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Introduction To The Purpose, Use and Care of Centrifugal Pumps

Training For Operators, Maintainers, Technicians and Engineers.

Objective

This training teaches users and maintainers of centrifugal pumps why they are used, how they work, what causes them to go wrong and what is necessary to keep them operating properly.

Training Contents

- Purpose of the equipment.
- The principles of how the equipment works.
- Important parts and assemblies.
- In-service design and operation.
- How the equipment achieves its purpose and the necessary operating conditions.
- Most likely failure modes, their causes and what to do about them.
- On-Site, workshop or test bench observations of an equipment installation.
- Conduct site tests and trails on the equipment operation.
    - Compare the installation to the minimum design required.
    - Predict effect of changes.
    - Observe actual changes.
    - Identify impact of changes to the equipment operation.
- Learning Assessment
    - Explain purpose and use of equipment.
    - Identify how the equipment achieves its purpose.
    - Specify the required operating conditions for proper performance.
    - List what failures are possible at the workplace and how to fix them.
    - Training Supervisor review.

Outcomes of the Training

This training will introduce the trainee to the proper use, care and maintenance of centrifugal pumps. It will give them a deeper knowledge of the equipment and the factors that affect its operation. They will use the new know-how to better operate, care-for and maintain such equipment in future.

Time Required

The training takes one hour to complete for able people with some industry experience.

Introduction to the Purpose, Use and Care of Centrifugal Pumps

Purpose of the Equipment

A centrifugal pump moves liquids through pipelines from a reservoir, tank or vessel to another.

It does this by supplying energy to the liquid through a spinning impeller which builds-up the pressure in the liquid and gives it speed to flow through the pipe from one place to another.

These pumps can also be used to move slurries of liquid containing suspended matter like sand, powders and even some foods.

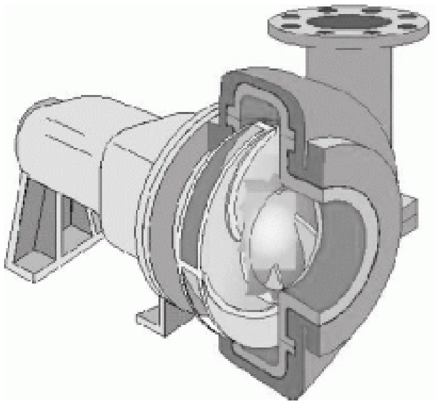


Figure 1 A Centrifugal Pump

Principles of How the Equipment Works

Centrifugal pumps convert the input power from a motor to kinetic (motion) energy in the liquid by speeding-up the liquid in a rotating impeller Figure 2 shows three common types of impeller used in centrifugal pumps. The type of impeller chosen depends on the pump's service duty and what is contained in the liquid it pumps.

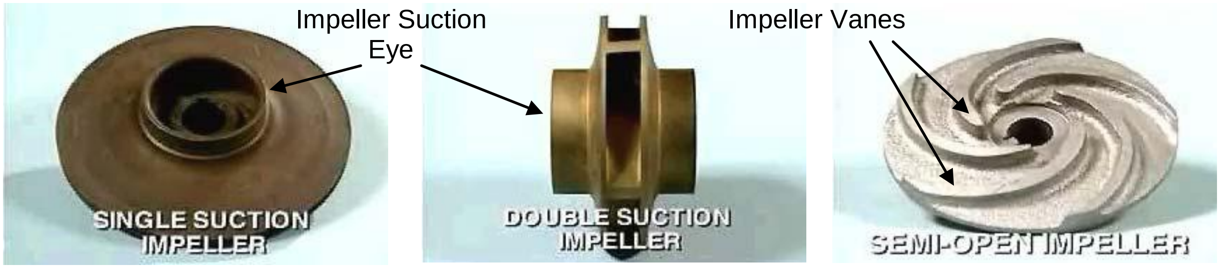


Figure 2 Impellers Types Used in Centrifugal Pumps

The way the impeller in a centrifugal pump works is like swinging around a bucket of water in a circle at the end of a rope. When spun the water is pushed against the bottom of the bucket by centrifugal force which drives it in an outward direction from the centre.

If the bucket had a hole at the bottom then the water would flow through the hole and away at the speed of the bucket.

