CENTRIFUGAL PUMP

SELECTION AND APPLICATION INTO THE SYSTEM

Foreword

This article is a note or manual for mechanical engineer where work as rotating engineer or where concern to apply centrifugal pump into the system. Article contain how to select pump, performance analysis, power estimation, NPSH estimation and also to create or complete calculation sheet, datasheet and specification sheet as a part of detail engineering and purchasing activity.

The following sequence of rotating engineer activity that usually do in engineering, procurement and construction for pumps.

Receive, review and to complete **Pump Calculation Sheet** from Process Engineer
Preliminary selection of appropriate pump. **Plan to apply to system**. Discuss and send back to Process engineer
Receive, review and to complete **Pump Data Sheet** from Process Engineer
Produce **Specification Sheet** based on Data Sheet Information where related National Standards may be applied.
Produce **General or Individual Specification** for selected pump where related National Standards may be applied.
Produce **Technical Inquiry or Technical Requisition**
Collect appropriate **Vendors**. Send those documents in systematic bundle to Purchaser : Technical Inquiry, General or Individual Specification for Pump, Specification Sheet of Pump and other related Specification such as motor driver or turbine specification and the turbine specification sheet, Painting Specification. Purchaser will send the bundle to Vendors to inquire proposals.
Technical evaluation Vendor's proposal.
Ask winner vendor for detail information about complete pump will be supplied. Base on this, create **loading data** for Civil Engineer and also send information related to pump nozzles to Piping Engineer include nozzle size & rating, position and allowable force and moment.
Approval vendor's documents before fabricating the pump.
Witness during pump test as specified in the specification.
Quality Control when pumps are received. Item to be checked are : manufacturer name, model no., serial no, painting color and completeness of supply that should be same with proposed and approved documents. Other detail items such as damages parts, main dimension of pump, shaft easy to rotate by hand, correct driver, correct coupling.
Install the pumps. Electrical and instrument **cables connection**.
Pre-commissioning. Making pre-commissioning procedure and supervise precommissioning.
Commissioning. Prepare commissioning procedure and supervise commissioning

CONTENT

I. GENERAL

1.1. Purpose of This Manual.

This manual guides the reader for selection and application of centrifugal pump into the system. This manual does not guide to design centrifugal pumps or the related components.

1.2. Type and Construction Feature of Centrifugal Pump.

Type and construction features of centrifugal pump :

1. Position
   - Vertical
   - Horizontal
   - Submerged

2. Casing, Mechanically
   - Horizontal Split
   - Radial Split
   - Barrel Casing
   - Rings

3. Casing, Hydraulically : Volute , Diffuser

4. Number of Impellers in One Casing : Single Stage, Multi Stage

5. Impeller Type

   - Radial (closed or open impeller)
   - Francis
   - Mixed Flow
   - Axial

   Usually the name of centrifugal pump is for radial & francis impeller. Mixed flow and axial are named same as impeller types.

6. Impeller mounting : Over hung, Between bearing

7. Other type and features :

   - Suction type : Single suction or Double suction
   - Type of support : Centerline support, foot mounted or bracket
   - Services type such as cryogenic service, slurry pump.

1.3. Components of Centrifugal Pump.

Main components of centrifugal pump :
- Baseplate
- Casing
- Coupling
- Impeller
- Shaft
- Wear rings
- Shaft sleeve
- Stuffing box or sealing chamber, Packing/Mechanical seal and Auxiliary Piping & the Instruments

- Bearing and Lube system and the instruments
- Barrel or column pipe for vertical pump.

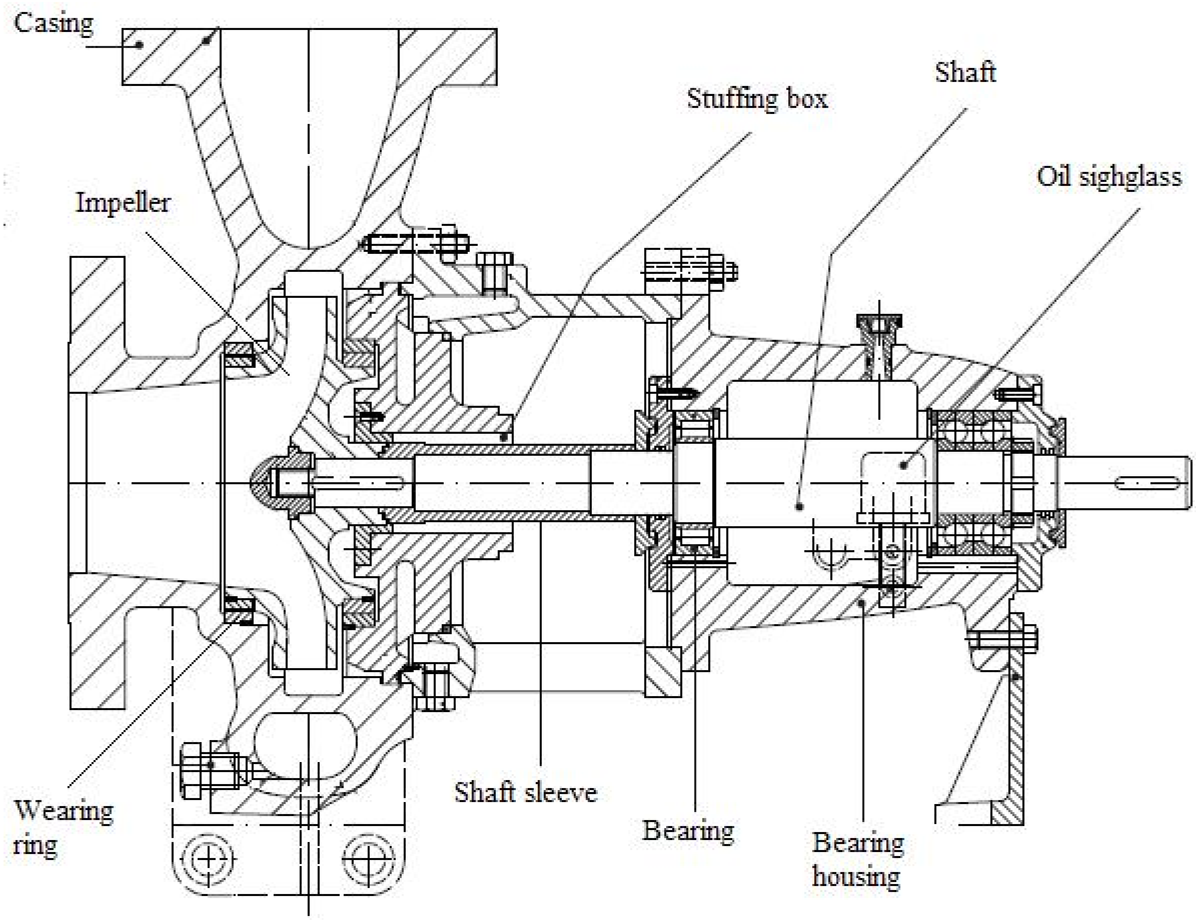


Fig.1. Cross sectional drawing of typical overhung single impeller centrifugal pump

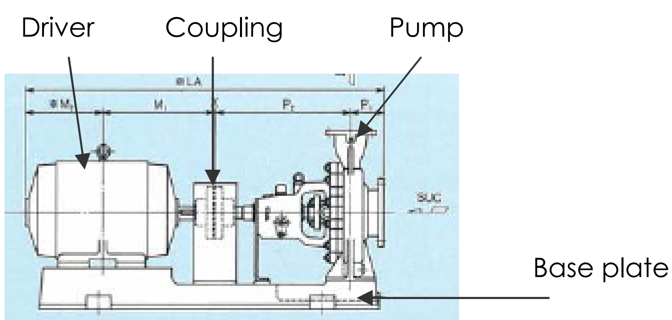


Fig. 2. Typical Complete Pump Arrangement Drawing

1.4. <u>Operating Range Of Centrifugal Pump.</u>

1.4.1. Mechanically .

Casing Pressure : Up to about 300 kg/cm^2
Speed : Up to about 4500 rpm for pump without increasing gear and up to 15000 rpm for high speed pump with increasing gear.
Power : Up to about 2 MW.

1.4.2. Hydraulically.

Capacity : Up to about 20000 m^3/h for axial impeller pump, 10000 m^3/h for mixed flow impeller vertical pump, up to about 4000 m^3/hr for double suction radial, up to 10000 m^3/hr for francis impeller pump and up to about 2000 m^3/h for single suction radial type impeller pump.
Total head : Up to about 200 m for single stage and up to about 2000 m for multistage centrifugal pump.

The following chart shows the operating range of centrifugal pumps.

