
SECTION 9.7

PETROLEUM INDUSTRY

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USE OF PUMPS

Pumps of all types are used in every phase of petroleum production, transportation, and refining.

Production pumps include reciprocating units for mud circulation during drilling and sucker-rod, hydraulic rodless, and motor driven submersible centrifugal units for lifting crude to the surface. The most common use of centrifugal pumps in production is for water flooding (secondary recovery, subsidence prevention, or pressure maintenance).

Transportation pumps include units for gathering, for on and offshore production, for pipelining crude and refined products, for loading and unloading tankers, tank cars, barges, or tank trucks, and for servicing airport fueling terminals. The majority of the units are centrifugal.

Refining units vary from single stage centrifugal units to horizontal and vertical multistage barrel type pumps handling a variety of products over a full range of temperatures and pressures. Centrifugal pumps are also used for auxiliary services, such as cooling towers and cooling water.

Except for some comments about the use of displacement pumps for handling viscous liquids, this section is restricted to centrifugal pumps, the type most frequently used in the petroleum industry. It also includes an overview of the requirements for some of the principal types of centrifugal pumps.

REFINERY PUMPS

Major refinery processes are crude distillation, vacuum tower separation, catalytic conversion, alkylation, hydrocracking, catalytic reforming, coking, and hydrotreatment for the removal of sulfur and nitrogen. The products resulting from these processes include motor

gasoline, commercial jet fuel and kerosene, distillate fuel oil, residual fuel oil and lubricating oils. The American Petroleum Institute Standard 610, "Centrifugal Pumps for Petroleum, Heavy Duty Chemical, and Gas Industry Services" (API 610), has established specifications for the design features required for centrifugal pumps used for general refinery service. The standard also includes guidance with respect to lighter duty, non-flammable/nonhazardous services where the requirements of API 610 may not be required.

API 610 first edition was published in October of 1954. In its initial form, the document contained only 15 pages of text and applied to single stage overhung pumps only. Since the original publication, the standard has been updated on a regular basis, approximately every five to six years. In the eighth edition, it now contains 60 pages of text, 146 pages of appendices, and covers the specification of as many as 18 different pump types. The eighth edition, for the first time, shows a "family tree" (Figure 1) of pump types that are potentially covered, and a document organization that makes it clear which requirements apply to what pumps.

Construction Figure 2 illustrates the details of a single-stage overhung refinery process pump meeting API 610 requirements. Such a pump is referred to as a Type OH2. The suction nozzle may be located either at the end or at the top. A spacer coupling is used between the pump shaft and the driver shaft so the bearing bracket and cover may be removed without disconnecting the suction or discharge piping. This is referred to as a back pull-out design. Figure 3 illustrates the details of a between bearings, two-stage, radially split pump of type BB2. Type BB2 pumps can have one or two stages. Figures 4 and 5 show horizontal multistage pumps. Figure 4 is an axially split machine, Type BB3, and Figure 5 is a radially split or barrel-type pump, Type BB5. It is a requirement of all present day horizontal refinery pumps that the mechanical seal can be changed and the rotor removed without disconnecting the piping or moving the driver.

API 610 requires standardized seal chamber dimensions for all pumps. For overhung designs, there is only one seal chamber to seal against leakage to the atmosphere. For between bearings designs, there are two seal chambers. In single stage overhung pumps, the seal chamber pressure during pump operation is between suction and discharge pressure, depending on the design of the wear rings and impeller balance holes. For between bearings pumps, a leak off or balance line system is usually included so both seal chambers operate at the same pressure. That pressure is usually suction pressure. Although most refiners strongly prefer single seals for cost and reliability reasons, environmental requirements increasingly drive them toward dual seals. In either case, for each seal, one of the sealing rings is made of carbon, and the mating ring is either silicon carbide or tungsten carbide. API 610 gives standardized auxiliary piping plans for the support of all liquid-type mechanical seals and requires that seals meet requirements of API Standard 682, "Shaft Sealing Systems for Centrifugal and Rotary Pumps" (API 682). Mechanical seals have proved extremely reliable and virtually no new pumps are supplied with packing for process services.

The thrust bearing for single stage overhung pumps is subject to axial loading caused by exposure of one end of the shaft to suction pressure and forces on the impeller due to the differential between suction pressure and discharge pressure. When single stage overhung pumps are used for suction pressures in excess of 250 psig (17 MPa), it is common practice to "unbalance" the impeller wear rings. This is done by making the diameter of the back wear rings smaller than that of the suction side wear rings, or by eliminating the back wear rings completely. This produces an unbalanced axial thrust load in the opposite direction to that created by high suction pressure and, thus, decreases the net axial load on the thrust bearing. In the case of multistage pumps, the differential pressure across the impellers builds with each stage and some method must be employed to reduce the load on the thrust bearing. In some designs, axial thrust is balanced by means of a balance piston/leak-off arrangement; in others, an opposed impeller arrangement helps to balance axial loads. In all cases, to meet API 610 requirements, the bearings must be designed for a minimum life of 25,000 hours of continuous operation at rated conditions and 16,000 hours at maximum radial and axial loads, at rated speed.

CENTRIFUGAL PUMP TYPES

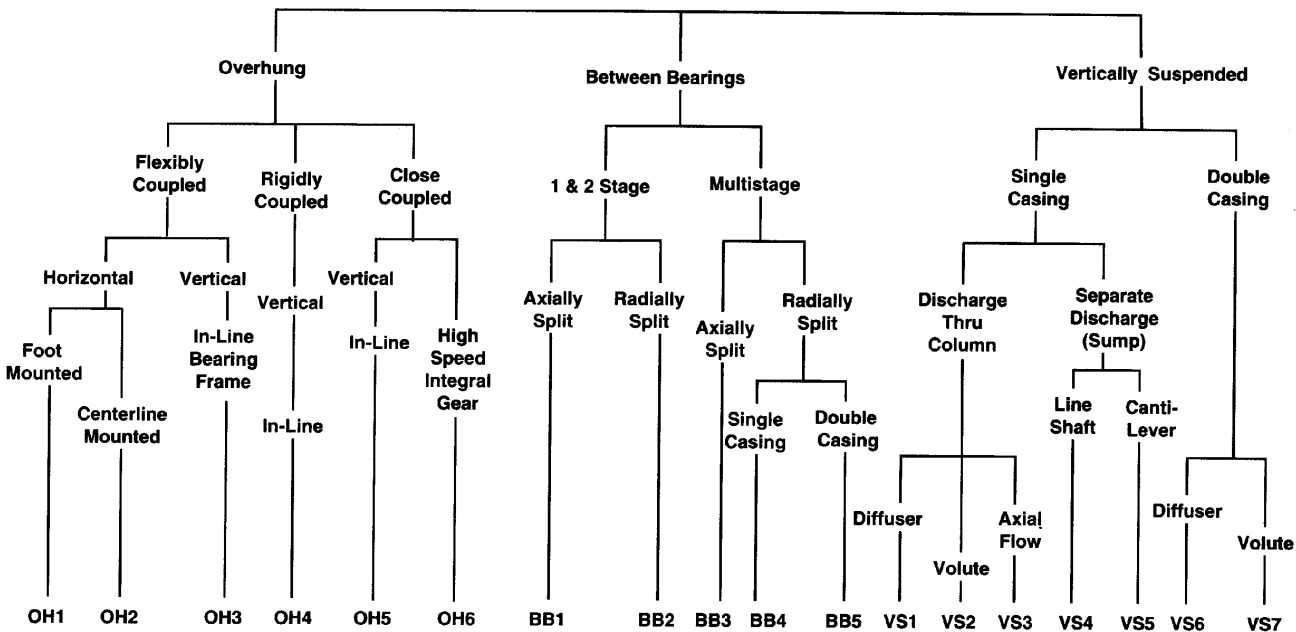


FIGURE 1 Pump classification type identification (Courtesy of the American Petroleum Institute¹)