Figure 3 A Spinning Water Bucket

An impeller works in exactly the same way. The liquid enters the eye, or centre, of a spinning impeller within the pump and is flung outwards. How hard the liquid is thrown out against the casing wall depends on how fast and big is the spinning impeller.

A small diameter impeller spinning slow will not give the liquid much energy and it would not be flung against the casing wall to hard. The same impeller spinning fast will give the liquid more energy and hit the volute casing harder.

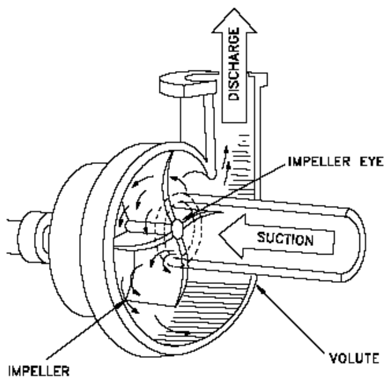


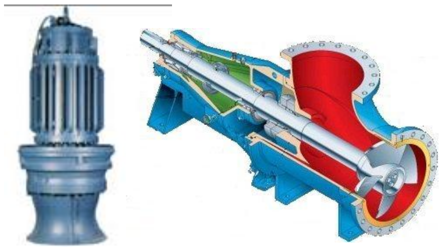
Figure 4 A Spinning Impeller

If we now use a bigger diameter impeller spinning at the same speed as the smaller, we will also give the liquid more energy because it is in contact with the impeller for longer. And if we make the bigger impeller spin at the faster speed it will give the liquid the most energy of all.

All centrifugal pumps can be classified into the following three groups based on impeller design:

- Radial-flow pumps - centrifugal force action outwards
- Axial-flow pumps – propelling/lifting action of vanes
- Mixed-flow pumps – some centrifugal force and some lifting action

Figure 5 Radial Flow Pump



Axial Flow Pumps

Mixed Flow Impeller

Radial flow pumps are the most common and we will focus on them in this training.

<u>Changing From Motion to Pressure Inside The Pump</u>

In radial flow centrifugal pumps, liquid enters the pump at the suction nozzle and flows into the eye of the rotating impeller. By centrifugal force, like the spinning bucket in Figure 3, the liquid is thrown radially outward into the pump volute casing. The casing traps the liquid and forces it through to the discharge nozzle.

The speed and power given to the liquid by the impeller, as it turns with the electric motor, needs to be converted into pressure to push the liquid through the pipeline. The pump makes the pressure by using the casing around the impeller, the volute, to stop the liquid being flung away. When the liquid hits the casing the energy of its motion smashes into the volute and changes into pressure.

Like clapping your hands together, there is energy in the impact. Within a radial flow pump the specially shaped, widening, spiral volute wall turns the energy of motion (kinetic energy) into pressure energy to push the liquid through the pipe.

<u>The Pump Characteristic Curve or Performance Curve</u>

A pump adds pressure energy into the liquid. If the liquid has low energy the pump boosts it. If the liquid already has pressure energy the pump adds its energy to that which is already there and lifts the total pressure higher. This happens in multi-stage pumps where several impellers are stacked one on top of the other, as shown in Figure 6, or one beside the other.

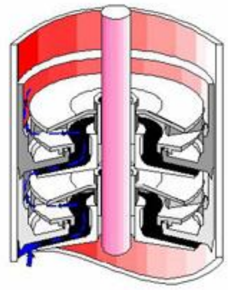


Figure 6 Multistage Pump

A pump can change the pressure energy it creates and the amount of liquid it flings out by altering the impeller diameter or the impeller speed.

When a pump runs at a fixed speed, the amount of liquid it pulls into, the impeller eye and pushes through the passages between the vanes, depends on how much inlet pressure it has to suck against and the outlet pressure it has to push against. This means that the flow through the pump depends on both the suction pressure and discharge pressure of the piping system in which the pump sits.

We can graph, or plot, the pump flow against its pressure on a diagram called the pump characteristic curve. Examples of pump curves are shown in Figure 7. They are used to select a pump with the right impeller size and speed to deliver the needed pressure energy required to move a flow rate through the pipe.

The curved line is characteristic, or standard, for an impeller/pump combination. In the bottom picture of Figure 7 the three curves are each for different impeller diameters. You read the curve by picking either the pressure or flow you want, and then projecting from the curve to the respective flow or pressure delivered by the pump.