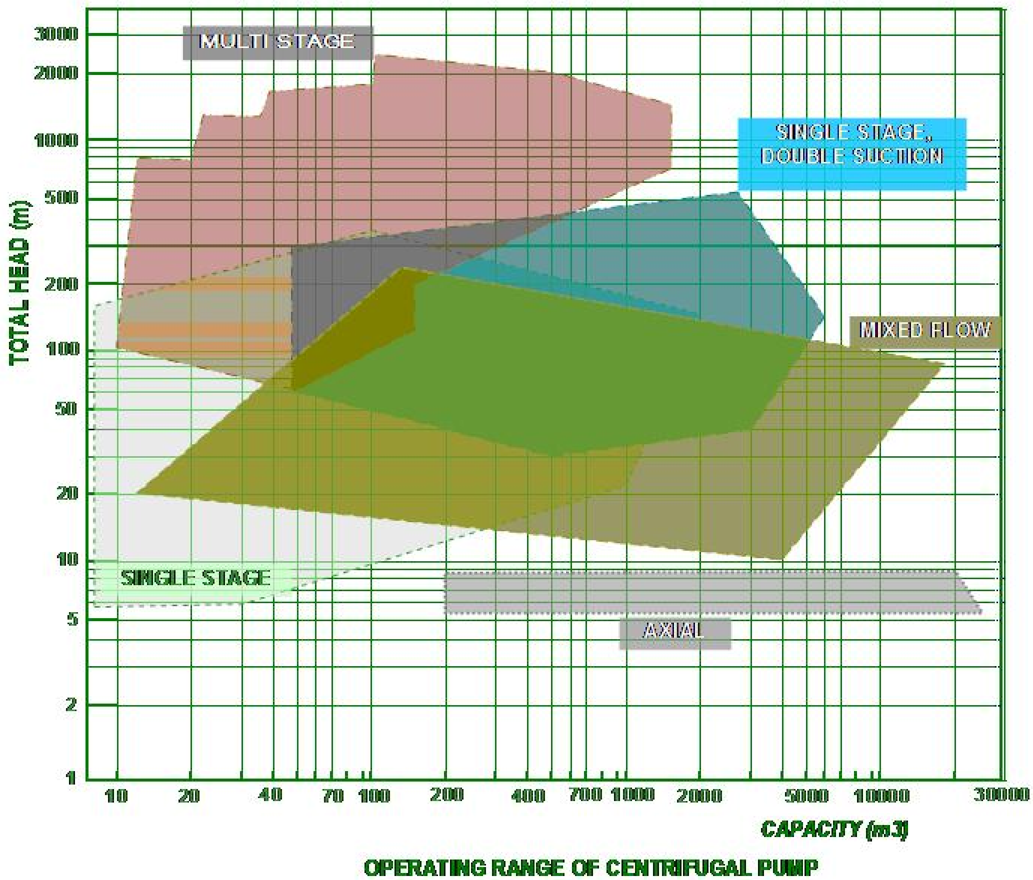


Fig. 3. Operating range of Centrifugal pumps.

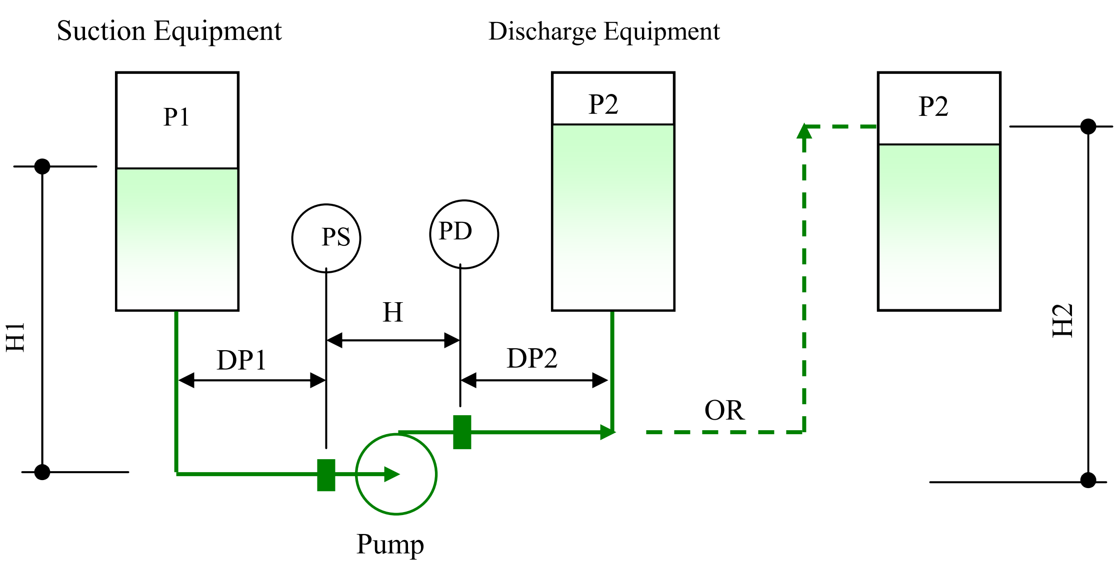


Fig. 4. Simplified System Flow Diagram Around Centrifugal Pump

1.5. Nomenclature In This Manual.

All equations in this manual use the following nomenclature.

P1	: Suction Equipment Pressure (kg/cm^2 A)
H1	: Suction liquid head (m)
	+ (plus or positive) when liquid level is higher than the pump shaft
	- (minus or negative) when liquid level is lower than pump shaft
DP1	: Pressure loss in the suction line (kg/cm^2)
PS	: Pump suction pressure (kg/cm^2A)
H	: Pump total head (m)
PD	: Pump discharge pressure (kg/cm^2A)
DP2	: Pressure loss in the discharge line (kg/cm^2)
DIP	: Differential pressure = PD – PS (kg/cm2)
H2	: Discharge liquid head (m)
V	: Liquid average velocity at suction flange (m/s)
PV	: Vapor pressure of liquid at pumping temperature (kg/cm^2A)
SG	: Specific gravity of liquid at pumping temperature
VIS	: Viscosity at pumping temperature (cP, Centipoise)
NPSHA	: Net positive suction head available (m) given by system
NPSHR	: Net positive suction head required (m) given by pump characteristic
LHP	: Liquid horse power (kW)
BHP	: Brake horse power (kW)
Q	: Pump capacity (including minimum required flow, m^3/h)
E	: Pump efficiency (%)
D	: Impeller diameter (m)
N	: Speed (RPM, rotary per minute)
Nsq	: Specific speed based on quantity or capacity (RPM)
Nsp	: Specific speed based on power (RPM)

Note :
See appendixes for NPSHR, liquid properties (SG, VP, VIS), Pump Efficiency and Unit conversion.

II. LIQUID AND THE PUMP PERFORMANCE

2.1. Mathematical Relations

1. Suction Pressure, $$PS = P1 - DP1 + 0.1(H1.SG) - (500.SG.\frac{V^2}{98066.5})$$

Where $V = \frac{0.5481(Q)}{D^2}$ if D in inch, Q in m^3/hr

$V = \frac{353.63(Q)}{D^2}$ If inside diameter D in mm (millimeter), Q in m^3/hr

When velocity (V) low or neglected, PS become

$$PS = P1 - DP1 + 0.1(H1.SG)$$

2. Discharge Pressure, $$PD = P2 + DP2 + 0.1(H2.SG)$$

3. Differential Pressure, $DIP = PD - PS$

4. Pump Total Head, $H = (H2 - H1) + 10(\frac{P2 - P1}{SG}) + 10(\frac{DP2 + DP1}{SG})$

$$= \frac{10.DP}{SG}$$

5. NPSHA, $= \frac{10(PS - PV)}{SG}$

NPSHA should be greater than NPSHR

6. Liquid Horse Power (LHP), *LHP = 0.00272* x *DH* x Q x *SG*

7. Brake Horse Power (BHP), $BHP = \frac{100(LHP)}{E}$

2.2. <u>Centrifugal Pump Performance</u>.

Usually, centrifugal performance is shown in Head vs Capacity curve. The performance curve shows the relation between capacity and total head for available impeller diameter in one model number and included also the NPSH Required, BHP and Efficiency.

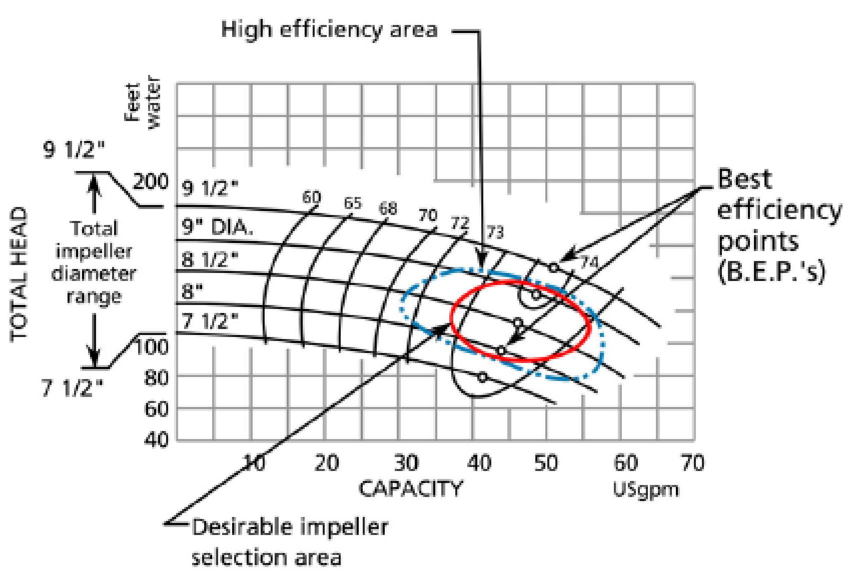


Fig. 5. Typical Centrifugal Pump Performance Curve For One Casing or Model.

Usually, performance curve presents impeller diameter range that possible to be installed in one casing or model, efficiency and NPSHR. In the proposal, manufacturer or vendor will extract in specific impeller diameter together with pump specification sheets that been designed in accordance with purchaser specification. See fig. 6.

2.3. Best Efficiency Point.

In case of selection or evaluation, the capacity of the best efficiency point shall be at between normal capacity and the rated capacity . Best efficiency point is important when the pump is operated on continues duty (See Fig. 5 and Fig. 6).

