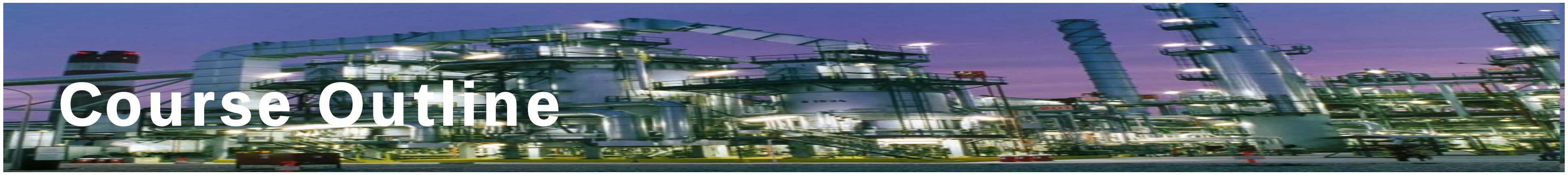
CENTRIFUGAL PUMP SIZING, SELECTION AND DESIGN PRACTICES

By: M. Arshadul Huda, M.Eng, P. Eng



Course Outline

- Definition of Energy Machines
- Basic Components of a Centrifugal pump
- Definition of Important Terms
- Pressure and Head Relationship.
- Hydraulics
- Centrifugal Pump Sizing
  - Procedure Flow Chart
  - Fluid Properties
  - Suction Pipe Sizing
  - Discharge Pipe Sizing
  - Differential Head Calculation
  - Understand NPSH and Cavitations
  - NPSH Calculation
  - Power Calculation
  - Shut off Head Estimation
- Understand Pump Characteristics Curves
- Pump Selection
- Understand System Curve
- Pump Curve Correction (Viscosity Correction)
- Affinity Laws
- Temperature Rise due to pumping
- Minimum Flow
- Pump Datasheet

Definition of Energy Machines

- Pumps can be formed into two distinct machine categories:
  - Kinetic energy machines
  - Positive displacement machines
- Centrifugal pumps are Kinetic energy machines
- Rotary, Diaphragm and Reciprocating pumps are positive displacement machines

Basic Components of a Centrifugal Pump

Pump Casing (Volute) - converts high velocity (energy) into a pressure head.

Impeller - imparts kinetic energy to the liquid. (accelerates the liquid)

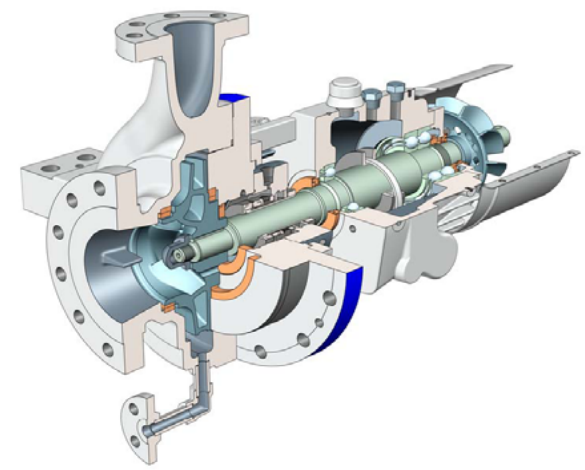
Shaft - transmits rotational energy from driver (Used to spin the impeller).

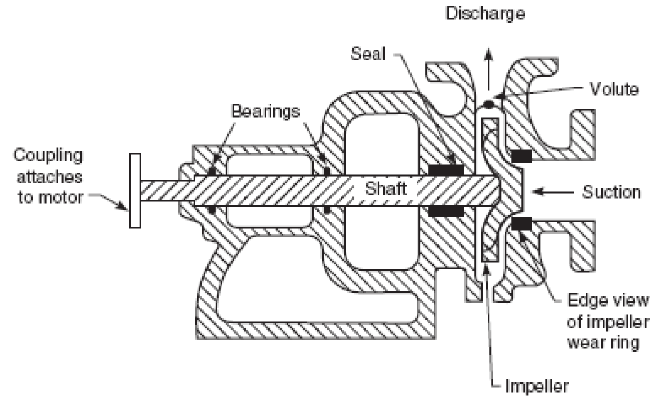
Wear rings - reduce leakage between high and low pressure regions.

Seal - prevents leakage where shaft exits casing.

Bearings – support the shaft.

Coupling – attaches the shaft to the driver.





DEFINITION OF IMPORTANT TERMS

- **Capacity** means the flow rate with which liquid is moved or pushed by the pump to the desired point in the process.
- **Head** is a measurement of the height of a liquid column that the pump could create from the kinetic energy imparted to the liquid.
- **Static Suction Head** (Hs) resulting from elevation of the liquid relative to the pump center line.
- **Static Discharge Head** (Hd) is the vertical distance in feet/meter between the pump centerline and the point of free discharge or the surface of the liquid in the discharge tank.
- **Friction Head** (Hf) is required to overcome the resistance to flow in the pipe and fittings.
- **Vapour Pressure Head** (Hvp) is the pressure at which a liquid and its vapour co-exist in equilibrium at a given temperature.
- **Pressure Head** (Hp) must be considered when a pumping system either begins or terminates in a tank which is under some pressure other than atmospheric.
- **Velocity Head** (Hv) refers to the energy of a liquid as a result of its motion at some velocity ‘v’.

DEFINITION OF IMPORTANT TERMS

- **Net Positive Suction Head (NPSH)** is the total head at the suction flange of the pump less the vapour pressure converted to fluid column height of the liquid.
- **Pump input or brake horsepower (BHP)** is the actual horsepower delivered to the pump shaft.
- **Pump output or water horsepower (WHP)** is the liquid horsepower delivered by the pump.
- **Pump Efficiency** is the ratio of BHP and WHP.
- **Best Efficiency Point (BEP)** is the capacity at maximum impeller diameter at which the efficiency is highest.
- **Specific speed (Ns)** is a non-dimensional design index that identifies the geometric similarity of pumps. It is used to classify pump impellers as to their type and proportions. Pumps of the same Ns but of different size are considered to be geometrically similar, one pump being a size- factor of the other.
- **Suction specific speed (Nss)** is a dimensionless number or index that defines the suction characteristics of a pump. It is calculated from the same formula as Ns by substituting H by $NPSH_R$.
- **Affinity Laws** are mathematical expressions that define changes in pump capacity, head, and BHP when a change is made to pump speed, impeller diameter, or both

COMMON UNIT CONVERSION FOR PUMP

FLOW RATE

Given ⇒ multiply by to get ⇓	US gal/min	UK gal/min	ft^3/sec	bbl/day	liters/s	kg/h
m^3/h	0.2271	0.2728	101.9	$6.624 \bullet 10^{-3}$	3.6	1/(999 • RD)