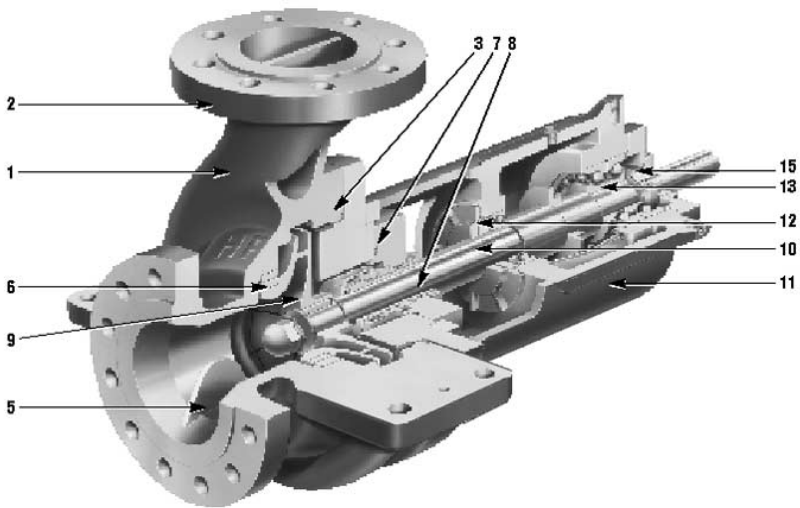


FIGURE 2 Single stage overhung refinery process pump—API 610 Type OH2. (1) Pump casing, (2) Discharge flange; flanges are standard ANSI B16.5 Class 300, (3) Metal-to-metal casing joint with fully confined, controlled compression gasket, (4) Casing drain at bottom of volute (not shown), (5) Suction nozzle guide vane (featured on some models), (6) Renewable casing and impeller wear rings, (7) Seal chamber with minimum standard dimensions, (8) Cartridge mechanical seal, (9) Impeller—dynamically balanced, (10) Shaft—heavy duty to minimize deflection, (11) Bearing housing, (12) Finned bearing housing cover for air circulation and cooling, (13) Single-row radial and back-to-back mounted angular contact thrust bearings are standard, (15) Labyrinth-type bearing housing closures on both ends, (Flowsolve Corporation)

Where casting limitations permit, double volute pumps are used to limit the radial load imposed on the impeller by uneven pressure distributions in the casing. To comply with API 610, the shaft deflection at the wear rings for one and two stage pumps, under most severe dynamic conditions, must be limited to one half the minimum diametrical (internal) clearance specified (the design clearance). For operating temperatures above 500°F (260°C), or where the pump wear rings are made of materials with higher galling tendencies, API 610 requires that 0.005 in. (0.13 mm) be added to the minimum specified diametrical clearances. Whenever hardenable wear ring materials are used, the mating wear rings are required to have a differential hardness of at least 50 BHN (Brinell Hardness Number) unless both rings are harder than 400 BHN. This requirement is to minimize the chances of the mating wear rings galling and seizing together if contact occurs.

To aid in maintaining alignment at various operating temperatures, pump mounting feet are located on the case at the same centerline as the shaft for all horizontal pumps. Earlier editions of API 610 also suggested using bearing or seal chamber cooling at elevated pumping temperatures. However, the industry has moved toward less and less cooling water usage because of cost and availability of quality water sources in many areas. Currently, API 610 leaves cooling as an item to be jointly agreed upon by the purchaser and the pump vendor.

In general, pumps meeting API 610 are designed for operation at elevated temperatures. In all services, but particularly in high temperature services, pumps are subject to loads at the nozzles due to thermal movements of piping, fabrication errors in the piping, and movements of the piping supports. These forces and moments tend to “move” the pump relative to its driver and result in misalignment of the pump and driver shafts. This misalignment can increase vibration levels and impose forces on the shafting that contribute to poor reliability. API 610 prescribes minimum forces and moments, by nozzle size, that complying

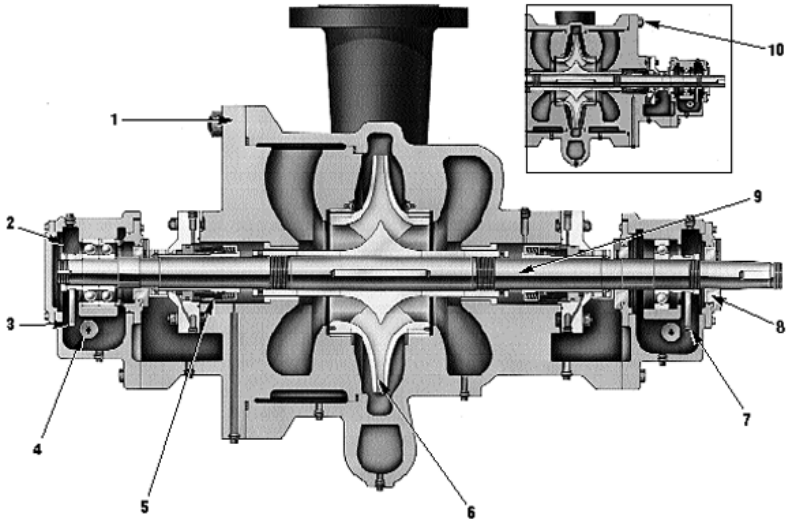


FIGURE 3 Between bearings, single stage, double section radially split pump—API 610 Type BB2. (1) Pump casing and cover with metal-to-metal confined gasketed joint, (2) Thrust bearing housing with back-to-back angular contact ball bearings, (3) Oil ring lubrication, (4) Cooling insert, (5) Seal chamber and cartridge mechanical seal, (6) Double suction impeller, dynamically balanced, (7) Radial bearing housing with deep-groove radial ball bearing and oil ring lubrication, (8) Labyrinth-type flingers at all bearing housing—shaft openings, (9) Heavy duty shaft to limit deflection at the seals and impeller, (10) Double cover design on some models. (Flowserve Corporation)

pumps must be able to withstand. Further, it outlines a test procedure to allow verification that a pump meets these minimum nozzle load requirements. The coordinate system for orientation of nozzle loads is in accordance with ISO 1503 standard convention.

Inline pumps have been developed, in part, to avoid the problem of misalignment due to nozzle loads. Figure 6 shows a single stage, overhung, inline pump with a separate bearing frame, Type OH3. Figure 7 shows a high-speed integrally geared inline pump, Type OH6. For a given flange size, inline pumps are required to withstand twice the magnitude of nozzle loads allowed for horizontal pumps. In addition, installation is simplified and less expensive because a block foundation is not required, and the pump mounts in a pipeline similar to a valve, although most users supply a support of some kind for the pump. Furthermore, the vertical arrangement causes the pump to take up much less space. The Type OH6 pump (Figure 7) has a gear box that increases the speed at which the impeller spins and typically produces high heads at relatively low flows. This type of design has many advantages in certain low flow, high head services. Some alternative inline pump designs utilize high-speed motors that eliminate the need for the gearbox. High-speed pumps may also be supplied with inducers in front of the typically radially bladed impellers to improve suction (*NPSH*) performance. When this is done, the range of operation of the pump may be restricted to avoid off-design flow instability. This should be recognized and the required range of pump operation should be addressed during the applications stage of pump selection.

Pumps of overhung shaft construction are nominally limited by most manufacturers to drivers rated below 500 hp (375 kW). Units with greater power requirements are usually designed with bearings on both ends of the shaft and the impeller—or impellers—in between the bearings (designated by API 610 as between bearings, or Type BB, pumps). Ball bearing construction, in compliance with requirements of API 610, is used to a limit of a bearing Nd_m factor of 500,000. The Nd_m factor is the product of the pump operating speed (N), in revolutions per minute and the mean bearing diameter (d_m), equal to the bearing bore plus the bearing outside diameter, divided by 2 (all dimensions in millimeters). For values of Nd_m above 500,000, or where the bearing basic life rating (L_{10h}) does not meet the

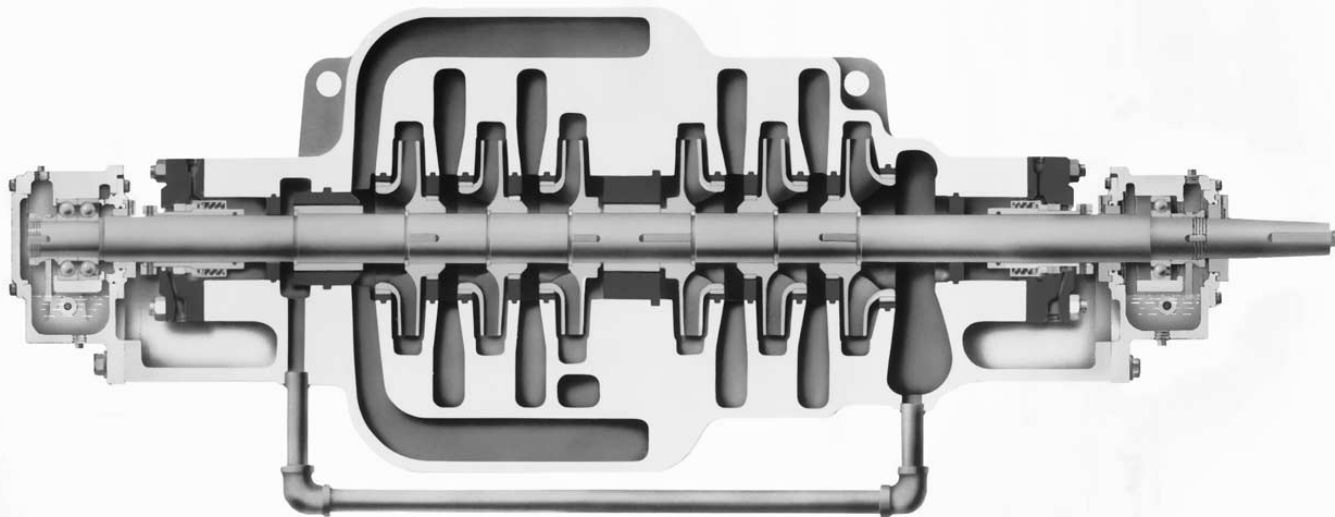


FIGURE 4 Axially split multistage pump API 610 Type BB3 (Flowsolve Corporation)

