Reliance
Industries Limited
Hazira Manufacturing Division

Summer Internship Project Report

"Study of Centrifugal Pumps and Comparison of different Overhung Pumps used @RIL HMD Complex with API Standard 610, with Proposed Improvement Strategies focusing on Pump reliability."

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ACKNOWLEDGEMENT

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I also express my heartfelt thanks Mr. Dhaval A. Patel for his patience and clarity in explaining plant operations and processes, helping me strengthen my conceptual foundation.

My thanks also go to the Rotary Team and Central Engineering Services for their support and for providing a professional environment conducive to learning.

Finally, I gratefully acknowledge the Department of Mechanical Engineering at NIT Rourkela, for equipping me with the academic foundation that enabled me to navigate this learning experience effectively.

PROJECT TITLE

Study of Centrifugal Pumps and Comparison of different Overhung (OH) pumps used @RIL HMD Complex with API Standard 610, with Proposed Improvement Strategies focusing on Pump reliability.

PROJECT SCOPE

- Study the construction and working procedures of centrifugal pumps used @RIL Hazira Complex.
- Study technical data for selected OH pumps and compare the key parameters of these pumps with API Standard 610.
- Identify deviations and suggest possible improvements based on the analysis.

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EXECUTIVE SUMMARY

This project, titled "Study of Centrifugal Pumps and Comparison of OH Pumps with API 610 Standards with Focus on Engineering Improvements," was carried out during a summer internship at Reliance Industries Ltd., Hazira. It involved the technical assessment of three OH-type centrifugal pumps against API 610 guidelines covering constructional features, performance parameters, and material specifications.

The study began with a theoretical overview of centrifugal pumps, their working principles, and classification. Each pump's datasheet was analyzed to identify compliance or deviation from API 610 in areas such as casing type, bearing arrangement, flow vs. BEP, shut-off head, MCSF, and material class.

While most parameters met the standard, deviations like excessive impeller trimming, low MCSF, and non-standard bearing combinations were observed. These were technically justified and improvement strategies were proposed — such as speed optimization, material surface treatments, and use of smaller casing frames.

To extend the project's value, several engineering innovations were suggested:

- Modular impeller hub to avoid frequent trimming,
- Self-regulating bypass system for MCSF protection,
- AI-based compliance & health monitoring using real-time sensor data,
- A Compliance Gap Table to flag missing API-critical parameters.

Overall, the project bridges practical pump evaluation with future-oriented reliability and design enhancement strategies, contributing to safer and more efficient pump operation in line with API 610 and Industry readiness.

1. About Reliance Industries Limited

Reliance Industries Limited (RIL), founded in 1966 by Dhirubhai Ambani and headquartered in Mumbai, is one of India's largest and most diversified conglomerates. Under the leadership of Mukesh Ambani, it operates across sectors including petrochemicals, refining, oil & gas, retail, telecommunications, and renewable energy.

RIL owns the world's largest refining complex in Jamnagar and is a major producer of polymers, polyesters, and fiber intermediates. Its telecom arm, Jio Platforms, has revolutionized India's digital landscape and is now expanding into 5G and broadband. Reliance Retail is the country's largest retail network with over 18,000 stores.

The company is investing heavily in clean energy, committing ₹75,000 crores toward solar, wind, and hydrogen projects, with a target of net-zero emissions by 2035. Strategic partnerships with global players like Google, Facebook, and BP further bolster its digital and energy ambitions.

Looking forward, RIL aims to expand its 5G infrastructure, strengthen retail leadership, and invest in next-gen technologies like AI, cloud computing, and fintech.

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1.1 History of Reliance Industries Limited:

1960–1980: Reliance was founded by Dhirubhai Ambani in the 1960s as Reliance Commercial Corporation, Reliance started as a textile business with Vimal becoming a major brand. The first manufacturing unit was set up in Naroda, Gujarat.

1981–2000: The company was renamed as Reliance Industries Ltd.(RIL) in 1985. The Hazira petrochemical plant was commissioned in 1991-92 and the world's largest refinery in Jamnagar was built by 2000. The Company entered the LPG market through Reliance Gas.

2001–Present: RIL merged with Indian Petrochemicals Corporation Ltd. (IPCL) in 2007, adding major petrochemical facilities in Vadodara, Nagothane, and Dahej. Developed the Dahej complex around rich oil and gas reserves and strategic raw material access.

1.2 Reliance Industries—A Global Leader in Chemicals

- Operates one of the world's most integrated refining and petrochemical complexes in Jamnagar, Gujarat.
- Has multiple chemical manufacturing units across Hazira, Dahej, Vadodara, and Nagothane.
- Produces a wide range of chemicals used in packaging, textiles, automotive, agriculture, and consumer goods.
- India's largest producer of polymers like Polyethylene(PE), Polypropylene(PP), and Polyvinyl Chloride(PVC).
- World's largest integrated polyester producer, manufacturing Polyester Staple Fiber(PSF) and Purified Terephthalic Acid(PTA).
- Major producer of synthetic rubbers- Polybutadiene Rubber(PBR), Styrene-Butadiene Rubber(SBR) and Aromatics (Benzene, Toluene, Paraxylene).

- Incorporating renewable energy and hydrogen into chemical production.
- Exports to 100+ countries, with strong domestic supply capabilities.
- Among the top global petrochemical players, contributing significantly to RIL's revenue and growth.
- Plans to expand capacity, develop eco-friendly alternatives, and strengthen global partnerships in specialty and performance chemicals.

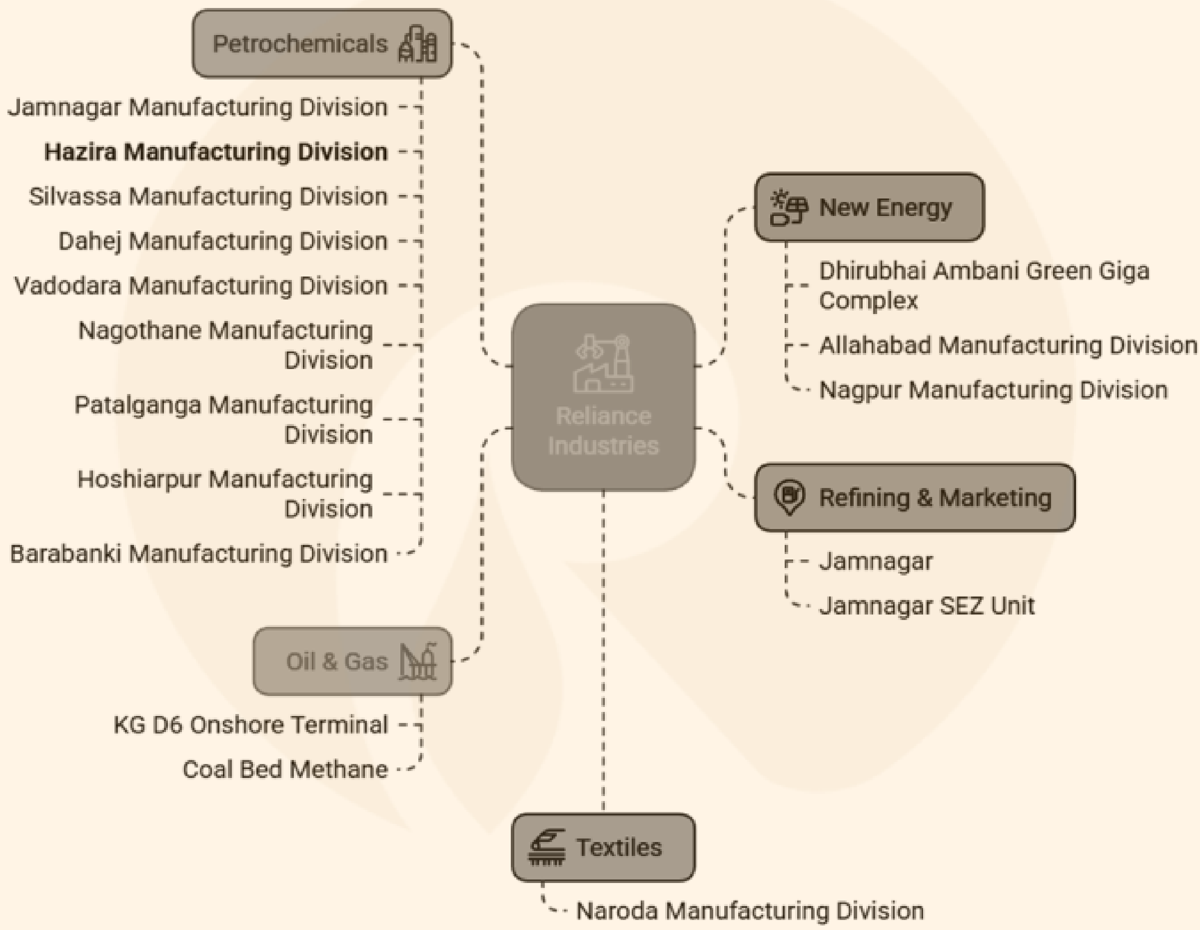


Figure 1—RIL Manufacturing Locations

2. Overview of Hazira Manufacturing Division

Established in 1991 with the Mono-Ethylene Glycol (MEG) plant, Hazira Manufacturing Division(HMD) expanded rapidly with the commissioning of PVC-VCM and Polyethylene plants in 1992. The key facility, the Naphtha Cracker plant, began operations in 1997, forming the heart of the integrated petrochemical complex.

Currently, HMD Complex operates with over 20 plants including Polyethylene (PE-1, PE-2), Polypropylene (PP), MEG (three units), Terephthalic Acid (PTA-1, 2, 3), Butadiene Rubbers (SBR, PBR), Butene, Aromatics, Polyester Staple Fiber (PSF), Partially Oriented Yarn (POY), and an Effluent Treatment Plant (ETP).

Power is supplied by two plants: a gas-based Captive Power Plant (CPP) and a coal-based Captive Cogeneration Power Plant (CCPP) installed in 2015, featuring four 90 MW turbines and five 500 TPH Circulating Fluidized Bed Combustion (CFBC) boilers. Biomass is partially blended with coal to enhance sustainability. Storage facilities include two Tank Farms and warehouses for product handling.

The process at Hazira begins with the Naphtha Cracker, which breaks down naphtha into ethylene and propylene—two essential building blocks. Ethylene is further used to produce Mono-Ethylene Glycol (MEG) for polyester fibers and antifreeze, Vinyl Chloride Monomer (VCM) for making Polyvinyl Chloride (PVC), and Paraxylene (PX), which is used to make Purified Terephthalic Acid (PTA).

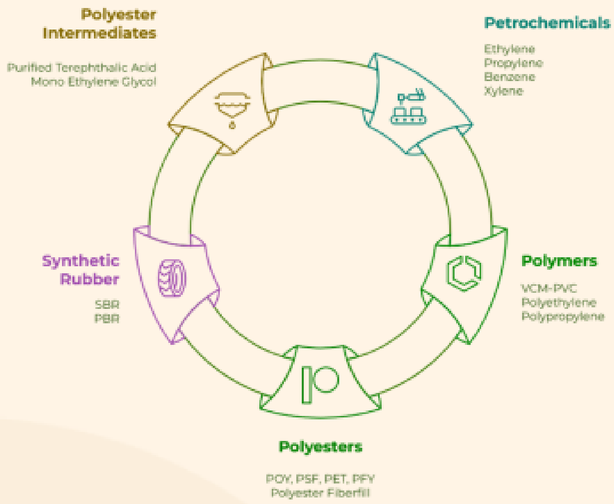


Figure 2—Products @HMD Complex

Propylene is primarily converted into Polypropylene (PP), a versatile polymer used in packaging, automotive, and consumer goods. The C_4–C_6 stream from cracking yields butadiene, which is processed into synthetic rubbers like Polybutadiene Rubber (PBR) and Styrene-Butadiene Rubber (SBR), essential for tire and industrial applications.

The aromatics stream (benzene, toluene, xylene) is further processed into PX and PTA, which combined with MEG, produce polyester fibers and resins.

HMD's products serve various industries including textiles (POY, PSF), construction (PVC), and automotive (PBR, SBR), reflecting Reliance's focus on innovation, efficiency, and sustainability.

Figure 3— Hazira Manufacturing Division Layout

3. Pumps- Introduction & Classification

3.1 Introduction to Pumps:

A pump is a mechanical device used to transfer fluids—liquids or gases—from one location to another. It plays a critical role in various industrial, domestic, and commercial applications. Pumps are primarily used to:

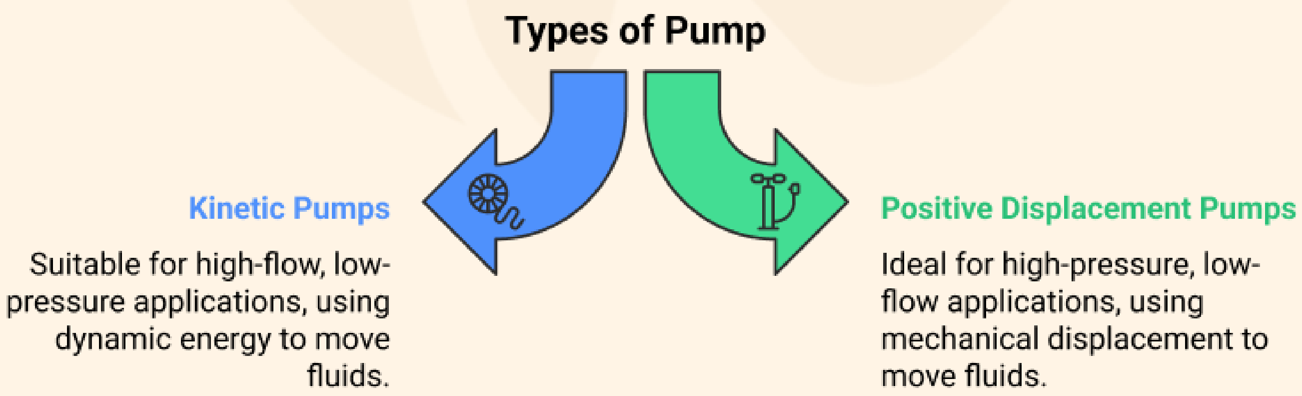
- Move fluids from a lower level to a higher level.
- Enable flow from regions of low pressure to high pressure.
- Transport fluids over long distances through pipelines.

Pumps are the fundamental devices in ensuring efficient fluid handling across sectors like oil & gas, water treatment, chemical processing, and manufacturing.

3.2 Classification of Pumps:

Pumps are primarily divided into 2 types:

1. Kinetic Pumps
2. Positive Displacement Pumps



1. **Kinetic Pumps-** operate on the principle of continuous energy addition. The key features of kinetic pumps are:

- *Continuous Energy Addition:* These pumps continuously add energy to the fluid, allowing for a steady flow.

- *Conversion of Added Energy:* The energy added to the fluid is converted into kinetic energy, which results in an increase in the fluid's velocity.

- *Pressure Increase:* As the velocity of the fluid increases, this kinetic energy is then converted into pressure, enabling the fluid to be transported through the system.

Kinetic pumps are commonly used where a constant flow rate is required, such as in water supply systems and cooling systems.

2. **Positive Displacement Pumps-** rely on periodic energy addition. The main features of this type of pump include:

- *Periodic Energy Addition:* These pumps add energy to the fluid in discrete amounts, rather than continuously.

- *Fluid Displacement:* The added energy forces the displacement of fluid within an enclosed volume, effectively moving the fluid from one location to another.

- *Direct Pressure Increase:* The displacement of fluid directly results in an increase in pressure, making these pumps ideal for applications requiring high pressure.

Positive displacement pumps are often used in scenarios where precise flow control is necessary, such as in hydraulic systems and chemical processing.

A broader classification of pumps is shown below:

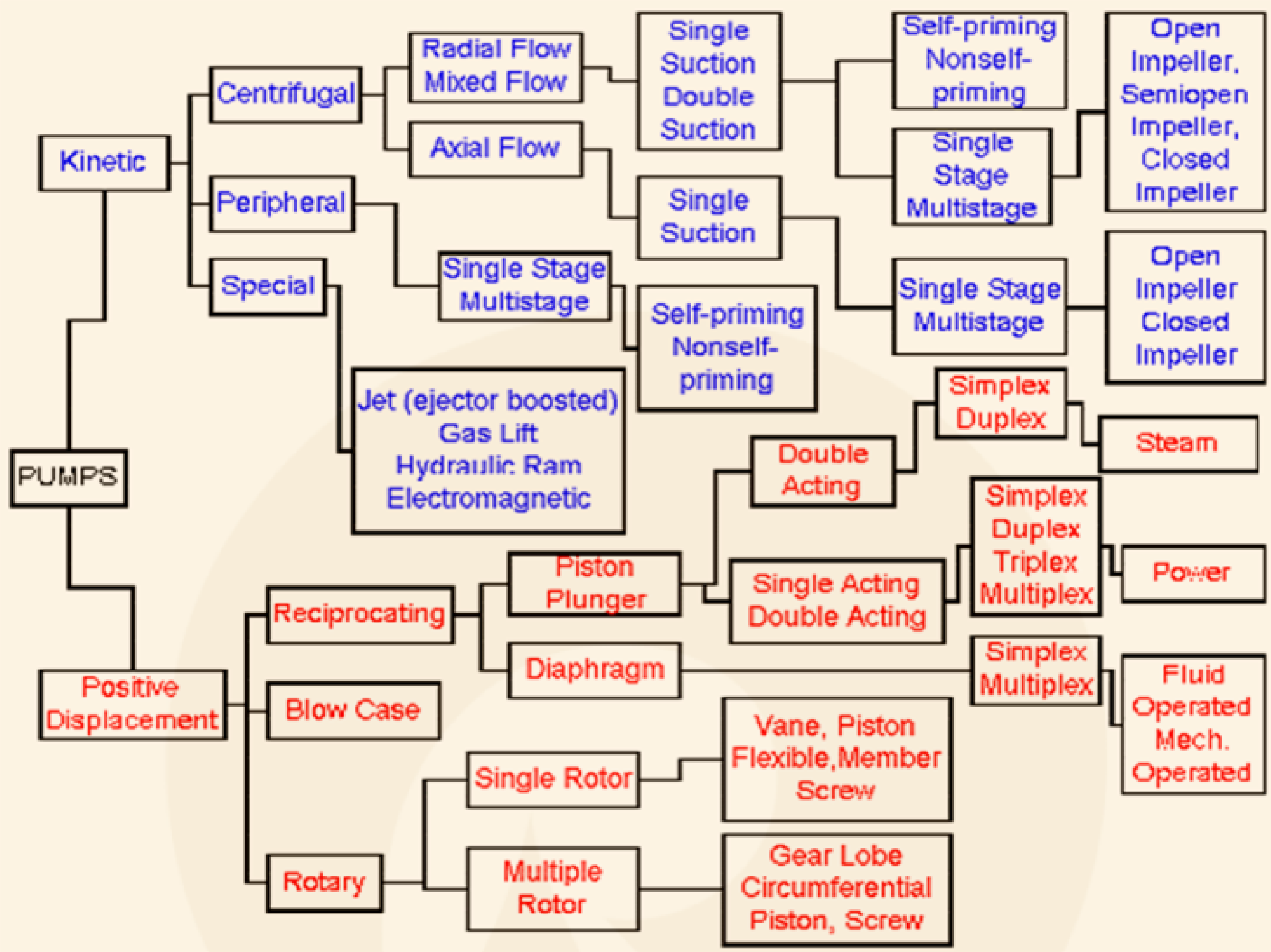


Figure 4—Classification of Pumps

4. Centrifugal Pumps- Introduction & Classification

4.1 Introduction to Centrifugal Pumps:

A centrifugal pump is a type of pump that uses rotational energy—typically from an electric motor—to move fluid. It operates on the principle of centrifugal force: fluid enters the pump impeller at the center (impeller eye), gets accelerated by the rotating impeller blades, and is pushed outward to the periphery into the discharge pipe.