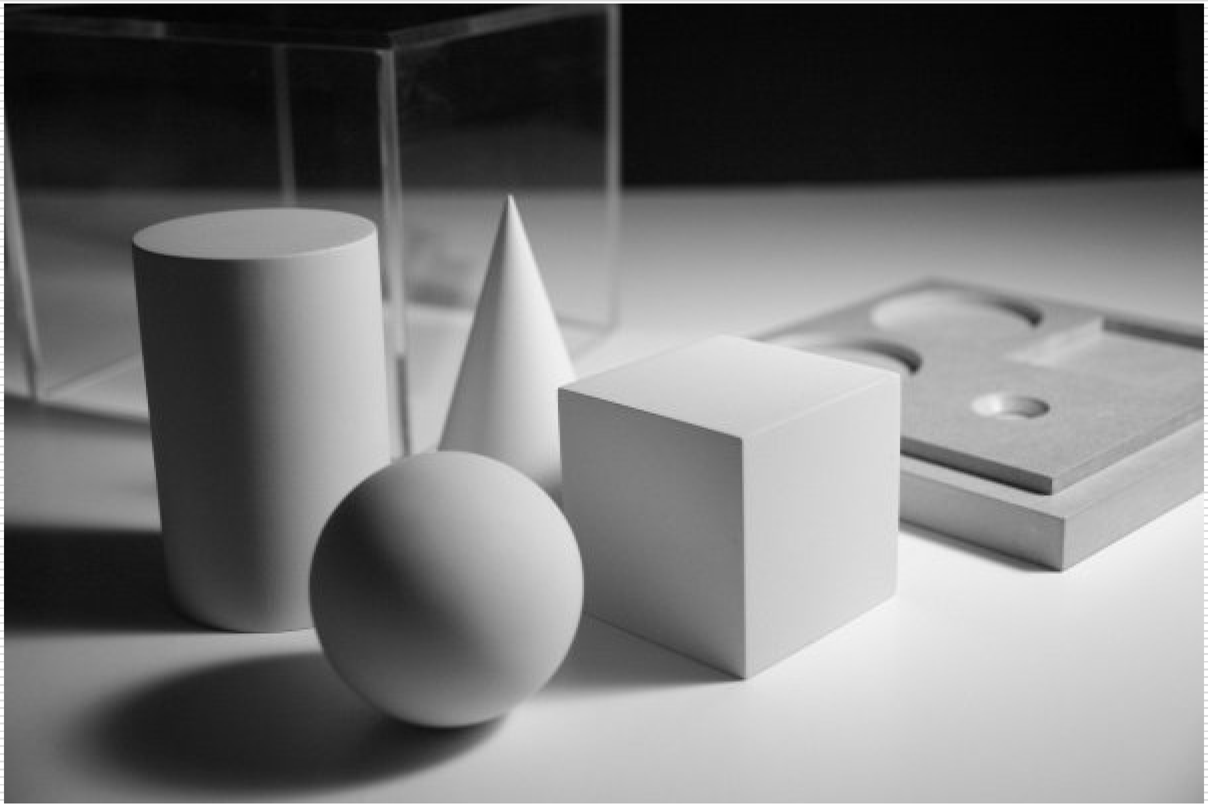
PRESSURE

Given ⇒ multiply by to get ⇓	lb/in^2	ft water at 39.2°F	m water at 0°C	m liquid	bar	* std atm 760 mm Hg at 0°C	kgf/cm^2
kPa	6.895	2.989	9.8066	$\rho \bullet g/1000$	100	101.325	98.066

DENSITY

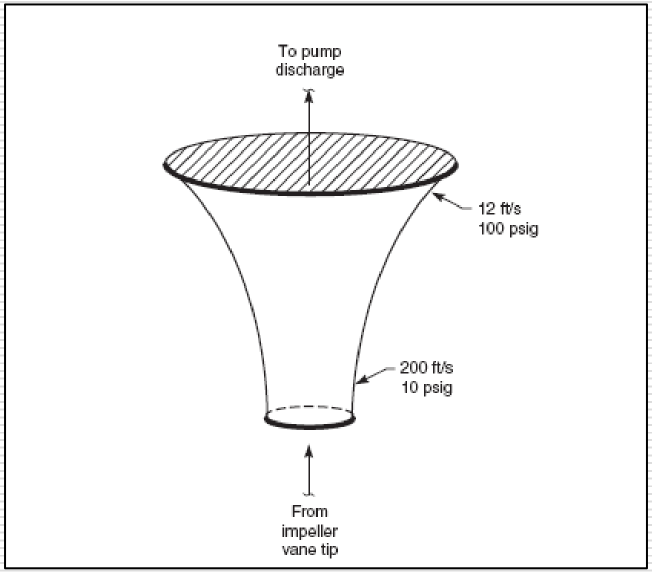
Given ⇒ multiply by to get ⇓	lb/ft^3	lb/US gal	lb/UK gal	kg/lt	API gravity	Baumé gravity
kg/m^3	16.018	119.83	99.77	1000	See Fig. 1-3	

BACK TO BASICS………



PRESSURE HEAD DEVELOPMENT

- Impeller is the working part of pump.
- It increases the velocity of kinetic energy.
- The liquid flows into the impeller and leaves the impeller at the same pressure.
- The pressure at the vane tip is the same as suction pressure.
- As the high velocity liquid escapes from the impeller and flows into the volute, its velocity is reduced and the lost velocity is converted into feet of liquid.
- **Remember, Centrifugal pump produce Liquid Head not the pressure**.



HOW MUCH HEAD?

- The head produced by a centrifugal pump is proportional to the velocity attained by the fluid as it exits the vanes at periphery of the impeller.
- Lets assume 9” dia impeller with 1800 rpm.
- Circumference of the impeller

$$C = \Pi d = 3.14 \times 9'' = 28.3'' = 2.36'$$

- Velocity as it exits the vanes

$$V = C \times RPM = 2.36 \times 1800 = 4248 \text{ ft / min} = 70.80 \text{ ft/sec}$$

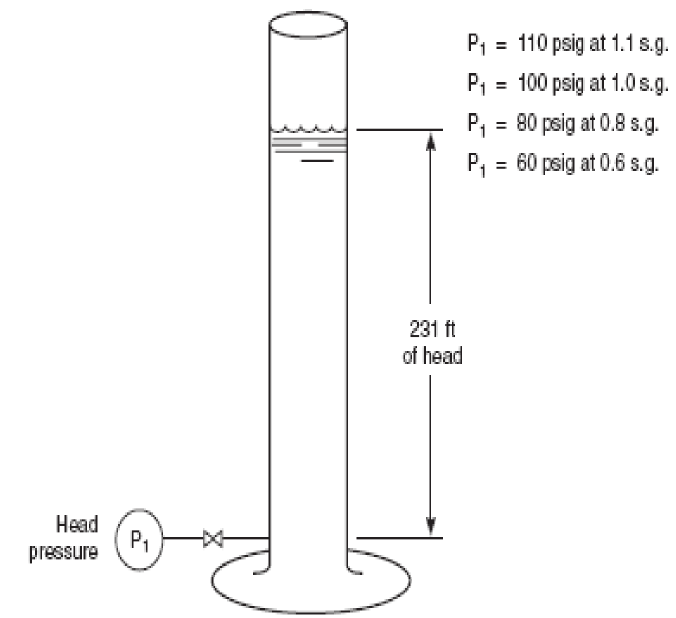
- Equation for height is

$$h = V^2 / 2g = (70.8)^2 / 2 \times 32 = 78.32 \text{ ft}$$

- The head that can be produced by a 9” impeller rotating at 1800 rpm is ~ 78 ft (23.8 m)

HEAD

- The pressure at any point in a liquid can be thought of as being caused by a vertical column of the liquid due to its weight.
- The height of this column is called the static head and is expressed in terms of length of liquid.
- Rule of Thumb: 1 kg/cm^2 = 10 m Head (Water at SG = 1.0)