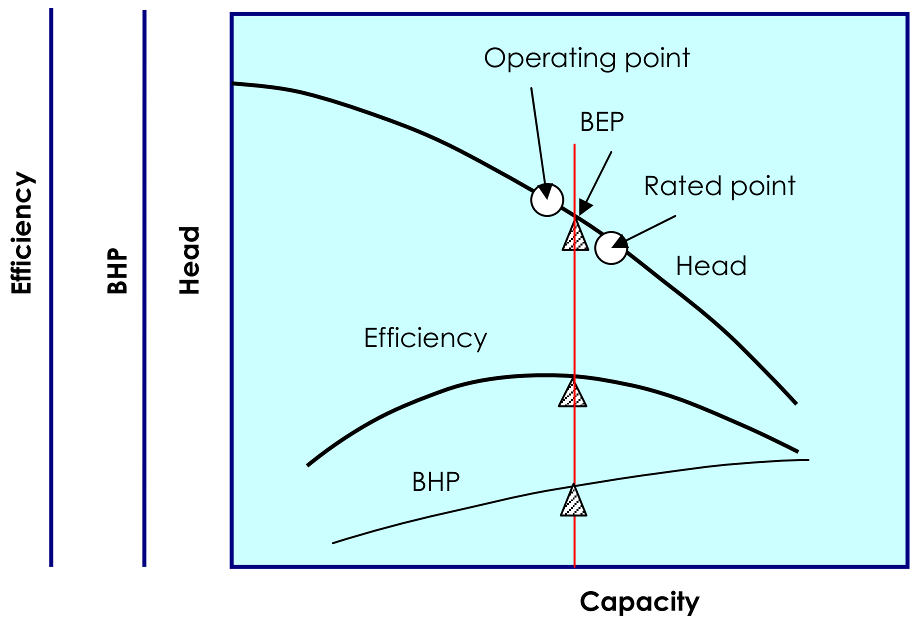


Fig. 6. Typical Single curve

2.4. Affinity Law.

Based on following velocity diagram,

Q = A x Cr where A = Outlet impeller gap area and Cr is radial velocity

Cr = K1 . D . N where K1, K2 , K3 …… are constants

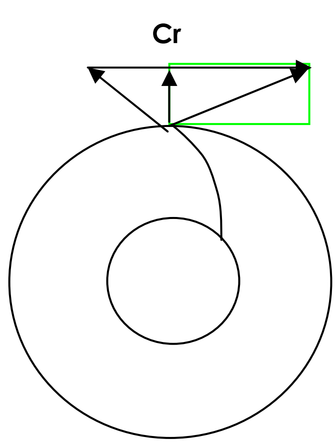
Then, _if A is designed in constant_ value :

Q = K2 . D . N

If SG of liquid constant or based on water,

$H = K3 . Cr^2 = K4 . D^2 . N^2$

If D constant, Q become = K5. N, $H = K6 . N^2$ and $LHP = K7 . N^3$



When a centrifugal pump operates at different speed, relation between speed and other variables become :

$H2 = H1 \times (N2 / N1)^2$

$Q2 = Q1 \times (N2 / N1)$

$LHP2 = LHP1 \times (N2 / N1)^3$

And when centrifugal pump and axial pump operates at different total head and capacity but at the same speed and impossible to modify the system, impeller diameter shall be resized and the performance will depend on diameter, see fig. 3.

H2 $= H1 \times (D2 / D1)^2$

Q2 $= Q1 \times (D2 / D1)$

LHP2 $= LHP1 \times (D2 / D1)^3$

D2, N2, H2, Q2 and LHP2 are new condition. D1, N1, H1, Q1 and LHP1 are previous condition. Please note that those equations are only for impeller that possible to be applied in one casing and at speed range that permitted by manufacturer.

2.5. Specific Speed

The speed where geometrically similar shape impellers (even different size) deliver liquid 1 liter / second (3.6 m^3/hr) against 1 meter head is defined as "Specific speed based on unit quantity", Nsq. And when absorb 1 metric HP for 1 meter head defined as "Specific speed based on power", Nsp.

$$Nsq = \frac{0.527 N.Q^{1/2}}{H^{3/4}})$$ where Q in m^3/hr

$$Nsp = \frac{1.341 N.BHP^{1/2}}{H^{3/4}})$$ where BHP in kW

Specific speed is helpful for selection a centrifugal pump. The following table presents specific speed for various type of pump.

Type of impeller	Specific speed, Nsq
- Radial impeller	10.5 – 60
- Mixed flow	38 – 85
- Fast runner mixed flow	85 – 165
- Axial pump	165-500

2.6. Special Liquids in The Centrifugal Pump.

2.6.1. Viscous Liquid.

When a centrifugal pump is tested with water and to be applied for high viscosity liquid (higher than 5 centipoise) at the same speed, the performance of pump will decrease. The following equations are the decreasing factors due to viscous liquid.

Defined capacity factor : Qf

$Qf = 0.71162 \times (Q/60)^{-0.22767} \times (H)^{-0.13292} \times (VIS/SG)^{0.497}$

If Qf <= 0.6 , Pump performance no need any correction
If Qf > 0.6 , Pump efficiency shall be corrected by correction factor Ce
If Qf > 0.9 , Pump head shall be corrected by correction factor Ch
If Qf > 3 , Pump capacity shall be corrected by correction factor Cq

Ce = 0.01 x (102.27 - 7.291 x Qf)
Ch = 0.01 x (101.65 - 1.829 x Qf)
Cq = 0.01 x (109.64 - 3.214 x Qf)

Written in water test performance :

$Q_{WATER} = Q_{VIS} / Cq$

$DH_{WATER} = DH_{VIS} / Ch$

$E_{WATER} = E_{VIS} / Ce$

Qvis, DHvis, E vis: Conditions shall be performed by pump to service the viscous liquid . Qwater, DHwater, Ewater : Conditions shall be performed by water tested pump to provide the correct performance on viscous liquid.

2.6.2. Hydrocarbon Liquids.

When the centrifugal pump to be applied for hydrocarbon liquid, NPSHR of water tested pump shall be corrected.

NPSHR water tested = NPSHR hydrocarbon / Chyd

Where Chyd = $0.01 \times \{ 60 + 551.2 \times (1 - SG) \times (14.223 \times PV)^{-0.4757} \}$

For ammonia liquid, typical user require NPSHR < (NPSHA - 1 meter)

III. CENTRIFUGAL PUMP IN THE APPLICATION.

3.1. Pump and The System.

The system is defined as overall piping and equipment where liquid is flowing from defined suction equipment to defined discharge equipment. See Fig. 4.

3.1.1. Single Pump in System.

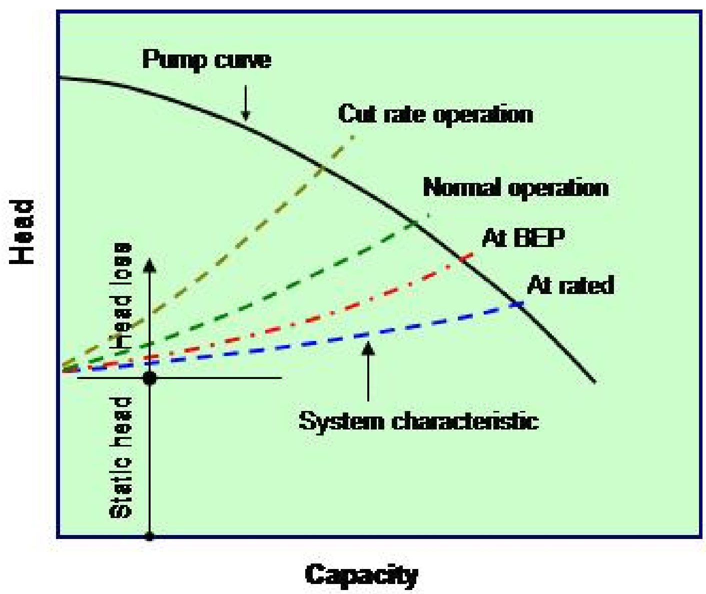


Fig. 7. Centrifugal Pump in Operation.

Operating point is condition where characteristic curve of system cross with the pump curve. In plant operation, there are several operating condition : Normal operation (100 %), cut rate (below 100%), uprate (more than 100%). Rated point for pump is condition where pump operates continuously at upper the normal condition and mechanically (include driver), is still permitted. Those conditions are listed in API standards.

Fig. 7 shows static head and head loss. Static head is static liquid head plus differential pressure head between discharge equipment and suction equipment (P2-P1 in head). Head loss is total differential pressure drop head (DP1+DP2 in head), see Fig. 4. Simple conversion from pressure to head H = 10 x (Differential pressure) / SG or 10 time diff. pressure divided by SG. Please note that unit shall be as Nomenclature above.

To create or plot system characteristic, pressure drop along of system shall be calculated for each flow on Excel sheet or using software. See Piping Manual for this purpose.

3.1.2. Centrifugal Pump in The Parallel Duty.

When centrifugal pumps operate in parallel, equal pump is recommended. The following figure shows performance curve of two equal pump in parallel duty in the same system. For high head loss system, capacity in new operating point will not equal to 2 time.

