CONTENTS

Section **Page**

SCOPE 2

REFERENCES 2

DEFINITIONS 3

BACKGROUND 3
- GENERAL 3
- TYPES OF PUMPS 3
- JOB SPECIFICATION INFORMATION LOCATIONS 3
- GLOBAL PRACTICE COVERAGE 3

BASIC DESIGN CONSIDERATIONS 4
- EQUIPMENT TYPE SELECTION 4
- GENERAL INSTRUCTIONS AND INFORMATION (GII) CONTENT 4
- INDIVIDUAL PUMP DESIGN SPECIFICATION CONTENT 4
  - Sparing and Multiplicity 5
  - Process Requirements 5
  - Design and Construction 10
- DESIGN FLOW PLAN CONTENT 12

NOMENCLATURE 13

FIGURES
- Figure 1A Typical Performance Data For High Head-Capacity Centrifugal Pumps (Customary) ... 20
- Figure 1B Typical Performance Data For High Head-Capacity Centrifugal Pumps (Metric) 21
- Figure 2A Application Range Of Various Centrifugal Pump Construction Styles (Customary) 22
- Figure 2B Application Range Of Various Centrifugal Pump Construction Styles (Metric) 23
- Figure 3A Application Range Of Various Centrifugal Pump Construction Styles (Customary) 24
- Figure 3B Application Range Of Various Centrifugal Pump Construction Styles (Metric) 25
- Figure 4A Centrifugal Pump Performance Data (Customary) 26
- Figure 4B Centrifugal Pump Performance Data (Metric) 27
- Figure 5A Centrifugal Pump Performance Data (Customary) 28
- Figure 5B Centrifugal Pump Performance Data (Metric) 29
- Figure 6 Control Valve Modulation Of Centrifugal Pump Flow Rate 30

Revision Memo

12/01 Added reference to Section XV, deleted GP 18-6-1 reference, added GP 18-10-1 reference, added EHM Reference, added EBV refernce in design flow plan, added vent reference to design flow plan, added reference to Section X-D Table 1.

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SCOPE

This section presents procedures for designing and specifying pumping services with special emphasis on services for which centrifugal pumps are commonly applied. Only the general aspects of design that are common to the various pump types are covered. Details relating to specific types of pumps, shaft sealing, drivers, and specialized aspects of pump service design are presented in other subsections.

REFERENCES

DESIGN PRACTICES (BESIDES SUBSECTIONS OF SECTION X)

Section II	Design Temperature, Design Pressure, and Flange Ratings
Section XII	Instrumentation
Section XIV	Fluid Flow
Section XVIII	Guidelines and Considerations for Industrial Hygiene
Section XV	Safety in Plant Design

GLOBAL PRACTICES

GP 3-3-2	Suction and Discharge Piping for Centrifugal Pumps
GP 3-3-12	Oil Mist Lubrication Systems
GP 3-9-1	Winterizing and Protection Against Ambient Temperatures
GP 10-1-1	Heavy Duty Centrifugal Pumps
GP 10-1-2	Medium Duty Centrifugal Pumps
GP 10-2-1	Positive Displacement Pumps-Reciprocating
GP 10-2-2	Positive Displacement Pumps-Rotary
GP 10-2-3	Positive Displacement Pumps-Controlled Volume
GP 10-7-1	General Purpose Steam Turbines
GP 10-7-2	Special Purpose Steam Turbines
GP 10-10-1	High Speed Special Purpose Gear Units
GP 10-10-2	General Purpose Steam Turbines
GP 16-9-1	A-C Motors
GP 16-9-2	Additional Requirements For AC Motors Over 1500 HP (1100 kW)
GP 16-14-1	Variable Frequency Drives
GP 18-10-1	Additional Requirements for Materials