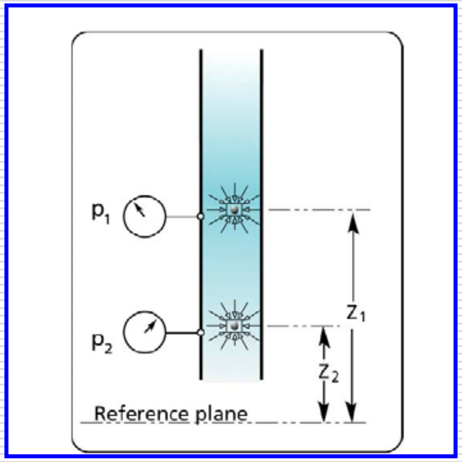
PRESSURE & HEAD RELATIONSHIP

- Pressure (P) = SG x g x Head (H)

- **H = P / (SG x g)**
- **P = H x g x SG**

Where

H	=	head, in meter
P	=	pressure, kPa
SG	=	specific gravity of liquid
g	=	9.8 m/sec^2

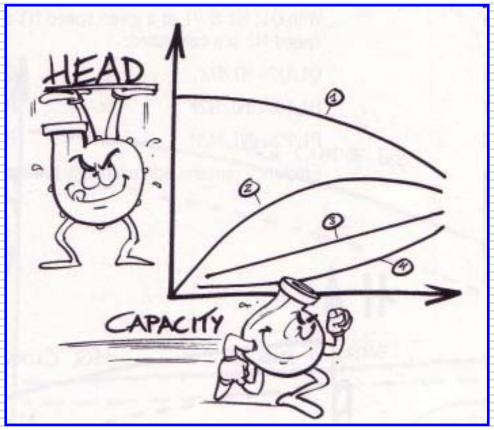


- **H = P x 2.31 / SG**

- $$\mathbf{P = \frac{H \times SG}{2.31}}$$

Where

H	=	head, in feet
P	=	pressure, in PSI
SG	=	specific gravity of liquid
2.31	=	conversion factor



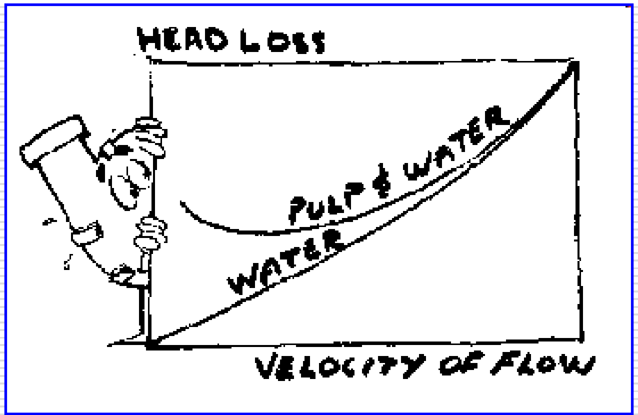
HYDRAULICS PRESSURE DROP (Frictional Losses)

- Determine Reynolds Number

$N_{RE} = D\ V\ \rho\ /\ \mu$

Where D = m (inches x 0.0254)
V = meter / sec
ρ = kg/m^3
μ = Pa.sec (cP x 0.001)

- Laminar flow regime for Re < 2,000
- Critical flow regime for 2,000 < Re < 4,000
- Turbulent flow regime for Re > 4,000



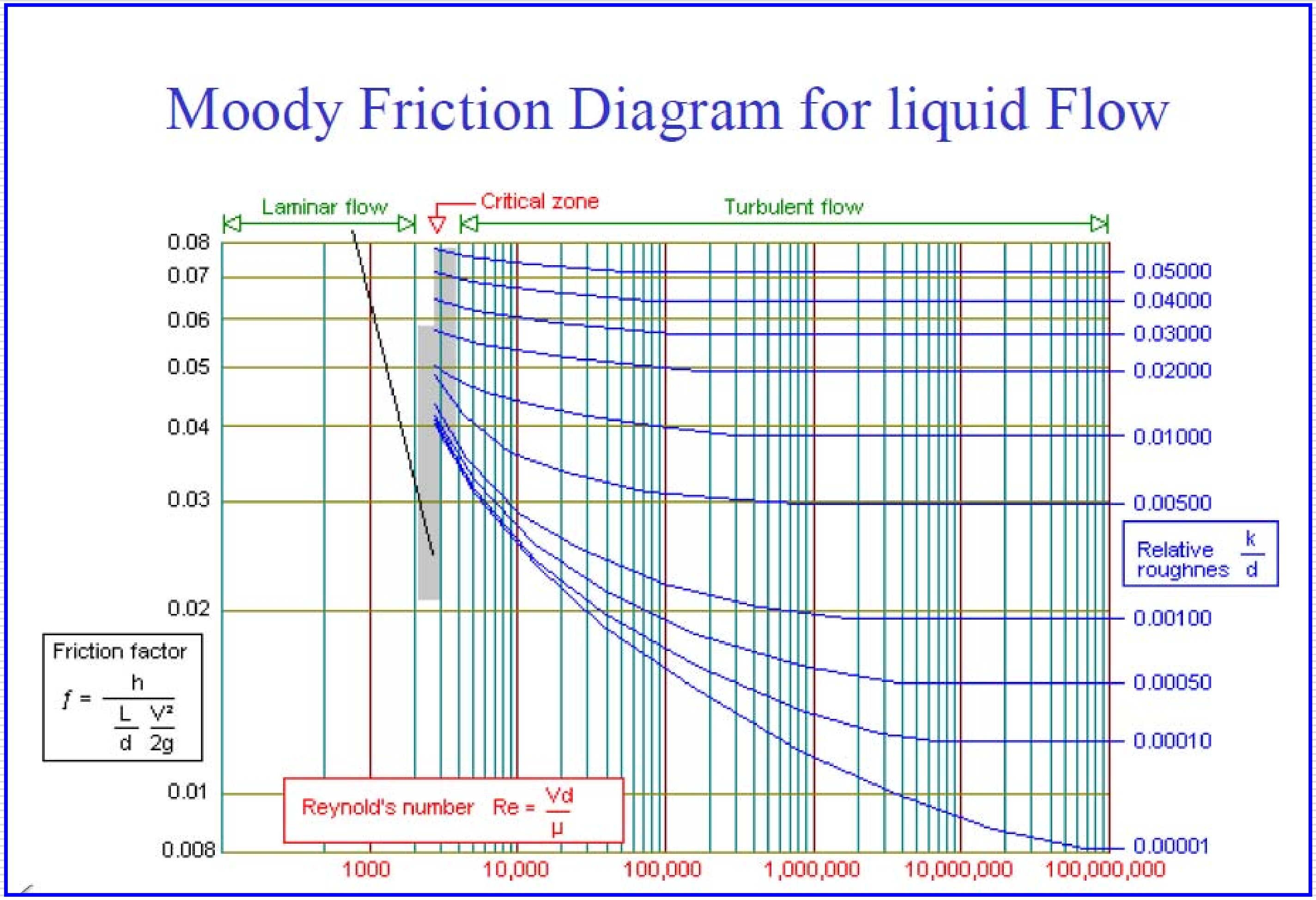
- Determine Relative Roughness

ε = Material Roughness / Pipe ID

- Calculate Friction Factor

1. Use Moody Diagram OR
2. Use Formula Calculate Friction Factor

MOODY DIAGRAM



FRICTION FACTOR FORMULA

- $f = 0.0055 \times [1 + (36/D + 10^6/N_{RE})^{1/3}] \times 1.10$

  Where Dia. Of pipe in "inches".