From the curves you can see that when the discharge, or outlet, valve is closed (known as 'dead-head') there is no flow and the pressure is highest. In this case the pump turns all the electric motor energy into pressure and heating of the liquid. When there is zero back pressure, or 'total head' in the discharge pipe the flow is greatest. This time the electric energy is mostly converted into flow.

In theory the pump can deliver any combination of flow and pressure in-between 'dead-head' and fully open with no outlet back-pressure. But in reality a centrifugal pump is used only in the top two thirds of the curve where it is most efficient and there is no chance of cavitation from too low a suction pressure.

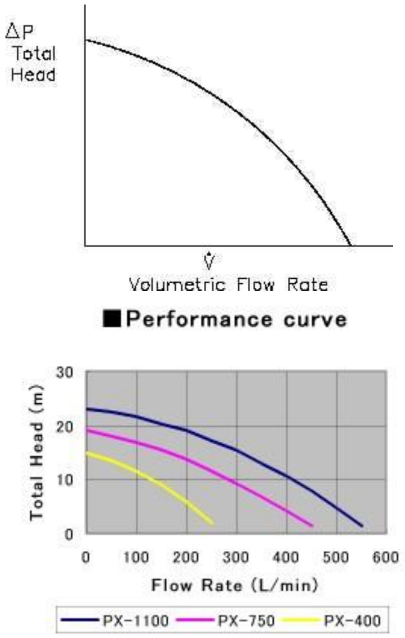


Figure 7 - Pump Curves

Important Parts and Assemblies

A standard centrifugal radial-flow pump is shown in Figure 8. Its main parts are identified. They belong to either the rotating element (impeller and shaft) or the stationary element (casing, stuffing box/seal chamber and seals, bearings) of the pump.

The pump is further categorised by the wet end (volute, impeller, back plate and seal) and the drive end (shaft, bearing casing, and bearings). The assembly of pump, motor and connecting drive coupling, all mounted on a base frame, is known as a 'pump set'.

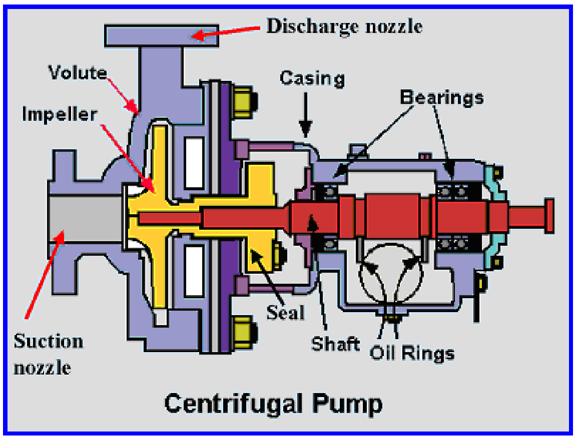


Figure 8 - Radial Flow Centrifugal Pump

In-Service Design and Operation

Centrifugal pumps form part of the piping system. They are mounted on a sturdy base plate, which is itself fixed firmly to a rigid, solid pump plinth of large mass to take the vibration and forces generated internally by the pump and the movement of the piping. The pipes move because of temperature changes causing expansion and from bending by forces in the pipe produced as the liquid changes direction and pressure. Figure 9 shows a large, solid plinth.

Figure 9 - A Solid Pump Plinth

Figure 10 shows a basic arrangement of pump, valves, pressure gauges and piping which are often used in a pump set installation.