OTHER REFERENCES

API 610, *Centrifugal Pumps for General Refinery Service*
API 611, *General Purpose Steam Turbines for Refinery Service*
API 612, *Special Purpose Steam Turbines for Refinery Services*
API 613, *Special Purpose Gear Units for Refinery Services*
API 674, *Positive Displacement Pumps-Reciprocating*
API 675, *Positive Displacement Pumps-Controlled Volume*
API 676, *Positive Displacement Pumps-Rotary*
API 677, *General Purpose Gear Units for Refinery Service*
ExxonMobil Blue Book, EMRE Manual Nos. 012 and 011
Refinery Construction Materials Manual, EMRE Manual No. EETD 028
Chemicals Construction Materials Manual, EMRE Manual No. CED 009
Pump Sealing Technology Manual, EMRE Manual No. TMEE-23
Hydraulic Institute Standards

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DEFINITIONS

Head - The amount of energy per unit mass required to achieve a desired pressure increase. It is expressed in an equivalent column height of the fluid pumped; e.g., feet or meters.

Net Positive Suction Head Available ($NPSH_A$) - The total suction head, in feet (meters) of liquid absolute, determined at a datum elevation, minus the vapor pressure of the liquid in feet (meters) absolute.

Net Positive Suction Head Required ($NPSH_R$) - The reduction in total head as the liquid enters the pump. This includes losses due to friction and turbulence. The $NPSH_A$ must always be greater than the $NPSH_R$ to avoid cavitation.

BACKGROUND

GENERAL

The application of pumping equipment is accomplished in three major phases:

1. Pumping service design and specification.
2. Pump vendor and model selection.
3. Detailed pump and installation design.

Pumping service design and specification, including pump and driver type selection, are part of the overall process design effort. The pump vendor and model are chosen by machinery specialists during the detail engineering phase of a project. Pump and driver design are vendor responsibilities, while installation design is left to the detail engineering contractor.

TYPES OF PUMPS

Section X-C provides a summary of the various types of commercially available pumps. The two basic types are centrifugal and positive displacement pumps. Centrifugal pumps are available in vertical and horizontal casing arrangements, single and multiple stage arrangements, baseplate and inline mounted casings, and sealed and sealless designs. Positive displacement pumps are of the reciprocating, rotary, and metering or controlled volume type. Rotary type positive displacement type pumps are available in sealed and sealless designs.

JOB SPECIFICATION INFORMATION LOCATIONS

Pump service design and specification information is generally located in the following job specification documents:

1. The General Instructions and Information, **(GII)**, section of the Design Specifications.
2. The individual unit (where pump is located) Design Specification including Design Flow Plans.
3. Global Practices.

GLOBAL PRACTICE COVERAGE

The applicable Global Practice for centrifugal pumps of all casing and stage arrangements is **GP 10-1-1**. Positive displacement pump Global Practices are **GP 10-2-1** for reciprocating, **GP 10-2-2** for rotary, and **GP 10-2-3** for controlled volume pumps. The pump Global Practices include the requirements of the applicable API Standards. They are **API 610** for medium and heavy centrifugal pumps, **API 674** for reciprocating pumps, **API 676** for rotary pumps, and **API 675** for controlled volume pumps.

There are also Global Practices covering the various types of pump drivers, namely, electric motors, gearing, and steam turbines. They are **GP 16-9-1** and **GP 16-9-2** for motors, **GP 10-10-1** or **GP 10-10-2** for gears, and **GP 10-7-1** or **GP 10-7-2** for steam turbines. The gear and steam turbine Global Practices also include the requirements of **API 613 or API 677** for gears and **API 611 or API 612** for steam turbines.

Currently there are no industry standards or Global Practices covering sealless pumps. Until these documents are issued, the designer should obtain machinery specialist assistance and consult **EMRE Manual TMEE-23,** *Pump Sealing Technology Manual* in preparing the job specification content for projects using sealless pumps.