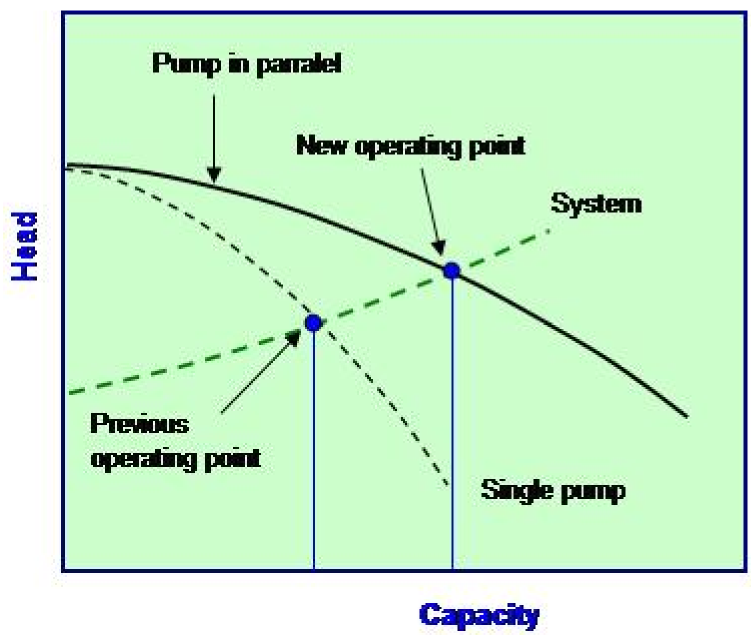


Fig. 8. Two Equal Pump in Parallel Operation

But for system where head loss is low comparing with differential pressure between discharge and suction equipment, capacity will nearly to 2 time of previous operating point.

3.2. Minimum Required Flow .

Centrifugal pump is not permitted to operate at no flow (shut off). There are two reason why centrifugal pump require minimum flow.

1. Flow Stability : Some pump have performance curve with uncontinous negative slope from zero flow until the stable region. If centrifugal pump shall operate at no flow to the system for

relatively long time, pump shall have minimum flow line or bypass line.

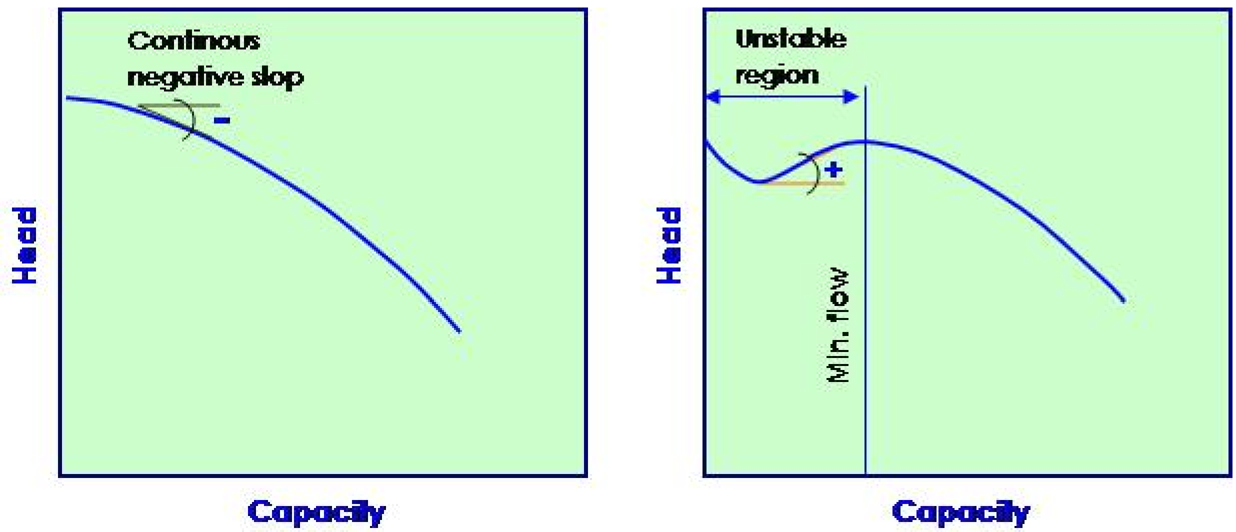


Fig. 9. Continuous and Uncontinuous Negative Slope Performance Curve.

2. Thermal : Heat is generated by the friction between impeller and liquid in the casing. And also packing or mechanical seal are generates heat. When casing is not enough surface to transfer the heat to surrounding, casing and related component temperature will gradually increase and may cause pump component damages. If pump shall be operated at shut off condition for long time for any reason, bypass line with cooler is required. But this condition is rarely used.

The exact values of minimum required flow is informed by the Pump vendor in the datasheet. But for roughly estimation (usually to determine the piping size for minimum flow), the required minimum flow is about 30 % of the normal capacity. When necessary, restriction orifice is required to provide more precise minimum required flow. For hydrocarbon liquid, the flash point of the liquid is recommended to be taken account. Purchaser (user) shall prepare the bypass line for this minimum required flow.

3.3. Piping Around Centrifugal Pump.

In general, piping around pump is shown as the following figure as minimum requirement.

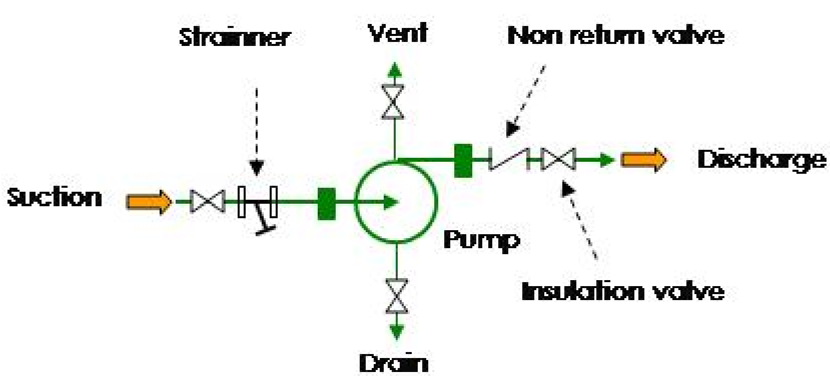


Fig. 10. Piping System Around Centrifugal Pump.

Two insulation valve at suction and discharge to insulate pump while repair or overhaul. Non return valve prevent pump from back flow. Back flow liquid entering to pump will rotate impeller and driver in reverse direction with un-controlled speed that may course pump or driver damage. Drain valve need to drain liquid in pump casing when pump will be repaired. Vent valve necessary for venting air or vapor during priming. Strainer contain screen inside to prevent pump from solid matter that may course damage to mechanical seal or wearing rings.

Priming is necessary before starting pump. The following figure shows which valve to be closed and open.

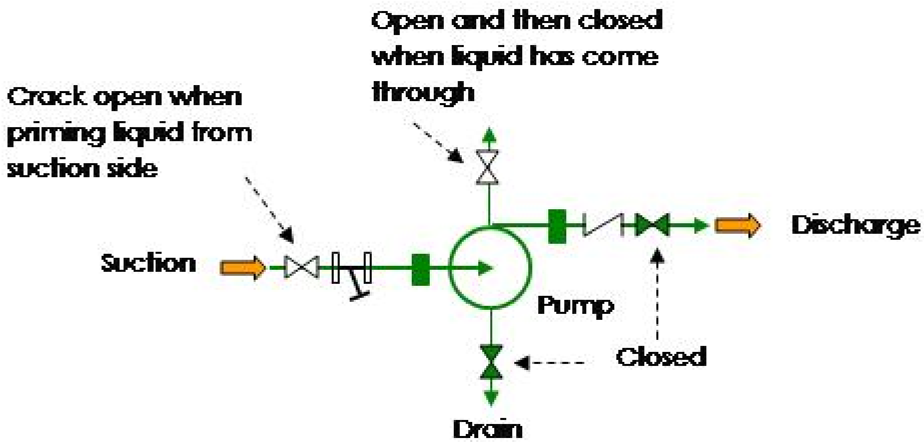


Fig. 11. Piping System While Priming

After priming has completely done, pump can be started. Opening discharge valve is gradually to prevent sudden flow or hammering at discharge line if pump is quite big.

Additional piping may required for bypass line and optional line. Bypass line or minimum required flow to prevent pump operate below minimum required flow. Optional line necessary for :

- Preheat the piping or equipment in the down stream, when liquid is very hot
- Cooling down the piping or equipment in the down stream, when the liquid is very cold
- Equalizing line to protect non return valve and valve from high different pressure.
- Initial opening when discharge line is sensitive for hammering

Optional line is opened when the pump is completely running and may be used for temporary opened if all item above has been completely done before discharge valve start to cracking open.