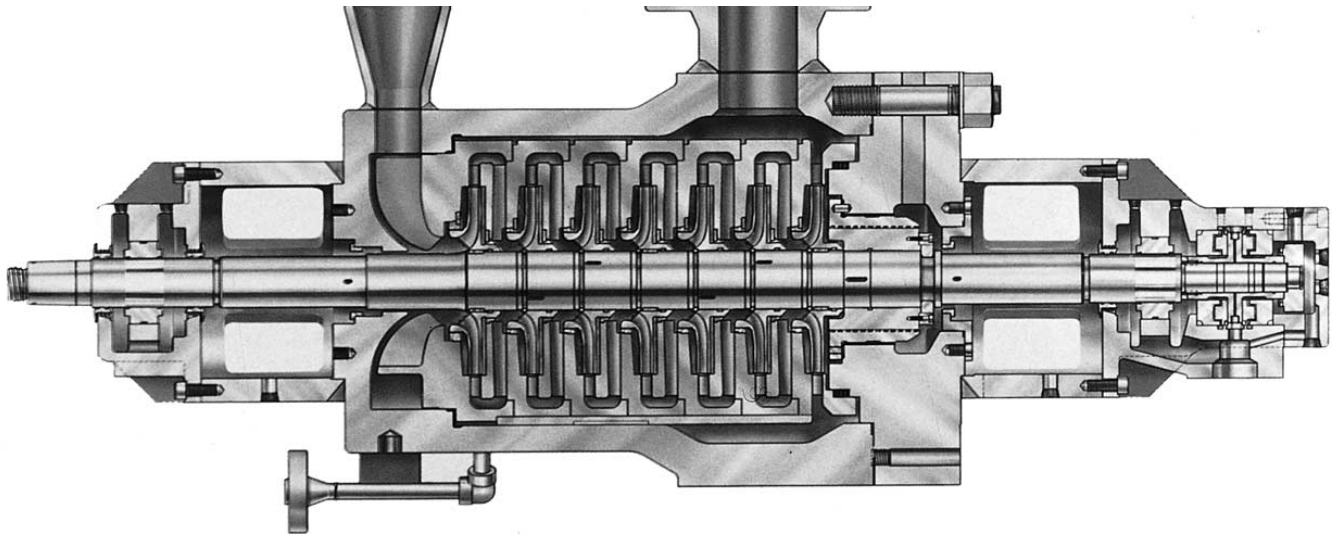


FIGURE 5 Radially split or barrel type pump—API 610 Type BB5 (Flowserve Corporation)



FIGURE 6 Single stage, overhung, vertical inline pump with separate bearing frame—API 610 Type OH3 (Flowserve Corporation)

minimum life requirements mentioned earlier, hydrodynamic bearings are required. This may result in a pump with sleeve radial and rolling element thrust bearings, or with both hydrodynamic radial and thrust bearings. API 610 also establishes an energy density limit of four million, above which hydrodynamic radial and thrust bearings are always required.

To ensure safety and reliability, it is an API 610 requirement that pump pressure casings and flanges be designed for maximum pump discharge pressure plus allowances for head increases at the rated pumping temperatures. API 610 also establishes minimum pressure ratings for all covered pumps. For horizontal radially split pumps, the minimum

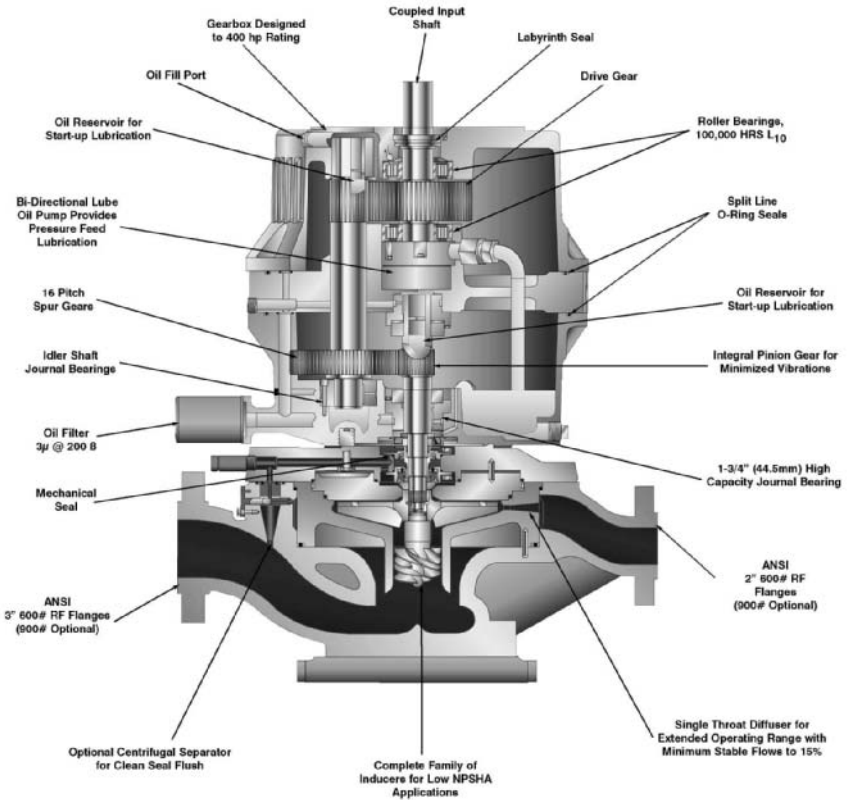


FIGURE 7 Integrally geared inline pump—API 610 Type OH6 (Sundyne Corporation)

pump pressure rating is that of an ANSI/ASME B16.5 Class 300 (ISO 7005-1 PN50) steel flange of the material grade corresponding to that of the casing, or 600 psig (4 MPa), whichever is less. Furthermore, all pumps are subjected to a hydrostatic test at 1.5 times the case rating. It is a requirement for one- and two-stage pumps that the suction and discharge flanges have the same pressure rating and that the casing have a minimum pressure rating equivalent to the flange rating.

Performance Figure 8 illustrates the wide range of capacity and head requirements that can be met by one- and two-stage refinery pumps. The range shown varies slightly with the manufacturer. The range of inline pumps is almost identical to that of horizontal overhung units. Multistage centrifugal units are available for extremely large flows and heads.

API 610 requires a performance test in accordance with Hydraulic Institute standards for all pumps. The only deviation from Hydraulic Institute (HI) standards is that efficiency is calculated for information and is not a rating or guarantee value. Power is the guarantee quantity and includes all losses (such as for mechanical seals and bearings). Vibration levels are taken during the test and acceptance criteria are established for both bearing housing and shaft measurements on the pump manufacturer's test stand. In general, refiners have lowered vibration levels in their plants through conscientious maintenance

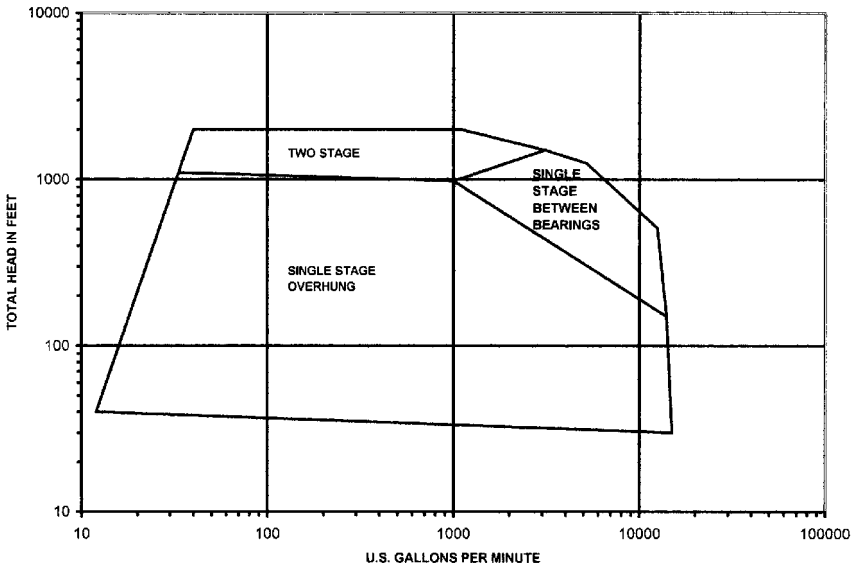


FIGURE 8 Performance coverage for single stage and two-stage refinery pumps.
(U.S. gpm \times 0.227 = m³/h; ft \times 0.305 = m)

practices, particularly in the areas of balance and alignment. The API vibration acceptance criteria are somewhat more liberal than typical plant values because of the temporary nature of a manufacturer's performance test setup. If critical service suction conditions warrant it, an NPSH test may also be conducted.