The Global Practices, including API standards, cover many aspects of pump, driver, and auxiliary system design. However, there are many Global Practice issues which require that the purchaser make a decision or furnish additional information. The Global Practices define the purchaser as the party originating the technical requirements for inclusion in an inquiry or direct purchase order. If a job is contracted, the Contractor is considered to be the purchaser; however, there are still some job specific issues which are best addressed by the process designer in the Design Specification.

Many of the issues to be addressed pertain to all types of centrifugal and positive displacement pumps, while some, of course, are peculiar to certain types. This Section directly addresses the issues pertaining to all pump types. For issues peculiar to a pump type, the appropriate Design Practice references are provided.

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BACKGROUND (Cont)

PUMPING SERVICE CALCULATION FORM - Tables 1A & 1B present a form for summarizing pumping service design calculations.

SAMPLE PUMP DATA SHEETS - Table 2 shows **Sample Design Specification Pump Data Sheets** for pumps.

BASIC DESIGN CONSIDERATIONS

EQUIPMENT TYPE SELECTION

Pumps - See Section X-C. Services having extreme operating conditions may require special engineering attention such as optimization studies, machinery specialist consultation, and use of the most current vendor data instead of generalized information. Centrifugal pump services having head-capacity requirements above the guidelines given in **Figures 1A & 1B,** should receive special attention to optimize the number of units used, determine exact NPSH and power requirements, and identify if a special construction style is needed.

Drivers - See **Section X-I.**

GENERAL INSTRUCTIONS AND INFORMATION (GII) CONTENT

The **GII** should include the following information which is assumed to relate generally to all pumps on a given project.

System of Measurement - The system of measurement to be used in preparing Design Specifications and doing the detail engineering, e.g., metric or customary units.

Noise and Industrial Hygiene - Facility industrial hygiene considerations including any special noise level requirements.

Characteristics of Utilities - Provide the characteristics of the cooling water, steam, instrument and utility air, inert gases, fuels, and electric power available.

Meteorological Data - This includes site temperatures, relative humidity, wind speeds and direction, rainfall, and site altitude.

Critical Exposure Temperature (CET) - Casing CET must be specified for all pump types. CET is defined in **GP 18-10-1,** *Additional Requirements For Materials*. It may be given in the GII, when the same value applies to all pumps, or on the pump data sheet if service specific.

Shaft Sealing - See Section X-G, *Shaft Sealing* for GII information requirements.

Oil Mist Lubrication - If oil mist lubrication is to be applied to pump oil lubricated bearings, the GII should so indicate. **See GP 3-3-12,** *Oil Mist Lubrication Systems* for definitions of pure and purge mist and the layout of a typical oil mist system. GPs require that pumps be initially installed with a purge mist arrangement and be convertible to pure mist in the future. Some users prefer to install pumps with pure mist initially. Oil mist lubrication is generally applied to only onsite pumps since the mist generator can be centrally located and serve a large number of pumps within a unit. The geographical scattering of offsite pumps usually makes the application of oil mist impractical.

Preferred Suppliers - The GII should contain any Owner preferences for suppliers and/or models of items such as bearings, constant level oilers, couplings, and mechanical shaft seals. This is done to minimize the sources of supply and the inventory of spare parts.

- **Equipment Health Monitoring (EHM) Requirements** - The GII should indicate whether or not EHM will be applied to pumps which meet criteria established by the Owner. The criteria utilized should also be included in the GII. In the event that EHM will be used, a general note on the requirements for pump features related to EHM should be included. This may include specification that a machined, drilled, and tapped flat be provided on the bearing housing of all pumps and in which orientation the flat should be located. There may also be provisions for monitoring the health of the seals. Consult Machinery Specialists on a Project by Project basis for the requirements for EHM specifications.
- **Design Notes -** The GII normally contains design notes that the process designer provides to the detail engineering contractor explaining the methods used to determine values provided on the pump data sheets. Typical examples are explanations of the bases used to determine the NPSH available in a pumping service and the maximum allowable working pressure of a pump casing. See the following discussions of **Pump Capacity, NPSH Available** and **Casing Maximum Allowable Working Pressure** for examples of GII design notes.