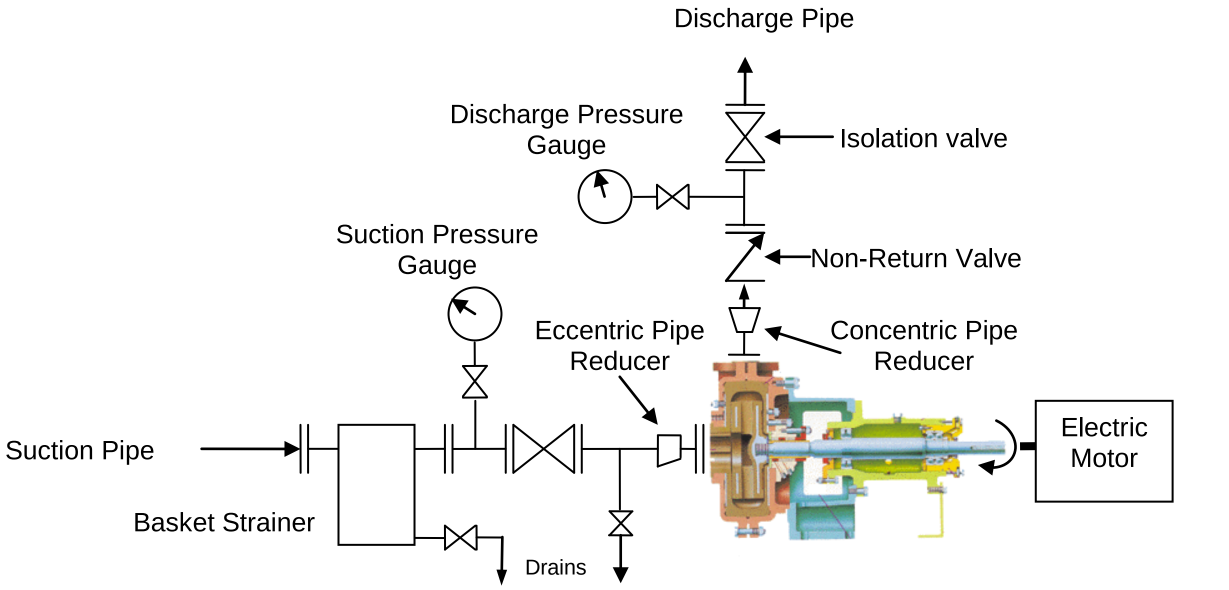


Figure 10 – Basic Centrifugal Pump Installation

Liquid enters the pump through the suction pipe. A basket strainer with a course screen mesh is often used where unwanted solids may clog the pump impeller passages. Once into the pump the impeller boosts the liquid's pressure and expels it out the discharge nozzle and onto its destination.

How The Equipment Achieves Its Purpose And The Necessary Operating Condition

Understanding Priming

Centrifugal pumps are not self-priming and must be primed by filling them with liquid, otherwise pumping will stop, and the shaft seal will probably burn out. The purpose of priming is to remove air from the pump and suction line to permit atmospheric pressure and flooding pressure to cause liquid to flow into the pump.

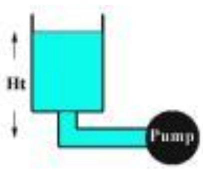


Figure 11 Flooding

The best way to mount a centrifugal pump is to locate it lower than the surface of the liquid it is drawing from. This is referred to as "flooded suction" and liquid will fill the pump, i.e. 'prime' the pump, by gravity as in Figure 12.

The ideal position for a pump is under the tank it is drawing from. Another location nearly as good is to have the pump at the same level as the floor of the tank. These spots almost always guarantee a self-primed, flooded suction.

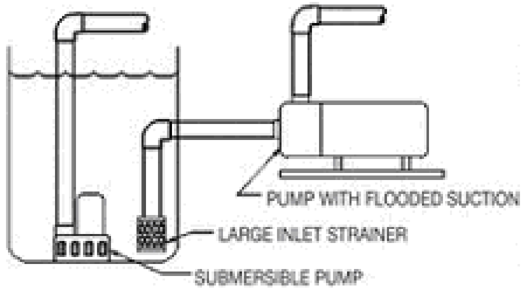


Figure 12 A Self-Primed Pump

A non-self-priming centrifugal pump can be located above the liquid surface by installing a foot valve (also known as a, non-return valve, one-way valve, or check valve) below the liquid surface. The check valve is typically installed at the end, or the foot, of the suction pipe, along with an inlet strainer to stop solid objects and rubble being sucked into the pump.

In addition install a priming pot (or some other sealable pressure container) at the highest point in the suction pipe. Manually fill, or prime, the pot. With the pot is sealed at the top and a foot valve at the bottom, it will not lose its prime. If the suction pipe has a leak, it can either lose liquid when the pump is off, or allow air in when the pump is running.

When the inlet of the suction pipe is below the pump, the pump's performance is reduced. Lifting liquid on the suction side restricts flow. Do not lift liquid higher than necessary and always use a free-flowing foot valve, suction pipe and strainer if you must do so.