- It consists of a set of rotating vanes, enclosed within a casing.
- it is used to impart energy to a fluid through centrifugal force.
- Liquid is forced by atmospheric or other pressure into a set of rotating vanes.
- Vanes constitute an impeller which discharges the liquid at its periphery at higher velocity.
- Velocity is converted into pressure energy by means of a volute or by a set of stationary diffusion vanes surrounding the impeller periphery.

4.2 Principle of Working:

Centrifugal pumps depend on kinetic energy rather than mechanical means to move liquid. Liquid enters the pump at the center of a rotating impeller and gains energy as it moves to the outer diameter of the impeller. The kinetic energy gained is converted into Pressure Energy in Volute/ Diffuser to further push into discharge pipeline. Liquid is forced out of the pump by the energy it obtains from the rotating impeller.

4.3 Introduction to API

The American Petroleum Institute (API) is a recognized body that formulates and maintains the standards of all processes and equipments to enhance their safety, efficiency, and reliability in the oil & gas and petroleum industry.

Its standards are adopted to ensure compatibility & uniformity across vendors. These guidelines help the industries maintain operational consistency, reduce risks, and improve the longevity of machinery in demanding environments.

American Petroleum Institute

One such important standard is API 610, which specifically governs the design, construction and performance parameters of centrifugal pumps used in petroleum, petrochemical, and natural gas industries. This standard ensures that pumps are suitable for continuous, high-temperature, and high-pressure applications typically found in refinery and chemical process plants.

API 610 outlines strict criteria related to materials of construction, mounting, couplings, shaft alignment, bearing systems, and sealing arrangements. It also defines rigorous testing procedures for performance and reliability. Pumps conforming to API 610 are engineered to reduce vibration, increase mean time between failures (MTBF), and facilitate easier maintenance, thereby enhancing the overall safety and efficiency of the plant. The use of API 610-compliant pumps is often a mandatory requirement in critical services where failure could lead to significant operational losses or safety hazards.

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<u>4.4 Classification of Centrifugal Pumps as per API 610:</u>

Centrifugal pumps generally are classified according to:

1. Number of stages
2. Type of mounting
3. Orientation of shaft
4. Type of casing split

<table>
<tr><th colspan="3">Pump Type</th><th colspan="2">Description</th><th>Type Code</th></tr>
<tr><td rowspan="19">Centrifugal pumps</td><td rowspan="6">Overhung</td><td rowspan="3">Flexibly coupled</td><td rowspan="2">Horizontal</td><td>Foot-mounted</td><td>OH1</td></tr>
<tr><td>Centerline-supported</td><td>OH2</td></tr>
<tr><td>Vertical in-line with bearing bracket</td><td>—</td><td>OH3</td></tr>
<tr><td>Rigidly coupled</td><td>Vertical in-line</td><td>—</td><td>OH4</td></tr>
<tr><td rowspan="2">Close-coupled</td><td>Vertical in-line</td><td>—</td><td>OH5</td></tr>
<tr><td>High-speed integrally geared</td><td>—</td><td>OH6</td></tr>
<tr><td rowspan="6">Between-bearings</td><td rowspan="3">1- and 2-stage</td><td>Axially split</td><td>Foot-mounted</td><td>BB1-A</td></tr>
<tr><td>Axially split</td><td>Near-centerline mounted</td><td>BB1-B</td></tr>
<tr><td>Radially split</td><td>Centerline supported</td><td>BB2</td></tr>
<tr><td rowspan="3">Multistage</td><td>Axially split</td><td>Near-centerline supported</td><td>BB3</td></tr>
<tr><td rowspan="2">Radially split</td><td>Single casing</td><td>BB4</td></tr>
<tr><td>Double casing</td><td>BB5</td></tr>
<tr><td rowspan="7">Vertically suspended</td><td rowspan="5">Single casing</td><td rowspan="3">Discharge through column</td><td>—</td><td>VS1</td></tr>
<tr><td>—</td><td>VS2</td></tr>
<tr><td>—</td><td>VS3</td></tr>
<tr><td rowspan="2">Separate discharge pipe</td><td>Line shaft</td><td>VS4</td></tr>
<tr><td>Cantilever shaft</td><td>VS5</td></tr>
<tr><td rowspan="2">Double casing</td><td rowspan="2">Radially split</td><td>—</td><td>VS6</td></tr>
<tr><td>—</td><td>VS7</td></tr>
</table>

Table 1—Pump Classification Type Identification according to API Standard 610.

4.5 Pump Designations and Descriptions:

- **Pump Type OH1**

  Foot-mounted, single-stage overhung pumps shall be designated pump type OH1.

  Suitable for all cold application, however, not used for API application.

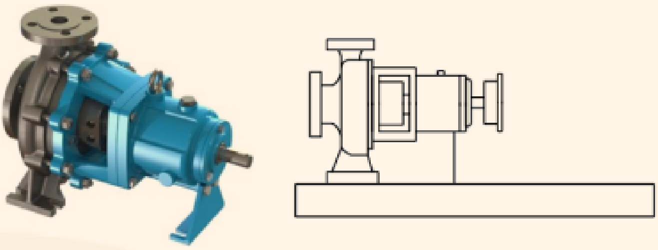


Figure 5—Pump Type OH1

- **Pump Type OH2**

  Centreline-mounted, single-stage overhung pumps shall be designated pump type OH2.

  They have a single bearing housing to absorb all forces imposed upon the pump shaft and maintain rotor position during operation.

  The pumps are mounted on a baseplate and are flexibly coupled to their drivers.

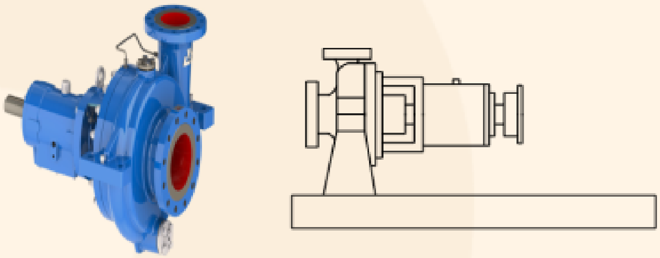


Figure 6—Pump Type OH2

- **Pump Type OH3**

  Vertical, in-line, single-stage overhung pumps with separate bearing brackets shall be designated pump type OH3.

  They have a bearing housing integral with the pump to absorb all pump loads. The driver is usually mounted on a support integral to the pump. The pumps and their drivers are flexibly coupled.

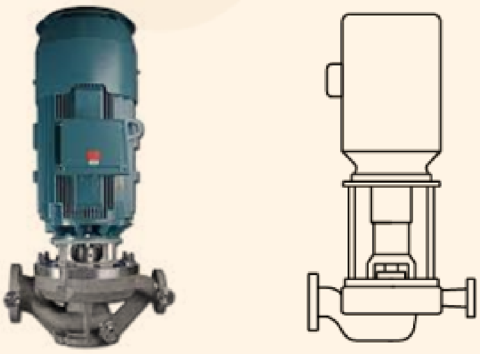


Figure 7—Pump Type OH3

- **Pump Type OH4**

  Rigidly coupled, vertical, in-line, single-stage overhung pumps shall be designated pump type OH4.

  Rigidly coupled pumps have their shaft rigidly coupled to the driver shaft.

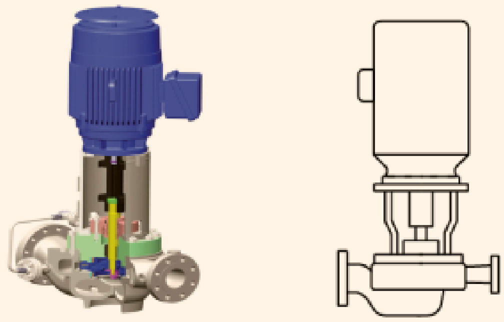


Figure 8—Pump Type OH4

- **Pump Type OH5**

  Close-coupled, vertical, in-line, single-stage overhung pumps shall be designated pump type OH5.

  Close-coupled pumps have their impellers mounted directly on the driver shaft.

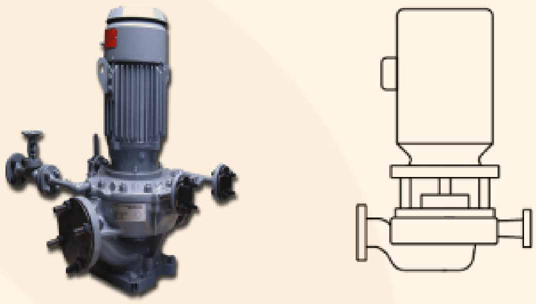


Figure 9—Pump Type OH5

- **Pump Type OH5**

  High-speed, integral, gear-driven, single-stage overhung pumps shall be designated pump type OH6.

  These pumps have a speed-increasing gearbox integral with the pump. The impeller is mounted directly to the gearbox output shaft.

  There is no coupling between the gearbox and pump; however, the gearbox is flexibly coupled to its driver.

  The pumps may be oriented vertically or horizontally.

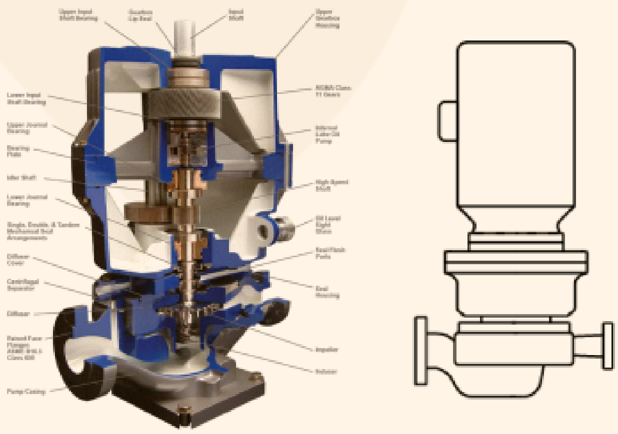
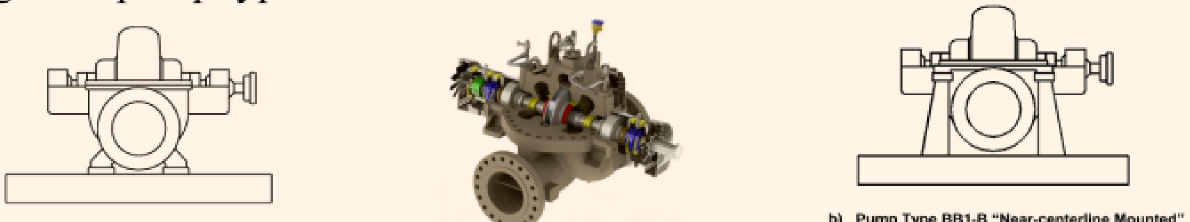


Figure 10—Pump Type OH6

- **Pump Type BB1**

  Axially split, one- and two-stage, between-bearings pumps shall be designated pump type BB1.



a) Pump Type BB1-A "Foot Mounted"

b) Pump Type BB1-B "Near-centerline Mounted"

Figure 11—Pump Type BB1

- **Pump Type BB2**

  Radially split, one- and two-stage, between-bearings pumps shall be designated pump type BB2.

  Widely used for moderate heads exceeding OH pump limits.

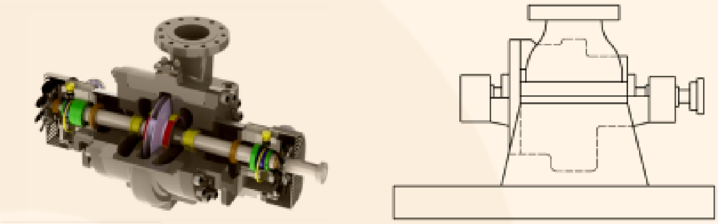


Figure 12—Pump Type BB2

- **Pump Type BB3**

  Axially split, multistage, between-bearings pumps shall be designated pump type BB3.

  Though API Limits usage up to 100 bar, practically above 70 bar, these pumps are not used.

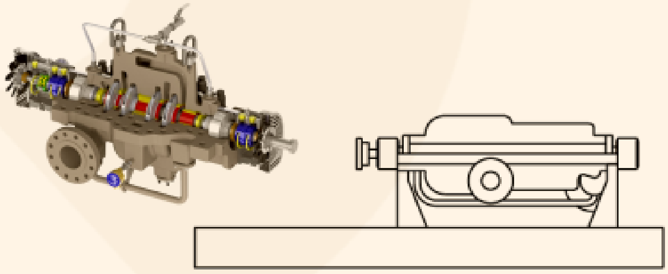


Figure 13—Pump Type BB3

- **Pump Type BB4**

  Single-casing, radially split, multistage, between-bearings pumps shall be designated pump type BB4.

  These pumps are also called ring-section pumps, segmental-ring pumps or tie-rod pumps.

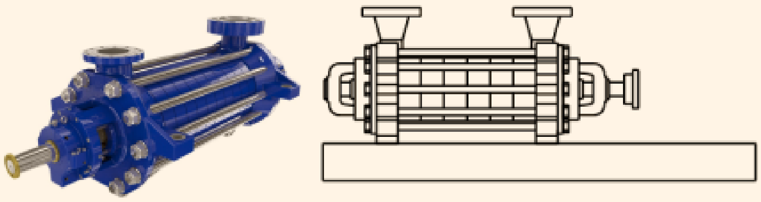


Figure 14—Pump Type BB4

- **Pump Type BB5**

  Double-casing, radially split, multistage, between-bearings pumps (barrel pumps) shall be designated pump type BB5.

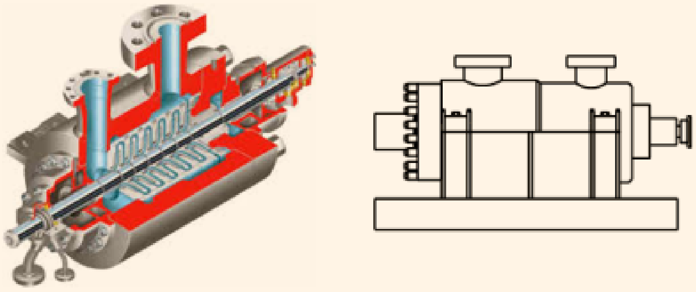


Figure 15—Pump Type BB5

- **Pump Type VS1**

  Wet pit, vertically suspended, single-casing diffuser pumps with discharge through the column shall be designated pump type VS1.

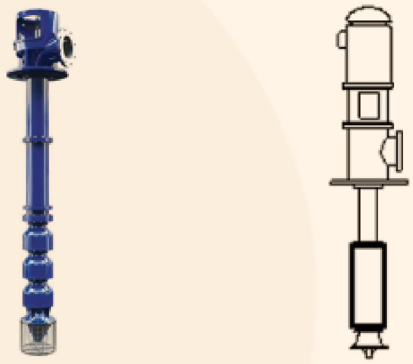


Figure 16—Pump Type VS1

- **Pump Type VS2**

  Wet pit, vertically suspended, single-casing volute pumps with discharge through the column shall be designated pump type VS2.

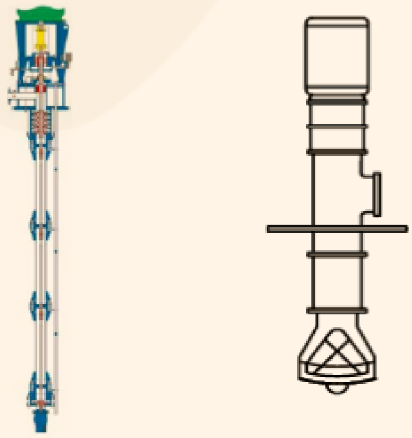


Figure 17—Pump Type VS2

- **Pump Type VS3**

  Wet pit, vertically suspended, single-casing axial-flow pumps with discharge through the column shall be designated pump type VS3.

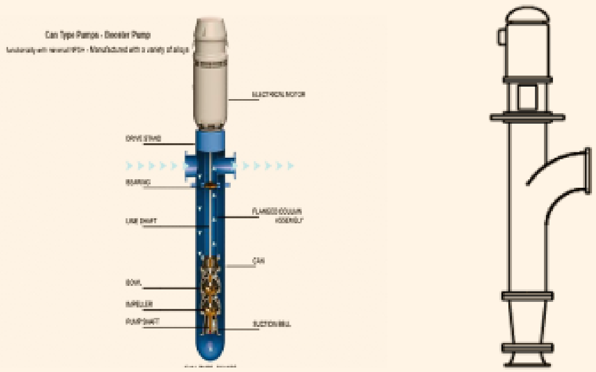


Figure 18—Pump Type VS3

- **Pump Type VS4**

  Vertically suspended, single-casing, volute, line-shaft-driven sump pumps shall be designated pump type VS4.

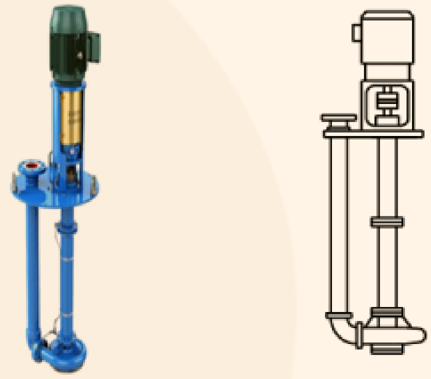


Figure 19—Pump Type VS4

- **Pump Type VS5**

  Vertically suspended, cantilever sump pumps shall be designated pump type VS5.