Materials Refinery pumps handle a variety of products with specific gravities ranging from 0.3 to 1.3 and viscosities from values below that of water to as high as 15,000 SSU (3240 centistokes) for centrifugal pumps and even higher for rotary pumps, over a wide range of temperatures. The product may be as inert as a lubricating-type oil or extremely corrosive. Many materials are utilized to satisfy these varied product requirements; the most common material classes are given in Table 1 (API 610 Table G-1: Material Class Selection Guide). Material classes and specifications are given in Table 2 (API 610 Table H-1: Materials for Pump Parts).

Drivers Drivers for refinery pumps are usually either electric motors or steam turbines. Centrifugal pumps running backward as hydraulic turbines are also used. The vast majority of refinery pumps are run at a fixed, 2-pole speed of either 3600 rpm in 60 cycle locations or 3000 rpm in 50 cycle locations.

PIPELINE PUMPS

Centrifugal pumps are used on every major liquid pipeline in the world to transport a variety of fluids, including crude oil, motor gasoline, fuel oil, jet fuel, liquefied petroleum gases, and anhydrous ammonia. Pump efficiency is of primary importance because of the power required to transport the liquid. Most pipeline systems install pumps in series because the differential head requirement is primarily energy loss due to friction, and an outage of one of the units would result in only a partial loss in the throughput capacity. For pipelines

TABLE 1 Material class selection guide (Courtesy of the American Petroleum Institute)^a

Service	Temperature Range		Pressure Range	Material Class	See Reference Note
	°C	°F			
Fresh water, condensate, cooling tower water	<100	<212	All	I-1 or I-2	
Boiling water and process water	<120	<250	All	I-1 or I-2	5
	120-175	250-350	All	S-5	5
	>175	>350	All	C-6	5
Boiler feed water	>95	>200	All	C-6	
	>95	>200	All	S-6	
Boiler circulator	>95	>200	All	C-6	
Foul water, reflux drum water, water draw, and hydrocarbons containing these waters, including reflux streams	<175	<350	All	S-3 or S-6	6
	>175	>350	All	C-6	
Propane, butane, liquefied petroleum gas, and ammonia (NH ₃)	<230	<450	All	S-1	
Diesel oil; gasoline; naphtha; kerosene; gas oils; light, medium, and heavy lube oils; fuel oil; residuum; crude oil; asphalt; synthetic crude bottoms	<230	<450	All	S-1	
	230-370	450-700	All	S-6	6, 7
	>370	>700	All	C-6	6
Noncorrosive hydrocarbons, e.g., catalytic reformat, isomaxate, desulfurized oils	230-370	450-700	All	S-4	7
Xylene, toluene, acetone, benzene, furfural, MEK, cumene	<230	<450	All	S-1	
Sodium carbonate, doctor solution	<175	<350	All	I-1	
Caustic (sodium hydroxide) concentration of ≤20%	<100	<210	All	S-1	8
	≥100	≥200	All	—	9
	>95	>200	All	—	10
Seawater	<260	<470	All	D-1	
Sour water	All	All	All	S-1	
Sulfur (liquid state)	All	All	All	S-1	
FCC slurry	<370	<700	All	C-6	
Potassium carbonate	<175	<350	All	C-6	
	<370	<700	All	A-8	
MEA, DEA, TEA-stock solutions	<120	<250	All	S-1	
DEA, TEA-lean solutions	<120	<250	All	S-1	8
MEA-lean solution (CO ₂ only)	80-150	175-300	All	S-9	8
MEA-lean solution (CO ₂ and H ₂ S)	80-150	175-300	All	—	8, 11
MEA, DEA, TEA, rich solutions	<80	<175	All	S-1	8
Sulfuric acid concentration >85%	<38	<100	All	S-1	6
	85% - <1%	<230	<450	All	A-8
Hydrofluoric acid concentration of >96%	<38	<100	All	S-9	6

General Notes:

- The materials for pump parts for each material class are given in Appendix H.
- Specific materials recommendations should be obtained for services not clearly identified by the service descriptions listed in this table.
- Cast iron casings, where recommended for chemical services, are for non-hazardous locations only. Steel casings (2.11.1.4) should be used for pumps in services located near process plants or in any location where released vapor from a failure could create a hazardous situation or where pumps could be subjected to hydraulic shock, for example, in loading services.
- Mechanical seal materials: For streams containing chlorides, all springs and other metal parts should be Alloy 20 or better. Buna N and Neoprene should not be used in any service containing aromatics. Viton should be used in services containing aromatics above 95°C (200°F).

Reference Notes:

- Oxygen content and buffering of water should be considered in material selection.
- The corrosiveness of foul waters, hydrocarbons over 230°C (450°F), acids, and acid sludges may vary widely. Material recommendations should be obtained for each service. The material class indicated above will be satisfactory for many of these services, but must be verified.
- If product corrosivity is low, Class S-4 materials may be used for services at 231°-370°C (451°-700°F). Specific material recommendations should be obtained in each instance.
- All welds shall be stress relieved.
- Alloy 20 or Monel pump material and dual mechanical seals should be used with a pressurized seal oil system.
- For seawater service, the purchaser and the vendor should agree on the construction materials that best suit the intended use.
- Class A-7 materials should be used except for carbon steel casings.

^aAPI Standard 610, 8th Edition (Reference 1)

where the differential head is mostly static, such as in mountainous areas, pumps are often installed in parallel. A series installation arrangement in a static system would be unsuitable because the differential head required could not be obtained unless all of the units were operating. In certain cases, however, where differential head requirements exceed levels practical for a single multistage pump, a combination of series and parallel arrangements may be desirable.

Construction A single-stage double-suction pump, a two-stage double-suction pump, and a four-stage pipeline pump are shown in Figures 9, 10, and 11, respectively. All the units are double volute and are of axially split construction. The single-stage double-suction

TABLE 2 Materials for pump parts (Courtesy of the American Petroleum Institute)^a