INDIVIDUAL PUMP DESIGN SPECIFICATION CONTENT

The pump individual Design Specification including the pump data sheet should cover the following requirements:

Item Number and Service Name - The pump data sheet should show pump item number(s) and service name.

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BASIC DESIGN CONSIDERATIONS (Cont)

Type of Pump - Give the type of pump as centrifugal, reciprocating, rotary, or controlled volume (metering) type. The selection of the best construction style to meet service requirements is normally done during project detail engineering based on Design Specification guidelines. **Figures 2A** & **2B**, and **3A** & **3B** provide the designer with an indication of the construction styles of centrifugal type pumps applicable to various head-capacity requirements. If an investigation has determined that specific construction features are best for the service, those features should be specified. For instance, if a vertical or high speed centrifugal pump offers advantages, the preferred arrangement should be noted.

Sparing and Multiplicity

- **Considerations in Deciding Sparing - Table 3** presents a summary of considerations in deciding when to provide spare pumps.

  When optimum service design requires two or more pumps to normally operate in parallel, a single spare pump should be provided when maintenance requirements alone dictate the need for the spare. If the pump service must continue to operate during a failure of the primary drive utility supply, a sufficient number of spare units must be provided to adequately cover the utility supply outage.

- **Common Sparing -** Centrifugal pumps are reliable enough that 100% sparing; i.e., provision of a full sized standby pump for each operating pump, is not necessary in a majority of services. Adequate service reliability is often obtainable by having a single spare pump serve as the spare for two or more services. The use of common sparing is limited by the proximity of the services to be commonly spared and the compatibility of their service conditions. The following service conditions should be compared:

  a. The required head capacity range of each service must lie within the performance range of the common spare.

  b. Service pumping temperatures should not differ by more than 150°F (85°C).

  c. Service suction pressures should not differ by more than 50 psi (3.5 bar).

  d. NPSH available to the common spare must be adequate for each service.

  e. If a high and low flow service share a common spare, the common spare must be sized for the high flow and may require a low flow recycle when operating in the low flow service to avoid cavitation and overheating.

  f. The pump casing maximum allowable working pressure and design temperature, and connected line and flange ratings for the common spare must be adequate for both services.

  g. If a high and low head service share a common spare, the common spare must be sized for high head and a pressure drop taken across a control valve in the low head service.

  h. Shaft seal design must be adequate for both services.

Common sparing should not be used in the following cases:

a. Where two services are incompatible such as hydrocarbon and water or water and acid. There is the possibility of the two streams mixing through the suction and discharge piping manifolding.

b. Service where continuous fluid flow is required but high pump maintenance requirements must be expected, such as cat plant and coker slurry services.

Process Requirements

- **General -** Operating conditions should be provided on a per-pump basis. From all of the possible operating conditions, one point should be designated as the rated operating point. For all pump types, the rated operating point per API Standards is the point at which the vendor certifies that the pump performance is within the tolerances of the standard.

  API Standards also refer to a normal operating point defined as the point at which the pump is expected to operate under normal process conditions. In our work, the normal and rated operating points are usually identical and the pump data sheet generally provides process requirement data for the rated point only.

  For pumping services having significant differences in operating conditions such as pumps in alternate services or handling alternate feeds, process data requirements should be specified for all operating conditions.

- **Startup Conditions -** Startup operating conditions may differ significantly from rated operating conditions and affect pump design and performance. For example, process units are sometimes started using feedstocks different from the design feedstock. This can cause flow rates and fluid properties of various intermediate streams to differ from rated operating point values. Initial operations, even with design feedstock, can be off control for long enough to have the same effects on operating conditions. When off design startup conditions exist, the designer must decide whether or not to design the pumping service for both off design and rated operating conditions.