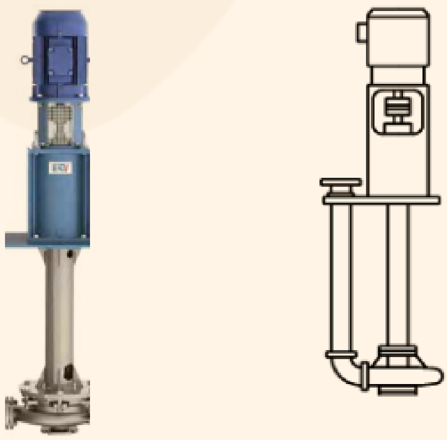


Figure 20—Pump Type VS5

- **Pump Type VS6**

  Double-casing, diffuser with vertically suspended pumps shall be designated pump type VS6.

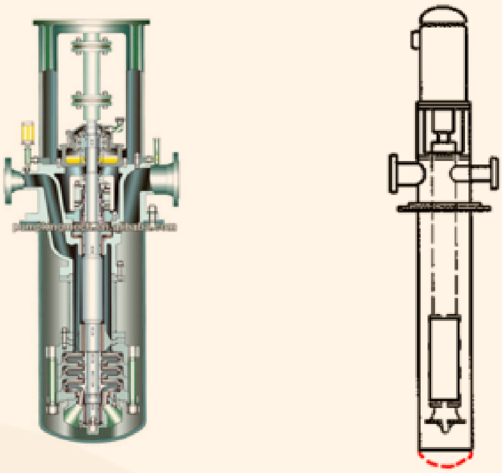


Figure 21—Pump Type VS6

- **Pump Type VS7**

  Double-casing, volute or volute plus diffuser, vertically suspended pumps shall be designated pump type VS7

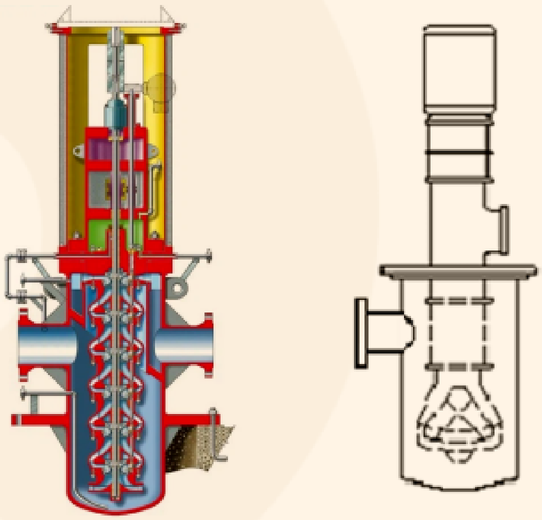


Figure 22—Pump Type VS7

5. Components of Centrifugal Pump

The main components of a centrifugal pump are:

- Casing
- Impeller
- Wear Rings
- Impeller Shaft
- Seal
- Bearings
- Coupling
- Lubrication System

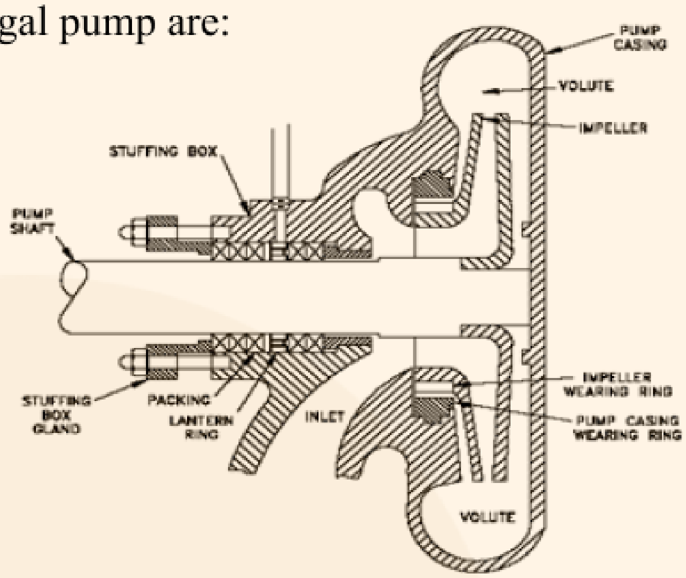


Figure 23—Parts of a centrifugal pump

- ## Casing:

It is the part of a pump within which energy is imparted to the liquid by impeller driven by prime mover.

Casings are generally of two types: **volute** and **diffuser**. The impellers are fitted inside the casings. Volute casings build a higher head while Diffuser casings are used for low head and high capacity.

Volute is a curved funnel increasing in area to the discharge port. As the area of the cross-section increases, kinetic energy of the liquid reduces and increases the pressure of the liquid.

Main purpose of a volute casing is to help balance the hydraulic forces on the shaft. Double-volute casings are used when the radial forces become significant at reduced capacities.

The figures of both types of volute are shown below:

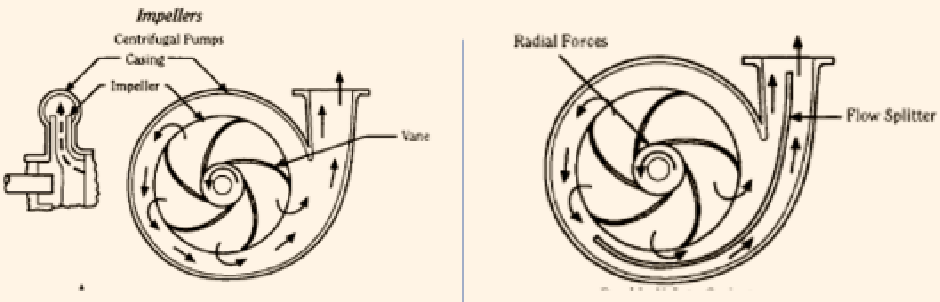


Figure 24—Single and Double volute casing

Diffuser casings have stationary diffusion vanes surrounding the impeller periphery that convert kinetic energy to pressure energy. Conventionally, the diffusers are applied to multi-stage pumps

Figure 25—Diffuser casing

- **Impeller:**

The impeller is the main rotating part that provides the centrifugal acceleration to the fluid. It is fitted inside the casing.

They are often classified in many ways:

1. Based on **major direction of flow** in reference to the axis of rotation,
- Radial flow
- Axial flow
- Mixed flow
2. Based on **suction type**,
- Single-suction: Liquid inlet on one side.
- Double-suction: Liquid inlet to the impeller symmetrically from both sides.

3. Based on **mechanical construction,**
- Closed: Shrouds or sidewall enclosing the vanes.
- Open: No shrouds or wall to enclose the vanes.
- Semi-open or vortex type.

Figure 26—Types of impellers

1. Closed Impellers
- Have shrouds on both sides of the vanes.
- Require wear rings to reduce leakage and maintain efficiency.
- Suitable for clean liquids with low solids content.

2. Open Impellers
- Vanes are exposed.
- Less likely to clog, making them good for handling solids.
- Require manual adjustment to the volute or back plate to ensure proper clearance and prevent internal re-circulation.

3. Vortex Impellers
- Designed to create a vortex that helps pass stringy or solid materials.
- Excellent for solids-handling applications.

Multi-Stage Pumps have multiple impellers arranged in series. Each impeller adds more head (pressure), making them ideal for high-head applications.

- ## Wear Ring:

It provides an easily and economically renewable leakage joint between the impeller and the casing. The clearance between the impeller wear ring and casing wear ring is maintained and if it becomes too large, the pump efficiency will be lowered causing heat and vibration problems due to flow recirculation and in the worst condition can cause the cavitation.

- ## Shaft:

The basic purpose of a centrifugal pump shaft is to transmit the power required when starting and during operation while supporting the impeller and other rotating parts, with a deflection less than the minimum clearance between the rotating and stationary parts

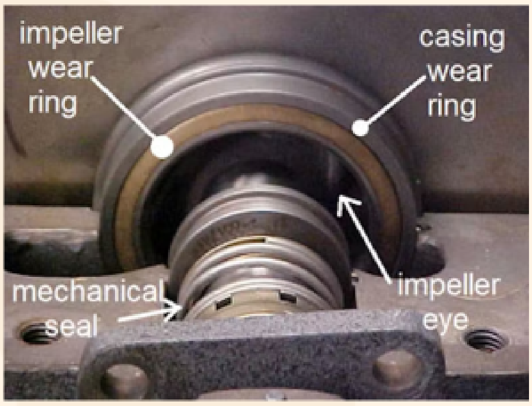


Figure 27—Wear Rings

- ## Seals:

To prevent leakage of pumping liquid to atmosphere through the clearance between rotor and casing.

Types of seal are: **Gland Packing** & **Mechanical Seals**(with different types of Seal Plans).

Gland Packing	Mechanical Seal
Low Cost	High Cost
Easy and fast maintenance	Maintenance is time consuming
Always some amount of leakage	Leakage is negligible
Wear of shaft over a period	No wear of shaft
High Friction Loss	Negligible Friction Loss
Cannot be used in hazardous application	Suitable for hazardous application

Table 2—Difference between Types of Seals

• Bearings:

Bearings play a crucial role in supporting the rotating shaft and maintaining proper alignment between the pump and driver. They absorb radial and axial loads generated during operation and ensure smooth rotation with minimal friction. The types of bearings are given below:

Based on **type of friction**— Sliding contact bearing
Roller contact bearing

Based on **direction of force acting upon them**— Radial bearing
Thrust bearing

Based on **type of rolling element used**— Deep groove ball bearing
Cylindrical roller bearing
Angular contact bearing
Self aligning bearing
Spherical roller bearing
Taper roller bearing
Thrust Ball bearing
Needle bearing

Condition	Bearing type and arrangement
Radial and thrust bearing speed and life within limits for rolling-element bearings and Pump energy density below limit	Rolling-element radial and thrust
Radial bearing speed or life outside limits for rolling-element bearings and Thrust bearing speed and life within limits and Pump energy density below limit	Hydrodynamic radial and rolling-element thrust or Hydrodynamic radial and thrust
Radial and thrust bearing speed or life outside limits for rolling-element bearings or Pump energy density above limit	Hydrodynamic radial and thrust

Table 3—Bearing selection

• Coupling:

Coupling is the mechanical element that connects the pump shaft to the driver shaft, allowing torque and power transmission while accommodating slight misalignments. It ensures that the rotation from the driver is smoothly transferred to the pump for continuous fluid flow.

Rigid Couplings— provide a solid shaft connection but require perfect alignment and can't handle misalignment.
Flexible Couplings— are widely used as they allow slight misalignment and absorb shocks. Examples: gear, grid, elastomeric.
Closed Couplings— single shaft connects the impeller as well as motor for rotation.

• Lubrication System:

Lubrication helps to reduce friction, prevent corrosion, remove wear debris, provide efficient cooling and shock absorption.

When greases?

★Normal speed and temp conditions
★Simpler / cheaper installation
★Better adhesion
★Protection against impurities
★Less frequent application required

When Oils?

★High Speed and temp
★Excellent cleaning and flushing characteristics
★Can be used in re-circulative systems
★Can serve better in excessive dirt environment
★More stable than greases

Types of Lubrication System:

- Grease Lubrication
- Oil Bath Lubrication (most commonly used for bearings)
- Ring Oil Lubrication
- Flinger *or* Slinger Disc Lubrication
- Forced Lubrication
- Oil Mist Lubrication

6. Working of Centrifugal Pumps

1. ***Suction Eye***
   - Fluid enters the pump through the suction eye located at the center of the impeller.
2. ***Impeller Rotation***
   - The impeller rotates at high speed, driven by a motor.
   - This rotation imparts kinetic energy to the fluid.
3. ***Vanes Guide Flow***
   - The vanes on the impeller push the fluid outward by centrifugal force.
   - This increases the fluid's velocity and pressure.

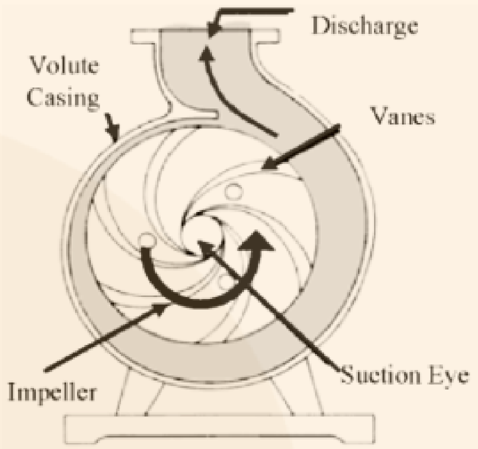


Figure 28—General Operation

4. ***Volute Casing***
   - The high-velocity fluid enters the volute casing, which has a gradually increasing area.
   - This converts the kinetic energy into pressure energy.
5. ***Discharge***
   - Finally, the fluid is directed out through the discharge nozzle at a higher pressure than it entered.

A single-stage centrifugal pump operates by converting mechanical energy into hydraulic energy to transport fluids efficiently. The process begins at the suction side, where fluid enters the pump and is directed toward the center (or eye) of the impeller. The impeller, mounted on a rotating shaft, is powered through a coupling connected to a motor. As the impeller spins, it imparts kinetic energy to the fluid, accelerating it outward through centrifugal force.

This high-velocity fluid is then guided into the volute casing, a spiral-shaped chamber surrounding the impeller. Inside the volute, the fluid's velocity energy is converted into pressure energy, enabling it to flow through the discharge pipe under high pressure. The entire transfer relies on a smooth energy conversion process, driven by the impeller's motion and the volute's design.

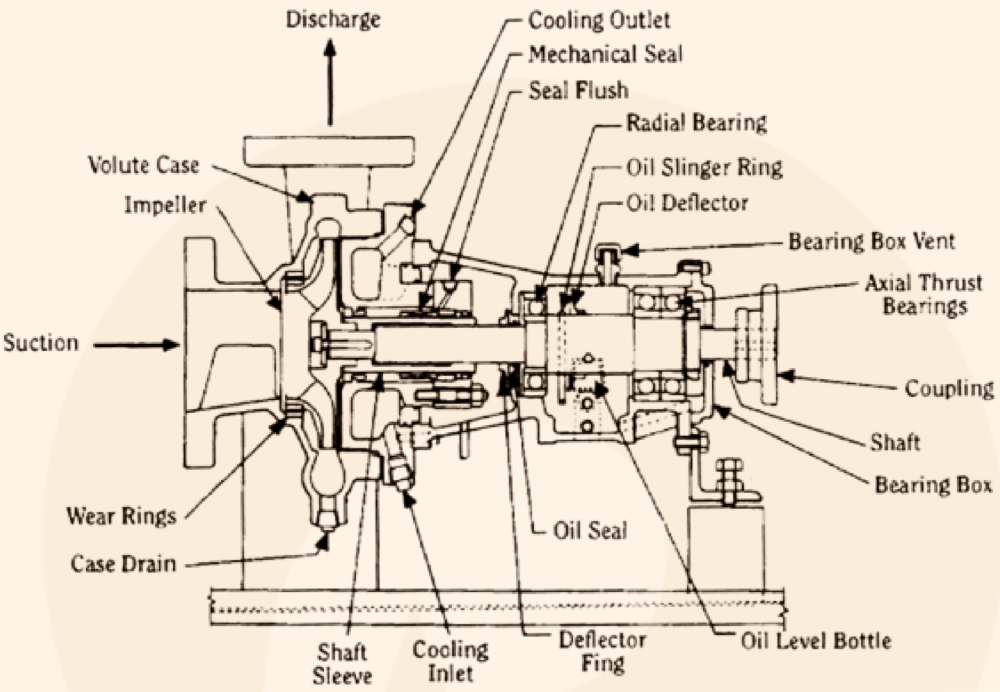


Figure 29—Cross Sectional view of a Centrifugal Pump

To prevent fluid leakage along the rotating shaft, a mechanical seal is installed. The seal is supported by a seal flush system and a dedicated cooling circuit (cooling inlet and outlet) to maintain operational temperature and prolong seal life. The shaft itself is protected by a shaft sleeve and supported by radial and axial thrust bearings housed in the bearing box. These bearings reduce friction and absorb both radial and axial loads, maintaining the alignment and stability of the rotating assembly.

Lubrication is managed through an oil slinger ring and oil deflector, which ensure even oil distribution to the bearings. An oil level bottle is used to monitor and maintain appropriate lubrication levels.

7. Forces in Centrifugal Pump

In a centrifugal pump, liquid enters through the impeller eye, moves through impeller passages, and exits via the volute casing, where kinetic energy is converted into pressure.

During this flow, the liquid applies both **radial** and **axial** forces on the rotor assembly. To manage these forces, specific design features are incorporated to balance them effectively.

Radial Forces— are sideways forces on the impeller and shaft caused by uneven fluid flow inside the pump. These forces can affect both rotating and fixed parts.

Methods to reduce radial forces: *(Refer to Figure)*

1. ***Double Volute Casing:*** The casing is split into two paths, guiding flow evenly to a common outlet. This balances forces around the impeller, reducing radial load on the shaft and bearings. It allows use of a lighter shaft, making the pump more cost-effective.

2. ***Diffuser Pump:*** A diffuser is placed between the impeller and casing. It slows down the fluid before it hits the casing, preventing sudden impact. This reduces shock and balances the radial forces smoothly.

Axial Thrust— is the unbalanced force along the shaft direction caused by pressure differences on either side of the impeller. During startup and shutdown, when fluid enters or leaves the impeller suddenly, it causes a jerk on the shaft, stressing the bearings and this leads to bearing wear or failure, reducing pump life.

Main Forces Causing Axial Thrust:

1. **F_1** – Pressure on front shroud (fluid between casing and impeller front).
2. **F_2** – Pressure on back shroud (fluid between cover and impeller back).
3. **F_m** – Force due to fluid momentum change (fluid flow direction).

These three forces combine to create total axial thrust.