Part	Full Compliance Material?	Material Class and Material Abbreviations ^b												
		I-1	I-2	S-1	S-3	S-4	S-5	S-6	S-8	S-9	C-6	A-7	A-8	D-1
		CI	CI	STL	STL	STL	STL	STL	STL	STL	STL	12% CHR	AUS	316AUS
		CI	BRZ	CI	NI-RESIST	STL	STL 12% CHR	12% CHR	316 AUS	MONEL	12% CHR	AUS (1&2)	316 AUS(1&2)	DUPLX
Pressure Casting	Yes	Cast iron	Cast iron	Carbon steel	Carbon steel	Carbon steel	Carbon steel	Carbon steel	Carbon steel	Carbon steel	12% CHR	AUS	316 AUS	Duplex
Inner case parts (bowls, diffusers, diaphragms)	No	Cast iron	Bronze	Cast iron	Ni-resist	Cast iron	Carbon steel	12% CHR	316 AUS	Monel	12% CHR	AUS	316 AUS	Duplex
Impeller	Yes	Cast iron	Bronze	Cast iron	Ni-resist	Carbon steel	Carbon steel	12% CHR	316 AUS	Monel	12% CHR	AUS	316 AUS	Duplex
Case wear rings	No	Cast iron	Bronze	Cast iron	Ni-resist	Cast iron	12% CHR	12% CHR	Hard Faced 316 AUS (3)	Monel	12% CHR hardened	Hard Faced AUS (3)	Hard Faced 316 AUS (3)	Duplex (3)
Impeller wear rings	No	Cast iron	Bronze	Cast iron	Ni-resist	Cast iron	12% CHR Hardened	12% CHR Hardened	Hard faced 316 AUS (3)	Monel	12% CHR Hardened	Hard Faced AUS (3)	Hard Faced 316 AUS (3)	Duplex (3)
Shaft (2)	Yes	Carbon steel	Carbon steel	Carbon steel	Carbon steel	Carbon steel	AISI 4140	AISI 4140 (4)	316 AUS	K-Monel	12% CHR	AUS	316 AUS	Duplex
Shaft sleeves, packed pumps	No	12% CHR hardened	Hard bronze	12% CHR hardened	12% CHR hardened or hard faced	12% CHR hardened or hard faced	12% CHR hardened or hard faced	12% CHR hardened or hard faced	Hard Face 316 AUS (3)	K-Monel, hardened	12% CHR hardened or hard faced	Hard Faced AUS (3)	Hard Faced 316 AUS (3)	Duplex (3)
Shaft sleeves, mechanical seals	No	AUS or 12% CHR	AUS or 12% CHR	AUS or 12% CHR	AUS or 12%CHR	AUS or 12% CHR	AUS or 12% CHR	AUS or 12% CHR	AUS or 12% CHR	K-Monel, hardened	AUS or 12% CHR	AUS	316 AUS	Duplex
Throat bushings	No	Cast iron	Bronze	Cast iron	Ni-resist	Cast iron	12% CHR	12% CHR	316 AUS	Monel	12% CHR hardened	AUS	316 AUS	Duplex
Interstage sleeves	No	Cast iron	Bronze	Cast iron	Ni-resist	Cast iron	12% CHR hardened	12% CHR hardened	Hard Faced 316 AUS (3)	K-Monel, hardened	12% CHR hardened	Hard Faced AUS (3)	Hard Faced 316 AUS (3)	Duplex (3)
Interstage bushings	No	Cast iron	Bronze	Cast iron	Ni-resist	Cast iron	12% CHR hardened	12% CHR hardened	Hard Faced 316 AUS (3)	K-Monel, hardened	12% CHR hardened	Hard Faced AUS (3)	Hard Faced 316 AUS (3)	Duplex (3)
Seal gland	Yes	316 AUS (5)	316 AUS (5)	316 AUS (5)	316 AUS (5)	316 AUS (5)	316 AUS (5)	316 AUS (5)	316 AUS (5)	Monel	316 AUS (5)	316 AUS (5)	316 AUS (5)	Duplex (5)
Case and gland studs	Yes	Carbon steel	Carbon steel	AISI 4140 steel	AISI 4140 steel	AISI 4140 steel	AISI 4140 steel	AISI 4140 steel	AISI 4140 steel	K-Monel, hardened (8)	AISI 4140 steel	AISI 4140 steel	AISI 4140 steel	Duplex (8)
Case gasket	No	AUS, spiral wound (6)	AUS, spiral wound (6)	AUS, spiral wound (6)	AUS, spiral wound (6)	AUS, spiral wound (6)	AUS, spiral wound (6)	AUS, spiral wound (6)	316 AUS, spiral wound (6)	Monel, spiral wound, PTFE filled (6)	AUS, spiral wound (6)	AUS, spiral wound (6)	316 AUS spiral wound (6)	Duplex SS spiral wound (6)
Discharge head / suction can	Yes	Carbon steel	Carbon steel	Carbon steel	Carbon steel	Carbon steel	Carbon steel	Carbon steel	Carbon steel	Carbon steel	AUS	AUS	316 AUS	Duplex
Column / bowl shaft bushings	No	Nitrite (7)	Bronze	Filled carbon	Nitrite (7)	Filled carbon	Filled carbon	Filled carbon	Filled carbon	Filled carbon	Filled carbon	Filled carbon	Filled carbon	Filled carbon
Wetted fasteners (bolts)	Yes	Carbon steel	Carbon steel	Carbon steel	Carbon steel	Carbon steel	316 AUS	316 AUS	316 AUS	K-Monel	316 AUS	316 AUS	316 AUS	Duplex

^a The abbreviation above the diagonal line indicates the case material, the abbreviation below the diagonal line indicates trim material. Abbreviations are as follows: BRZ = bronze; STL = steel; 12% CHR = 12% chrome; AUS = austenitic stainless steel; CI = cast iron; 316 AUS = Type 316 austenitic stainless steel. See 2.11.1.1.

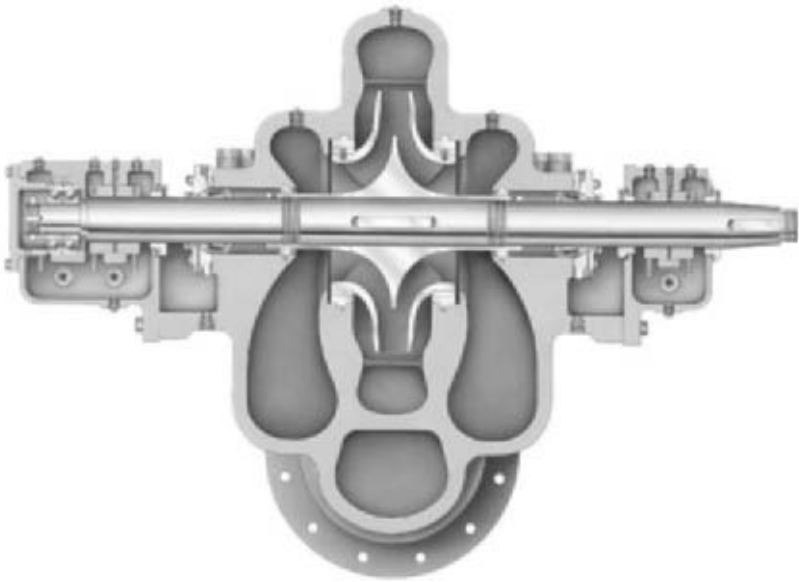


FIGURE 9 Single-stage double suction, axially split pump (Flowsolve Corporation)

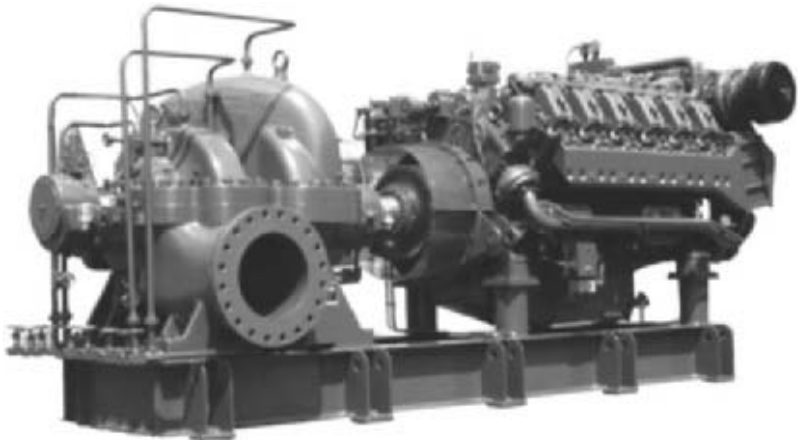


FIGURE 10 Two-stage, double suction pump with engine drive (Flowsolve Corporation)

unit (Figure 9) is typical of those used in series operation on large diameter pipelines with capacities as high as two million barrels per day. One pipeline alone has installed more than one hundred 5000 hp (3730 kW) pumps of this construction. The two-stage double-suction pump (a smaller unit is shown in Figure 10 with an engine driver) is typical for higher head applications, and sizes are available for power ratings to 20,000 hp (15,000 kW). For lateral and smaller diameter pipeline pumping stations, multistage units (Figure 11) are used. The number of stages chosen corresponds to the differential head