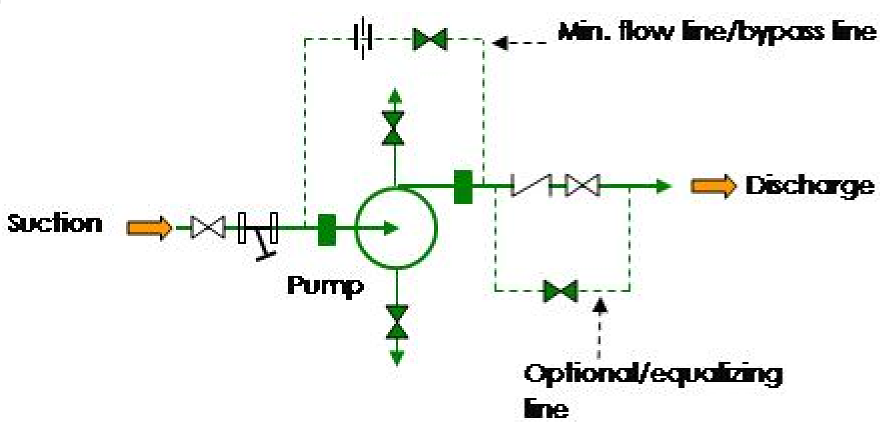
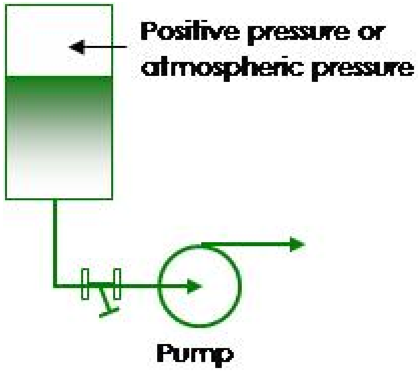
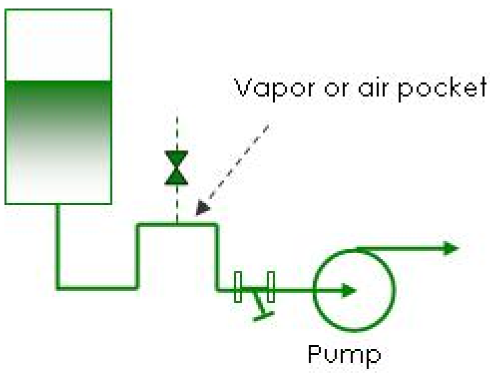


Fig. 12. Optional Piping and Bypass Line

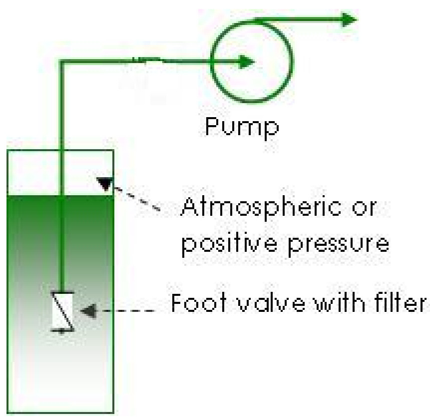
Suction pipe shall be planned to provide enough NPSHA and no vapor or air pocket. The following figures show the recommended suction piping.



Good. When the suction liquid head is positive or NPSHA higher than estimated NPSHR



Generally not accepted.



Accepted when completed with foot valve and NPSHA is higher than estimated NPSHR

Fig. 13. Suction piping for Centrifugal Pump.

IV. DRIVER

1. MOTOR DRIVER

When API-610 is specified, power rating on motor nameplate shall be higher or equal to (>=) BHP time multiplier :

Nameplate power	Multiplier
19 < kW	1.25
22 - 56 kW	1.15
>= 75 kW	1.10

Example : Pump rated BHP = 18.3 kW. Motor nameplate power shall be >= 1.25 x 18.3 kW = 22.875 kW. But now, multiplier become 1.15, because 22.875 at between 22 and 56 kW. Recalculate : Pump rated BHP x multiplier = 18.3 x 1.15 = 21.045 kW. Selected motor HP = 22 is accepted, because 22 kW > 21.045 kW.

Example : Pump rated BHP = 25 kW. Motor nameplate HP shall be >= 1.15 x 25 = 28.75 kW. Multiplier is 1.15 because 28.75 kW at between 22 to 56 kW.

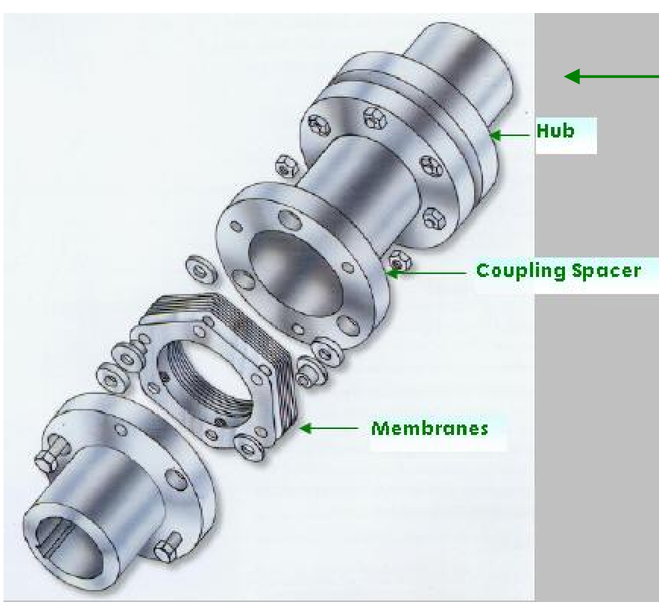
For autostart operation, motor HP shall be > max. pump BHP. User shall specify autostart operation in the data sheet and also check the quotation.

2. TURBINE DRIVER

When API-610 pump is specified, power rating of steam turbine driver shall be > 1.1 x Pump rated BHP.

V. COUPLING

When pumping temperature is taken account or driver produces heat such as steam turbine, flexible coupling is better than rigid coupling. Flexible coupling will eliminate the thermal expansion of pump or driver during operation. Rubber bush type coupling is also flexible coupling and lower cost, but does not for high temperature services.



Typical membrane coupling

Typical rubber bush coupling

Flexible coupling may be gear, membrane coupling or rubber bush coupling. Flexible coupling is more tolerates with misalignments. Coupling spacer is usual for flexible coupling to make more tolerable on the angular misalignment.

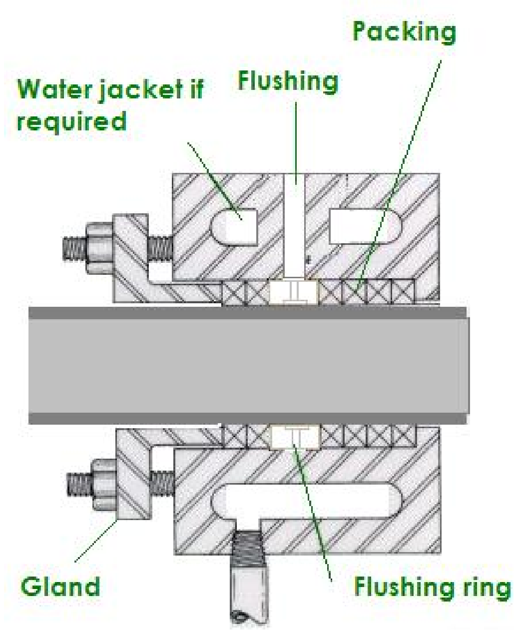
VI. PUMP SUPPORT

When horizontal pump will be operated at high temperature, centerline support is most suitable. Foot type support is suitable when pumping temperature is close to ambient temperature and driver is fan cooled motor or when the motor driver is integrated on the small pump.

VII. VERTICAL PUMP

When caned vertical pump is installed in the concrete or metal lined concrete well and operating temperature is high, vent hole is necessary. When operating temperature is very low (below 0 °C), insulation is necessary to prevent the concrete cracked or iceing. Remove any water in the well and purge well with dry gas (N2 or dry air) to remove water vapor before priming.

VIII. PACKING or MECHANICAL SEAL



To prevent leakage from pump through the shaft , there are seals with packing or mechanical seal. Packing seal is less cost but more power loss due to large of contact surface between packing and shaft or shaft sleeve and suitable for limited speed.

Mechanical seal is less power loss and suitable for higher speed and no wear on shaft sleeve. When the pumping liquid is toxic and flammable, there are bellow mechanical seal type.
Flush piping is necessary for mechanical seal or packing seal. Flushing liquid shall be clean. Purpose of flushing liquid is for cooling the contact seal parts that always produce heat and remove dirty matter that cause a damages on those parts. Pumping liquid is usual for flushing liquid when the liquid is clean. Cooler and strainer are necessary when pumping temperature is very high.

Clean external flushing is applied when :

- Pumping liquid is dirty.
- External flushing liquid is permitted to mix with the pumping liquid.
- External flushing liquid pressure is higher than the stuffing box pressure.

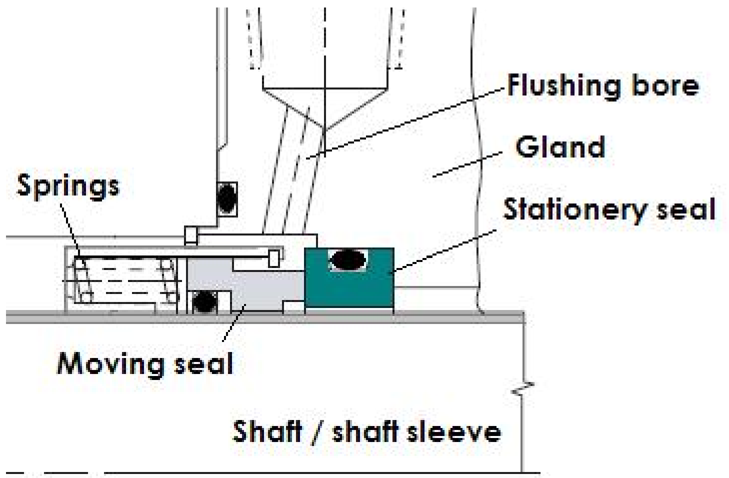
Vent on the seal gland of mechanical seal is necessary to bleed air or vapor before starting the pump.