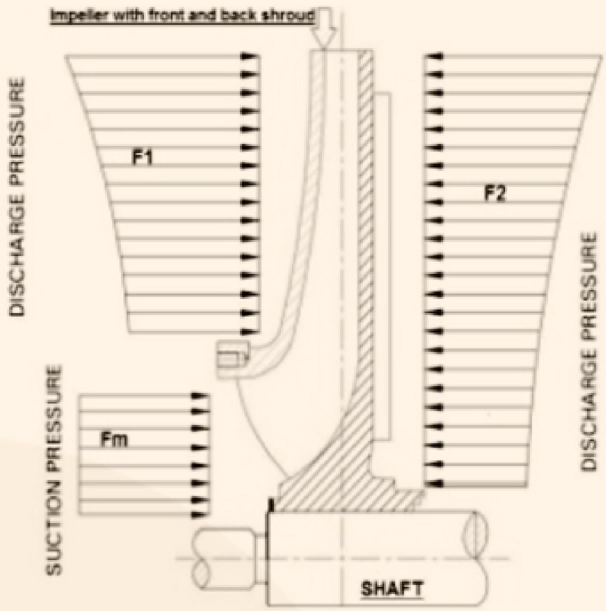


Figure 30—Axial Thrust on a Centrifugal Pump

Methods to reduce axial forces:

1. By providing ***balancing holes,*** the fluid from discharge region moves to suction region, so forces acting on impeller shroud reduces.

2. ***Back vanes*** are small radial ribs on the impeller's back side that reduce pressure behind the impeller and prevent liquid from entering the gap between the impeller and casing, helping to minimize axial thrust.

3. A ***double suction impeller*** helps balance axial thrust by allowing equal and opposite flow on both sides. However, this balance can be disturbed if the casing is asymmetrical or if there's unequal leakage through the suction sides.

4. By using ***multistage pumps*** with opposed impellers.

5. Using a ***balancing disc:*** High-pressure fluid from the last impeller stage exerts force on the balancing disc, and flows through a variable gap. The counter disc adjusts the counter thrust dynamically, maintaining balance.

8. Performance Curves for Centrifugal Pumps with related Terminologies

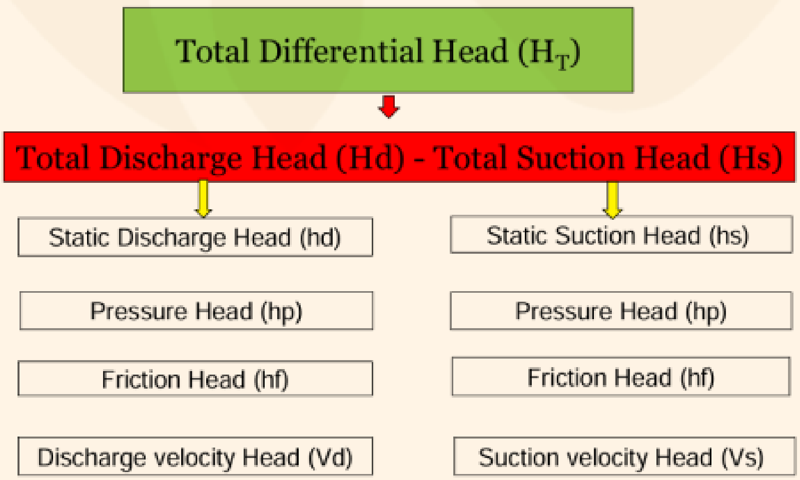
Basic Terminologies of Centrifugal Pump:

1. **Capacity:** It is the flow rate with which liquid is moved by the pumps, generally expressed in m^3/hr.

   Capacity depends on:

- Impeller geometry—width and diameter
- Impeller rotational speed RPM
- Liquid characteristics – viscosity
- Back Pressure from the System

2. **Head:** It is a measurement of the height of a liquid column that the pump could create from the kinetic energy imparted to the liquid. The reason for using head instead of pressure to measure the centrifugal pumps energy is that the pressure changes with respect to the specific gravity of the pumping fluid whereas head does not.



3. **Hydraulic Power(WKW):** Power delivered by the pump as fluid energy.

$$WKW = Q \times H \times \text{Specific Gravity}/367$$

Q = Flow rate (m^3/hr)

H = Total differential head (m)

4. **Brake Power(BKW):** Mechanical power supplied to the pump shaft.

$$BKW = Q \times H \times \text{Specific Gravity}/367 \times \eta$$

η (eta) = Pump efficiency (%)

5. **Pump Efficiency(η)=** WKW/BKW = Efficiency is the ratio of useful hydraulic power to the total mechanical power input.

6. BKW = WKW + Mechanical Losses + Hydraulic Losses

7. **Heat Generation in Centrifugal Pump**: No torque is applied to a fluid particle once it has left the impeller. The angular momentum of fluid is therefore conserved ($V\omega_r$ =constant). Velocity decreases when fluid enters the volute at higher radius. Velocity also decreases as fluid passes through increasing cross section(continuity law). These reductions results in increase in pressure(Bernoulli's principle).

Law of Continuity

$$A_1V_1 = A_2V_2$$

Bernoulli's Principle

$$P + (1/2)\rho v^2 + \rho gh = \text{constant}$$

8. **Rated Flow:** The design flow rate of pump operation.

9. **Rated Head:** The Differential head required at the rated flow.

10. **Shut off head:** Differential head at zero flow.

11. **Best Efficiency Point(B.E.P):** The flow rate at which pump achieves maximum efficiency.

1. **Maximum Efficiency Continuous Safe Flow(MCSF):** Lowest flow at which the pump can operate without exceeding the vibration limits imposed by API 610 (3.6 mm/sec).

1. **Run out flow:** maximum flow at which the pump can operate without exceeding the vibration limits imposed by API 610 (3.6 mm/sec).

1. **Preferred Operating Region:** Portion of a pump's hydraulic coverage over which the pump's vibration is within the base limit of API 610 (3mm/sec). It ranges from 70% to 120% of BEP Flow.

1. **Allowable Operating Region:** Portion of a pump's hydraulic coverage over which the pump's vibration is within the upper limit of API 610 (3.6 mm/sec). It ranges from MCSF to Run-out flow.

1. **Net Positive Suction Head(NPSH):** It is expressed as additional head required above the vapor pressure of the liquid at the pump centerline. NPSH is a measure to ensure that the pump does not cavitate (i.e., vapor bubbles don't form inside the pump, which can damage it).

What happens at the pump suction (impeller eye)?

- Liquid enters a narrowing flow area (like a Venturi).
- Velocity increases, so pressure drops due to the Venturi effect + friction.
- Lowest pressure is at the impeller eye.
- Pressure drops more as liquid hits the impeller blades.
- If pressure falls below vapor pressure, cavitation starts – vapor bubbles form.

What is Cavitation?

- Vapor bubbles form inside the liquid.
- These bubbles grow and move with the flow.
- As they reach higher-pressure areas, they collapse suddenly (implode).
- This causes micro-jets of liquid that hit the impeller surface.
- This leads to:
  - Pitting (surface damage)
  - Noise (shock waves)
  - Loss of performance
  - Possible pump failure

NPSHa (available): is a function of the system design, i.e. depends on your system (tank level, pipe size, fluid, etc.). It is the excess pressure of the liquid in meters over its vapour pressure as it arrives at the pump impeller centerline, to ensure that the pump does not cavitate. This is the **actual pressure available at the pump suction.**

NPSHa = Pressure at suction + Static head – Vapor pressure – Friction losses

NPSHr (required): This is the **minimum pressure the pump needs at the suction** to avoid cavitation. It is determined based on actual pump test by the vendor.

NPSHa >= NPSHr *(to avoid cavitation)*

NPSH3 is a Net Positive Suction Head value that indicates the point where the total head of a centrifugal pump drops by 3% due to cavitation. It is essential to determine the necessary margin to avoid cavitation.

$NPSH_3$ is the suction pressure (head) required by a pump where cavitation causes a 3% drop in pump head (i.e., output pressure/height).

- It shows how resistant a pump is to cavitation.
- Cavitation starts damaging performance at this point — even though the pump is still working.
- Vendors must test their pumps and give this value.

Measuring NPSH3:

- For horizontal pumps: from the shaft centerline.
- For vertical pumps: from the suction eye of the impeller.

The difference: $NPSHA-NPSH_3$

This margin ensures the pump won't cavitate under real conditions.

Ususally, NPSHr is referred to as NPSH3, i.e the NPSHA at which 3% flashing of fluid occurs at impeller eye.

Too low a margin increases the chances of the pump to cavitate.

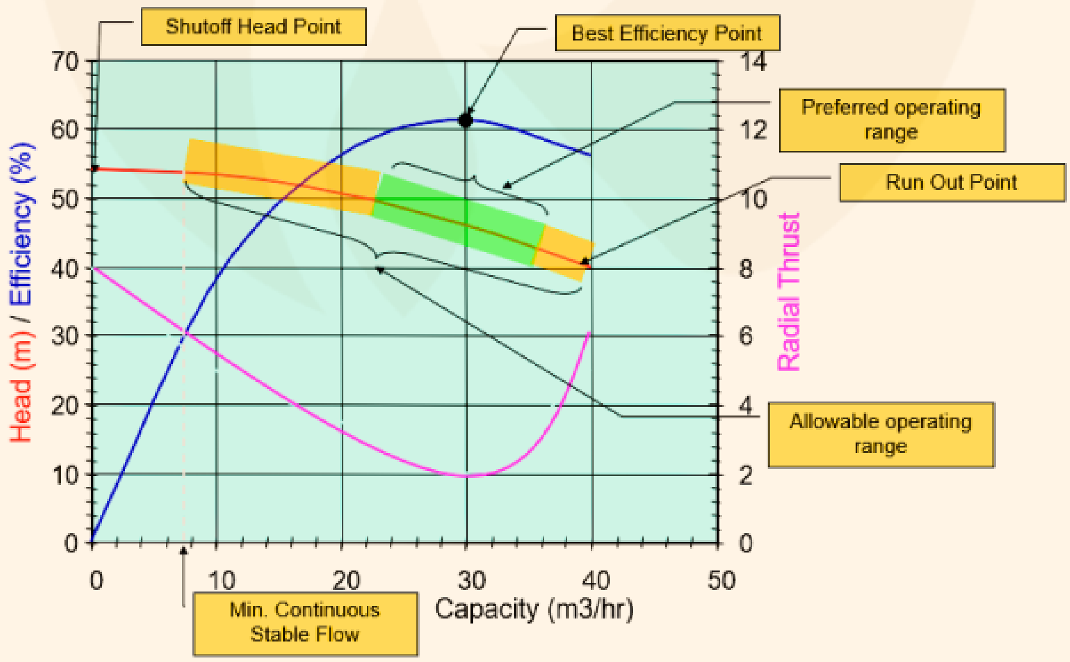


Figure 31—Performance curve of a Centrifugal Pump

1. **Specific Speed (N_s):** It is a dimensionless number that relates the speed, flow rate, and head of a pump.

$$\boxed{N_s = N.Q^{0.5}/H^{3/4}}$$

Where:
N= Pump speed (RPM)
Q = Flow rate (m^3/s or GPM)
H = Head (m or ft)

Purpose & Significance:

- Identifies impeller geometry:
  a)Low Ns → Radial flow (high head, low flow)
  b)Medium Ns → Mixed flow
  c)High Ns → Axial flow (low head, high flow)
- Helps in pump selection based on application (e.g., boiler feed, cooling water, etc.)

1. **Suction Specific Speed (N_{ss}):** It relates the pump's speed, flow rate, and NPSH required (Net Positive Suction Head).

$$\boxed{N_{ss} = NQ^{0.5}/(NPSH_r)^{3/4}}$$

Where:

- N = Pump speed
- Q = Flow rate
- $NPSH_r$ = Net Positive Suction Head required (in meters or feet)
-

Purpose & Significance:

- Indicates the pump's tendency to cavitate.
  a)Higher N_{ss} values → higher risk of cavitation.
  b)Lower Nss values → safer operation under low NPSH.
- API 610 typically recommends $N_{ss} \leq 110$ (metric units)

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9. Datasheets given in API 610

API 610 provides standardized datasheets to ensure clear and consistent documentation of centrifugal pump specifications. These are used throughout bidding, design, procurement, inspection, and testing phases to streamline communication and maintain quality.

Pump Type & General Info

- Service Type
- Equipment Tag Number
- API 610 Pump Type (OH, BB, VS)
- Applicable Standards (API)
- Driver Type (Motor, Turbine)
- Mounting Type (Baseplate, Skid)
- Casing Split Type
- Number of Stages
- Impeller Type

Process Fluid Properties

- Pumping temperature
- Viscosity and Specific gravity
- H2S and Chloride Concentration
- Design Temperature

Operating Conditions

- Rated Flow (m^3/hr)
- Rated Differential Head (m)
- Rated Speed (RPM)
- Design Temperature (°C or °F)
- Design Pressure (bar or psi)
- Operating Suction Pressure
- Operating Discharge Pressure
- Maximum & Minimum Flow
- Service Type

Performance Parameters

- Rated speed (RPM)
- Efficiency at Rated Flow
- NPSHr
- Maximum allowable working pressure (MAWP)
- Maximum allowable speed
- Minimum Continuous Stable Flow(MCSF)
- Shut-off head
- Specific speed
- Suction Specific Speed
- Max-Min Impeller Diameter
- Rated Power
- Max Power
- Driver Speed

Seal & Auxiliary Piping

- Primary Flush Plan
- Secondary Flush Plan
- Cooling Water Piping Plan

Construction

- Suction and Discharge nozzle size, facing & orientation
- Drain and vent sizes
- Casing mounting, Split, and Design type
- Impeller Design
- Shaft dimensions
- Sealing System
- Bearing type and size
- Coupling type and material

Materials

- API table H-1 Class
- Barrel/Pressure casing
- Impeller Material
- Piping Material
- Shaft Material
- Wear Ring Material
- Coupling Guards, Hubs & Spacers Material

Site Conditions

- Site elevation above sea level
- Ambient temperature range (min–max, °C/°F)
- Relative humidity (%)
- Area classification (hazardous/ non-hazardous)
- Location(indoor/outdoor)

Inspection & Testing

- Performance Test
- Hydrostatic Test
- NPSH Test
- Sound level Test
- Maximum Allowable Working Pressure (MAWP)

Masses & Dimensions

- Mass of Pump
- Mass of Motor
- Mass of Gear
- Mass of Coupling
- Mass of Baseplate
- Mass of Seal Flushing
- Mass of Lubrication System
- Dimensions of Baseplate

Pump Nozzle Loads(forces and moments)

- Suction Nozzle
- Discharge Nozzle

Baseplate

- Standard Baseplate(Yes/No)
- Baseplate Number and Type

Figure shows the template of Standard datasheet provided in API 610.

CLIENT: ______________________

PROJECT TITLE: ______________________

JOB NUMBER: ______________________

EQUIPMENT NUMBER: ______________________

EQUIPMENT SERVICE: ______________________

SERIAL NUMBER: ______________________

REQ / SPEC NUMBER : ______________________

PURCHASE ORDER NUMBER : ______________________

Cells coloured thus [ ] contain drop-down options
Text in BLACK color are by Purchaser
Text in BLUE color are by Supplier
Text in RED color are by Purchaser OR Supplier

COMMENTS: ______________________

	ADDITIONAL / RELATED DATASHEETS					
	ITEM / TAG NUMBERS	ATT	ITEM / TAG NUMBERS	ATT	ITEM / TAG NUMBERS	ATT
PUMP(s)						
MOTOR(s)						
GEAR(s)						
TURBINE(s)						

APPLICABLE OVERLAY STANDARDS ______________

Rev	Date	Description	By	Checked				

	CENTRIFUGAL PUMP DATASHEET	DATASHEET No.
		Sheet of

Figure 32—Sample Data Sheet Template given in API 610

CENTRIFUGAL PUMP DATASHEET

GENERAL

1 Note APPLICABLE TO: ______ APPLICABLE NATIONAL / INTERNATIONAL STANDARD : ______ Rev
2 CLIENT ______ UNIT ______
3 SITE ______ SERVICE ______
4 NO. REQ ______ PUMP SIZE ______ TYPE ______ No. STAGES ______
5 MANUFACTURER ______ MODEL ______ SERIAL NO. ______
6 EQUIPMENT NUMBER ______
7
8 **LIQUID CHARACTERISTICS**

#		Units	@ RATED TEMP	@ MAXIMUM TEMP	@ MINIMUM TEMP	Alternate LIQUID
10	LIQUID TYPE OR NAME :					
11	PUMPING TEMPERATURE :	°C				
12	VAPOR PRESSURE :	kPa a				
13	RELATIVE DENSITY (3.1.62) :					
14	SPECIFIC HEAT :	kJ/(kg-K)				
15	VISCOSITY :	Pa s				
16						

17 **OPERATING CONDITIONS (6.1.3)**

#		Units	Rated	Normal	Alt Condition 1 (Name 1)	Alt Condition 2 (Name 2)	Alt Condition 3 (Name 3)	Alt Condition 4 (Name 4)
20	NPSHA Datum							
21	PUMPING TEMPERATURE :	°C						
22	FLOW :	m³/s						
23	DISCHARGE PRESSURE (6.3.2) :	kPa a						
24	SUCTION PRESSURE :	kPa a						
25	DIFFERENTIAL PRESSURE :	kPa						
26	DIFFERENTIAL HEAD :	m						
27	NPSHA :	m						
28	HYDRAULIC POWER :	kW						

29
30
31 SERVICE (CONTINUOUS/INTERMITTENT) : ______ INSTALLATION LOCATION : ______
32 • IF INTERMITTENT, NO. OF STARTS : ______ IF INDOOR, TEMPERATURE: MAX: ______ °C MIN: ______ °C
33 PUMPS OPERATE IN: ______ ELECTRIC AREA CLASSIFICATION (6.1.28): ______
34 CORROSION DUE TO : (6.12.1.9) ______ DIVISION ______ ZONE ______
35 EROSION DUE TO : (6.12.1.9) ______ GROUP ______
36 H2S CONCENTRATION (ppm) : (6.12.1.13) ______ TEMP CLASS ______
37 CHLORIDE CONCENTRATION (ppm) : ______ PUMP VALVE START POSITION : ______
38 PARTICULATE SIZE (DIA IN MICRONS) ______
39 PARTICULATE CONCENTRATION (ppm) ______
40 CORROSION ALLOWANCE (6.3.10) : ______
41 DESIGN NOTES: ______
42 ______
44
45 **PERFORMANCE** | **DRIVER (7.1)**

46 PROPOSAL CURVE NO. ______ RPM ______ | DRIVER TYPE ______
47 IMPELLER DIA.: RATED ______ MAX. ______ MIN. ______ mm | GEAR ______
48 RATED POWER : ______ kW EFFICIENCY ______ (%) | VARIABLE SPEED REQUIRED ______
49 RATED CURVE BEP FLOW (at rated impeller diameter) (6.1.16) : ______ m³/s | SOURCE OF VARIABLE SPEED ______
50 MIN FLOW : THERMAL ______ m³/s STABLE ______ m³/s | MANUFACTURER ______
51 PREFERRED OPERATING REGION (6.1.16) ______ to ______ m³/s | NAMEPLATE POWER : kW ______
52 ALLOWABLE OPERATING REGION (6.9.4.1) ______ to ______ m³/s | NOMINAL RPM ______
53 MAX HEAD @ RATED IMPELLER ______ m | RATED LOAD RPM ______
54 MAX POWER @ RATED IMPELLER ______ kW | FRAME ______
55 NPSH3 AT RATED FLOW (6.1.9) : ______ m | ORIENTATION ______
56 CENTERLINE OF PUMP TO NPSHA DATUM ______ m | LUBRICATION ______
57 NPSH MARGIN AT RATED FLOW (6.1.10) : ______ m | BEARING TYPE ______
58 SPECIFIC SPEED (6.1.17) m3/s, rpm, m ______ | RADIAL ______
59 SUCTION SPECIFIC SPEED LIMIT (6.1.11) m3/s, rpm, m ______ | THRUST ______
60 SUCTION SPECIFIC SPEED (6.1.11) m3/s, rpm, m ______ | STARTING METHOD ______
61 MAX. ALLOWABLE SOUND PRESSURE LEVEL (6.1.19) ______ (dBA) | DRIVER DATASHEET NUMBER ______
62 ESTIMATED MAX. SOUND PRESSURE LEVEL ______ (dBA) | DRIVE DESIGN STANDARD ______
63 MAX. ALLOWABLE SOUND POWER LEVEL (6.1.19) ______ (dB)
64 ESTIMATED MAX SOUND POWER LEVEL ______ (dB)
65

DATASHEET No. ______ Rev: ______ SHEET ___ of ___

Figure 32—Data Sheet (contd.)