OR

- Jain's Approximation

  $f = [1.14 - 2*\mathrm{Log}(k/D + 21.25\mathrm{Re}^{-0.9})]^{-2}$

  for $10^{-6} < k/D < 10^{-2}$ and $5{,}000 < \mathrm{Re} < 10^8$

Pressure Loss Formula

- Calculate Pressure Drop

$$\Delta P = f\ L\ v^2\ \rho\ /\ 2\ g_c\ d$$

$$\Delta P / L = f\ v^2\ \rho\ /\ 2\ g_c\ d$$

where f = Moody friction Factor

L = Length, m

gc = Mass force gravitational constant = 1 kg.m/N.sec^2

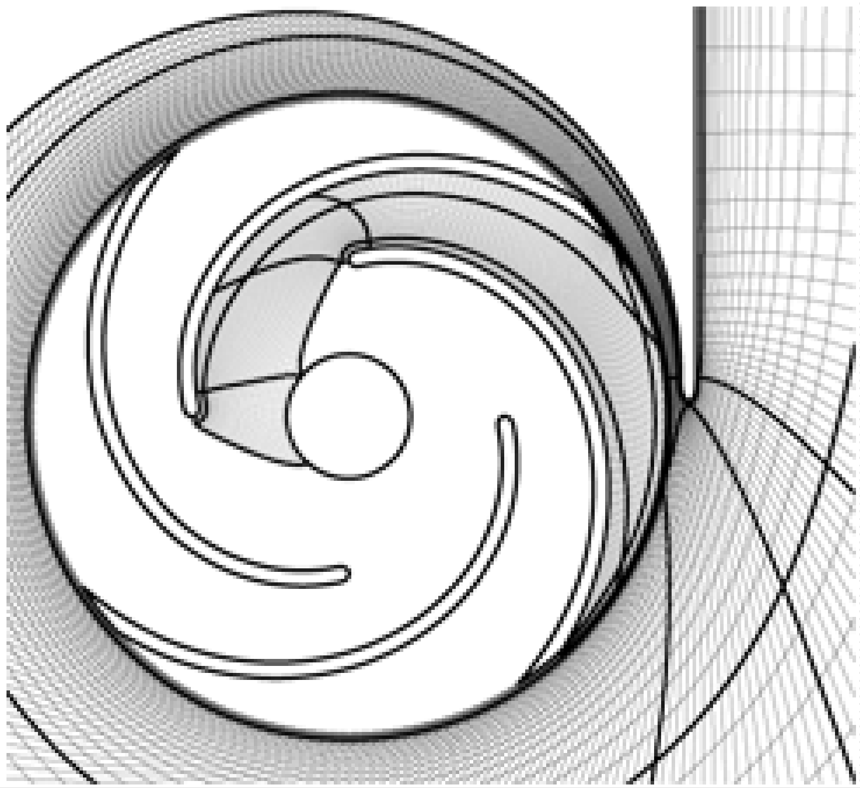
FIG. 17-4

Equivalent Length L_e for Valves and Fittings

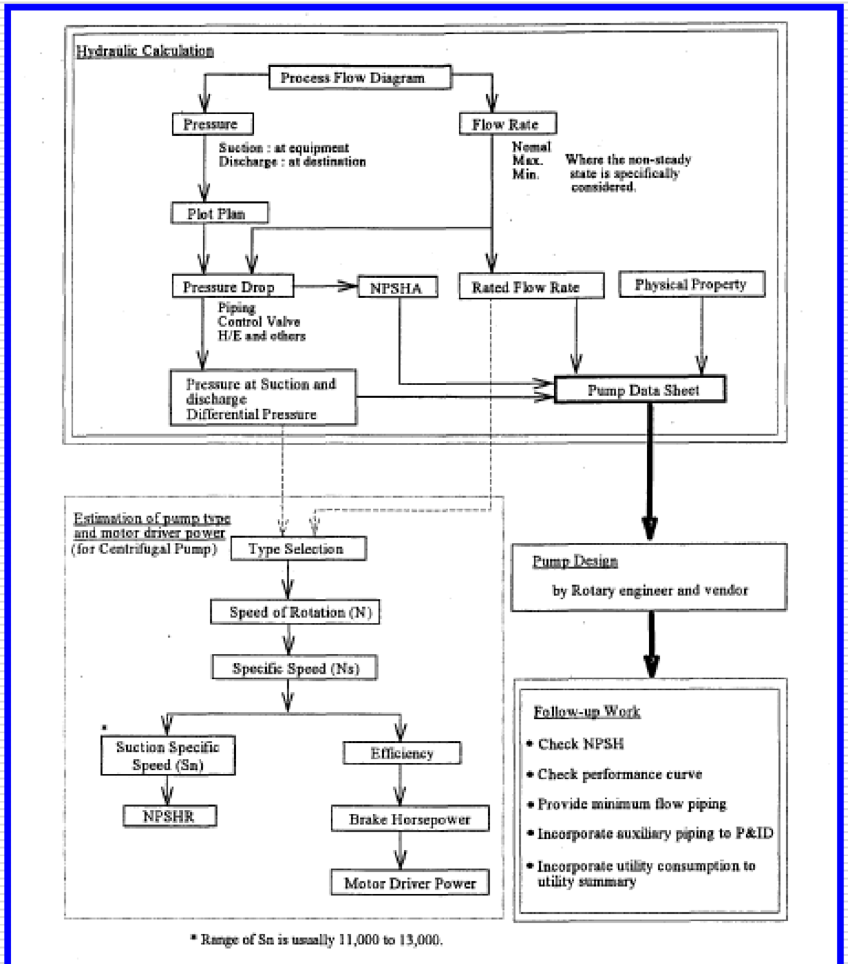
Valves (fully open)	Ball valve	Reduced bore 40 mm ($1\frac{1}{2}$ in.) and smaller	* 65 D
		Reduced bore 50 mm (2 in.) and larger	45 D
	Gate valve	Standard bore	13 D
		Reduced bore 40 mm ($1\frac{1}{2}$ in.) and smaller	65 D
	Globe valve	Straight pattern	340 D
		Y pattern	160 D
		Angle pattern	145 D
	Check valve	Swing type	135 D
		Ball or piston type 40 mm ($1\frac{1}{2}$) in. and smaller	340 D
	Plug valve	Regular pattern	45 D
	Butterfly valve	150 mm (6 in.) and larger	20 D
Fittings	Tee-equal	Flow straight-through	20 D
		Flow through side outlet	65 D
	Elbow	90°, R = $1\frac{1}{2}$ D	20 D
		45°, R = $1\frac{1}{2}$ D	16 D
	Bend	90°, R = 4 D	14 D
		90°, R = 5 D	16 D
		180°, R = 4 D	25 D
		180°, R = 5 D	28 D
Miscel-laneous	Strainer	Pump suction Y-type and bucket type	250 D
	Nozzle	Suction nozzle vessel/tank	32 D