Quenching is necessary when :

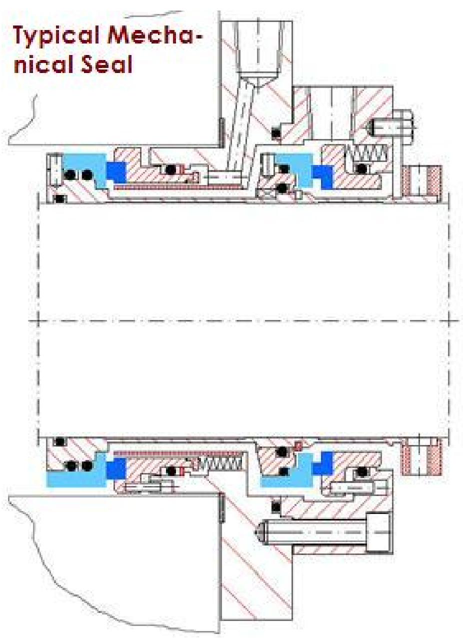
- Pumping temperature is very low that may cause built ice between shaft and seal gland.
- Pumping liquid is toxic or flammable. Quenching liquid shall dilute the pumping liquid.
- Pumping liquid is easy to crystallize at below pumping temperature.

Lip seal is required when necessary for sealing the quenching liquid. Quenching liquid and small amount of pumping liquid flow through the pipe and drained to sewer. But sometime, quenching liquid and small amount pumping liquid flows through bushing or labyrinth to drain.

Option about flushing, quenching, vent and drain and auxiliary piping are presented in API standard.



Typical mechanical seal. Single Seal (One pair of seal)



Typical mechanical seal. Double Seal (Two pair of seals)

Seal material Silicon carbide vs carbon and Tungsten carbide vs carbon are widely use in moderate temperature services. But for some liquid such as ammonia, facing seal material shall be selected carefully. Selection of mechanical seal type, material and auxiliary piping shall be based on pump specification sheet and other specification specially liquid properties to be handled, pressure, temperature and speed.

APPENDIX A. NPSHR (Net Positive Suction Head Required)

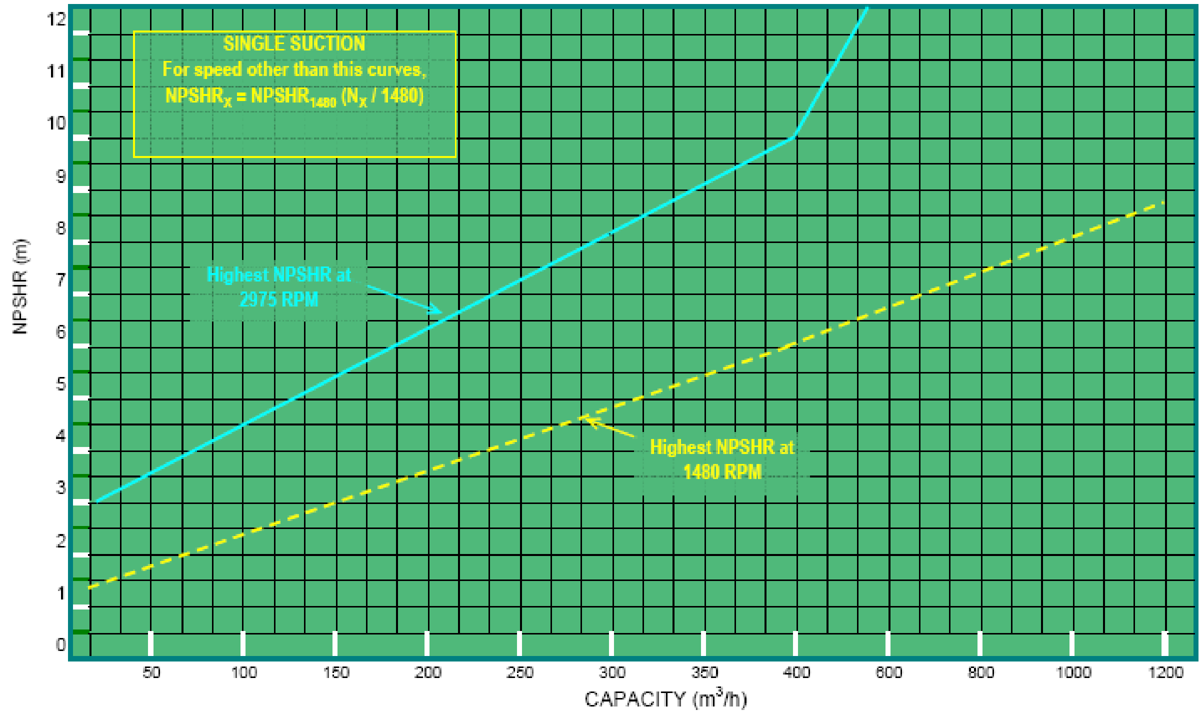


Fig. A.1. NPSHR for Single Suction Centrifugal Pump

All data presented in Fig. A.1 were collected from several manufacturers. Upper blue line is the highest NPSHR at 2975 RPM and lower yellow dot line is highest NPSHR at 1480 RPM. For speed below 1480 RPM, highest NPSHR can be calculated = Highest NPSHR at 1480 x (Speed in RPM / 1480). This chart is helpful for designing suction system of centrifugal pump.

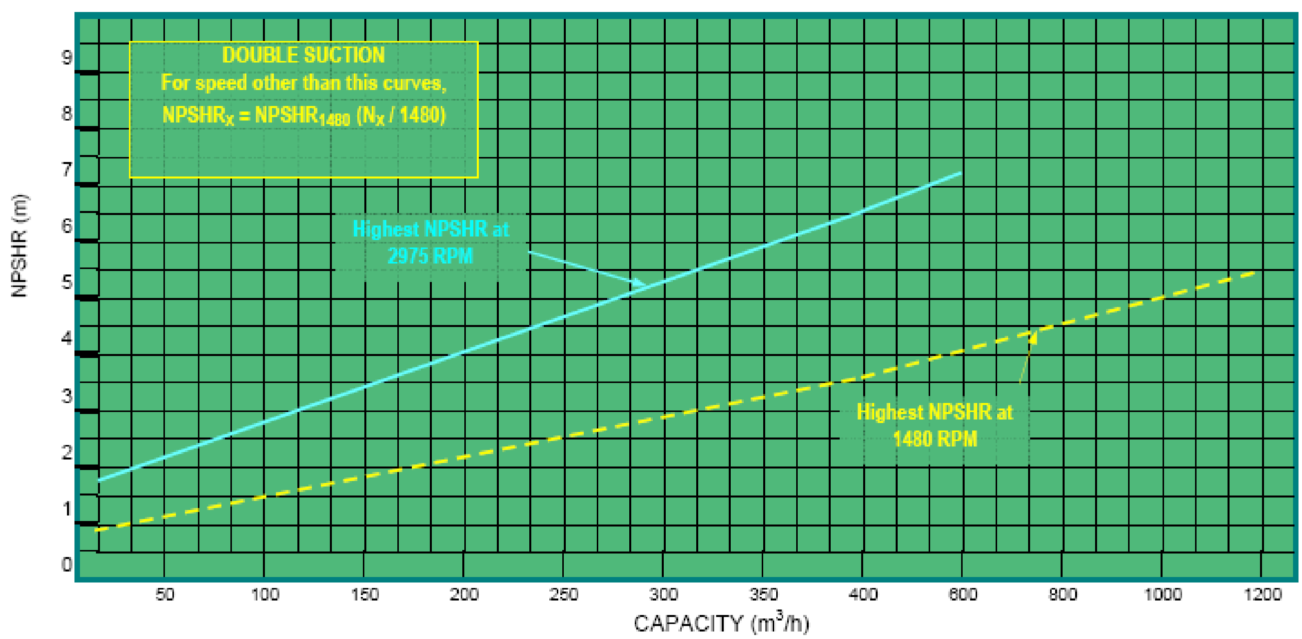


Fig. A.2. NPSHR for Double Suction Centrifugal Pump

Highest NPSHR at speed below 1480 RPM = NPSHR at 1480 x (Speed in RPM / 1480).