CENTRIFUGAL PUMP DATASHEET

	Note	CONSTRUCTION		Rev
1				
2		API PUMP TYPE (Table 1):	CASING MOUNTING (6.3.14, 9.3.8.3):	
3			CASING TYPE:	
4		NOZZLE CONNECTIONS (6.4.2):	OH3 BACK-PULLOUT LIFTING DEVICE REQD. (9.1.2.6)	
5		Size / Facing / Rating / Position	CASING PRESSURE RATING:	
6		SUCTION	MAWP (6.3.6): ___ kPa @ ___ °C	
7		DISCHARGE	HYDROTEST (8.3.2.2): ___ kPa @ ___ °C	
8		PRESSURE CASING AUX. CONNECTIONS: (6.4.3)	WETTING AGENT REQUIRED FOR HYDROTEST (8.3.2.7):	
9		No. / Size / Type / Facing / Rating / Posn.	HYDROTEST OH PUMP AS ASSEMBLY (8.3.2.14):	
10		BALANCE/LEAK OFF	SUCT'N PRESS. REGIONS DESIGNED FOR MAWP (6.3.8):	
11		DRAIN		
12		VENT	ROTOR:	
13		PRESSURE GAGE	SHAFT FLEXIBILITY INDEX (SFI) (9.1.1.3)	
14		TEMP GAGE	FIRST CRITICAL SPEED WET (MULTISTAGE PUMPS ONLY)	
15		WARM-UP LINE	COMPONENT BALANCE TO ISO 1940-1, G1 (6.9.3.4):	
16			SHRINK-FIT-LIMITED MOVEMENT IMPELLERS (9.2.2.3)	
17		DRAIN VALVE SUPPLIED BY (7.6.2.5)	ROTATION (VIEWED FROM COUPLING END):	
18		DRAINS MANIFOLDED (7.6.2.5)	IMPELLERS INDIVIDUALLY SECURED (6.6.3):	
19		VENT VALVE SUPPLIED BY		
20		VENTS MANIFOLDED	COUPLING: (7.2)	
21		THREADED CONS FOR PIPELINE SERVICE & < 55°C (6.4.3.2)	MANUFACTURER	
22		SPECIAL FITTINGS FOR TRANSITIONING (6.4.3.3)	MODEL	
23		CYLINDRICAL THREADS REQUIRED (6.4.3.2)	RATING (kW / 100 RPM)	
24		MACHINED AND STUDDED AUX CONNECTIONS (6.4.3.6)	SPACER LENGTH (7.2.2.d) ___ mm	
25		ROUTE DRAIN TO SKID EDGE	SERVICE FACTOR (7.2.3)	
26			RIGID-TYPE	
27			COUPLING WITH HYDRAULIC FIT (7.2.9)	
28		**MATERIAL (6.12.1.1)**	COUPLING WITH PROPRIETARY CLAMPING DEVICE (7.2.10)	
29		ANNEX H CLASS	COUPLING IN COMPLIANCE WITH (7.2.4)(7.2.2.f)	
30		MINIMUM DESIGN METAL TEMPERATURE (6.12.4.1) ___ °C	GUARDS (7.3)	
31		MAXIMUM ALLOWABLE TEMPERATURE (3.1.20) ___ °C	COUPLING AND SHAFT GUARD STANDARD (7.3)	
32		REDUCED-HARDNESS MATERIALS REQ'D (6.12.1.14)	IGNITION HAZARD ASSESSMENT PER EN 13463-1 (7.3.2.2; 7.3.3.4)	
33		APPLICABLE HARDNESS STANDARD (6.12.1.14)	COUPLING GUARD MATERIAL (7.3.2.1; 7.3.3.3):	
34		BARREL:	SHAFT GUARD MATERIAL (7.3.2.1; 7.3.3.3):	
35		CASE:	SPARK RESISTANT MATERIAL REQUIRED (7.3.2.1):	
36		DIFFUSERS		
37		IMPELLER:		
38		IMPELLER WEAR RING:	**BASEPLATE**	
39		CASE WEAR RING:	API BASEPLATE NUMBER (ANNEX D):	
40		SHAFT:	IF NON-STD BASEPLATE DIMENSIONS (LxW) (mm²):	
41		BOWL (IF VS-TYPE)	BASEPLATE CONSTRUCTION (7.4)	
42			BASEPLATE DRAINAGE (7.4.1)	
43			MOUNTING:	
44		**BEARINGS AND BEARING HOUSINGS (6.10.1)**	NON-GROUT CONSTRUCTION (7.4.1.e):	
45		BEARING (TYPE / NUMBER):	SUPPLIED WITH: • GROUT AND VENT HOLES	
46		RADIAL /	• DRAIN CONNECTION	
47		THRUST /	DEMONSTRATE BASEPLATE PAD FLATNESS (7.4.9)	
48		REVIEW AND APPROVE THRUST BEARING SIZE: (9.2.5.2.6)	PROVIDE SPACER PLATE UNDER ALL EQUIPMENT FEET (7.4.10)	
49		LUBRICATION (6.11.3) (9.3.12.4):	BOLT OH 3/4/5 PUMP TO PAD / FOUNDATION :	
50		PRESSURE LUBE SYSTEM TO API-614, CHAPTER:	PROVIDE SOLEPLATE FOR OH 3/4/5 PUMPS (9.1.2):	
51		API 614 DATASHEETS ATTACHED (9.2.6.4)		
52		PRESSURIZED LUBE OIL SYSTEM MOUNTED ON BASEPLATE:		
53		LOCATION OF PRESSURIZED LUBE OIL SYSTEM:		
54		INTERCONNECTING PIPING PROVIDED BY		
55		OIL VISC. ISO GRADE ___ VG		
56		VENT-TO-HOUSING CONSTANT LEVEL OILER (6.10.2.4):		
57		OIL MIST PROVISIONS (6.11.3)		
58		GREASE LUBRICATION (6.11.4)		

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Figure 32—Data Sheet (contd.)

CENTRIFUGAL PUMP DATASHEET

	Note			Rev
1	Note	**INSTRUMENTATION**	**SEAL SUPPORT SYSTEM MOUNTING**	Rev
2		INSTRUMENTATION PER API-670 (7.5.2)	MOUNTED ON PUMP BASEPLATE (7.6.1.4)	
3		ACCELEROMETERS (7.5.2.1)	LOCATION ON OR OFF BASEPLATE (7.4.6) :	
4		NUMBER OF ACCELEROMETERS		
5		MOUNTING LOCATION:	INTERCONNECTING PIPING BY	
6		PROVISION FOR MTG ONLY (6.10.2.13)		
7		FLAT SURFACE REQUIRED (6.10.2.14)	**MECHANICAL SEAL (6.8)**	
8			API 682 DATASHEET ATTACHED :	
9		VIBRATION PROBES (7.5.2.2)	ADDITIONAL CENTRAL FLUSH PORT (6.8.9)	
10		VIBRATION PROBES REQUIRED (7.5.2.2)	HEATING JACKET REQ'D. (6.8.11)	
11		NUMBER PER RADIAL BEARING		
12		NUMBER PER AXIAL BEARING		
13		THREADED PROVISION FOR MTG ONLY (6.10.2.13; 6.6.12)	**HEATING AND COOLING (6.1.23-6.1.27)**	
14		FLAT SURFACE PROVISION ONLY (6.10.2.14)	COOLING REQ'D	
15		MONITORS AND CABLES SUPPLIED BY (7.5.2.4)	COOLING WATER PIPING PLAN (7.6.3.1)	
16			COOLING WATER PIPING	
17		TEMPERATURE DETECTORS (7.5.2.3)	FITTINGS	
18		TEMP. PROBES REQUIRED (7.5.2.3)	COOLING WATER PIPING MATERIALS	
19		PROVISIONS FOR MOUNTING ONLY (6.10.2.2)	COOLING WATER REQUIREMENTS: SUPPLY PRESSURE ______ kPa	
20		RADIAL BEARING TEMP.	BEARING HOUSING ______ m^3/s	
21		NUMBER PER RADIAL BEARING	HEAT EXCHANGER ______ m^3/s	
22		THRUST BEARING TEMP.	TOTAL COOLING WATER ______ m^3/s	
23		NUMBER PER THRUST BEARING ACTIVE SIDE	HEATING MEDIUM	
24		NUMBER PER THRUST BEARING INACTIVE SIDE	HEATING PIPING	
25		TEMP. GAUGES (WITH THERMOWELLS) (9.1.3.5)		
26		TEMP. GAUGE LOCATION		
27		SUPPLY UPPER/LOWER CASING RTD'S FOR WARMUP	**PIPING & APPURTENANCES**	
28			TAG ALL ORIFICES (7.6.2.4)	
29		PRESSURE GAUGE TYPE	SOCKET WELD UNION ON 1st SEAL GLAND NIPPLE (7.6.2.8)	
30		PRESSURE GAUGE LOCATION	MANIFOLD AUX PIPING SYSTEMS AT SKID EDGE (7.6.1.6)	
31				
32				
33		**PRESSURE VESSEL DESIGN CODE REFERENCES**		
34		THESE REFERENCES SHALL BE PROVIDED BY THE MANUFACTURER		
35		CASTING FACTORS USED IN DESIGN (PER TABLE 4)		
36		SOURCE OF MATERIAL PROPERTIES (6.3.5)		
37				
38		**WELDING AND REPAIRS (6.12.3.1)**		
39		THESE REFERENCES SHALL BE PROVIDED BY THE PURCHASER (DEFAULT TO TABLE 11 IF NO PURCHASER PREFERENCE IS STATED)		
40		ALTERNATIVE WELDING CODES AND STANDARDS		
41		WELDING REQUIREMENT (APPLICABLE CODE OR STANDARD)		
42		ALTERNATIVE WELDER/OPERATOR QUALIFICATION STANDARD		
43		ALTERNATIVE WELDING PROCEDURE QUALIFICATION STANDARD		
44		NON-PRESSURE RETAINING STRUCTURAL WELDING STANDARD (BASEPLATES OR SUPPORTS)		
45		STANDARD FOR MAGNETIC PARTICLE OR LIQUID PENETRANT EXAMINATION (PLATE EDGES)		
46		STANDARD FOR POSTWELD HEAT TREATMENT		
47		STANDARD FOR POSTWELD HEAT TREATMENT OF CASING FABRICATION WELDS		
48				
49		**MATERIAL INSPECTION**		
50		THESE REFERENCES SHALL BE PROVIDED BY THE PURCHASER		
51		DEFAULT TO TABLE 14 ______ TABLE 14 INSPECTION CLASS: ______		
52		ALTERNATIVE MATERIAL INSPECTIONS AND ACCEPTANCE CRITERIA (SEE TABLE 15, 8.2.2.5)		

	TYPE OF INSPECTION	METHOD	FOR FABRICATIONS	FOR CASTINGS
53	**TYPE OF INSPECTION**	**METHOD**	**FOR FABRICATIONS**	**FOR CASTINGS**
54	RADIOGRAPHY			
55	ULTRASONIC INSPECTION			
56	MAGNETIC PARTICLE INSPECTION			
57	LIQUID PENETRANT INSPECTION			
58	VISUAL INSPECTION (all surfaces)			
59				
60				

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Figure 32—Data Sheet (contd.)

CENTRIFUGAL PUMP DATASHEET

1	Note	SURFACE PREPARATION, PAINT & SPARES	TEST	Rev
2		MANUFACTURER'S STANDARD (8.4.3.4)	SHOP INSPECTION (8.1.1.1)	
3		OTHER (SEE BELOW)	PERF. CURVE & DATA APPROVAL REQ'D PRIOR TO SHIPMENT (8.3.3.4.6) :	
4		SPECIFICATION NO.	TEST WITH SUBSTITUTE SEAL (8.3.3.3.1)	
5		PUMP:	MATERIAL CERTIFICATION REQUIRED (6.12.1.8): CASING	
6		PUMP SURFACE PREPARATION	IMPELLER	
7		PRIMER	SHAFT	
8		FINISH COAT	OTHER	
9		BASEPLATE:	CASTING REPAIR WELD PROCEDURE APPROVAL REQD (6.12.2.5):	
10		SURFACE PREPARATION	INSPECTION REQUIRED FOR CONNECTION WELDS (6.12.3.4)	
11		PRIMER:	MAG PARTICLE	
12		FINISH COAT	RADIOGRAPHY	
13		UNDERSIDE	LIQUID PENETRANT	
14			ULTRASONIC	
15		SHIPMENT: (8.4)	HARDNESS TEST REQUIRED (6.12.1.14; 8.2.2.7)	
16		EXPORT BOXING REQUIRED	ADDITIONAL SUBSURFACE EXAMINATION (6.12.1.6) (8.2.1.3)	
17		PREPARE FOR OUTDOOR STORAGE (NUMBER OF MONTHS) :	FOR:	
18			METHOD:	
19		SPARE ROTOR ASSEMBLY PACKAGED FOR:	PMI TESTING REQUIRED (8.2.2.8)	
20		ROTOR STORAGE ORIENTATION (9.2.8.2)	COMPONENTS TO BE TESTED :	
21		SHIPPING & STORAGE CONTAINER SUITABLE FOR	RESIDUAL UNBALANCE TEST (J.4.1.2)	
22		VERTICAL STORAGE (9.2.8.3) :	NOTIFICATION OF SUCCESSFUL PERFORMANCE TEST (8.1.1.3) (8.3.3.4.6)	
23		N2 PURGE REQUIRED (9.2.8.4) :	BASEPLATE (NOZZLE LOAD) TEST (7.4.24)	
24			HYDROSTATIC TEST (8.3.2)	
25		SPARE PARTS (10.3.4.2)	HYDROSTATIC TEST OF BOWLS & COLUMN (9.3.13.1)	
26		START-UP	PERFORMANCE TEST (8.3.3)	
27		NORMAL MAINTENANCE	RETEST ON SEAL LEAKAGE (8.3.3.3.2)	
28			TEST DATA POINTS TO (8.3.3.4)	
29			ALTERNATE TEST TOLERANCES PER (8.3.3.5)	
30		MASSES kg	NPSH (8.3.4.3)	
31		ITEM No / PUMP / DRIVER / GEAR / BASE / TOTAL	NPSH BASED ON 1ST STG ONLY ALLOWED (8.3.4.3.2)	
32			TEST NPSHA LIMITED TO 110% SITE NPSHA (8.3.3.7)	
33			RETEST REQUIRED AFTER FINAL HEAD ADJUSTMENT (8.3.3.8.2)	
34			COMPLETE UNIT TEST (8.3.4.4.1)	
35			SOUND LEVEL TEST (8.3.4.5)	
36		OTHER PURCHASER REQUIREMENTS	CLEANLINESS PRIOR TO FINAL ASSEMBLY (8.2.2.6)	
37		COORDINATION MEETING REQUIRED (10.1.3)	LOCATION OF CLEANLINESS INSPECTION:	
38		MAXIMUM DISCHARGE PRESSURE TO INCLUDE (6.3.2)	CHECK FOR CO-PLANAR MOUNTING PAD FLATNESS (7.4.8)	
39		MAX RELATIVE DENSITY	MECHANICAL RUN TEST UNTIL OIL TEMP STABLE (8.3.4.2.1)	
40		OPERATION TO TRIP SPEED	4 HR. MECH RUN AFTER OIL TEMP STABLE (8.3.4.2.2)	
41		MAX DIA. IMPELLERS AND/OR NO OF STAGES	BRG HSG RESONANCE TEST (8.3.4.7)	
42		CONNECTION DESIGN APPROVAL (9.2.1.4)	STRUCTURAL RESONANCE TEST (9.3.9.2)	
43		TORSIONAL ANALYSIS / REPORT (6.9.2)	REMOVE / INSPECT HYDRODYNAMIC BEARINGS AFTER TEST (9.2.7.4)	
44		PROGRESS REPORTS (10.3.3)	AUXILIARY EQUIPMENT TEST (8.3.4.6)	
45		OUTLINE OF PROCEDURES USED FOR OPTIONAL TESTS (10.2.5)	EQUIPMENT TO BE INCLUDED IN AUXILLIARY TESTS :	
46		ADDITIONNAL DATA REQUIRING 20 YEARS RETENTION (8.2.1.1)		
47		LATERAL ANALYSIS REQUIRED (9.2.4.1.2)	LOCATION OF AUXILIARY EQUIPMENT TEST :	
48		ROTOR DYNAMIC BALANCE TO 4W/N (6.9.3.5)		
49		INSTALLATION LIST IN PROPOSAL (10.2.3.l)	IMPACT TEST (6.12.4.3) PER EN 13445	
50		VFD STEADY STATE FORCED RESPONSE ANALYSIS (6.9.2.3)	PER ASME SECTION VIII	
51		TRANSIENT FORCED RESPONSE (6.9.2.4)	CASING DISASSEMBLY AFTER TEST (8.3.3.9)	
52		BEARING LIFE CALCULATIONS REQUIRED (6.10.1.11)	SPARE PARTS TEST (8.3.4.8)	
53		CASING RETIREMENT THICKNESS DRAWING (10.3.2.3)		
54		CONNECTION BOLTING (7.6.1.7)		
55		VENDOR TO KEEP REPAIR AND HT RCDS (8.2.1.1.c)		
56		VENDOR SUBMIT TEST PROCEDURES (8.3.1.1)		
57		SUBMIT INSPECTION CHECK LIST (8.1.5)		
58		ACOUSTIC ANALYSIS OF CROSSOVER PASSAGE (BB3, BB5)(9.2.1.5)		
59		API-691 DOCUMENTATION REQUIRED (6.1.3.1)		
60				

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Figure 32—Data Sheet (contd.)