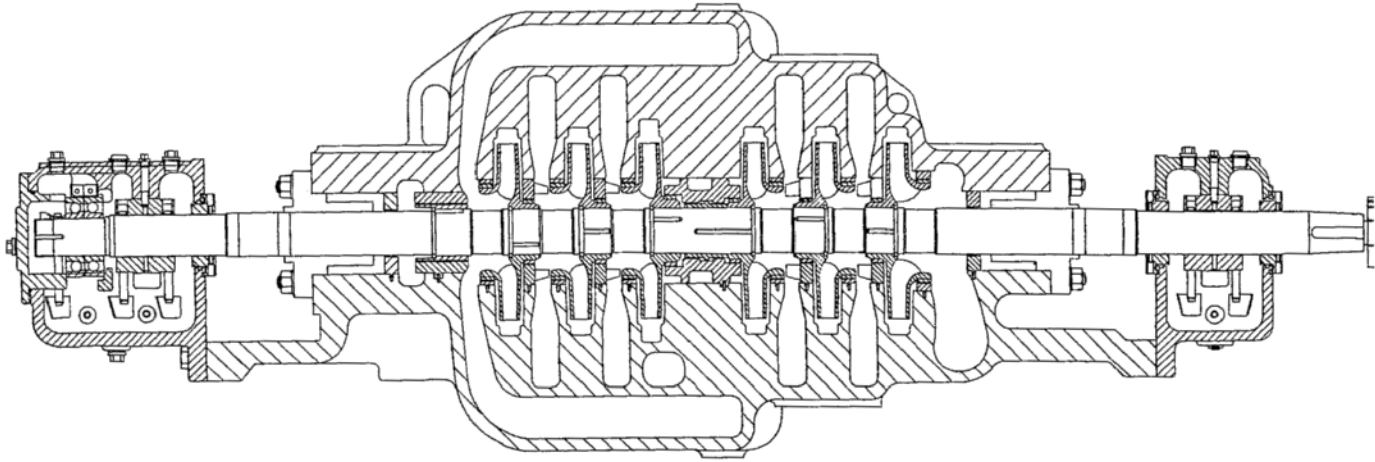


FIGURE 11 Single-suction, double-volute, axially split, six-stage pipeline pump (Flowserve Corporation)

required. Multistage units may be destaged initially to produce lower heads, with a subsequent power saving, or the nozzling may be arranged for series or parallel operation of a portion of the stages. The exact arrangement depends on the system characteristics and initial and ultimate capacities to be pumped.

All units are equipped with sleeve radial bearings and either ball or hydrodynamic thrust bearings, as dictated by power (size) and rotating speed. The single- and two-stage double suction pumps are inherently balanced axially. The multistage units utilize opposed impeller design to obtain axial balance. All modern units are equipped with mechanical seals in the seal chamber. Because most pipeline stations are now designed for unattended outdoor service, a number of safeguard controls are used. These include warnings for low suction pressure, high discharge pressure, high bearing or case temperature vibration, and excessive seal leakage. Tank farms utilize single- and double-suction inline vertical pumps or, if the tank is to be pumped dry, vertical canned pumps.

Performance Figure 12 indicates the typical available range for single- and two-stage pipeline pumps, and Figure 13 shows the range for multistage units. Pipeline units are custom designed, and the range is constantly being extended. Electric motors are normally used as drivers. With the utilization of gas turbines, the maximum power employed has increased dramatically in the last 30 years. Another use of gas turbines on existing pipelines is for peak capacity booster station service, in which case pumps are direct-driven at operating speeds as high as 6000 rpm.

Materials Pump part materials commonly specified for crude and product pipeline services are shown in Table 2 under columns S-1 through S-9. For the more aggressive services and liquids, the higher numbered material columns are preferred. All these material columns utilize carbon steel pump casings; the impellers, wear rings, and shaft materials are changed as the material grades increase in alloy and hardness (wear rings) with advancing material column grade number.

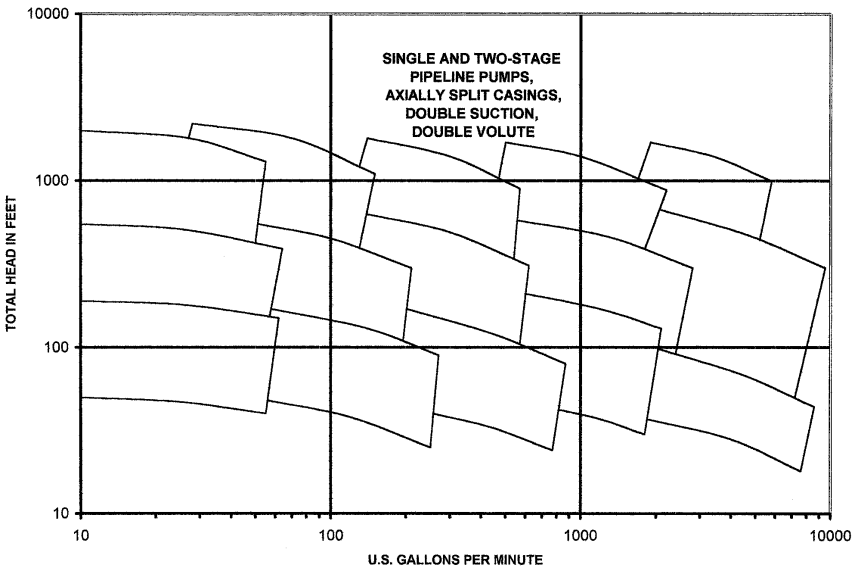


FIGURE 12 Performance coverage for single- and two-stage pipeline pumps

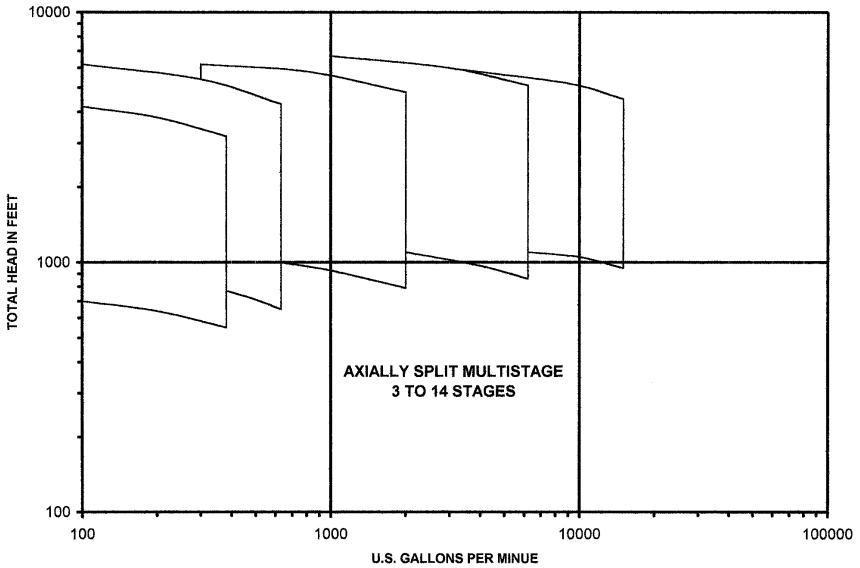


FIGURE 13 Performance coverage for multistage, axially split pumps

Pumping Stations The typical piping of a main line pump station in which the units are arranged in series is shown in Figure 14. As pipeline capacities have increased, one of the major problems has been the pressure loss at each station. For the station shown, three discharge valves (one 16 in (406 mm) ball valve manifolded in parallel with two 24 in (610 mm) control valves) were used. This arrangement limited the calculated pressure drop to that of a length of 36 in (914mm) pipe equal to the distance across the manifold and still allowed the use of control valves of proven size. When line conditions require throttling, the 16 in (406 mm) ball valve is first completely closed. If additional throttling is needed, the two 24 in (610 mm) control valves are closed to produce the required pressure drop. In order to move scrapers or batch separators through each station without interrupting flow through the pumps, signals (PIG SIG), hydraulically operated 24 in (610 mm) valves, and sequence control wiring are used. The distance between PIG SIG 1 and PIG SIG 2 represents the volume of station loop to be displaced. The tripping of PIG SIG 3 and PIG SIG 4 controls the valve opening and closing required to divert flow from the station discharge piping to behind the scraper or batch separator, thus forcing it to leave the station in the same relative position as it entered. Elbows at pump suction are arranged to avoid uneven flow distribution in the inlet of the double suction impeller.

Pipeline pumps are tested in accordance with Hydraulic Institute Standards. Reduced speed tests may be required because of the power limitations of manufacturing plants and available drivers, and such tests have proven to be extremely accurate indicators of full speed performance.

SPECIAL SERVICES

Waterflood Centrifugal pumps are also used for water injection service when the capacity required is greater than 10,000 barrels per day. Injection pressures requirements vary considerably from initial startup with operating time. For high-pressure services, usually above 2500 lb/in² (17Mpa), barrel-type pumps are used.

Barrel-type pumps (Figure 15), operating in series to speeds in excess of 6000 rpm using gears and gas turbine or engine drivers, are capable of injection pressures in excess of 8000 lb/in² (55 MPa) gauge. The barrel construction is typically of forged steel with an austenitic stainless steel welded overlay applied in areas of high velocity. Barrel-type casings are hydrostatically tested to 12,000 lb/in² (83 MPa) gauge and beyond (usually 1½ times barrel design pressure).