* D = nominal size in meters

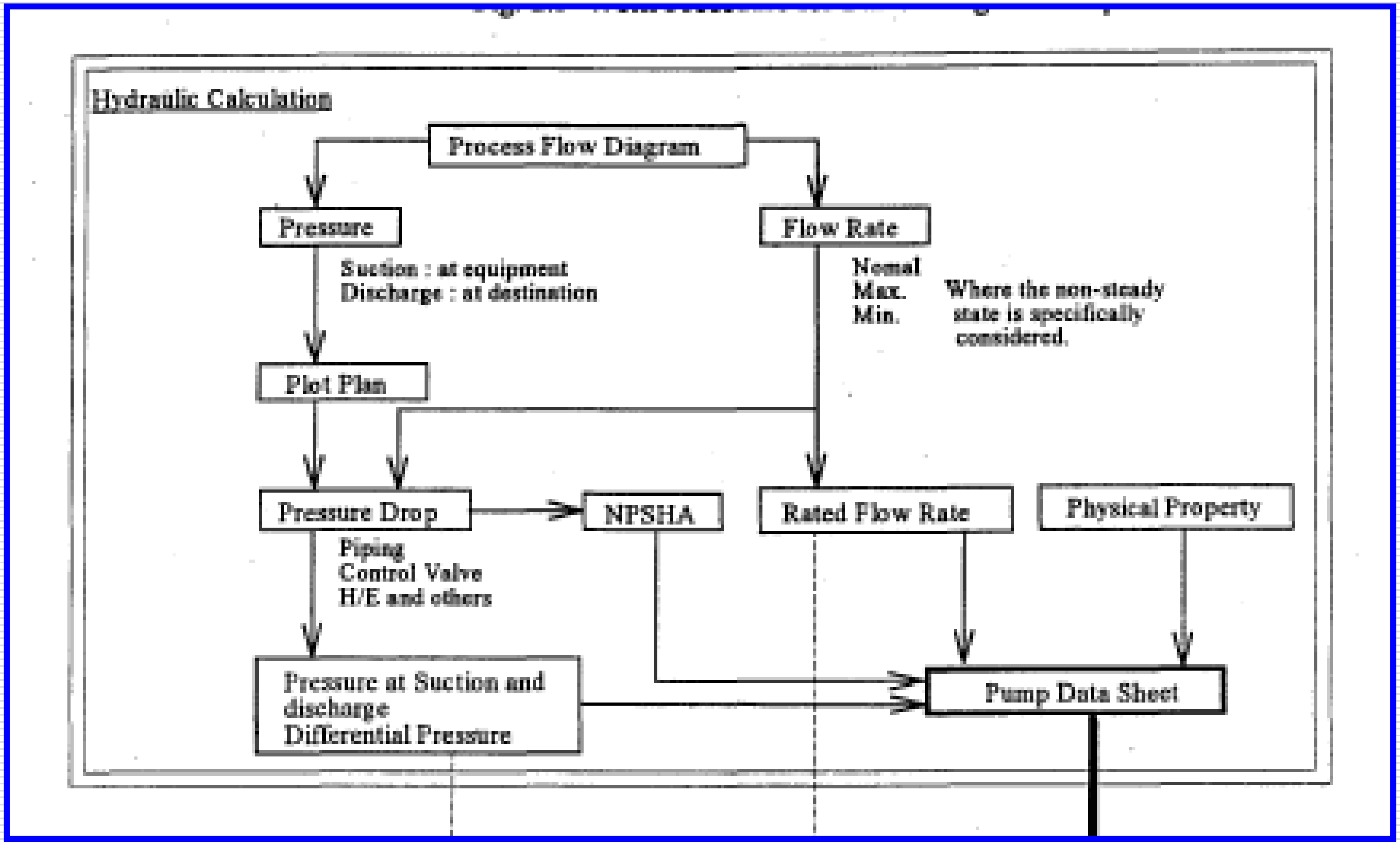
CENTRIFUGAL PUMP SIZING



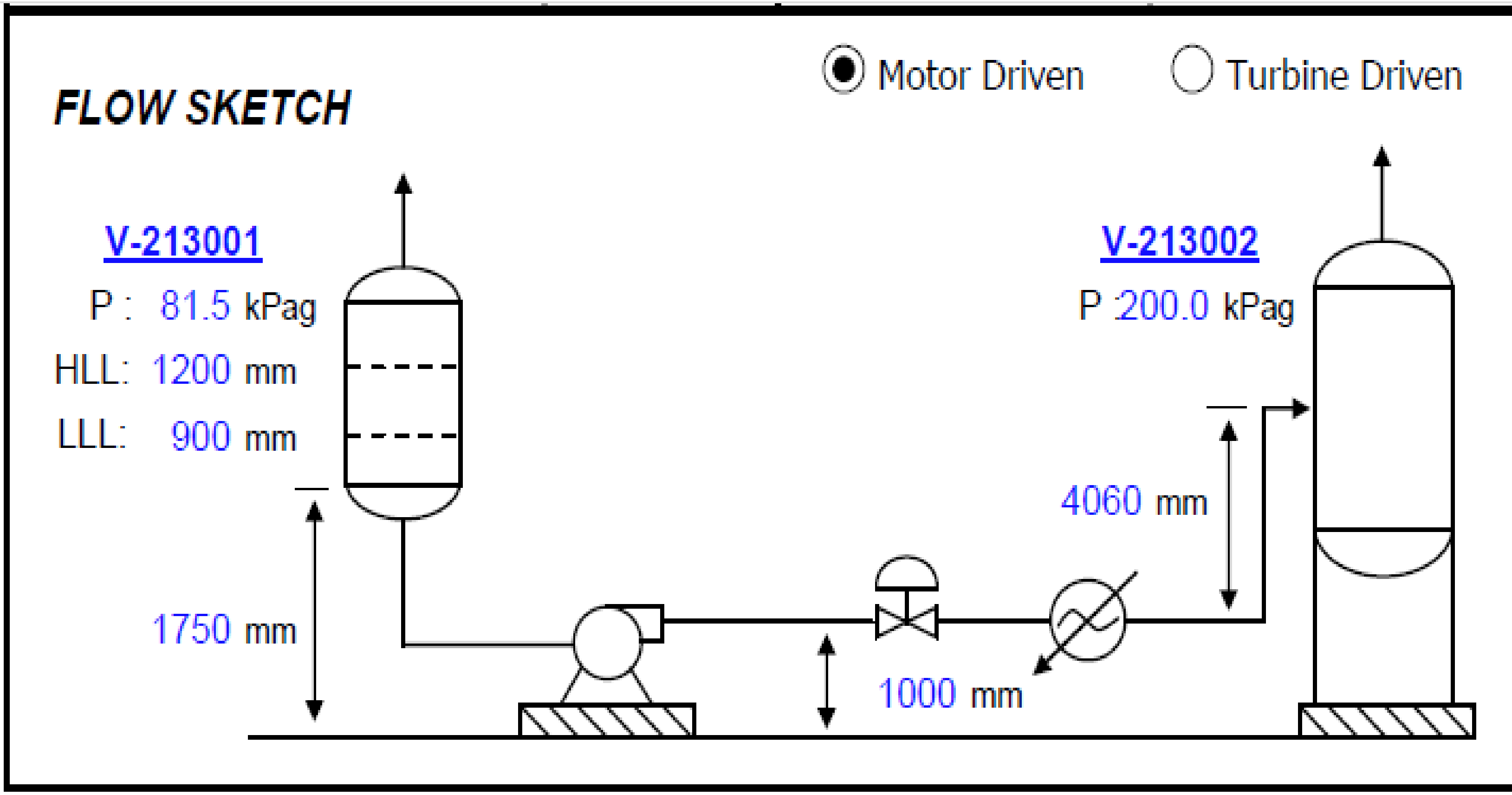
PROCEDURE FLOW CHART



HYDRAULIC CALCULATION



EXAMPLE: FLOW SKETCH



FLUID PROPERTIES

PUMP CALCULATION SHEET

SI Units

Client:	Tutorial	Rev.:	A
Item:	**P-1000**	Date:	05/05/2010
Description:	**UTILITY WATER PUMP**	By:	
Job Number:		Checked:	