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BASIC DESIGN CONSIDERATIONS (Cont)

- **Flexibility for Expansion -** Long-range planning and manufacturing facilities investment strategy occasionally justify pre-investment in plant equipment to allow future capacity expansion at low cost. Pumping services along with other unit operations can be initially specified to have the desired degree of expansion flexibility. The simplest way to prepare for a future flow rate increase is to specify that space be provided for an additional pump to operate in parallel with the existing pumps**.**

  The better way to provide for expansion, in most cases, is to specify the future operating conditions along with the initial conditions. It can then be specified that the pump and installation facilities be pre-engineered to reduce the cost of the future capacity increase.

- **Fluid Property Data Sources -** Fluid property data may be obtained through the use of the *ExxonMobil Data Library (EDL)* or the *ExxonMobil Blue Book*. Other data sources may be used when appropriately validated and endorsed.

- **Pump Capactiy** - The data sheet should provide the required volume flow rate in the appropriate units; e.g., gpm, m^3/hr etc.

  A minimum required flow rate should also be specified. It is important to determining if a minimum flow bypass is required for the selected pump to avoid pump overheating and mechanical damage. The turndown flow requirement for all pumps is generally given in the GII. A specific turndown requirement different than that contained in the GII should be noted on the pump data sheet.

  A statement recommended for inclusion in the GII regarding flow turndown requirements is as follows:

  "Pumps in clean liquid services shall be suitable for continuous operation at 30% of the rated capacity given on the pump data sheet. The contractor shall advise the Owner if any service requires a circulation system for continuous operation at the 30% level."

  "Turndown for pumps in slurry service shall be reviewed and approved by the Owner prior to pump selection."

  The 30% figure may, of course, be modified for the specific project, but experience shows that this is a reasonable minimum to specify generally without requiring the installation of large numbers of minimum flow recirculation systems.

- **Pumping Temperatures -** The data sheet should provide the rated and maximum operating temperatures for the service. The maximum operating temperature is important to the vendor in deciding pump construction style and pump cooling and mechanical seal requirements.

  The designer should consider the minimum operating temperature to ensure that materials with adequate impact strength are specified.

- **Specific Gravity -** Specific gravity at the rated pumping temperature should be specified. Specific gravity determines the pump head required to produce a desired pressure increase. For pumps with limited head capability such as centrifugal pumps, it affects pressure rise capability. Pump power requirements are also affected by specific gravity. **See Rated Differential Pressure and Head Requirement** and **Power Requirements** this Section.

- **Viscosity -** Viscosity at rated pumping temperature should be specified on the data sheet. Viscosity is important in the selection of pump type and can have a significant effect on centrifugal pump performance. **See Section X-C,** *Viscosity Sensitivity* **and X-E,** *Effect of Viscosity* for discussions on how viscosity affects pump type selection and the performance of centrifugal pumps. For a discussion of viscosity considerations for positive displacement pumps see **Section X-F.**

  Minimum values of viscosity are important in determining rotary pump performance while maximum viscosity are important in determining debits to centrifugal pump performance.

- **Vapor Pressure -** Provide the fluid vapor pressure at rated conditions.

- **NPSH Calculation and Suction Pressure**

  a. **Pump Datum Level -** The pump rated suction pressure is calculated for an arbitrary pump datum level 2 ft (0.6 m) above the grade datum level. This level is typical of the impeller centerline in the most commonly used pump style; i.e., horizontal single stage centrifugal pumps in the 200 to 1000 GPM (55-230 m^3/hr) flow range. The pump centerline elevation eventually selected for a service will differ slightly from this value depending on foundation height and pump style, size, and orientation. The difference between the arbitrary and actual datum levels is too small to be of significance in determining the pressure rise or head requirements in most services; however, it can significantly affect the NPSH available to the installed pump. The NPSH available must, therefore, be checked again when the pump and foundation designs are selected.

     A check of actual centerline elevation against the 2 ft (0.6 m) datum level is especially necessary for high capacity pumps because they are large and may have their centerlines more than 2 ft (0.6 m) above grade.