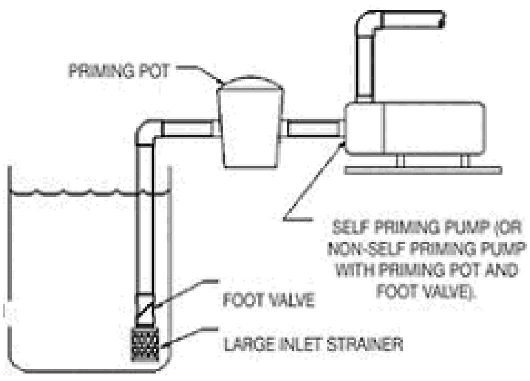


Figure 13 Non-Self-Priming Pump

Understanding Cavitation

Cavitation is a major problem to centrifugal pumps. Bubbles take up space so the flow capacity (performance) of the pump drops. Cavitation means cavities or holes in a liquid. Another name for a hole in a liquid is a bubble, so cavitation is all about bubbles forming and collapsing. Figure 14 shows the effect of cavitation bubbles on an impeller.

Collapsing bubbles can damage the impeller and volute. This makes cavitation a problem for both the pump and the mechanical seal. Cavitation happens when the suction pressure in the pump falls below the boiling pressure, or vapour pressure, of the liquid. A boiling saucepan of water on a stove is cavitating. The bubbles you see are the same phenomenon as what happens in the suction pipeline and suction eye of a pump.

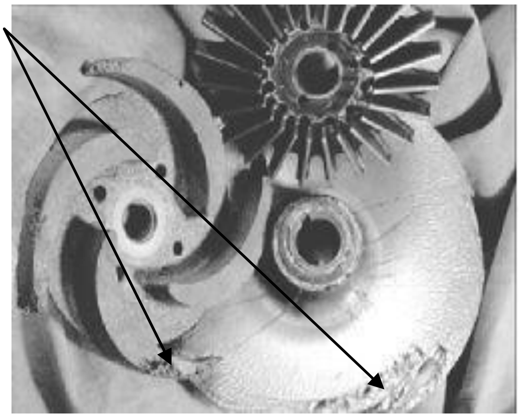


Figure 14 Cavitation Bubble Damage

Vapour pressure is about liquids boiling. Every product will boil (make bubbles) at some combination of pressure and temperature. Cavitation is the formation and collapse of vapour bubbles in the fluid being pumped. Vapour bubbles are caused by too low a pressure, below vapour pressure, or too high a fluid temperature at the pump suction/impeller eye (i.e. the fluid reaches a partial boiling condition, like the boiling saucepan mentioned previously). As the fluid moves along the pump impellers vanes, the rise in pressure causes the vapour bubbles to collapse. Implosions of these vapour pockets can be so rapid that a rumbling/crackling noise is produced (it sounds like pebbles passing through the pump).

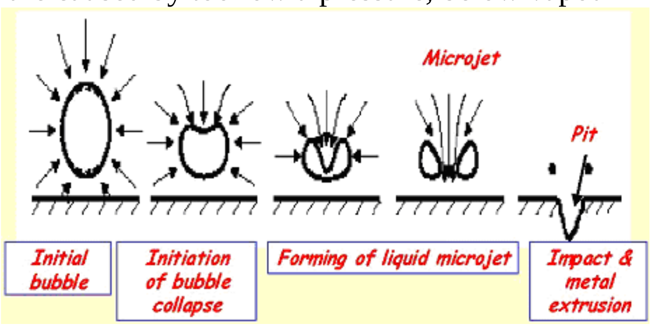


Figure 15 - Cavitation Bubbles Collapsing

When the bubbles collapse the liquid microjet reached sonic speeds. The collapsing vapour bubbles can cause:

- Pitting of metal surfaces
- Vibration and Noise
- Reduced pump capacity

To cure or avoid cavitation problems you need to check for some of the following conditions:

- Check the liquid level in the supply tank is sufficient
- Checking for a collapsed supply line (if rubber hosing or tube)
- Check for a blocked suction strainer
- Check that supply tank is venting properly
- Check for a stuck, broken or closed valve restricting the suction line
- Check for a clogged suction pipeline

Some important pumping concepts:

- **Air-Locking** - occurs when air is trapped at high points in piping that has dips, such as "dog-legs". It is important to bleed-off and expel any air when using pipelines that have dips, as this can prevent the pump from getting its 'prime'.