APPENDIX B. CENTRIFUGAL PUMP EFFICIENCY

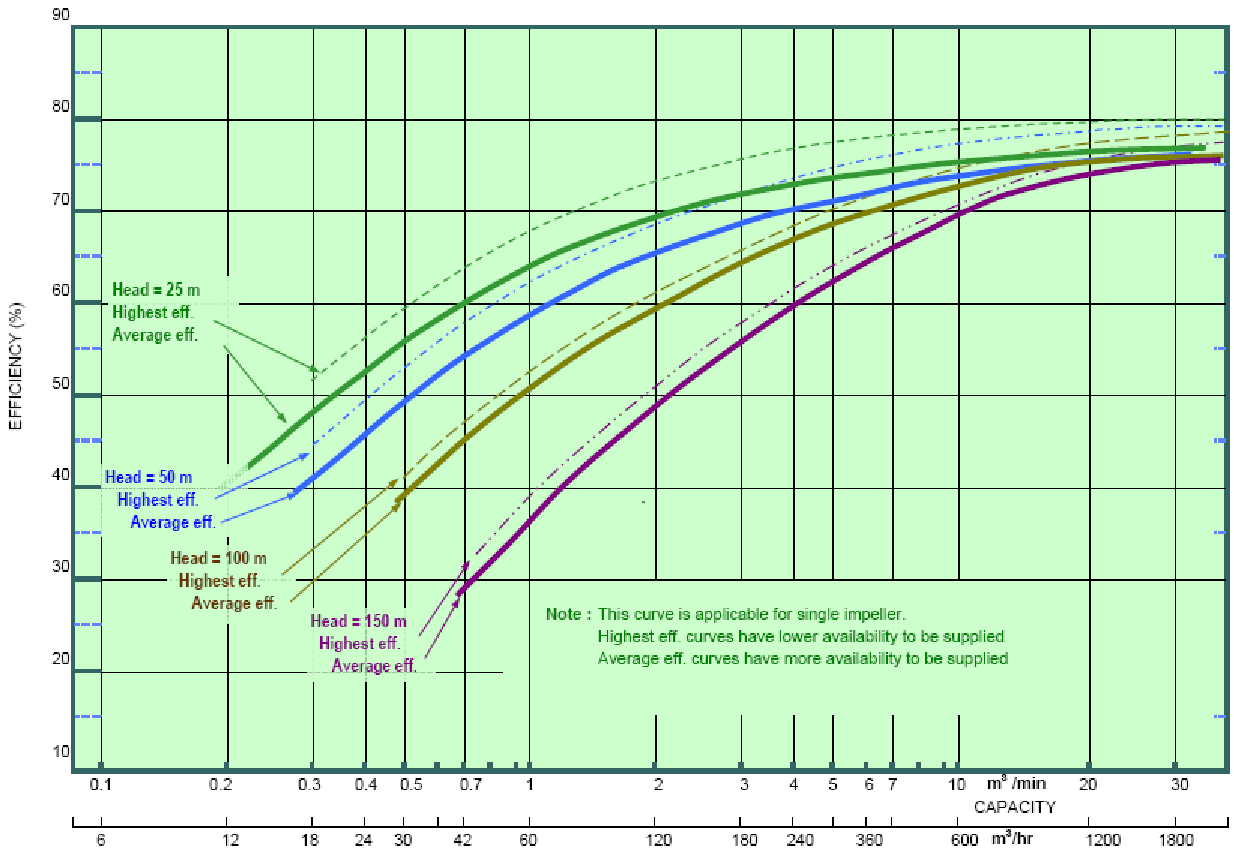


Fig. B.1. Efficiency of Single Impeller Centrifugal Pump

Efficiency curves presented in Fig. B.1. is generalized curve from data that are taken from several manufacturers without diameter and speed as variables. This chart is helpful in basic and detail engineering where overall project need information about power consumption of pump in their power balance plan or needed by other discipline where they plan for supporting equipments, materials or in cost estimation.

APPENDIX C. PROPERTIES OF SOME LIQUID

Following table presents properties of some liquids.

FLUID NAME	VAPOR PRESSURE		SG (Specific Gravity)		VISCOSITY	
	kg/cm^2A	@ °C	SG	@ °C	cP	@ °C
Water	0.0123 1.013 39.78	10 100 250	1.003 0.994 0.984	5 50 95	0.58 0.28 -	50 90 -
Ammonia Liquid	0.605 4.43 10.62	-43 1 27	0.738 0.719 0.701	-72.7 -55.5 -38.4	0.37 0.27 -	-55.5 -38.4 -
Methane Liquid	0.35 3.67 19.56	-173 -143 -108	0.684 0.671 0.658	-177.5 -172 -166.5	- - -	- - -
Methanol	0.06 0.476 2.265	7 47 87	- - -	- - -	- - -	- - -
Gasoline at 1 atm			0.8		0.752 0.448 0.256	10 65.56 148.9

APPENDIX D. SUCTION NOZZLE SIZE

Following table presents typical nozzle sizes. Nozzle size is necessary when dynamic pressure or velocity of liquid is important in determing NPSH. Diameters are presented in inches as per ANSI standard. These dimensions shall be converted to meter before equations in section 2.1 are used. Velocity can be determined with equation V = Q / (3600.A) in m/s, where Q is capacity in m^3 /hr and A is suction nozzle area = 3.14 x 0.25 x ID^2 in m^2 where ID in meter.

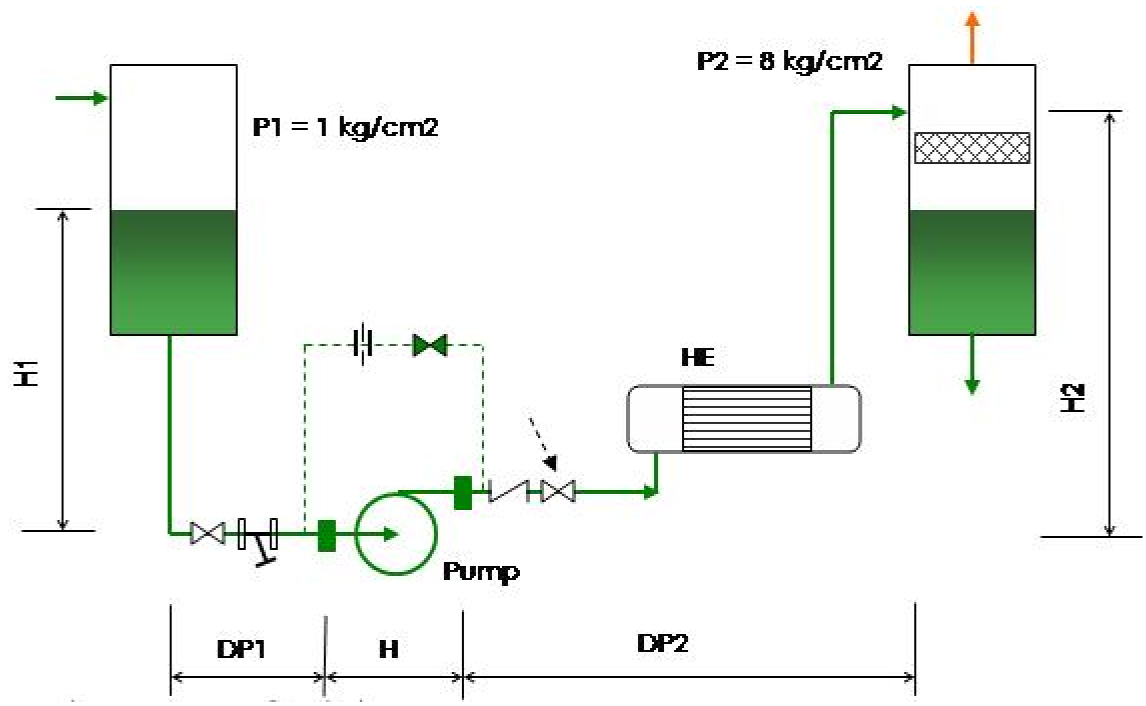
Single Suction API 610 at 2980 rpm		Double Suction, API 610, at 2980 rpm		Single Suction API 610 at 1480 rpm		Double Suction, API 610, at 1480 rpm	
max.cap m^3/hr	Nom. dia. inches	max.cap m^3/hr	Nom. dia. inches	max.cap m^3/hr	Nom. dia. inches	max.cap m^3/hr	Nom. dia. inches
30	2	250	6	15	2	600	10
60	3	400	8	30	3	800	12
120	4	700	10	60	4	1200	14
200	6	1200	14	120	6	1600	16
450	8			200	6	2200	20
				450	8		
				900	10		
				1200	12		
Double Suction, Low Pres.&Tem 1480 rpm		Double Suction, Low Pres.&Tem 980 rpm					
max.cap m^3/hr	Nom. dia. inches	max.cap m^3/hr	Nom. dia. inches				
330	8	220	8				
480	10	330	10				
660	12	450	12				
900	12	600	12				
1260	14	840	14				
1800	16	1080	16				
		1680	18				
		2280	20				

APPENDIX E. EXAMPLES

A quantity of process liquid shall be delivered by centrifugal pump from vertical vessel to process vessel through discharge system shown in following figure. Net volume flow to be delivered is 200 m^3 / h. Pump is possible to shut off at any time and by pass valve is always open in normal operation. Liquid properties are, vapor pressure = 0.43 kg/cm^2 A, viscosity = 0.09 cP and Spec. Gr. = 0.87 at pumping temperature. Liquid is not hydrocarbon. Driver is 50 Hz electric motor. Other given data, P1=1 kg/cm2 A, P2= 8 kg/cm2 A, suction system pressure drop DP1=0.2 kg/cm2, DP2 include HE = 0.5 kg/cm2, discharge liquid head at minimum level H2=40 m.

Items to be estimated :

- Select pump type
- Estimate the NPSHR,
- Minimum level of liquid at suction equipment H1
- Expected NPSHA after deciding the minimum level of the suction equipment H1.
- Total head required.
- Capacity required in normal operation.
- Estimate BHP



Calculation without H1.

1. Suction pressure PS = P1 – DP1 = 1 – 0.2 = 0.8 kg/cm2 A
2. Discharge pressure PD = P2 + DP2 + 0.1 (H2)(SG) = 8 + 0.5 + 0.1 (15)(0.87) = 9.805 kg/cm2 A
3. Total head H = 10 (PD – PS)/SG = 103.506 m
4. Estimate minimum required flow 15 %. Capacity include minimum flow ***Q*** = 1.15 x 200 = 230 m3/h. From Fig.3 in chapter 1.4 , the point of Q =230 m3/h and H=103.5 m is in ***single stage, single suction centrifugal pump*** range. Select this pump type.
5. At 2975 RPM (50 Hz motor without reduction gear), the highest ***NPSHR*** from Appendix A = 7 m
6. NPSHA = 10(PS-PV)/SG = 10(0.8-0.43)/0.87 = 4.25 m

Calculate H1.

1. Minimum liquid level required ***H1*** = NPSHR – $NPSHA_{without\ H1}$ = 7 - 4.25 = 2.75 m

Calculation with considering of H1.