10. API 610 Standards for different parameters

API 610 specifies the minimum requirements for the design, construction, and testing of centrifugal pumps used in petroleum, petrochemical, and natural gas industries. It standardizes critical aspects such as materials, components, and performance parameters to ensure pumps operate safely and reliably under severe conditions. These guidelines help minimize maintenance needs and enhance equipment longevity in critical process environments.

10.1 API 610-compliant Pump Construction norms:

- ***Pump Type:*** The pump selected must belong to one of the Overhung (OH) categories, specifically OH1 to OH6, as defined by API 610.

- ***Casing Split Configuration:*** The pump casing may be either radially split or axially split, depending on design requirements and ease of maintenance.

  Unless otherwise specified by the purchaser, radially split casings shall be used for pumps operating under any of the following conditions:

1. Pumping temperatures ≥ 400 °F (200 °C)
2. Fluids with relative density < 0.7 at the specified pumping temperature
3. Rated discharge gauge pressure > 1450 psi (10 MPa / 100 bar)
4. Temperature transients > 100 °F (55 °C)
5. Casing metal temperature change rates > 5 °F (3 °C) per minute

- ***Pressure Endurance:*** The casing must be capable of withstanding a hydrostatic test pressure not less than 1.5 times the Maximum Allowable Working Pressure (MAWP).

- ***Impeller Design:*** Acceptable impeller types include closed, semi-open, or open, selected based on the fluid characteristics and performance requirements.

- ***Casing Mounting Type***: The mounting of the casing should be designed for either foot-mounted or centerline-mounted configurations, depending on the thermal growth and alignment stability requirements.

  Guidelines for Casing Mounting Based on Service Temperature

1. Pumps operating below 300 °F (150 °C) may use foot-mounted casings.
2. Above this temperature, Centerline-mounted casings are required.

- ***Noise Limitations:*** The sound pressure level measured at a distance of 1 meter from the pump must not exceed 85 dBA during full-load operation.

- ***Bearing Requirements and Configurations:***

1. Each shaft shall be supported by two radial bearings and one double-acting axial (thrust) bearing. Load distribution depends on the bearing types:
   a. <u>Rolling-element radial and thrust bearings:</u> Thrust bearing carries both axial and radial loads on one rotor end.
   b. <u>Hydrodynamic radial + rolling-element thrust:</u> Radial loads handled by hydrodynamic bearings; axial thrust by rolling-element bearing.
   c. <u>Hydrodynamic radial and thrust bearings:</u> Used for high loads/speeds, fully supporting both radial and axial loads.

- ***Couplings:*** The pump may be flexibly coupled, rigidly coupled, or close coupled with the driver. All couplings must be all-metal, spacer-type. The coupling design shall meet the following criteria:
  (a) Flexible elements must be made of non-lubricated, corrosion-resistant metal.
  (b) The coupling must be capable of positively retaining the spacer in case of flexible element rupture.
  (c) All coupling hubs shall be constructed from steel for durability and strength.

- ***Baseplates:***
  Single-piece baseplates designed for grouting shall be provided for all horizontal pumps. Types of baseplates:
  (a) Flat deck plate with a sloped gutter drain around the entire perimeter.
  (b) Sloped full deck plate mounted between side rails.
  (c) Sloped partial deck plate under the pump and coupling only.
  (d) Open deck version with no top plate (requires added structural reinforcement).
  (e) Non-grouted versions of the above, with sufficient rigidity for uniform support without grout fill.
  (f) Non-grouted baseplates with mounts like gimbal, AVM, spring, or 3-point support, requiring a stiffer structure.

  For OH2 pumps, no auxiliaries or flush plans shall be mounted above or beside the coupling or bearing housing. If mounting is required, use a longer standard baseplate and position components adjacent to the suction nozzle.

  The centerline height of the pump shaft above the baseplate should be minimized because this reduces bending moments and torque on the pump and piping due to thermal and operational loads.

10.2 API 610-Compliant Performance Standards:

- ***Minimum Continuous Stable Flow (MCSF):*** typically ranges from 10% to 80% of the BEP flow depending upon pump dimesnions. Operating below this range may result in vibration, internal recirculation, and reduced reliability. It is the lowest flow at which the pump can operate without exceeding the vibration limits imposed by API 610 (3.6 mm/sec)

- ***Preferred Operating Region:*** for continuous and stable operation is defined between 70% to 120% of BEP flow. It is the part of a pump's hydraulic coverage over which the pump's vibration is within the base limit of API 610 (3mm/sec)

- ***Allowable Operating Region:*** extends from the MCSF up to the run-out (maximum)flow. It is the part of a pump's hydraulic coverage over which the pump's vibration is within the upper limit of API 610 (3.6 mm/sec)

- ***Rated Flow:*** should ideally fall within 80% to 110% of BEP, ensuring efficient and safe operation.

- ***To avoid cavitation:*** Net Positive Suction Head Available (NPSHa) must always exceed the Net Positive Suction Head Required (NPSHr).

- ***Increase of 30% in vibration levels:*** acceptable outside the preferred operating region but within the allowable limits at both the bearing housing and the pump shaft, as per API 610 guidelines.

- ***Maximum Allowable Working Pressure (MAWP):*** MAWP shall be at least equal to the maximum discharge pressure plus 10% of the maximum differential pressure.

- ***Shut-off Head:*** should not exceed 120% of the head at BEP, to avoid excessive hydraulic loading.

- ***Performance Testing Requirements:***

1. The test shall be performed using water at a temperature not exceeding 130 °F (55 °C) unless approved by the purchaser.
2. The vendor must record head, flowrate, power, and vibration across multiple points to fully define the pump's performance curve.
3. Each test point within the allowable range should be within 35% rated flow of any other point in that range.
4. Typical test points (±3% flow tolerance) include:
   a. Shutoff (no vibration data)
   b. Minimum continuous stable flow
   c. Midpoint between minimum stable & preferred flow
   d. Minimum preferred flow
   e. Midpoint between preferred & rated flow
   f. 95–99% of rated flow
   g. Rated to 105% rated flow
   h. End of preferred operating region
   i. End of allowable operating region (if different)

- ***Testing Requirements for Cooling and Auxiliary Piping***

1. All cooling passages and components (e.g., bearing jackets, seal chambers, oil and seal coolers) must be tested at a minimum pressure of 150 psi (10.5 bar).
2. Steam, cooling-water, and lubricating-oil piping, if welded, shall be tested at 1.5 times the maximum operating pressure or 150 psi (10.5 bar), whichever is greater.

- ***Complete Unit Test:***

1. If specified, the entire pump unit (pump, driver, auxiliaries) shall be tested together.
2. May include torsional vibration checks to confirm vendor analysis.
3. Can replace or supplement individual component tests.
4. Vibration limits must meet applicable standards (for engines, limits to be mutually agreed).

- ***Sound Level Test:***

1. If specified, sound level tests shall be conducted as agreed.
2. Sound pressure at 1 meter from the pump should not exceed 85 dBA under full load.

- ***Pumps shall be capable*** of at least a 5 % head increase at rated flow by replacement of the impeller(s) with one of larger diameter or different hydraulic design, variable-speed capability, or use of a blank stage.

- ***Parallel Operation Requirements:*** When pumps operate in parallel without individual flow control:

1. Head curve must continuously rise till shutoff.
2. Head rise from rated flow to shutoff must be ≥ 10%.
3. At any flow within the preferred operating range, head values must be within 3% of each other for pumps with >3 in. (80 mm) discharge.

- ***Motor nameplate rating:*** must exceed the rated pump power by:

1. 125% for motors < 22 kW
2. 115% for motors 22–55 kW
3. 110% for motors > 55 kW

   Minimum motor size allowed is 4 kW (5 hp). This margin ensures reliable operation during startup and transient conditions. Any exception requires purchaser approval.

10.3 Material Selection Guidelines as per API 610:

- ***Factors affecting material selection:*** temperature, pressure, pH, solids content, and compatibility with the working fluid.

- ***Presence of wet H_2S and Chloride:*** concentration of their presence must be specified under all possible conditions—including normal operation, start-up, shutdown, idle standby, process upsets, and abnormal events like catalyst regeneration.

- ***Coupling material selection:*** Flexible elements shall be made from non-lubricated, corrosion-resistant metal to ensure longevity and reliability under industrial operating conditions. All coupling hubs must be constructed from high-strength steel, ensuring structural integrity and compatibility with high-speed operations.

- ***Annex-G of API 610:*** provides Material Class Selection Guidance, which is primarily based on the fluid's physical and chemical properties.

- ***Annex-H of API 610:*** outlines Material Specifications for Pump Parts, selected according to the material class derived from Annex G.

- ***Hardness of Wear Rings:*** Mating wear surfaces shall have a difference in Brinell hardness number of at least 50, if both surfaces are stationary and 400, if they are rotating.

- ***Inner casing*** of double-volute casing pumps shall be designed to withstand the maximum differential pressure or 50 psi (350 kPa, 3.5 bar), whichever is greater.

- Impellers shall be single-piece castings, forgings, or fabrications.

11. Comparison of different OH Pumps with API 610 Standard [12th edition, January 2021]

To assess the compliance of the studied OH pumps with API 610, a comparative evaluation was conducted across three key dimensions: mechanical construction, hydraulic performance limits and materials. Each comparison highlights how the selected pump aligns with, exceeds, or deviates from the standard API 610 requirements.

Pump Type	Manufacturer / Model	Application
OH2	KSB Limited	Dowtherm A Recircualtion
OH2	Khimline Pumps Ltd.	Naptha Transfer
OH1	Flowserve	PTA Slurry Pump

Table 4— Pumps under study

11.1 Pump 1:

CONSTRUCTIONAL FEATURES				
Parameter	**API 610 Standard**	**Observed Pump Value**	**Compliant (Y/N)**	**Remarks**
Pump Type	OH 1/2/3/4/5/6	OH2	Y	
Casing Split Type	Radially/Axially Split [Radially split casing required if: •Pumping Temp. ≥ 200 °C •Relative density of Fluid< 0.7 •Rated Discharge pressure > 100 bar •Temp transient > 55 °C •Casing metal temp change > 3 °C/min]	Radially split	Y	Pumping temp=350°C
Casing Mounting	Foot-mounted/Centreline Mounted [Operation temp: •≤ 150 °C → Foot-mounted •> 150 °C → Centerline-mounted]	Centreline Mounted	Y	
Coupling Arrangement	Spacer-type	Flexi-metallic spacer	Y	
Impeller Design	Closed/Semi-open/Open	Closed	Y	
Bearing Requirements	2 Radial bearings + 1 double-acting axial(thrust) bearing	Radial: Roller/NU316C3/1 No. Thrust: AF/7315BMUA/2 No.	**N**	Uses **combined radial-thrust bearing** on one end and a **radial-only bearing** on the other.

Table 5—Constructional Features of Pump 1

Observation:
All constructional parameters for Pump 1 comply with API 610, except the bearing arrangement. API recommends two radial and one thrust bearing, but this pump uses two thrust and one radial bearing. While not standard, this configuration is commonly used in modern OH2 pumps for better axial load handling.

Inference:
The angular contact bearing can be arranged in Back-to-Back (DB) configuration and Face-to-Face (DF) configuration. The DB configuration is preferred for high rigidity applications and it allows the bearing pair to withstand moment loads and maintain shaft alignment under variable loading. DF configurations are better at compensating for slight misalignments.

►Bearing Arrangement Analysis:

The **bearing load** can be expressed as: $P = x.F_r + y.F_a$
P= equivalent dynamic bearing load
F_r = Radial load; F_a = Axial load; x, y= Load factors

Basic rating life: $L_{10} \propto (C/P)$ n
C=bearing dynamic load rating
N=3 for Ball Bearings; 10/3 for Roller Bearings

Even a small reduction in load increases the bearing life. To further optimize performance, spring/mechanical preload can be applied. It eliminates internal clearance, ensures continuous contact between rolling elements & raceways, and promotes equal load distribution between bearing pair. This enhances stiffness, minimizes deflection, and improves resistance to vibrations. Though this bearing configuration deviates from standard API 610 recommendations, it offers a valid and effective alternative when properly designed.

PERFORMANCE LIMITS				
Parameter	**API 610 Standard**	**Observed Pump Value**	**Compliant (Y/N)**	**Remarks**
MCSF	lies at 30%-80% of BEP Flow depending upon discharge sizes	145.8 m^3/h	Y	30.3% of BEP flow
Preferred Operating Region	ranges from 70% to 120% of BEP flow	336.7 m3/h to 577 m^3/h	—	
Allowable Operating Region	MCSF to Run-out flow	145.8 m^3/h to 577 m^3/h	—	
BEP Flow	Flow @BEP @Rated Dia.	481 m^3/h	—	
Rated Flow	80% to 110% of BEP, mostly to left of BEP	404 m^3/h	Y	83.99% OF BEP FLOW
NPSHa	NPSHa>NPSHr	5.5m @rated flow	Y	NPSHr=2.77m @rated flow
Max Differential Pressure		5.38 kg/cm^2	—	
Max Discharge Pressure		9.88 kg/cm^2	—	
MAWP	>(Max discharge pressure + 10% of the maximum differential pressure)	23.8 kg/cm^2	Y	
Run out flow		577 m^3/h	—	
BEP HEAD		68m	—	
Shut-off Head	<120% of BEP Head	77.70m	Y	<81.6m
Complete Unit Test	as per API 610 Standards	OK	Y	
Sound Test	≤85 dBA at 1m distance from pump under full load	85 dBA	Y	sound test witnessed
Head Increment at rated flow with Greater Impeller Diameter	>5%	18.75%	Y	head at rated dia= 72m head at max impeller dia=93.5m
Hydrostatic Test Pressure	>1.5 × MAWP	60 kg/cm^2	Y	
Rated Pump Power		75.4 kW	—	
Power of Motor	Must exceed rated pump power: 125% for motors < 22 kW 115% for motors 22–55 kW 110% for motors > 55 kW Min motor size: 4 kW (5 hp)	110 kW	Y	Rated pump power= 75.4 kW

Table 6—Performance Parameters of Pump 1

Observation:

All evaluated performance parameters of the pump were found to be compliant with API 610 standards. This includes rated flow, BEP flow, NPSH margin, shutoff head, head rise with impeller diameter increase, hydrostatic test pressure, sound level, and motor sizing. No deviations were observed in any of the listed criteria.

Inference:

The pump demonstrates full compliance with API 610 performance requirements, indicating a well-optimized and robust hydraulic design. Adequate margins in NPSH and head rise provide operational flexibility and reliability. The selection meets all critical service demands and can be considered suitable for long-term, stable operation.

MATERIAL SELECTION				
Parameter	**API 610 Standard**	**Observed Pump Value**	**Compliant (Y/N)**	**Remarks**
Material Class	S-4/5/6/8/9, C-6, A-7/8, D-1/2	S-6	Y	
Casing Material	The inner casing of double-volute casing pumps shall be designed to withstand the maximum differential pressure or 50 psi (350 kPa, 3.5 bar), whichever is greater	ASTM A216 Grade WCB	Y	Carbon steel as per S-6 class; BHN=137-187
Impeller Material	single-piece castings, forgings, or fabrications.	A743 Gr CA6NM	Y	12% Cr Steel BHN=290
Shaft Material	corrosion-resistant metal	A276 Type 410 (12% Cr Steel)	Y	12% Cr Steel; Martensitic Stainless Steel; Corrosion Resistant; BHN= 240-280
Coupling Hubs Material	high-strength steel	AISI 1045	Y	BHN= 170-210
Coupling Spacer Material	corrosion-resistant metal	AISI 1045	Y	Epoxy coated
Impeller Wear Rings Material(rotating)	high-strength steel	1.4024.19(12% Cr Steel)	Y	12 % Cr hardened;Martensitic stainless steel; BHN= 225
Case Wear Rings Material(stationary)	high-strength steel	Cr Hard 400	Y	12 % Cr hardened; Martensitic stainless steel; BHN=400
Sleeve Material	corrosion-resistant metal	SS316	Y	12 % Cr hardened; BHN= 79 to 95

Table 7 – Component Material Selection for Pump 1

Observation:

All components meet the material guidelines of API 610 and fall under Material Class S-6, which provides adequate resistance to moderate corrosion and ensures structural rigidity. The coupling spacer is made of AISI 1045, a carbon steel material that provides sufficient mechanical strength and, with the applied epoxy coating, achieves the necessary corrosion resistance.

Inference:

The use of AISI 1045 for the coupling spacer, along with epoxy coating, ensures both strength and corrosion protection. This configuration aligns with API 610 requirements, provided purchaser approval is obtained.

11.2 Pump 2:

CONSTRUCTIONAL FEATURES				
Parameter	**API 610 Standard**	**Observed Pump Value**	**Compliant (Y/N)**	**Remarks**
Pump Type	OH 1/2/3/4/5/6	OH2	Y	
Casing Split Type	Radial/Axial Radially split casing required if: Pumping Temp. ≥ 200 °C Relative density of Fluid< 0.7 Rated Discharge pressure > 100 bar Temp transient > 55 °C Casing metal temp change > 3 °C/min	Radially Split	Y	Relative density of fluid=0.69
Casing Mounting	Foot-mounted/Centreline Mounted Operation temp: ≤ 150 °C → Foot-mounted(OH 1 only) > 150 °C → Centerline-mounted	Centreline	Y	
Coupling Arrangement	Spacer-type	Metaflex Spacer	Y	
Impeller Design	Closed/Semi-open/Open	Closed	Y	
Bearing Requirements	2 Radial bearings + 1 double-acting axial(thrust) bearing	Radial: NU312/1 No. Thrust: 7315/2 No.	**N**	Uses a **combined radial-thrust bearing** on one end and a **radial-only bearing** on the other.

Table 8—Constructional Features of Pump 2

Observation:

All constructional features comply with API 610, including pump type, casing split, mounting, impeller design, and coupling arrangement. The only deviation, similar to the first pump evaluated, is in the bearing configuration, where a combined radial-thrust bearing is used instead of the standard two radial and one thrust bearing layout.