- **Priming** - centrifugal pumps are not self-priming and must be primed by filling them with liquid otherwise pumping will stop, and the shaft seal will probably burn out.

- **Cavitation** – is the formation and collapse of vapour bubbles in the fluid being pumped. Vapour bubbles are caused by too low a pressure, below vapour pressure, or too high a fluid temperature at the pump suction/impeller eye. Collapsing bubbles result in pump damage. (It sounds like a rumbling/crackling noise).

- **Dead Heading** - occurs when the discharge of the pump is closed off by a closed valve or a blockage. This condition must be especially avoided for too long as the liquid will heat up and boil. Pumps have exploded from the super heated pressure caused by running a pump with the discharge valve accidentally shut.

- **Dry Running** – it is important not to run pumps dry as this can cause catastrophic damage to pump components, especially pump seals.

<u>Starting-up a Centrifugal Pump</u>

There is a preferred sequence of starting centrifugal pumps.

1. Check that there is a supply of process liquid from the tank/sump.
2. Where applicable heck the supply of cooling/flushing fluid to the stuffing box or mechanical seal is on and getting all the way to the pump.
3. Open fully all the pump valves in the suction circuit – including valves at both the pump and the tank. (The suction line valves must always be fully open)
4. Open fully the pump delivery/discharge circuit valves throughout the pipeline. (If you have to regulate pump pressure or flow then do it with the discharge valve nearest the pump.)
5. Open bleed valves to remove air from the system and vent potential air-locks. Use local vent valves at high points and then shut after venting.
6. Flood the pump and ensure the pump is primed. Priming can be confirmed by checking that the tank level is higher than the pump discharge flange – this may be done by eye or by process control instrumentation levels.
7. Close the air bleed valves.
8. Bump-start the pump briefly to check the direction of rotation is correct. The rotation should be indicated by an arrow on the pump or drive motor - if not check the operating manual.

9. Start the pump and check that pumping occurs by observing a fall in the source tank level.
10. Finally, prove the pump is operating correctly:
    - Look for leaks, including pipe work and flanges.
    - Check for vibration or abnormal noise (e.g. rattling cavitation sounds or out of balance impeller, rubber from drive couplings, etc).
    - Where applicable see that stuffing box/mechanical seal is getting coolant.
    - Note that pump amps and discharge pressure is within normal range (refer to the plant operating manuals).

Note:

- In all cases avoid blockage of flow to the pump suction because this may cause 'cavitation' due of too much vacuum. Absolutely keep suction pipelines and strainers clean.
- Don't run pumps with a closed discharge valve, as this causes over-heating and will damage the pump and hurt people when the pump explodes when the liquid boils inside the pump.
- There is much debate over whether to start a pump with the discharge valve closed or open. Starting the pump with the discharge valve closed allows the motor to start unloaded, as no liquid is flowing. Once the motor is running the outlet valve is gradually opened and the motor gradually loaded. Starting the pump with the discharge valve open causes the motor to start under the load of the liquid. The start-up surge of liquid can also produce pressure hammer in the piping. However, where the motor and power supply has been designed for a fully loaded starting condition, and no pressure hammer occurs, there is no need to shut the discharge valve. Electric motor soft starters that ramp-up the motor speed can also be fitted.

Shutting-Down a Centrifugal Pump

- Unless automatically process controlled, stop the pump once the source tank level has reached the minimum or empty level.
- If the tank must be completely emptied then wait until pump cavitation can be heard and then slowly close the discharge valve, and then immediately stop the pump. This should be monitored closely as catastrophic pump damage can occur if cavitation goes on for more than a few seconds.
- After the pump has been stopped, the discharge circuit valves should be closed.
- The suction circuit valves should also be closed.
- Open the drain valve to release any remaining fluid from the pump if it will be not be operational for long periods of time (most fluids will cause internal corrosion in time). The correct drainage procedures should be followed safely.
- Where applicable turn off the cooling/flushing fluid to the seal.

Most Likely Failure Modes Causes, Prevention and Corrective Actions

There are several key factors that must be confirmed to insure successful equipment operation.

Troubleshooting

Once the pump has been started and is in operation, any problems or abnormal events can be diagnosed by referring to the following general troubleshooting guidelines.