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BASIC DESIGN CONSIDERATIONS (Cont)

The 2 ft (0.6 m) conventional datum level should also be used for vertical multistage process pumps even though the first stage impeller is located below grade and the available NPSH at that level is higher than at the 2 ft (0.6 m) level. The pump vendor can make the necessary conversion using the actual location of the pump suction flange and the selected pump length.

Selecting and specifying datum level requires special consideration in the following cases:

(1) Application of inline pumps in elevated piping systems rather than at grade.

(2) Application of vertical deep well water pumps and cooling water pumps which are located relative to water surface level rather than grade level.

Special datum level information should be noted on the individual pump data sheet.

In evaluating the adequacy of a proposed pump, it should be recognized that **API 610** requires that pump vendors state the NPSH required for horizontal pumps as that required at the shaft centerline, for vertical inline pumps as that required at the suction nozzle centerline, and for other vertical pumps as that required at the top of the foundation.

b. **Suction Vessel Level -** The suction vessel liquid level used in the calculation of NPSH available should be the minimum operable level. For vertical vessels with convex dished heads, this is usually assumed to be at the vessel bottom tangent line. To meet the NPSH requirements of commercial centrifugal pumps, economic design usually places the bottom tangent line of suction vessels containing liquids at their bubble point about 15 ft (4.5 m) to 25 ft (7.6 m) above grade. High capacity process units may require higher vessel elevations due to the higher NPSH requirements of larger capacity pumps. **Figures 4A & 4B** and **5A & 5B** provide information on the NPSH requirements of commercial centrifugal pumps. For high capacity pumps, individual case studies are required to determine optimum vessel elevation. **Figures 1A & 1B** indicate which services normally require individual study.

c. **Suction Pressure Calculation for Use in NPSH Determination-** The calculation of the suction pressure at rated operating conditions is performed using the methods presented in **Section XIV,** *Fluid Flow*. When permanent suction strainers are required, a pressure drop of 1 psi (.07 bar) should be allowed for the strainer.

For services where suction lines are long, or if the margin of NPSH available over the pump NPSH required is known to be small, an accurate estimate of suction piping pressure drop is required. Equivalent length estimates should be based on the actual plot plan and a close approximation of line routing.

Rated suction pressure is not reported in the Design Specification since the values needed to calculate it, namely rated discharge and differential pressures, are specified.

d. **NPSH Available -** The calculated NPSH available should be given on the pump data sheet. See **Section X-D,** *NPSH*.

The GII should contain the following design note advising the detail engineering contractor of the design bases for NPSH calculations:

"**The available NPSH values listed at 2 ft (0.6 m) above grade are estimated. These values are based on the following criteria:**

(1) **Source elevation is shown on the design flow plan.**

(2) **Unless otherwise specified, pump suction friction loss is based on the use of standard weight pipe of the line size shown on the design flow plan and the total equivalent length is assumed to equal (32 D +200) ft [(0.39D +61)] meters, plus 1 psi (.07 bar) for a permanent suction strainer where specified. D is the nominal pipe size in inches (mm).**

(3) **Unless otherwise specified, the available NPSH listed contains a 1.1 margin of safety. That is, the listed NPSH available equals the calculated NPSH available divided by 1.1.**

(4) **During detail design, the Contractor shall confirm that the NPSH available at the pump suction, with the above margin of safety included, is greater than the NPSH required by the pump at all specified conditions. No pump shall require an NPSH greater than 25 ft (7.6 m) without approval from the Owner."**

e. **Maximum Suction Pressure -** The pump data sheet should provide the maximum pump suction pressure. This value is obtained by adding the set pressure of the safety valve (if any) on the vessel from which the pump takes suction, the pressure drop from the safety valve to the point where liquid level is held, and the maximum static head of liquid on the suction side. Pump suction pipe friction drop is not considered since the maximum suction pressure condition is assumed when the flow through the pump is zero and stopped by a blockage downstream.