Most waterflood injection pressure requirements, however, are such that axially split multistage pumps of the design shown in Figure 4 may be used. As many as 14 stages in one pump are often utilized to obtain the required differential head. In addition, if still greater pressures are required, the units may be piped in series. Axially split pumps have been hydrostatically tested to 6000 lb/in² (41 MPa) for a working pressure of 4000 lb/in² (27.5 MPa).

For applications where injection liquid is highly corrosive, materials of construction may include austenitic and duplex stainless steels. Commonly used materials for major pump components in waterflood applications are shown in Table 2 under material columns A-8 and D-1. Seal chambers for high pressure and high-speed services may contain a limited leakage breakdown bushing preceding a mechanical seal for increased reliability.

Reactor Feed Pumps One of the most difficult services encountered in the petroleum industry is the high-temperature, high pressure reactor feed, or charge pump. Type BB5 pumps, such as the one shown in Figure 5, are most commonly used for these services. Reactor feed pumps can be subject to operating temperatures in excess of 800°F (425°C) with discharge pressures in excess of 2500 lb/in² (17 MPa) gauge. To produce such high pressures requires either a large number of stages or high speed. Historically, refiners have preferred 3600 rpm (3000 rpm in 50 Hz areas) pumps with large numbers of stages. However, the trend more recently is for shorter, more robust pumps, with fewer stages operating at higher speeds.

The high temperatures and corrosiveness of the pumped fluids often require the use of a number of dissimilar metals. Compensation must be made for the different rates of expansion of the various components at operating temperatures. This presents a critical design problem for the manufacturer and a significant operability issue for the refinery. Extreme care is required in the startup and operation of these units. Even so, it is common for refiners to buy only a single pump for such services (no spare), and for these pumps to run continuously for five or more years without maintenance.

LPG Pumps Multistage axially split centrifugal pumps have been installed in pipelines transporting liquefied petroleum gases (LPG) with specific gravities as low as 0.35. The low lubricity of the pumped fluid required careful selection of wearing part materials. Seal chambers may utilize single or double (dual) mechanical seals, depending upon local environmental issues. At ambient temperatures, the suction pressures can be 1000 lb/in² (69 MPa) gauge or more. These fluids may also experience a large temperature rise as a result of compression that occurs during the pumping process.

Many additional special designs could be mentioned. The wide range of operating conditions and products in the petroleum industry frequently requires pumps specifically engineered for a certain service. The pump designer is continually challenged to provide a safe, reliable, and economical design.

PUMPING OF VISCOUS LIQUID

Viscosity of the pumped liquid is a very important factor that must be considered to properly select and size pumps in many petroleum industry applications. A thorough understanding of the relationship between liquid viscosity and pump performance is essential to proper sizing of both the pump and its driver.

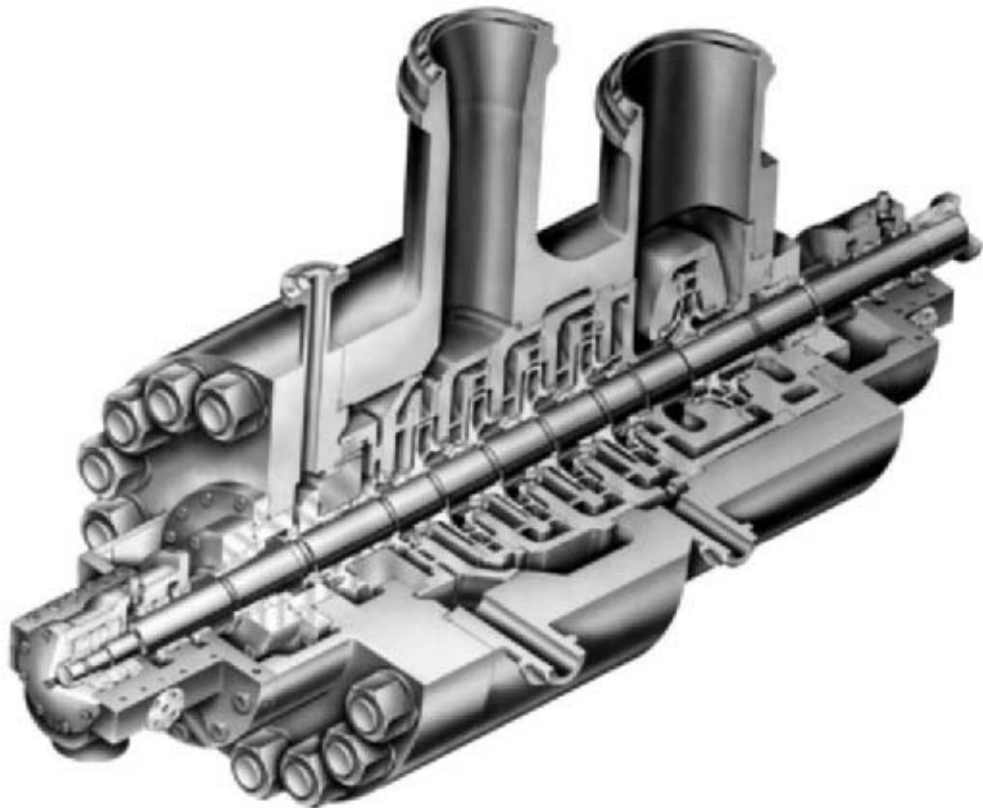


FIGURE 15 Double-casing multistage barrel-type pump with radially split inner casing (Flowsolve Corporation)

TABLE 3 Effect of viscosity on performance of a typical centrifugal pump operating at best efficiency point

Viscosity SSU (cSt)	Capacity gpm (m ³ /h)	Total head ft (m)	Efficiency %	Brake power bhp (kW) ^a
Nil	3000 (681)	300 (91)	85	241 (180)
500 (110)	3000 (681)	291 (89)	71	279 (208)
2,000 (440)	2900 (658)	279 (85)	59	312 (233)
5,000 (1100)	2670 (606)	264 (80)	43	373 (278)
10,000 (2200)	2340 (531)	243 (74)	31	417 (311)
15,000 (3300)	2100 (477)	228 (69)	23	473 (353)

^aAll values of brake power based on liquid having a specific gravity of 0.90.

Centrifugal pumps are routinely applied on services with liquids having viscosities below 3000 Saybolt Seconds Universal (SSU) or 660 centistokes (cSt), and may be used up to at least 15,000 SSU (3300 cSt). (For background information on viscosity, refer to Section 8.1.) Centrifugal pumps are sensitive, however, to changes in viscosity and will exhibit significant reductions in capacity and head and rather drastic reductions in efficiency at moderate to high values of viscosity. The extent of these effects may be seen in Table 3, constructed with the aid of Figure 16, which provides a convenient means of determining the viscous performance of a centrifugal pump when its cold water performance is known. To use Figure 16, enter at the bottom with the pump capacity, and then proceed vertically upward to the total head (head per stage for multistage pumps), proceed horizontally right or left to the viscosity value, and finally proceed vertically upward again to the curves for correction factors. The values thus obtained for the respective correction factors are multiplied by the water performance values for capacity, total head, and efficiency to obtain the equivalent values for viscous performance. By using the individual correction factors for total head, it is even possible to approximate the shape of the head-capacity characteristic curve when the viscous liquid is being pumped, at least to 120% of the best efficiency point flow (Q_N). The total head at shutoff will remain essentially constant regardless of liquid viscosity.

Centrifugal pump performance is nearly always specified by the pump manufacturer basic pumping clean, cold water, even when the pump has been specifically designed for petroleum industry applications. Cold water is a universal pumping medium. Pumps selections, however, must necessarily be made to satisfy viscous conditions of service and require application of these correction factors in the reverse direction. In this case, Figure 16 provides an approximation of equivalent water performance that is probably within the limits of accuracy of the graph for liquid viscosities in SSU numerically equal to pump capacity in gallons per minute. (In other words, for a pump with a capacity of 3000 gpm, Figure 16 is probably quite accurate to viscosities of 3000 SSU.) For higher viscosities, the initial solution of equivalent water performance, determined in accordance with the following paragraph, may need to be adjusted and then checked by conversion of water performance to viscous performance again.

To determine approximate equivalent water performance when required viscous pump performance is known, enter Figure 16 at the bottom with the viscous capacity, proceed vertically upward to the desired viscous head (head per stage for multistage pumps), and then horizontally right or left to the viscosity, and vertically upward to the correction factor curves for capacity and head. In this case, divide the viscous performance values by the correction factors to obtain the equivalent water performance values. The pump selection can then be made, basic ratings established for water, and efficiency can be calculated for the viscous liquid using the efficiency correction factor applied to the pump efficiency for water.