Inference:

Though the bearing configuration deviates from API 610, it is a commonly accepted practice in OH2 pumps. We have already evaluated this arrangement in Pump 1 [GA 3408 AX/BX/SX] With proper validation for load, deflection, and life, the overall construction remains suitable for reliable operation.

PERFORMANCE LIMITS				
Parameter	**API 610 Standard**	**Observed Pump Value**	**Compliant (Y/N)**	**Remarks**
MCSF	lies at 30%-80% of BEP Flow depending upon discharge sizes	80 m^3/hr	Y	
Preferred Operating Region	ranges from 70% to 120% of BEP flow	140 m^3/hr to 240 m^3/hr	—	
Allowable Operating Region	MCSF to Run-out flow	80 m^3/hr to 226 m^3/hr	—	
BEP Flow	Flow @BEP @Rated Dia.	200 m^3/hr	—	
Rated Flow	80% to 110% of BEP, mostly to left of BEP	180 m^3/hr	Y	
NPSHa	NPSHa>NPSHr	3.59m	Y	NPSHr= 2.1m
Max Differential Pressure		10.939 kg/cm^2	—	
Max Discharge Pressure		12.1 kg/cm^2	—	
MAWP	Max discharge pressure + 10% of the maximum differential pressure	13.19 kg/cm^2	—	
Run out flow		226 m^3/hr	—	
BEP HEAD		151 m	—	
Shut-off Head	<120% of BEP Head	173m	Y	
Head Increment at rated flow with Greater Impeller Diameter	>5%	13.92%	Y	Head at rated dia= 158m Head at higher impeller dia=180m
Rated Pump Power		79.82kW	—	
Power of Motor	Must exceed rated pump power by: 125% for pump motors < 22 kW 115% for pump motors 22–55 kW 110% for pump motors > 55 kW Min motor size: 4 kW (5 hp)	110kW	Y	

Table 9—Performance Parameters of Pump 2

Observation:
All key performance parameters are API 610 compliant, including rated flow (90% of BEP), NPSH margin, shut-off head, head increment, and motor power sizing. The pump achieved a 13.92% head rise with a larger impeller and maintained adequate NPSHa over NPSHr (3.59 m vs. 2.1 m). MCSF is within the acceptable range, and the shut-off head (173 m) is below the 120% BEP head limit (181.2 m). No non-compliance was observed.

Inference:
The pump demonstrates stable hydraulic behavior and complies with all critical API 610 performance criteria. The generous NPSH margin and head flexibility indicate robust design and safe operation, making it suitable for long-term, reliable service.

MATERIAL SELECTION				
Parameter	**API 610 Standard**	**Observed Pump Value**	**Compliant (Y/N)**	**Remarks**
Material Class	S-4/5/6/8/9, C-6, A-7/8, D-1/2	S-5	Y	
Casing Material	The inner casing of double-volute casing pumps shall be designed to withstand the maximum differential pressure or 50 psi (350 kPa, 3.5 bar), whichever is greater	ASTM A216 Grade WCB	Y	Carbon steel
Impeller Material	single-piece castings, forgings, or fabrications.	ASTM A216 Grade WCB	Y	Carbon steel
Shaft Material	corrosion-resistant metal	EN-19	Y	Same as 4140 alloy steel
Impeller Wear Rings Material(rotating)	high-strength steel	AISI 410	Y	12 % chrome steel
Case Wear Rings Material(stationary)	high-strength steel	AISI 410H	Y	12 % chrome steel

Table 10 – Component Material Selection for Pump 2

Observation:

All selected materials conform to API 610 Material Class S-5. The casing and impeller use ASTM A216 Grade WCB (carbon steel), while the shaft is made of EN-19, equivalent to 4140 alloy steel. Both impeller and case wear rings are made from AISI 410/410H, meeting the required BHN criteria. No deviations were observed.

Inference:

The pump's material selection is fully API-compliant for its service conditions, offering appropriate strength, hardness, and corrosion resistance for reliable and safe operation.

11.3 Pump 3:

CONSTRUCTIONAL FEATURES				
Parameter	**API 610 Standard**	**Observed Pump Value**	**Compliant (Y/N)**	**Remarks**
Pump Type	OH 1/2/3/4/5/6	OH1	Y	
Casing Split Type	Radial/Axial [Radially split casing required if: Pumping Temp. ≥ 200 °C Relative density of Fluid< 0.7 Rated Discharge pressure > 100 bar Temp transient > 55 °C Casing metal temp change > 3 °C/min]	Radially Split	Y	**Radially split casings are required under certain high-stress conditions,** but they can be used at any operating condition if specified by the purchaser or deemed more reliable
Casing Mounting	Foot-mounted/Centreline Mounted [Operation temp: ≤ 150 °C → Foot-mounted > 150 °C → Centerline-mounted]	Foot mounted	Y	Operational temp=150°C
Coupling Arrangement	Spacer-type	Flexible Spacer	Y	
Impeller Design	Closed/Semi-open/Open	Semi-open	Y	
Bearing Requirements	2 Radial bearings + 1 double-acting axial(thrust) bearing	Radial: Ball 6311 C3 Thrust: Ball 3311 C3	**N**	Uses a **combined radial-thrust bearing** on one end and a **radial-only bearing** on the other.

Table 11—Constructional Features of Pump 3

Observation:

Pump 3 complies with API 610 in terms of pump type (OH1), radially split casing, foot mounting, semi-open impeller, and spacer-type coupling, consistent with the previous pumps analyzed. However, the bearing arrangement again deviates from API norms by using a combined radial-thrust bearing (Ball 6311 C3) on one end and a radial-only bearing (Ball 3311 C3) on the other.

Inference:

As seen in the previous pumps analyzed, this non-standard bearing configuration (combined radial-thrust bearing with a radial-only bearing) has been consistently used. In earlier analysis, it was reasoned that such arrangements offer load sharing and acceptable performance when properly supported by vendor-provided load and life calculations. Except for this bearing deviation, all constructional features are compliant, indicating that the pump is suitable for the intended service under API 610 guidelines.

PERFORMANCE LIMITS				
Parameter	API 610 Standard	Observed Pump Value	Compliant (Y/N)	Remarks
MCSF	lies at 30%-80% of BEP Flow depending upon discharge sizes	74.4 m^3/hr	N	Unusually low- only 17.9% of BEP Flow
Preferred Operating Region	ranges from 70% to 120% of BEP flow	290.29 m^3/hr to 497.64 m^3/hr	—	
Allowable Operating Region	MCSF to Run-out flow	74.4 m^3/hr to 537 m3/hr	—	
BEP Flow	Flow @BEP @Rated Dia.	414.7 m^3/hr	—	
Rated Flow	80% to 110% of BEP, mostly to left of BEP	282 m^3/hr	N	68% of BEP Flow-The selected impeller is trimmed to 292 mm — just 1 mm above the minimum (291 mm) — in a casing designed for up to 380 mm. This indicates extreme trimming, causing the BEP to shift far left. As a result, the rated flow falls below 80% of BEP
NPSHa	NPSHa>NPSHr	3.435 m	Y	NPSHr=2.8m
Max Differential Pressure		3.647 bar	—	
Max Discharge Pressure		5.034 bar	—	
MAWP	> [Max discharge pressure + 10% of the maximum differential pressure]	16.5 bar	Y	
Run out flow		537 m^3/hr	—	
BEP HEAD		~25m		By affinity law
Shut-off Head	<120% of BEP Head	37.1 m	N	Nearly 50% increase
Hydrostatic Test Pressure	>1.5 × MAWP	24.75 bar	Y	
Rated Pump Power		47.1 kW	—	
Power of Motor	Must exceed rated pump power: 125% for motors < 22 kW 115% for motors 22–55 kW 110% for motors > 55 kW Min. motor size: 4 kW (5 hp)	75 kW	Y	

Table 12—Performance Parameters of Pump 3

Observation:

Most performance parameters comply with API 610. However, some unusualities are observed:

- The rated flow is only 68% of BEP flow, below the 80% minimum requirement, which is mainly due to an extremely trimmed impeller (292 mm in a 380 mm casing).
- The shut-off head exceeds the API limit of 120% of BEP head, showing a ~150% increase.
- MCSF was only 17.9% of BEP Flow- this proportion is not so low usually.

Inference:

Due to extreme impeller trimming, the rated flow drops below API limits and the shut-off head exceeds acceptable range. While other parameters are compliant, these deviations may affect efficiency & reliability of the pump.

►MCSF: Analysis and Operational Impact:

1. Relation with Discharge Size and Specific Speed:

MCSF is generally directly proportional to both discharge size and suction specific speed, due to the following reasons:

- Discharge Size: Larger pumps have wider flow passages and impellers. At low flow, these create more hydraulic instability, recirculation, and radial thrust, which demand a higher MCSF to maintain stable operation.

- Suction Specific Speed: Pumps with higher suction specific speeds are optimized for high flow and low head. Their geometry makes them less tolerant to low-flow conditions, increasing the need for a higher minimum stable flow to avoid vibration and cavitation.

2. Effect of Pump Size on MCSF:

Smaller pumps generally have a lower MCSF relative to their Best Efficiency Point (BEP), while larger pumps require a higher MCSF. This difference is due to how recirculation and radial thrust affect pump stability at low flows.

At flows below BEP, recirculation within the impeller and unbalanced radial forces increase, leading to vibration and shaft deflection. These effects are less severe in smaller pumps due to their compact design, lower flow rates, and smaller impeller sizes. As a result, they can operate stably at 10–20% of BEP flow.

In contrast, larger pumps handle higher flow volumes and have bigger impellers, making them more prone to instability at low flows. The impact of recirculation and radial thrust is more significant, often requiring MCSF values of 30–50% of BEP to maintain stable, reliable operation.

Low MCSF	High MCSF
Wide range of operation	Low operational range
Pump is stable at low flow	Pump becomes unstable at low flow
Internal recirculation increases at lower flow rates	Reduced vibration and mechanical wear

3. Effects of operating pump below MCSF:

- Recirculation within the impeller, leading to pressure pulsations and vibration.
- Increased radial thrust, causing shaft deflection and bearing/seal wear.
- Local heating, due to stagnant fluid regions.
- The pressure reduces within the impeller which may lead to cavitation.

Nss or S	Q in m^3/Sec (SI Unit)	Q in m^3/hr (USC Unit)
	NPSHR in meters	
Maximum allowable (all pumps)	252	15100
Maximum preferred	213	12780
Maximum allowable for pumps handling liquefied gases, volatile liquids or containing dissolved gases	213	12780

The pump's suction specific speed (N_{ss}) is 11133, which is significantly below the maximum limit of 15,100 and also well below the preferred limit of 12780.

A lower Nss implies improved suction stability and reduced susceptibility to cavitation and suction recirculation at low flows — further justifying the low MCSF.

Justification for Low MCSF

The evaluated pump exhibits an MCSF of 17.9% of BEP flow, which is low but acceptable. As discussed previously, smaller pumps with lower discharge size and suction specific speed naturally tolerate lower flow operation due to reduced recirculation and radial thrust effects.

This is consistent with the previously established trend that smaller pumps can have MCSF values as low as 10–20% of BEP, compared to larger pumps that typically require 30–50%. Therefore, while the value is low, it is acceptable and aligned with both pump design principles and API 610 performance expectations for small-scale OH pumps.

Therefore, despite the low percentage, the value is appropriate for the pump's design and operating range, and does not pose reliability concerns.

►Analysis of Rated Flow:

The pump under study has a rated flow of 282 m³/h, while the BEP flow is 414.7 m³/h. This places the rated flow at approximately 68% of BEP flow, which is below the API 610 recommended range of 80–110% of BEP.

Possible causes for this deviation:

1. Excessive Impeller Trimming
- Impeller diameter trimmed to 292 mm, just 1 mm above the minimum (291 mm), in a casing designed for 380 mm.

2. Oversized Pump Selection
- Pump may be selected for a higher system capacity than required, forcing the actual operation into a low-flow regime.

A larger impeller diameter generally results in higher flow rates, but it may also require more power to operate.

Trimming the impeller not only reduces head but also shifts the BEP to the left (i.e., lower flow) and consequently, the system rated flow also reduces, violating API 610 norms.

According to the Affinity Laws: $Q \propto D$

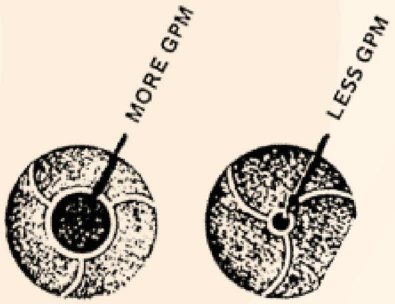
A significant reduction in diameter leads to a sharp decrease in flow capacity. Trimming to 292 mm from 380 mm theoretically reduces rated flow and it gradually shifts to left.

Also, the Casing is relatively larger than the Impeller. This contributes to Internal Recirculation leading to drop in rated flow.

Improvement Strategies for Rated Flow Deviation:

1. <u>Smaller Pump Frame:</u> Selecting a pump with a smaller casing size so that the trimmed impeller (e.g., 292 mm) becomes close to the BEP. This avoids running far left of the performance curve.

2. <u>Custom Impeller Geometry:</u> Modifying impeller eye diameter. Larger the diameter, greater is the rated flow rate.



3. <u>Using Parallel Pumps:</u> If system flow is low, operate two smaller pumps in parallel. Each handles a part of the flow near its own BEP, improving efficiency and stability.

4. <u>Increasing Pump Speed:</u> According to the pump affinity laws:
   - $Q \propto N \rightarrow$ Flow increases linearly with speed

   Raising pump speed is an effective and flexible method to correct rated flow deviation caused by impeller trimming, helping to restore alignment with BEP and ensure API 610 compliance, provided mechanical and NPSH limits are not exceeded(since $NPSH_r$ increases with higher speed, it must be ensured that it remains within the $NPSH_a$ limit.)

►Analysis of Relatively High Shut-off Head:

According to API 610, the shut-off head for a single-stage pump should not exceed 120% of the head at the Best Efficiency Point (BEP).

In this pump, the shut-off head was recorded at 37.1 m, while the BEP head is approximately 25 m, resulting in a shut-off to BEP ratio of 148%. This exceeds the API 610 allowable limit of 120%, indicating a significant deviation.

Causes of Excessive Shut-Off Head:

1. Severe Impeller Trimming
   - Affinity laws dictate that head varies with the square of impeller diameter: $H \propto D^2$
   - Trimming reduces head at BEP, but the shut-off head doesn't reduce proportionally. This is because:
     - Shut-off head is governed by impeller tip speed and static pressure buildup at near-zero flow.
     - Even with a trimmed impeller, the volute continues to develop high pressure at low flow, due to momentum being converted directly to pressure (since flow velocity is minimal).
   - As a result, while BEP head drops significantly, shut-off head remains relatively high, increasing the head rise ratio (shut-off/BEP) far beyond API limits.

2. Casing Geometry Mismatch
   - The pump casing is designed for a much larger impeller (380 mm).
   - Using a small impeller in a large casing causes hydraulic imbalance, affecting shut-off behavior.
   - A smaller impeller can't fully engage the casing's geometry, causing inefficient energy recovery at BEP.
   - However, at shut-off (zero flow), the casing's larger chamber traps more pressure, keeping shut-off head high.

- Result: Steep head curve — low BEP head, but high shut-off head.

3. Single Volute Design
    - In single volute pumps, the casing wraps around the impeller once, collecting flow into one discharge path.
    - At shut-off or low flow:
        - Pressure distribution around the impeller becomes highly asymmetric.
        - High pressure builds on one side of the impeller, contributing to both increased radial thrust and higher shut-off head.

Effects of Excessive Shut-Off Head:

1. Risk of Exceeding MAWP:
- A high shut-off head increases the pressure at the pump discharge.
- If not properly controlled, this pressure may exceed the MAWP of downstream piping, valves, or pump casing.
- This poses a safety risk, especially during start-up, shutdown, or blocked discharge conditions.

2. Steep Curve Behavior – Small Flow, Big Pressure Swings:
- Pumps with steep head–flow curves generate large pressure changes for small reductions in flow.
- This makes the system sensitive to valve movement.

3. Excessive Radial and Axial Thrust:
- High shut-off head amplifies hydraulic forces, especially in single volute pumps.
- This results in shaft deflection, increased bearing load, and seal wear, compromising alignment and pump life.

4. Internal Recirculation and Heat Generation:
- With low or no flow, fluid circulates inside the impeller passages, creating localized turbulence and recirculation zones.
- Most of the input energy turns into heat, potentially raising the temperature enough to cause fluid vaporization or seal damage.

5. Vibration & Noise:

- High pressure at shut-off can lead to vibration, acoustic resonance, and mechanical fatigue.
- This impacts the structural integrity of internal parts like the impeller, volute tongue, and shaft.

Corrective measures for Excessive Shut-Off Head:

To address this issue, the following corrective actions can be considered:

1. Ways to Flatten H-Q Curve:

   - Increasing number of impeller blades for smoother energy distribution.

More the number of vanes more the head

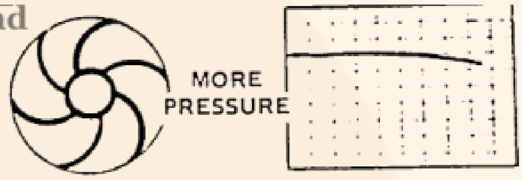


Figure 33— Variation of Head with No. of Vanes

   - Applying non-uniform or profiled impeller trimming to optimize blade loading. One way of doing this is is by adjusting the impeller width.
   - Adjusting impeller vane angles.

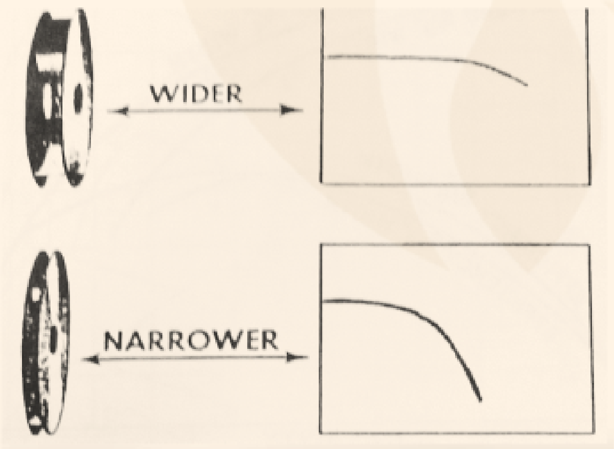


Figure 34— Variation of Head with Impeller Width

Larger the blade angle steeper the curve

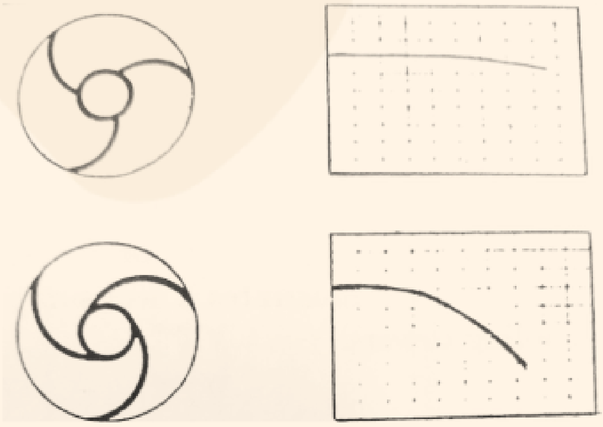


Figure 35— Variation of Head with Blade Angle

   - Adding vane diffusers or more vane inserts in the casing.