Common Problems in Centrifugal Pump Operation	
Problem	**Possible Causes**
No Liquid Delivered	- Pump not primed

	- Inlet pressure too low
	- Suction line strainer clogged
	- End of suction line not submerged
	- System total head higher than pump total head at zero capacity.
Pump Delivers Less Than Rated Capacity	- Air leak in suction line or pump seal
	- Inlet pressure too low
	- Suction line strainer partially clogged or of insufficient area
	- System total head higher than designed
	- Partially clogged impeller
	- Impeller rotates in wrong direction
	- Suction or discharge valves partially closed
	- Impeller speed too low
	- Impeller installed in reverse direction.
Loss of Prime While pump is Operating	- Water level falls below the suction line intake, check tank level
	- Air leak develops in pump or seal
	- Air leak develops in suction line
	- Water vaporizes in suction line.
Pump is Noisy	- Cavitation, the pump is starving
	- Misalignment of pump and driver
	- Foreign material inside pump
	- Bent shaft
	- Impeller touching casing
	- Pump has come loose from its base
Pump Takes Too Much Power	- Impeller speed too high
	- Shaft packing too light
	- Misalignment
	- Impeller touching casing and dragging
	- System total head too low causing the pump to deliver too much liquid
	- Impeller diameter too large
	- Impeller installed in wrong direction.
Motor runs Back / Reverse Rotation	- Phase Drop Out, a “humming” noise can be heard when single phasing occurs.
	- Phase Rotation

On-Site Test, Workshop or Lab Test of an Installation and Learning Assessment

It is now time to do some 'hands-on' training in the field, or with a spare, or on the test-bench. To thoroughly understand this topic it is best to see what happens in a working situation and practice by making and controlling changes. You will better understand what the equipment does, and how to run it well, if you can operate it. Locate suitable equipment in your plant that you will be allowed to adjust and inspect.

1. Locate the manufacture's operating manual if available or find it on-line over the Internet. Take the time to read it. Tag anything you don't understand and come back to it at the end of the training to see if you come to know what they mean.

2. Hand-sketch below the equipment installation at your workplace and write the name of the individual equipment items on the sketch. If there is more equipment used in the station than the minimum basic design shown previously, write down what each extra item of equipment is used for in the space under the drawing.

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3. Close Inspection

3.1. Get a centrifugal pump, open it and look inside. If that isn't possible get a manufacturer's manual to use. Using the manufacture's manual name and describe each equipment part.

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3.2. Write a short description of how the pump is built and how it is designed to work.

3.3. Describe how to set the pump up for start-up operation in your facility.

4. If at all possible, and once you have supervisor permission, operate the equipment to see what effects happen as the operating conditions change. If you cannot operate a real item of equipment, then describe as best you can using information from your reading and discussion with others, what will happen to the process due to the change.

4.1. Start-Up Conditions.

Flood the pump and start it with the discharge valve closed; describe what see and hear, and how much the pressure changes, upstream and downstream of the pump once it is up to full speed. After a minute maximum, slowly open the discharge valve fully, and note what changes.

4.2. Suction Loss.

With the pump running, slowly shut the downstream isolation valve, as if there were a blockage. Describe what you hear and what you see happening with the suction and discharge pressures. As soon as cavitation sound starts, open the valve back to the fully open position.

5. Possible Modes of Failure

5.1. List the ways that centrifugal pumps have failed to perform properly at your workplace. Talk to the experienced operators and maintainers if necessary.

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5.2. Getting the Equipment Back to Proper Operation.

For each failure mode listed above, describe in detail what needs to be done to correct them.

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This is the end of this training. Please record the following details and hand your answers back to the supervisor in charge of this training.

Trainee ______________________________ **Signature** ___________________________
(Print Name) (Trainee)

Supervisor ____________________________ **Signature** ___________________________
(Print Name) (Supervisor)

Assessment Result: ☐ Pass

☐ Repeat

Completion Date __________________ 'Pass' recorded in the Trainee's training records ☐

Pump Terminology

Air-Lock – air trapped at high points in piping that has dips, usually due to horizontal piping arrangements having excessive dog-legs.