EXAMPLE To select a pump for 500 gpm (114 m³/h) of 3000 SSU (660 cSt) liquid against a head of 150 ft (46 m), proceed as follows:

From Figure 16, determine $C_Q = 0.80$ and $C_H = 0.81$.

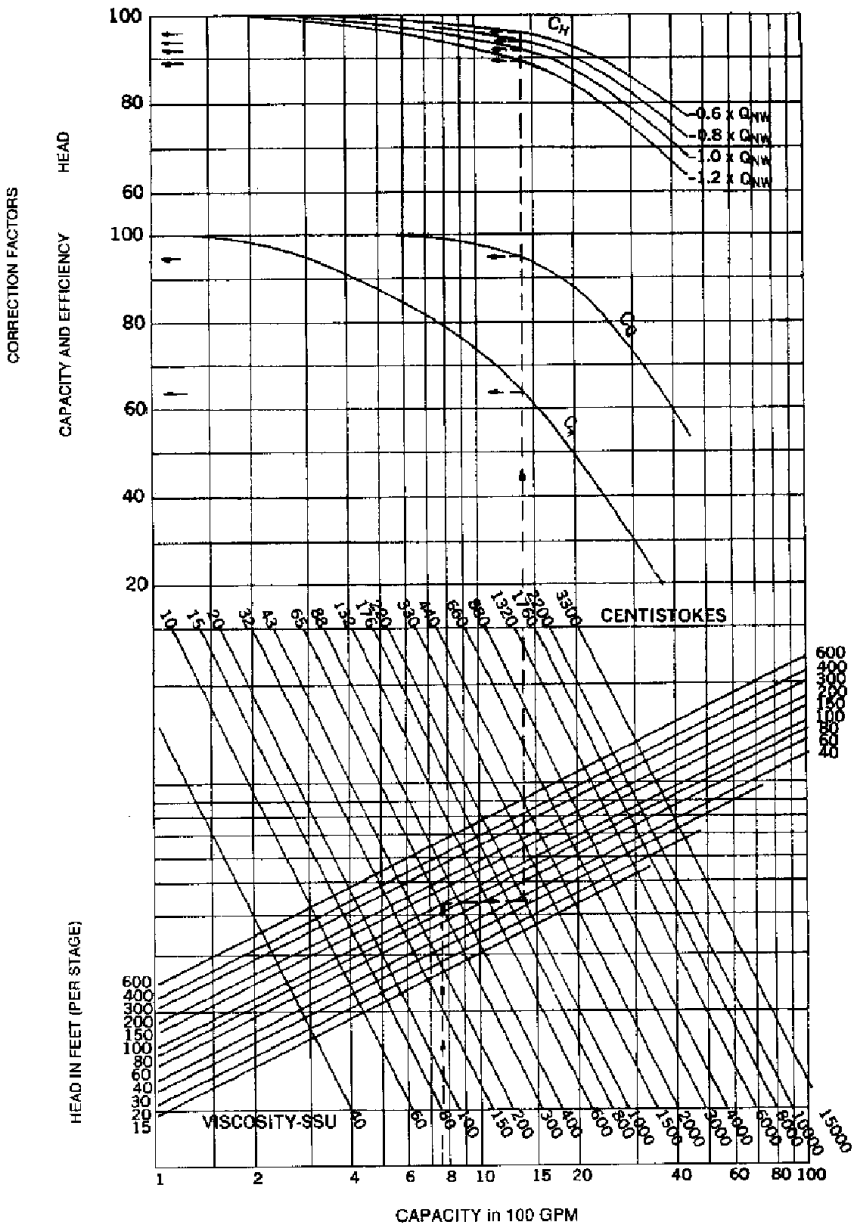


FIGURE 16 Performance correction chart for viscous liquids—Hydraulic Institute ANSI/HI 2000 Edition Pump Standards (Reference 3).

The water capacity, then, is

$$\text{In USCS units} \quad Q_W = 500/0.80 = 625 \text{ gpm}$$

$$\text{In SI units} \quad Q_W = 114/0.80 = 142 \text{ m}^3/\text{h}$$

And the water head is

$$\text{In USCS units} \quad Q_H = 150/0.81 = 185 \text{ ft}$$

$$\text{In SI units} \quad Q_H = 46/0.81 = 57 \text{ m}$$

For 625 gpm (142 m³/h), 185 ft (57 m), 3000 SSU (660 cSt), Figure 16 indicates $C_Q = 0.83$, $C_H = 0.85$, and $C_E = 0.42$. If the values for C_Q and C_H obtained from these calculations are roughly within 2% of those taken directly from Figure 16, the pump may be selected on the basis of the water capacity and water head already obtained. Because, in this case, these values differ from the first approximation by more than 3%, the water performance should be adjusted as follows:

Adjust the water capacity:

$$Q_W \times 0.80/0.83 = 602 \text{ gpm (137 m}^3/\text{h)}$$

Adjust the water head:

$$H_W \times 0.81/0.84 = 178 \text{ ft (55 m)}$$

Select the pump for 602 gpm (137 m³/h) and 178 ft (55 m) and determine water efficiency from the manufacturer's rating. Assuming the water efficiency in this case is 75%, the viscous efficiency

$$E_V = 0.75 \times 0.42 = 0.315, \text{ or } 31.5\%.$$

For a specific gravity (sp. gr.) of 0.90,

In USCS units

$$\begin{aligned} \text{bhp} &= \frac{\text{gpm} \times \text{ft of head} \times \text{sp. gr.}}{3960 \times \text{efficiency}} \\ &= \frac{500 \times 150 \times 0.90}{3960 \times 0.315} \\ &= 54 \end{aligned}$$

In SI units

$$\text{brake kW} = \frac{\text{m}^3/\text{h} \times \text{m} \times \text{sp. gr.}}{376.5 \times \text{efficiency}} = \frac{114 \times 150 \times 0.90}{376.5 \times 0.315} = 40$$

The Hydraulic Institute Standards limit the use of Figure 16 to radial flow centrifugal pumps with open or closed impellers, handling Newtonian liquids within the pump's normal operating range and within the capacity limits indicated on the chart. Failure to heed these limitations may result in misleading expectations of performance with viscous liquids. Tests on vertical turbine-type pumps, for example, which normally have mixed-flow rather than radial-flow impellers, have shown that, although the viscous efficiency predicted from this chart is quite accurate, the viscous head and viscous capacity predictions are substantially above the demonstrable values. In other words, the performance reductions determined from the chart would not be severe enough for that type of pump. For centrifugal pumps that do not fall within the limits of applicability of Figure 16, viscous performance can be accurately established only by testing.

DISPLACEMENT PUMPS Both rotary and reciprocating pumps are also frequently used for pumping viscous fluids, and some types are well suited for use where viscosities are beyond the limits for centrifugal pumps. In fact, many common designs are suitable only for use with liquids that are at least moderately viscous because they depend on the viscosity to maintain the lubricating and sealing films between various internal parts of the pumps. Most gear pumps and screw pumps are in this category.

As with centrifugal pumps, the performance of displacement pumps may be significantly affected by changes in liquid viscosity, but the nature of these changes may be quite different. At constant speed, changes in viscosity are likely to have little or no effect on pump capacity. Total head, or differential pressure across the pump, would probably increase with increasing viscosity because of higher system resistance. Thus, the brake power required would increase with even though pump efficiency would not suffer nearly so drastically, if at all, as for a centrifugal pump.

The influence of pump design on how performance varies with viscosity is greater in displacement pumps than in centrifugal pumps. Because there are so many designs, it is not practical to attempt to provide a general means of determining their viscous performance here. This should be done only on the basis of information provided by the pump manufacturer.

REFERENCES AND FURTHER READING

1. American Petroleum Institute Standard 610. "Centrifugal Pumps for Refinery, Heavy Duty Chemical, and Gas Industry Services." 8th ed., 1995.
2. American Petroleum Institute Standard 682. "Shaft Sealing Systems for Centrifugal and Rotary Pumps." 1st ed., 1994.
3. American National Standard for Centrifugal Pumps for Design and Application, ANSI/HI 1.3-2000, Section 1.3.4.1.11, Hydraulic Institute, Parsippany, NJ www.pumps.org.
4. Hydraulic Institute ANSI/HI 2000 Edition Pump Standards, Hydraulic Institute, Parsippany, NJ www.pumps.org.