But, in most applications exceeding 1,000 psig, reciprocating pumps are more suitable, particularly in low to medium capacity service. Both reciprocating and rotary pumps will continually increase pressure when pumping against a closed discharge to the extent allowed by the driver's horsepower. This can result in overpressure of the pump or piping components, so it is necessary to install a relief valve on the discharge of the pump capable of discharging the full capacity of the pump. A centrifugal pump's pressure rise is limited to the shut-off pressure on the pump curve, which is always less than the design pressure of the pump (and the piping system if properly designed). A relief valve is only needed if no other measures are provided to detect low flow conditions and shut down the pump to prevent damage. The relief valve need only be sized to pass the minimum flow rate required to maintain stable flow and prevent excessive temperature rise.

Smooth or Pulsating Flow

Centrifugal pumps and most rotary pumps provide smooth, non-pulsating flow, while reciprocating pumps produce a pulsating flow. A pulsating flow may require special design considerations in the piping system. If the pump is not located near the suction source, then acceleration head can contribute to low NPSHA problems, which may require the installation of a suction stabilizer. A pulsation dampener may need to be installed in the discharge piping to reduce pressure surges resulting from the pulsating flow.

Variable or Constant Flow

Centrifugal pumps operate on a variable-flow, variable-head curve. As the discharge pressure decreases, the pump delivers a higher flow rate. At any given speed, reciprocating and rotary pumps operate at a constant flow rate regardless of the discharge pressure. There are specific applications that require either constant flow or variable flow. Metering pumps rely on a constant flow at varying pressures, which makes reciprocating pumps and rotary pumps suitable for this application. Piston pumps used for metering will often use an adjustable stroke length to allow the operator to vary the flow rate to meet the system requirements. Centrifugal pumps are favored where process conditions often require varying flow rates. For example, a level control valve must throttle the flow rate from a vessel to maintain a constant level in the vessel. A centrifugal pump is well suited to handle this process condition, whereas a positive displacement pump would either require a continuous recycle to suction or a variable speed driver to accommodate the variable flow.

Self-priming

Reciprocating and rotary pumps are self-priming. This is an important consideration where a prime cannot be maintained on the pump. Centrifugal pumps are not inherently self-priming, although some manufacturers do specially design self-priming units. External priming sources, such as an eductor or vacuum pump can also be employed.

Costs and Space Considerations

In an overlap region where the conditions are suitable to use a centrifugal, reciprocating or a rotary pump, the following rules generally apply: The reciprocating pump will generally have higher initial capital costs and will require more space relative to the centrifugal pump or the rotary pump. The reciprocating pump will generally have higher maintenance costs relative to the centrifugal pump or the rotary pump. The centrifugal pump will generally have higher annual power consumption costs relative to the reciprocating pump or the rotary pump because of lower efficiencies. Of course, there are many exceptions. These are just general guidelines. A pump that is selected for an application outside of its optimum operating parameters will almost certainly not follow these rules. For example, a rotary pump operating in a high pressure, abrasive-slurry service would probably have higher maintenance costs than a properly selected reciprocating pump. The close running clearances (particularly for high pressure service) required in the rotary pump would likely result in premature wear and frequent maintenance.

Fluid Handling

Centrifugal pumps are suitable for transferring a variety of fluids ranging from clean, clear non-abrasive fluids to abrasive-slurries. However, a centrifugal pump is not the best choice for pumping highly viscous fluids due to dramatic drops in efficiency at high viscosities. Centrifugal pumps are not normally specified for viscosities higher than about 4,000 SSU. Centrifugal pumps are also not well suited to pumping entrained air. Most centrifugal pumps can handle up to about 2% entrained gas and specially-designed pumps can handle up to about 10%.

Reciprocating pumps are well suited for transferring clear, non-abrasive fluids, as well as abrasive slurries. In fact, the relatively low velocities of moving parts within a reciprocating pump make it particularly resistant to erosion in abrasive-slurry applications, provided that the pump is properly designed for the service. Reciprocating pumps maintain high efficiencies when pumping highly viscous fluids and can easily handle 50% and higher volumes of entrained gas.

Rotary pumps can also handle high viscosity fluids and high volumes of entrained gas. In fact, many rotary pumps operate at their best efficiency at higher viscosities. However, rotary pumps are not well suited for pumping corrosive fluids or fluids with abrasive solids because of close clearances between rotating and static pump components.

Summary

The comparisons between different pump categories presented in this course are general. The information is intended to familiarize the student with some of the basic differences between centrifugal, reciprocating and rotary pumps. However, there are many different subcategories of pumps within these broad categories and there are many regions of overlap where multiple types of pumps in the same category and even in different categories would be suitable. Since every pump application is unique, each of the factors that influence the pump selection must be considered in detail.