SUCTION LINE:	P-XX-001			DISCHARGE LINE:	P-XX-002
		CASE 1	**NOTES**	**CASE 2**	**NOTES**
SUCTION LINE SIZE	inches	3		3	
DISCHARGE LINE SIZE	inches	2		2	
FLUID PROPERTIES & FLOW RATE					
FLUID PUMPED		**WATER**		**WATER**	
PUMPING TEMP. (P.T.)	°C	43		43	
S.G. @ P.T./15° C		0.993		0.993	
VISCOSITY AT P.T.	cP	0.65		0.65	
ATMOS. PRESS.	kPa abs	93.5		93.5	
NORMAL FLOW	m^3/h	6		15	
DESIGN FACTOR	%	10		10	
RATED FLOW	**m^3/h**	**6.60**		**16.50**	

SUCTION PIPE SIZING

- Follow the steps described in Slide 13 thru Slide 16.

Stream Number (P & ID)			CASE 1	
Service			SUCTION P-XX-001	DISCHARGE P-XX-002
LIQUID	Liquid Flow	m3/h	6.60	6.60
	Specific Gravity		0.993	0.993
	Viscosity	Cp	0.650	0.650
Density		kg/m3	993.000	993.000
Mass Flowrate		kg/h	6,553.8	6,553.8
Nominal Pipe Size		**inches**	**3**	**2**
Sch. No. (Note 1)			40	40
Total Equivalent Length		ft	143	134
Pipe ID		inches	3.068	2.067
Friction Factor Contingency			10%	10%
Reynolds Number			45,761	67,922
Moody Friction Factor			0.0256	0.0253
	Flowing Velocity	**m/s**	**0.38**	**0.85**
	Pressure Drop	**kPa/100m**	**2.41**	**17.15**
	Total Pressure Drop	**kPa**	**3.44**	**23.04**
Next < Nom. Pipe Size		**inches**	**2.5**	**1.5**
	Pipe ID	inches	2.469	1.610
	Flowing Velocity	**ft/s**	**0.6**	**1.4**
	Pressure Drop	**kPa/100m**	**7.05**	**60.60**
Next > Nom. Pipe Size		**inches**	**4**	**2.5**
	Pipe ID	inches	4.026	2.469
	Flowing Velocity	**ft/s**	**0.2**	**0.6**
	Pressure Drop	**kPa/100m**	**0.64**	**7.05**

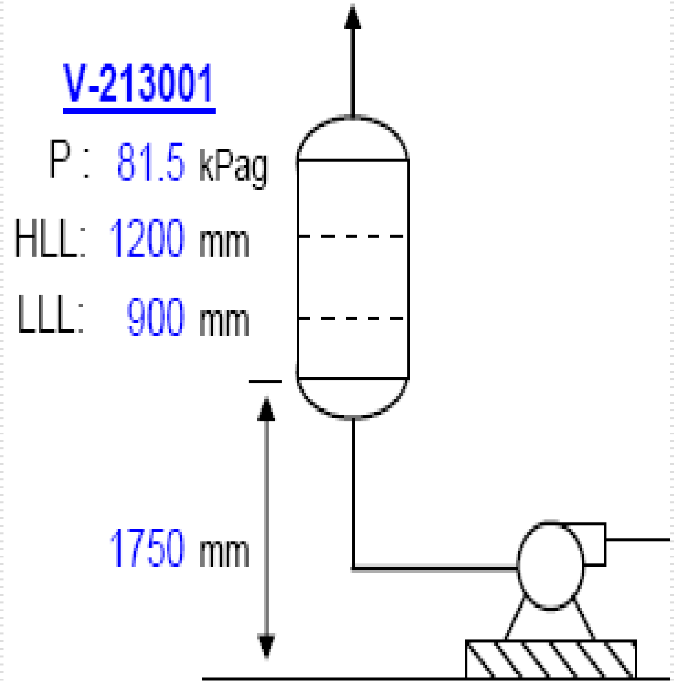
SUCTION PIPING DESIGN CRITERIA

- Pump suction piping is sized so that pressure drop through line and fittings should be minimum. Recommended pressure drop is **0.2 – 0.5 psi/100 ft (0.45 – 0.11 kPa/m)** for liquids below their boiling point and **0.05 – 0.025 psi/100ft (0.01 – 0.06 kPa/m)** for boiling liquids.
- Recommended velocity for **suction piping is 1 – 5 ft/sec (0.3 – 1.5 m/sec)** except boiling liquid. For Boiling liquid, velocity should be **0.5 – 3 ft/sec (0.15 – 0.90 m/sec).**

SUCTION PRESSURE

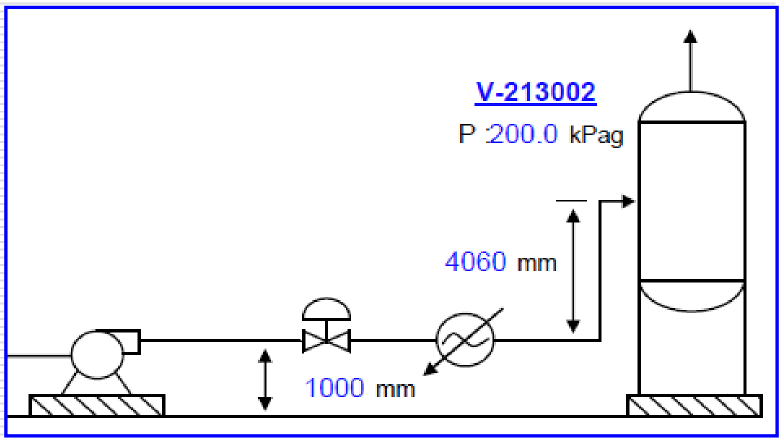
- Vessel Pressure = **81.5 kPag**
- Liquid Level (From pump center line to LLLL) = 1750-1000+900 = 1650 mm

  Converting into pressure = 0.993 x 9.8 x 1.65 = **16.06 kPa** ***[Ref. Slide 16]***
- Suspension Line Loss = **3.44 kPa** ***[Ref. Slide 12-15 and Slide 22]***
- ***Line Size =***
- Suction Pressure at Pump Flange = **81.5 +16.06 – 3.44 = 94.12 kPag**



DISCHARGE PIPE SIZING

- Follow the steps described in Slide 13 thru Slide 16.