1. PS = P1 – DP1 + 0.1 (H1)(SG) = 0.8 + 0.1(2.75)(0.87) = 1.039 kg/cm2 A
2. ***H*** = 10 (PD-PS)/SG = 100.76 m
3. ***NPSHA*** = H1 + 10 (PS-PV)/SG = 9.75 m
4. LHP = 0.00272 (Q)(H) = 0.00272 (230)(100.76) = 63 kW
5. From Appendix B, average eff. = 66% and highest eff. = 67.5%. Lower eff. E = 66-(67.5-66)= 64.5 %
6. ***BHP*** at lower efficiency = 100 (LHP)/E = 100 (63) / 64.5 = 97.7 kW

APPENDIX F. CREATING PUMP CALCULATION SHEET

Following is typical calculation sheet for Centrifugal Pump. In the first sheet shows formula and the next sheet is example using this sheet.

LOGO

COMPANY NAME
CITY - COUNTRY ETC.

PUMP CALCULATION SHEET ( )

CLIENT :
PROJECT
TITLE :
JOB NO. :
DOC. NO. : ( )

REV.	1	2	3	MADE	
BY				CHKD	
CHKD				APVD	
APVD					
DATE				DATE	

				Code	Formula
1	ITEM NO. :				
2	SERVICES :				
3	**FLUID**			**Code**	**Formula**
4	PUMPED LIQUID		WATER		
5	OPERATING TEMPERATURE	°C	90		Data
6	VISCOSITY AT OPERERATING TEMP.	cP	0.23	VIS	Data
7	VAPOR PRESSURE	kg/cm²	0.15	PV	Data
8	SP. GR. AT OPERATING TEMP.		0.99	SG	Data
9	GRAVITY	m/s²	9.81	g	Data
10					
11					
12	CAPACITY	m³/hr	150	Q	Data
13	EXCESS CAPACITY	%	30	X	Data
14	MAX. CAPACITY	m³/hr	195	Qe	Qe = 0.01(100+X)(Q)
15	**SUCTION**				
16	PRESSURE AT EQUIPMENT	kg/cm²	1.3	P1	Data
17	MIN. STATIC HEAD (+ or -)	m	0.4	H1	Data
18	PIPE FRICTION	kg/cm²	0.12	DPp1	Data
19	*EQUIPMENT(……………………)*	kg/cm²	0.15	DPe1	Data
20	SUCTION PUMP DIA.	m	0.17	ID	See Appendix
21	VELOCITY HEAD AT SUCTION	kg/cm²	0.0288	HV	V=Q/(0.25x3.14xID²x3600) , HV=0.05(SG)(V²)/g
22	NET SUCTION PRESSURE	kg/cm²	1.0408	PS	PS = P1+0.1(H1)(SG)-Dpe1-DPp1-HV
23	NPSH AVAILABLE	m	9.00	NPSHA	NPSHA=10(PS-PV)/SG
24	**DISCHARGE**				
25	PRESSURE AT EQUIPMENT	kg/cm²	12	P2	Data
26	STATIC HEAD	m	24	H2	Data
27	PRESSURE DROP AT :				
28	PIPE (include fittings & valves)	kg/cm²	0.2		Data
29	*Equipment 1 (……………………….*	kg/cm²	0.11		Data
30	*Equipment 2(……………………….*	kg/cm²	2		Data
31	*Equipment 3 (……………………….*	kg/cm²	0.05		Data
32	*Equipment 4 (……………………….*	kg/cm²	0.12		Data
33					
34					
35	DISCHARGE PRESSURE DROP	kg/cm²	2.48	DPp2	DPp2 = total discharge pressure drop
36					from line 28---34
37	TOTAL DISCHARGE PRESSURE	kg/cm²	16.856	PD	PD = P2+0.1(H2)(SG)+DpP2
38	SUCTION PRESSURE	kg/cm²	1.0408	PS	
39	DIFF. PRESSURE	kg/cm²	15.8152	DP	DP=PD-PS
40	TOTAL HEAD (NET)	m	159.75	H	H=10(DP)/SG
41	TOTAL HEAD (TAKE)	m	160.0	H	
42	SPECIFIC SPEED , Ns				
43	ESTIMATED EFFICIENCY	%	52	E	See curve in Appendix
44	ESTIMATED POWER	kW	161.57	BHP	BHP=(100/E)(0.00272)(Q)(H)
45	ESTIMATED NPSH R	m	5.5	NPSHR	See curve in Appendix
46	TYPE		Centrifugal		
47			Single Suction		
48	PACKING TYPE				
49	REMARKS :				
50					
51					
52					
53					
54					
55					
56					
57					

COMPANY NAME
CITY - COUNTRY ETC.

PUMP CALCULATION SHEET

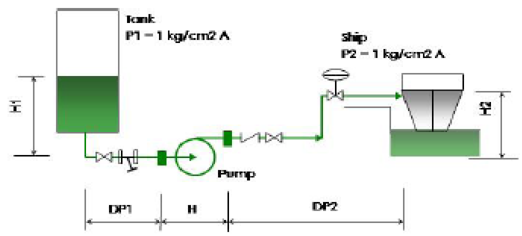
( )

CLIENT :
PROJECT
TITLE :
JOB NO. :
DOC. NO. : ( )

REV.	1	2	3	MADE	
BY				CHKD	
CHKD				APVD	
APVD					
DATE				DATE	

ITEM NO. :
SERVICES :

FLUID				
PUMPED LIQUID		Ammonia		
OPERATING TEMPERATURE	°C	-33		
VISCOSITY AT OPERERATING TEMP.	cP	0.26		
VAPOR PRESSURE	kg/cm²A	1		
SP. GR. AT OPERATING TEMP.		0.7		
GRAVITY	m/s²	9.81		
CAPACITY	m³/hr	200		
EXCESS CAPACITY	%	10		
MAX. CAPACITY	m³/hr	220		
SUCTION				
PRESSURE AT EQUIPMENT	kg/cm²A	1.025	1.025	
MIN. STATIC HEAD (+ or -)	m	2	6	New H1
PIPE FRICTION	kg/cm²	0.14	0.14	
EQUIPMENT(.........................)	kg/cm²	0	0	
SUCTION PUMP DIA.	m	0.17	0.17	
VELOCITY HEAD AT SUCTION	kg/cm²	0.0259	0.0259	
NET SUCTION PRESSURE	kg/cm²A	0.9991	1.2791	
NPSH AVAILABLE	m	-0.01	3.99	
DISCHARGE				
PRESSURE AT EQUIPMENT	kg/cm²A	1	1	
STATIC HEAD	m	15	15	
PRESSURE DROP AT :				
PIPE (include fittings & valves)	kg/cm²	0.4	0.4	
Equipment 1 (............CV..........	kg/cm²	0.11	0.11	
Equipment 2(...........................	kg/cm²	0	0	
Equipment 3 (..........................	kg/cm²	0	0	
Equipment 4 (..........................	kg/cm²	0	0	
DISCHARGE PRESSURE DROP	kg/cm²	0.51	0.51	
TOTAL DISCHARGE PRESSURE	kg/cm²A	2.56	2.56	
SUCTION PRESSURE	kg/cm²A	0.9991	1.2791	
DIFF. PRESSURE	kg/cm²	1.5609	1.2809	
TOTAL HEAD (NET)	m	22.30	18.30	
TOTAL HEAD (TAKE)	m	23.0	19.0	
SPECIFIC SPEED , Ns				
ESTIMATED EFFICIENCY	%	70	70	
ESTIMATED POWER	kW	13.76	11.37	
ESTIMATED NPSH R at 1480 RPM	m	3.6	3.6	
NPSHA-NPSHR	m	-3.61	0.39	
Pump need well to give more H1			Vertical centrifugal	
PACKING TYPE			pump	



REMARKS :

In the 1'st calculation where H1 = 2 m from liquid level to C.L. of pump, NPSHA-NPSHR= - 3.61 m. It is not acceptable because NPSHA-NPSHR shall be positive. Add more H1 in storage tank is not permitted because it will reduce net capacity of tank. The only one way is making well and use vertical type of centrifugal pump. Try by imputing H1 until NPSHA-NPSHR positive. In second column H1 shall be 6 m or add 4 m down from previous CL of pump.

APPENDIX G. UNIT CONVERSION

UNIT CAPACITY OR VOLUME FLOW

From unit	To unit	Conversion factor
US GPM	m^3 /hr	0.2271
l/s	m^3 /hr	3.6
Barrel / day	m^3 /hr	0.006625

UNIT PRESSURE

From unit	To unit	Conversion factor
Pa	kg/cm^2	1.02×10^{-5}
Psi	kg/cm^2	0.0703
Bar	kg/cm^2	1.0197
inch H2O	kg/cm^2	0.00254

UNIT POWER

From unit	To unit	Conversion factor
HP	kW	0.7457
PS metric	kW	0.7355

UNIT DENSITY

From unit	To unit	Conversion factor
lb/ft^3	kg/m^3	
kg/lt	kg/m^3	

UNIT VISCOSITY

From unit	To unit	Conversion factor
Pa.s	cP	1000
m^2 /s	Stoke	10^4
	cSt	10^6

UNIT LENGTH

From unit	To unit	Conversion factor
ft	m	0.3048
inch	m	0.0254
mile	m	1609

<u>Example :</u>

120 GPM = 120 x 0.2271 m^3 /hr
= 27.252 m3 /hr

50 m3 /hr = 50 / 0.2271 GPM
= 220.17 GPM

25 psi = 25 x 0.0703 kg/cm^2
= 1.758 kg/cm^2

3 kg/cm^2 = 3 / 0.0703 psi
= 42.67 psi