2. Installing Pressure Relief or Overpressure Protection:

- Adding a pressure relief valve (PRV) protects the system from exceeding MAWP during start-up or blocked discharge.
- Alternatively, using pressure sensors with suitable cutoffs ensures control-based intervention when shut-off head nears safe limits.

3. Incorporating a Minimum Flow Bypass System:

- A bypass line with flow control valve orifice ensures that the pump never operates at zero flow.
- This mechanical safeguard prevents the internal energy buildup that leads to excessive pressure at shut-off.
- It also stabilizes axial thrust and minimizes heat accumulation within the casing.

MATERIAL SELECTION				
Parameter	**API 610 Standard**	**Observed Pump Value**	**Compliant (Y/N)**	**Remarks**
Material Class	S-4/5/6/8/9, C-6, A-7/8, D-1/2	**NA**	**N**	materials do not belong to any particular class
Casing Material	The inner casing of double-volute casing pumps shall be designed to withstand the maximum differential pressure or 50 psi (350 kPa, 3.5 bar), whichever is greater	Duplex SS 2205	Y	
Impeller Material	single-piece castings, forgings, or fabrications.	Duplex SS 2205	Y	
Shaft Material	corrosion-resistant metal	SS 316L	Y	
Coupling Guard	copper alloy, or nonmetallic (polymer) materials	Aluminium	Y	

Table 13– Component Material Selection for Pump 3

Observation:

All individual materials are compliant with API 610 material guidelines. However, the selected materials do not fall under any defined API 610 material class, leading to non-compliance in classification.

Inference:

Although the materials used provide excellent strength and corrosion resistance, the pump does not follow any defined API 610 material class, resulting in classification non-compliance. However, since the selected materials are at par with API's minimum requirements, their use is acceptable if properly justified and approved by the purchaser.

Conclusion:

Although the selected materials are not listed under any specific API 610 material class, they fully meet the mechanical strength, corrosion resistance, and thermal performance requirements. From a mechanical engineering perspective, this poses no threat to pump reliability or life.

As per API 610 provisions, such deviations can be accepted with engineering justification. Hence, the materials are considered suitable for service, and no corrective action is necessary.

12. Suggestions for improvements

12.1 Creating a Compliance Table for missing Parameters

While evaluating the selected OH pumps for API 610 compliance, it was observed that several critical parameters were missing or unspecified in the vendor datasheets. To address this gap methodically, a compliance gap table was developed. This approach helps to:

- Identify which API parameters could not be verified.
- Highlight parameters that may affect pump reliability or safety.
- Suggest ways to validate or estimate these parameters if not available.

A table with the following columns can be created to assess the missing parameters systematically:

- Parameter: The measurable/design feature to be checked (e.g., Nss, shaft length, seal plan).
- Availability Status: States if the parameter is available, partially defined, or missing entirely.
- Impact: Explains how the absence of data prevents meaningful assessment or introduces operational risks.

Actions to be taken:

- Analyze Criticality of Each Missing Parameter.
- Suggest Methods to Estimate or Validate Missing Data.
- Show how missing parameters can impact the reliability of the pump.

The missing details introduce limitations in verifying full mechanical compliance. This exercise not only ensured thorough documentation review but also enhanced technical accountability and will serve as a reusable audit format for future pump evaluations.

12.2 Modular Impeller Hub Design Proposal

Objective:
To propose a flexible, reconfigurable impeller design that allows for interchangeable vane sets, reducing the need for extensive trimming and offering adaptability for varying duty points without altering the entire pump.

Feature	Benefit
Interchangeable vanes	Avoids one-time trimming, enables precise matching of BEP to rated flow
Preserves full blade geometry	Retains original hydraulic efficiency (unlike trimmed impellers)
Customizable vane angle and profile	Tailors performance curve (flatter or steeper) depending on process need
Reduces impeller stock variation	One hub, multiple blade sets → **inventory optimization**
Repeatable assembly	Easy to service, maintain, or reconfigure with minimal alignment issues
Suitable for prototyping & testing	Allows on-site hydraulic tuning without recasting or remanufacturing entire impeller

Table 14 – Features of Modular Hub Design

Design Concept:

- The impeller is split into two parts:
  a. A central hub core (solid or hollow) with a locking or mounting system.
  b. A set of detachable impeller vanes (radial or backward-curved), which can be mounted mechanically onto the hub via:
     - Slots and dovetail locks
     - Bolted clamps
     - Tapered press fits or splines

- Each vane set is designed for specific flow/head characteristics (e.g., steeper or flatter H-Q curve).

Customization options:

- Different vane angles, vane heights, or blade shapes can be fitted to suit flow range, head rise, and NPSH characteristics.
- Vanes can be swapped out to suit changing process requirements or site-specific performance demands.
- Modular blades are designed for repeatable mounting to ensure balance and alignment — possibly using machined locating pins or alignment grooves.
- Incorporate replaceable wear plates or tip inserts for high-abrasion applications.

Advantages of Modular Impeller Hub Design:

- Enables hydraulic reconfiguration without replacing entire impeller.
- Maintains original blade geometry – avoids efficiency loss due to trimming.
- Reduces inventory – one hub supports multiple performance curves.
- Supports rapid prototyping and testing of different vane designs.
- Improves field serviceability and maintenance time– damaged vanes can be replaced individually.
- Optimizes manufacturing – hub and vanes can be produced separately
- Customizable for different fluids/duties using varied blade profiles

The modular impeller hub concept merges hydraulic adaptability, manufacturing, and serviceability into a single design. By allowing customizable vane configurations, it offers a forward-looking solution for multi-duty pumps, particularly in plants with extensive usage.

12.3 Minimum Flow Auto-Bypass System

Centrifugal pumps, especially OH pumps, must not operate below their Minimum Continuous Stable Flow (MCSF) to avoid issues like cavitation, recirculation, excessive vibration, and overheating. Conventionally, bypass lines with manual valves are used to ensure this, but these setups are often complex and power-dependent..

To overcome this, we propose a **self-regulating**, pressure-actuated bypass system that provides a passive and automatic safeguard — ensuring pump protection under all operating conditions without relying on external control systems.

Design Concept:

- A spring-loaded or pilot-actuated valve is installed on the pump discharge line, routed back to the suction tank or low-pressure return line.
- The valve is calibrated to open when discharge pressure rises beyond a set threshold, indicating that the flow is falling below MCSF.
- When open, a controlled volume of fluid is diverted, maintaining continuous circulation through the pump.
- The valve closes automatically once the flow rate exceeds MCSF and the discharge pressure drops to normal.

Key Components:

- Pressure-sensing bypass valve
- Return line to tank or suction
- Optional check valves to avoid backflow

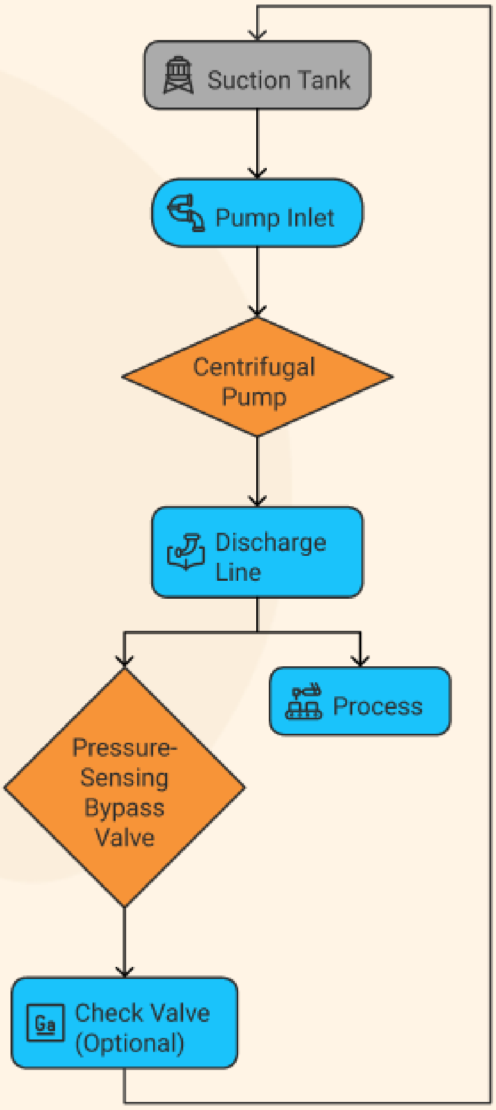


Figure 36— Self Regulating Bypass System

Advantages:

- Ensures safe operation at all times, even during startup/shutdown or flow reduction events.
- No need for electronic controllers, flowmeters, or operator action.
- Eliminates cavitation, seal failure, and overheating risk during low-flow operation.
- Protects the pump automatically — valve action is purely pressure driven.
- Reduces capital and maintenance cost of automation components.
- Ideal for existing setups with no MCSF control.

The self-regulating minimum flow bypass system provides a solution to prevent operation below MCSF — a common but often overlooked cause of pump failure.

Unlike complex control-based systems, this passive design ensures continuous protection without dependence on external inputs. Its simplicity, reliability, and compatibility with both new and existing pumps make it a highly practical enhancement, especially for applications where process fluctuations, low-flow conditions, or unattended operation are expected. Integrating such a system aligns with both API 610 reliability goals and best engineering practices for long-term pump health.

12.4 AI-Based Pump Compliance & Health Monitoring Framework

Introduction:

In modern industries, compliance with API 610 standards and early detection of pump deterioration are critical to ensure reliability, safety, and efficiency. Traditionally, such compliance is assessed through static datasheet reviews and periodic inspections, often missing real-time deviations and predictive insights.

To address this, we propose an AI-driven compliance and health monitoring system that uses both historical data and real-time sensor inputs to automate API compliance checking, maintenance forecasting, and deviation alerting. This system integrates machine learning, sensor analytics, and engineering logic, supporting predictive maintenance and data-driven decision-making.

System Overview:

The model combines:

- Historical pump data and API 610 thresholds to train the compliance model.
- Real-time sensor data from installed pumps.
- AI logic to identify deviations, predict failures, and suggest maintenance intervals.

Basically, it acts as a digital compliance auditor and health monitor, issuing alerts if a pump:

- Operates outside BEP range
- Falls below MCSF
- Shows abnormal NPSH margin
- Exceeds vibration limits; or many such other parametrical issues.

Additionally, the system learns from historical failure patterns and maintenance logs, enabling it to:

- Predict when inspections or overhauls will be needed
- Optimize preventive maintenance intervals
- Reduce unplanned shutdowns and reactive maintenance

Project Implementation:

Phase 1: Data Collection & Preparation

- Collect historical datasheets, test curves, and inspection logs.
- Include API-compliant and non-compliant cases.
- Extract and standardize key features: Flow, BEP, NPSHr, Nss, Power, Impeller Diameter, etc.

Phase 2: Labeling & Feature Engineering

- Label data as Compliant / Borderline / Non-Compliant.
- Engineer features:
    - % Rated Flow vs BEP
    - Shut-off head ratio
    - NPSH margin; and other details.

Phase 3: Model Training & Evaluation

- Use ML algorithms to train model and predict compliance and risk score.
- Run test scenarios on new pump entries.

Phase 4: Sensor Strategy & Real-Time Integration

- Identify sensor needs: Flow, Pressure, Temp, Power, Vibration, etc
- Connect to IoT gateway and live data is feed for the AI model.

Phase 5: Dashboard & Alerts

- Display:
    - Live compliance flags [Yes/No/Warnings (if any)]
    - % deviation from API thresholds and Based on the degree of deviation from safe operating conditions, the system adjusts the predicted MTBF.
    - Mean Time Between Failures (MTBF)-based maintenance schedule.
- Enable auto-generated reports.

The health of the pump is quantified as a function of MTBF. A lower MTBF suggests deteriorating health or higher failure risk. The AI uses MTBF trends to trigger maintenance recommendations before failure occurs.

Phase 6: Pilot Deployment & Feedback Loop

- Apply system to selected OH pumps.
- Validate accuracy, gather feedback.
- Calibrate and retrain as needed before full-scale use.

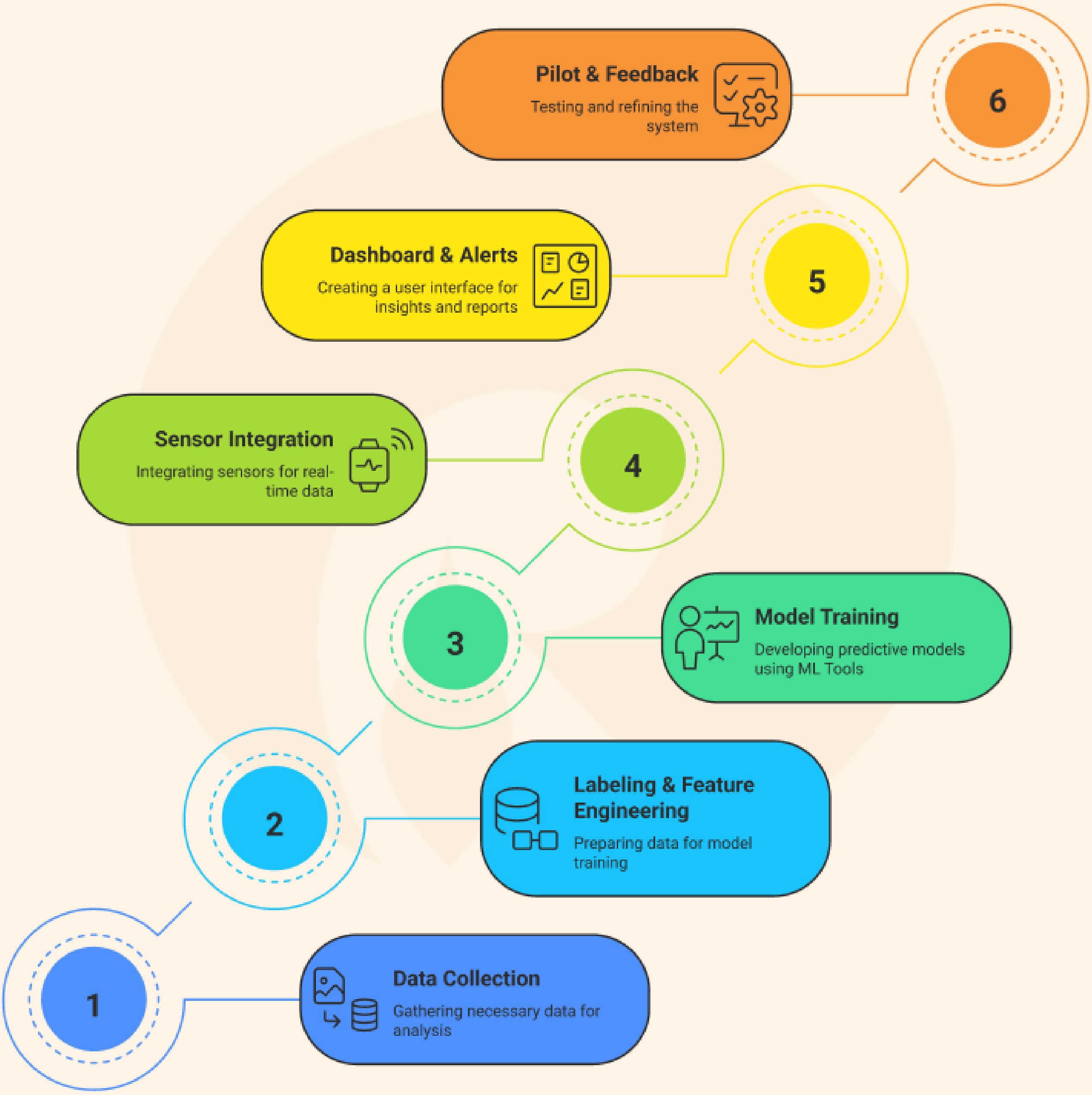


Figure 37— AI-Driven Pump Compliance & Health Monitoring System

Expected Benefits:

- Real-time Standard compliance validation.
- Predictive maintenance scheduling.
- Reduced downtime due to early alerts.
- Automated documentation for audit and inspection.

Pros

- Enhanced reliability
- Reduced downtime
- Lower costs
- Resource optimization
- Extended lifespan

Cons

- Initial investment
- Data dependency
- Complexity

13. Conclusion

This project, titled "Study of Centrifugal Pumps and Comparison of OH Pumps with API 610 Standards," combined theoretical understanding with practical evaluation of industrial centrifugal pumps. It began with an overview of pump fundamentals—working principle, energy conversion, key components, and classification by casing, impeller type, and mounting—forming the basis for interpreting pump datasheets in line with API 610, the global standard for pumps in petroleum and gas industries.

The core of the project involved analyzing and comparing three OH pumps with API 610 standards. Deviations in several parameters were identified and justified using engineering reasoning, considering mechanical behavior, fluid dynamics, and vendor design constraints.

While the pumps met key requirements, some design trade-offs—like trimmed impellers, unclassified materials, or altered bearings—were justified by real-world reasoning, site-specific fluid properties, or vendor flexibility.

Beyond evaluation, the project proposed key innovations to enhance design integrity and pump reliability:

- Compliance Gap Table – highlights missing API 610 data and suggests validation methods.
- Modular Impeller Hub – allows modification to impeller vanes as per need.
- Auto-Bypass System – protects against low-flow operation without external controls.
- AI-Based Monitoring Model – combines sensor data and history to automate compliance and predict maintenance via MTBF.

This project relates theory with real-world practice—studying how centrifugal pumps work, comparing them to API 610 standards, and suggesting practical solutions. It not only aims to improve current performance issues but also helps move towards easier maintenance and more reliable pump systems in the future.

14. References

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