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BASIC DESIGN CONSIDERATIONS (Cont)

- **Rated Discharge Pressure -** Rated pump discharge pressure should be given on the pump data sheet.

  The pump rated discharge pressure results from summing the following three types of pressure requirements:

  a. **Static, independent of flow rate**

     (1) Operating pressure at the pressure controlled point, usually a vessel, to which the pump discharges. This is atmospheric pressure in the case of atmospheric storage tanks.

     (2) Elevation difference between the pump datum level and the discharge vessel maximum liquid level which adds static head to the discharge head requirement. Maximum liquid height in the discharge vessel must be assumed to obtain the maximum elevation head required.

  b. **Kinetic, dependent upon flow rate**

     (1) Pressure drop across process equipment in the discharge circuit such as heat exchangers, reactors, filters, fired heaters, etc.

     (2) Injection nozzles, sometimes with high pressure drop for atomization and sometimes subject to fouling.

     (3) Orifices for flow measurement.

     (4) Piping system resistance including fittings and valves.

  c. **Variable, modulated according to process control requirements**. This is typical of control valves.

  For all factors dependent on flow rate, it is necessary to calculate the pressure drop for the maximum desired flow rate.

- **Pressure-Drop Calculations -** Pressure drops in suction and discharge lines may be calculated using the methods presented in **Section XIV,** *Fluid Flow*. Pressure drop across control valves may be calculated using the methods presented in **Section XII,** *Instrumentation*.

- **Flow Characteristics -** The vast majority of liquids in refineries and chemical process plants have flow characteristics referred to as Newtonian, meaning that the rate of shear (flow) is linearly proportional to shear stress (force-causing flow). Because the shear rate and shear stress are proportional, their ratio, which is termed absolute viscosity (centipoise), is constant. Therefore, the absolute viscosity of Newtonian fluids is constant as flow rate changes.

  Some slurries and other liquids handled in the chemical, synthetic fuels, plastics, and mining industries have flow characteristics which do not vary linearly with flow rate and are called non-Newtonian. Pressure drops through suction and discharge piping cannot be calculated by the usual methods when handling non-Newtonian liquids and slurries. Line sizing must assure that the critical carrying velocity of slurries is met. Data with which to perform the design should be obtained from fluid flow specialists.

- **Rated Differential Pressure and Head Requirement -** Rated pump differential pressure should be provided on the pump data sheet.

  Differential pressure is used to calculate the pump head requirement. The amount of energy which a pump must be capable of imparting to each unit of mass of liquid for conversion to pressure is termed the head requirement because the units of energy input are equivalent to a column of liquid.

  ft-lb of energy/lb of mass = ft, head or (kJ of energy/kg of mass) x (101.97) = m, head

  The head requirement is calculated by converting the rise in pressure from pump suction to discharge to the height of an equivalent column of pumped liquid at pumping conditions:

  H ft = ΔP psi x 2.31/SG_c or H m = ΔP. bar x 10.2/SG_c

  Rated head is not reported in the Design Specification since the values needed to calculate it, namely differential pressure and specific gravity, are specified.

  Care should be taken to express both the head requirement of the pump and the NPSH available in terms of the liquid pumped at pumping conditions rather than in terms of cold water. For example, when ΔP = 100 psi (6.9 bar) for a liquid with a specific gravity of 0.75,

  H = ΔP psi x 2.31/SG_c = 100 x 2.31/0.75 = 308 ft of specific gravity 0.75 liquid.

  or

  H = ΔP bar x 10.2/SG_c = 6.9 x 10.2/0.75 = 93.9 m of specific gravity 0.75 liquid.

  If the pump were handling cold water, the head required for the same ΔP would be:

  H = 100 x 2.31/1.00 = 231 ft of water with SG_c = 1.00

  or

  H= 6.9 x 10.2/1.00 = 70.3 m of water with SG_c = 1.00

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BASIC DESIGN CONSIDERATIONS (Cont)

- **Solids -** The pump data sheet should indicate the solids content of the pumped fluid in weight parts per million and give the solids mean size and specific gravity. If certain pump construction styles such as coke crusher or slurry type are known to be required based on prior experience, they should be specified.