Stream Number (P & ID)			CASE 1	
Service			SUCTION P-XX-001	DISCHARGE P-XX-002
LIQUID	Liquid Flow	m3/h	6.60	6.60
	Specific Gravity		0.993	0.993
	Viscosity	Cp	0.650	0.650
Density		kg/m3	993.000	993.000
Mass Flowrate		kg/h	6,553.8	6,553.8
Nominal Pipe Size		**inches**	3	2
Sch. No. (Note 1)			40	40
Total Equivalent Length		ft	143	134
Pipe ID		inches	3.068	2.067
Friction Factor Contingency			10%	10%
Reynolds Number			45,761	67,922
Moody Friction Factor			0.0256	0.0253
	Flowing Velocity	**m/s**	**0.38**	**0.85**
	Pressure Drop	**kPa/100m**	**2.41**	**17.15**
	Total Pressure Drop	**kPa**	**3.44**	**23.04**
Next < Nom. Pipe Size		**inches**	**2.5**	**1.5**
	Pipe ID	inches	2.469	1.610
	Flowing Velocity	**ft/s**	**0.6**	**1.4**
	Pressure Drop	kPa/100m	7.05	60.60
Next > Nom. Pipe Size		**inches**	**4**	**2.5**
	Pipe ID	inches	4.026	2.469
	Flowing Velocity	**ft/s**	**0.2**	**0.6**
	Pressure Drop	kPa/100m	0.64	7.05

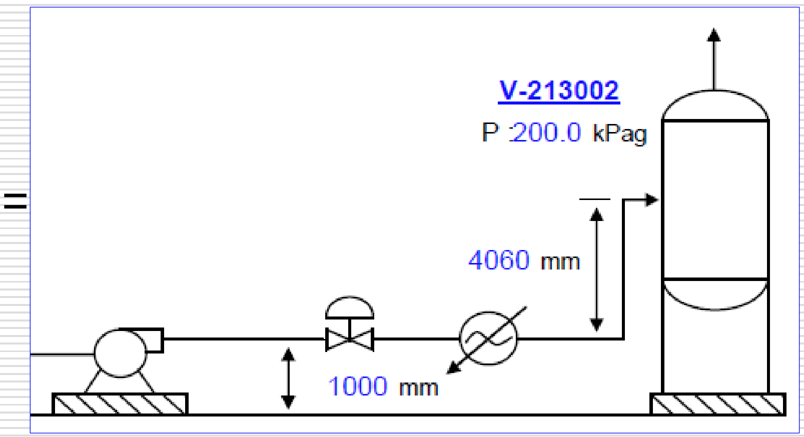
DISCHARGE PIPING DESIGN CRITERIA

- Pump discharge line size should be selected based on economic pumping cost.
- Recommended pressure drop is **1.0 – 2.0 psi/100 ft (0.23 – 0.45 kPa/m)** for the system having pressure less than 700 psi (4826 kPa) **and 3.0 – 4.0 psi/100ft (0.68-0.91)** for the system having pressure more than 700 psi (4826 kPa).
- Recommended velocity for **discharge piping is 3 – 10 ft/sec (0.9 – 3.0 m/sec)** for line size lesser than 4 inches and **10 – 15 ft/sec (3 – 4.6 m/sec).**

DISCHARGE PRESSURE

DISCH. LINE LOSS		kPa		23.04			118.02	
HEAT EXCH. LOSS		kPa		50.00			0.00	
FIRED HEATER LOSS		kPa		0.00			0.00	
ORIFICE LOSS		kPa		0.00			0.00	
CONTINGENCY		kPa		0.00			0.00	
CONTROL VALVE LOSS (3)		kPa		68.95			68.95	
DISCH. STATIC HEAD	m	kPa	4.06	39.55		4.06	39.55	
TERMINAL P		kPag		200.00			200.00	
DISCHARGE P		**kPag**		**381.54**			**426.51**	
DIFFERENTIAL P	**m**	**kPa**	**29.52**	**287.42**		**35.61**	**346.66**	

- Discharge line loss = 23.04 kPa
- Equipment ΔP = 50 kPa (Assumed)
- Control valve ΔP = 68.95 kPa
- Discharge Static Head = 4060 mm = 4.06 x 9.8 x 0.993 = 39.55 kPa
- Terminal Pressure = 200 kPa
- Discharge Pressure = 23.04 +50+ 68.95 + 39.55 + 200 = **381.54 kPag**



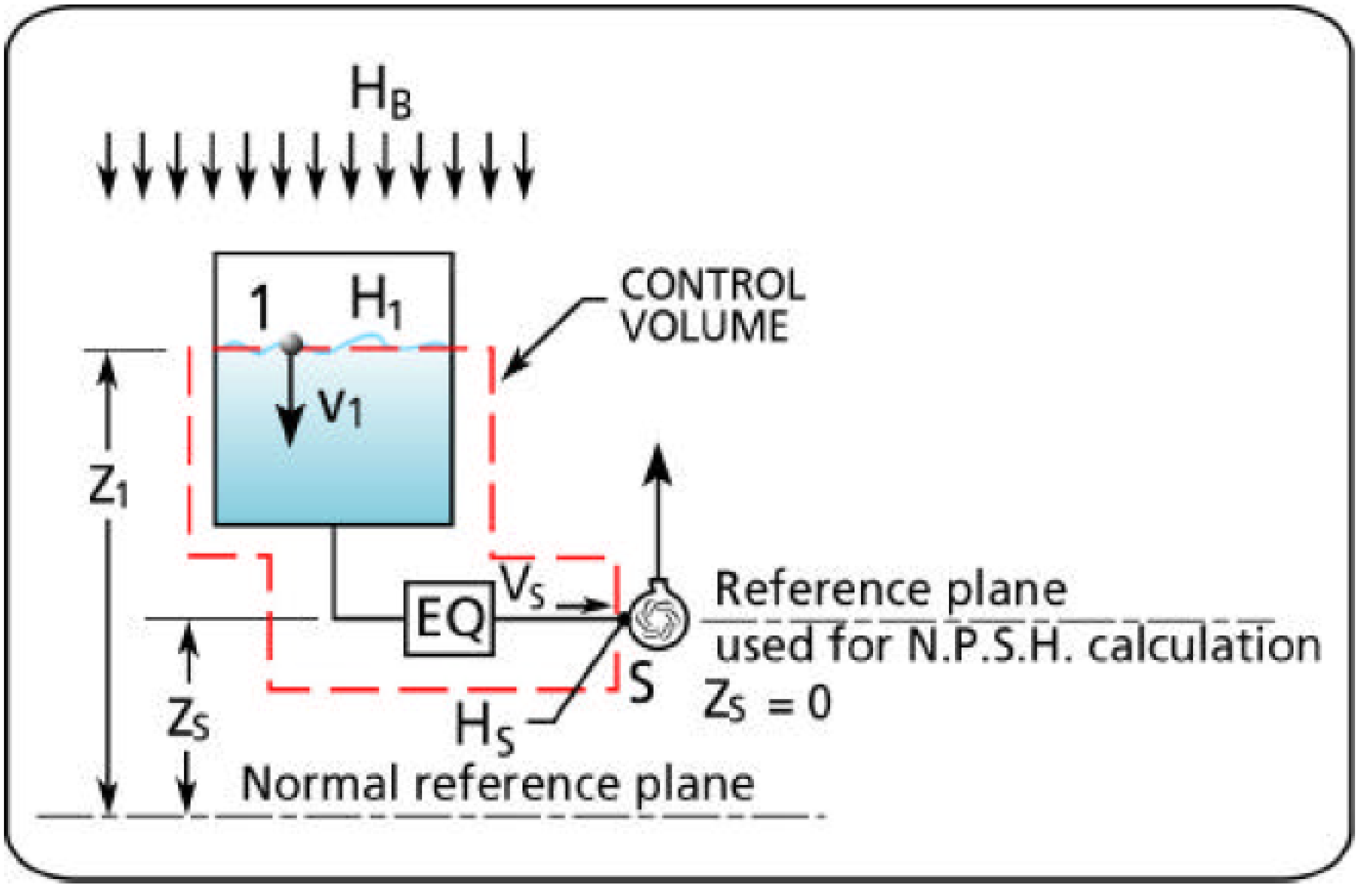
PUMP DIFFERENTIAL PRESSURE

- Suction Pressure = 94.12 kPag (Slide 24)
- Discharge Pressure = 381.54 kPag
- Differential Pressure = 381.54 – 94.12 = 287.42 kPa
- Convert Differential Pressure into Head = 287.42 / (9.8 x 0.993) = **29.5 m** ***(This is PUMP differential head)***