Cavitation - Process in which small bubbles are formed and implode violently, occurs when the inlet pressure falls below the vapour pressure, NPSHa < NPSHr. (See Note 'A')

Dead Head - The ability of a pump to continue running without damage when discharge is closed off. Only recommended for less than one minute for centrifugal pumps.

Discharge Head - The outlet pressure of a pump in operation.

Flooded Suction - Liquid flows to pump inlet from an elevated source by means of gravity. Recommended for centrifugal pump installations.

Flow - A measure of the liquid volume capacity of a pump.

Fluids - Include liquids, gases, and mixtures of liquids, solids, and gases. The terms fluid and liquid are both used to mean a pure liquid or a liquid mixed with gases or solids that acts essentially like a liquid in pumping applications.

Head - A measure of pressure, expressed in meters of head for centrifugal pumps. Indicates the height of a column of water being moved by the pump.

NPSHr - (Net Positive Suction Head Required) determines the required suction head (maximum suction lift). It is inherent to the design of the pump and is measured in meters of water. (See Note A)

NPSHa - (Net Positive Suction Head Available) is determined by the pipe system on the suction (inlet) side of the pump. (See Note A)

Pressure - The force exerted on the walls of a tank, pipe, etc., by a liquid.

Prime - Charge of liquid required to begin pumping action when liquid source is lower than pump. Held in the pump by a foot valve on the intake line, or by a valve or chamber within the pump.

Seal Chamber/Stuffing Box - a chamber, either integral with or separate from the pump case housing that forms the region between the shaft and casing where sealing media are installed for the primary function of protecting the pump against leakage. When the sealing is achieved by means of a mechanical seal, the chamber is commonly referred to as a Seal Chamber. When the sealing is achieved by means of a packing, the chamber is referred to as a Stuffing Box.

Seals - Devices mounted in the pump housing and/or on the pump shaft that prevent leakage of liquid from the pump. (See Mechanical Seal / Packing Seal training)

Mechanical Seal – eliminates the problem of excessive stuffing box leakage by means of a rotating seal assembly affixed to the pump shaft. A static seal is formed between the two seal faces and the sleeve. When a seal wears out causing intolerable leakage, it is simply replaced.

Packing Seal – the packing material is held in place by the stuffing box gland and compressed to form sealing against the shaft. During operation tightening the glands may be required to prevent leakage. It is important to do this gradually and evenly to avoid excessive shaft friction.

Self-Priming - Pumps that draw liquid up from below pump inlet (suction lift), as opposed to pumps requiring flooded suction.

Strainer - device installed in the inlet of a pump to prevent foreign particles from damaging the internal parts.

Sump - A well or pit in which liquids collect below floor level; sometimes refers to an oil or water reservoir.

Total Head - Sum of discharge head minus the suction head.

Valves:

Bypass Valve - internal to many pump heads that allow fluid to be recirculated if a given pressure limit is exceeded.

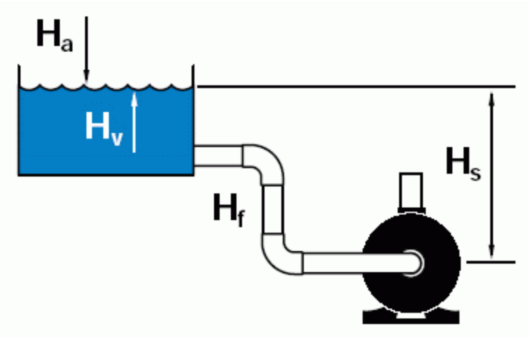
Check Valve - allows liquid to flow in one direction only. Generally used in discharge line to prevent reverse flow.

Foot Valve - a type of check valve with a built-in strainer. Used at point of liquid intake to retain liquid in system, preventing loss of prime when liquid source is lower than pump.

Relief Valve - used at the discharge of a positive displacement pump. An adjustable, spring-loaded valve opens when a preset pressure is reached. Used to prevent excessive pressure build-up that could damage the pump or motor.

<u>Note A:</u>

You must configure your system so NPSHa ≥ NPSHr (the head available from the system is greater than the head the pump requires). Failure to meet this requirement will cause reduced flow rate, cavitation, and vibration of the pump.



NPSHa = Ha + Hs - Hv - Hf

Ha = pressure on the liquid surface in the supply tank
Hs = suction head (+) or suction lift (-)
Hv = vapour pressure
Hf = friction loss in the suction piping