  The solids content of the liquid affects the following aspects of pump design:

  a. Flow characteristics of the fluid (Newtonian, non-Newtonian, etc.).

  b. Design for erosion resistance.

  c. Flow passage size, impeller style and peripheral speed.

  d. Design features to disintegrate large particles, such as coke crusher design.

  e. Shaft sealing design.

  The common solids found in refinery streams are coke and catalyst particles.

  In services with solids, pumps should be protected from large particles such as agglomerates of coke by permanent strainers in the pump suction and/or by devices such as coke strainers in the bottom of vacuum pipe stills.

  The abrasiveness of the solids in the slurry is important to pump design and maintenance requirements. The best means of describing the abrasiveness is to provide hardness data on the solids. Two scales frequently used in slurry engineering are the Moh's hardness scale and the Knoop number. If fracturing of the solids is detrimental to the process, as it is in some semi- solids applications, this should be indicated.

  A slurry is arbitrarily defined as more than 1% solids in liquid by weight. Conventional pump construction is usually suitable for solids concentrations up to 2.0 wt%, and when the solids are less than 100 microns in size.

- **Sealing Considerations -** The pump data sheet should provide pumped **fluid boiling range** and **specific heat information.** In addition, yes or no answers are required to the questions: (1) Are there **aromatics in the fluid?** (2) Are there **polymerizing agents in the fluid?** and (3) Is the **pump suction exposed to a vacuum?** See **Section X-G,** *Shaft Sealing Systems*, for background and guidance in specifying these Design Specification requirements.

- **Pour Point -** Indicate the pour point temperature of the fluid, if it is at or above minimum ambient temperature.

- **Power Requirements -** The power requirement of a pump is calculated as follows:

  Hydraulic power requirement = Mass flow rate x energy input to liquid/mass units of liquid

$$\text{Brake HP (kW)} = \frac{\text{Hydraulic HP (kW)}}{\text{Efficiency}}$$

$$\text{Brake HP (kW)} = \frac{\text{W (lb/min) x H (ft)}}{\text{Eo x 33,000 ft-lb/min/HP}} \quad \text{or} \quad \text{Brake P, kW} = \frac{\text{W (kg/s) x H(m) x 9.8}}{\text{Eo x 1000}}$$

Substituting gpm and SG_c for W yields: Substituting m^3/hr and SG_c for W yields:

$$\text{Brake HP} = \frac{\text{gmp} \times \text{H(ft)} \times SG_c}{3960 \times \text{Eo}} \quad \text{or} \quad \text{Brake P, kW} = \frac{\text{Q}(m^3/\text{hr}) \times SG_c \times \text{H(m)} \times 9.8}{3600 \times \text{Eo}}$$

If ΔP is available: If ΔP is available:

$$\text{Brake HP} = \frac{\text{gpm x } \Delta P\text{(psi)}}{1714 \text{ x Eo}} \quad \text{or} \quad \text{Brake kW} = \frac{\text{Q}(m^3/\text{hr}) \text{ x } \Delta P\text{(bar)}}{36 \text{ x Eo}}$$

Overall pump efficiency includes hydraulic and mechanical losses**.** Hydraulic losses are due to turbulence, skin and disc friction, and slip or internal leakage from the discharge zone of the pump back to the suction zone. The mechanical losses are due to bearing and shaft seal friction and are small relative to hydraulic losses. The hydraulic losses are such a large part of the total losses that the hydraulic and overall efficiencies can be used interchangeably for purposes of pump service design.

Efficiency values for use in power calculations are presented in **Figures 4A** & **4B** and **5A** & **5B** for centrifugal pumps. See **Section X-F** for positive displacement pump efficiency information.

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