Understand NPSH (NET POSITIVE SUCTION HEAD)

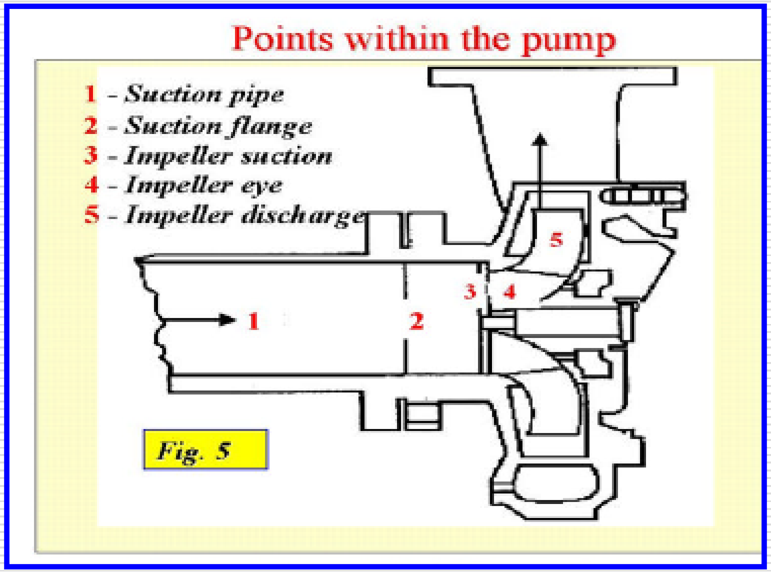
- The Hydraulic Institute (HI) defines NPSH as the total suction head in feet absolute, determined at the suction nozzle and corrected to datum, less the vapor pressure of the liquid in head of the fluid.
- Why do we need $NPASH_A$?
- The liquid must not vaporize in the eye/entrance of the impeller. (This is the lowest pressure location in the impeller. The lowest pressure occurs right at the impeller inlet where a sharp pressure dip occurs.
- This value is required to avoid cavitation of the fluid.
- Cavitation will be avoided if the head at the suction is higher than the vapor pressure head of the fluid.
- In addition, the pump manufacturers require a minimum NPSH to guarantee proper operation of the pump, they call this the $NPSH_R$, where "R" stands for required.
- NPSH is made up of the losses due to friction and shock plus the natural pressure reduction due to centrifugal force.
- NPSH = (pressure head at the source) + (static suction head) - (friction head in the suction line) - (vapor pressure of the liquid).

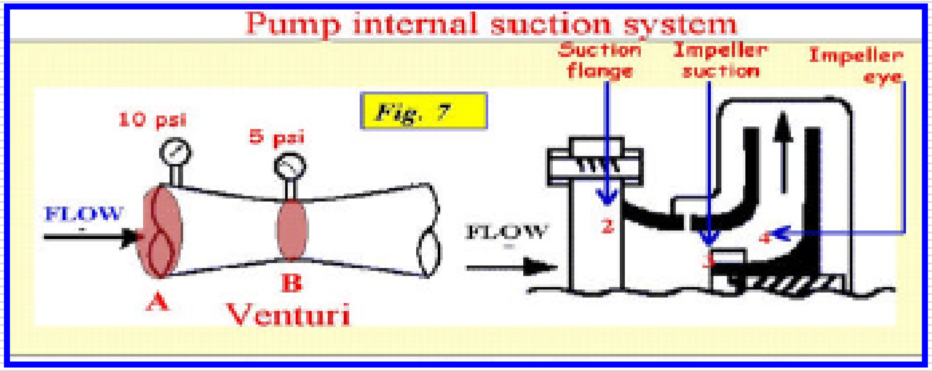
NPSH CALCULATION SKETCH



PRESSURE POINTS WITHIN THE PUMP

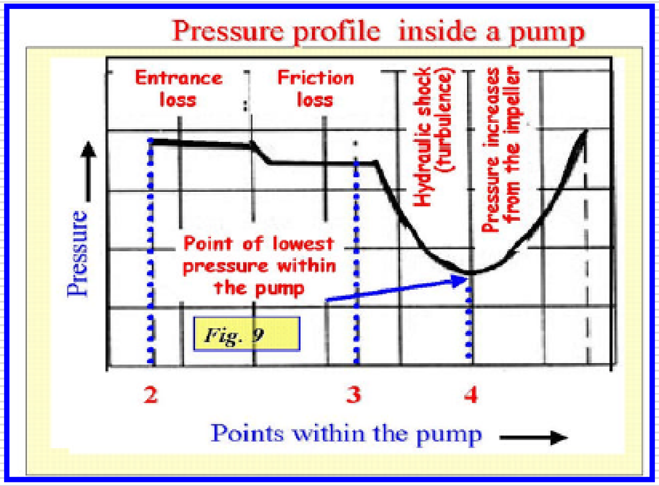
- The internal suction system is comprised of the pump's suction nozzle and impeller.
- It can be seen that the passage from the suction flange (point 2) to the impeller suction zone (point 3) and to the impeller eye (point 4) acts like a venturi i.e. there is gradual reduction in the cross-section area.

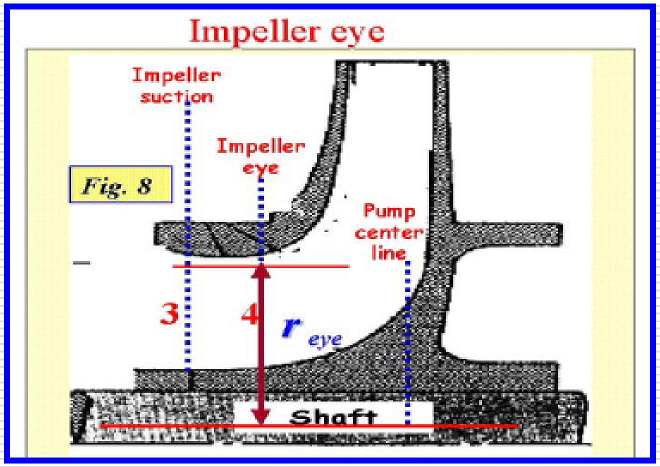




PRESSURE PROFILE INSIDE A PUMP

- The impeller eye is the point where the static pressure is at a minimum, P_4. During pump operation, if the local static pressure of the liquid at the lowest pressure becomes equal to or less than the vapor pressure (Pv) of the liquid at the operating temperature, vaporization of the liquid (the formation of bubbles) begins i.e. when $P_4 < Pv$.

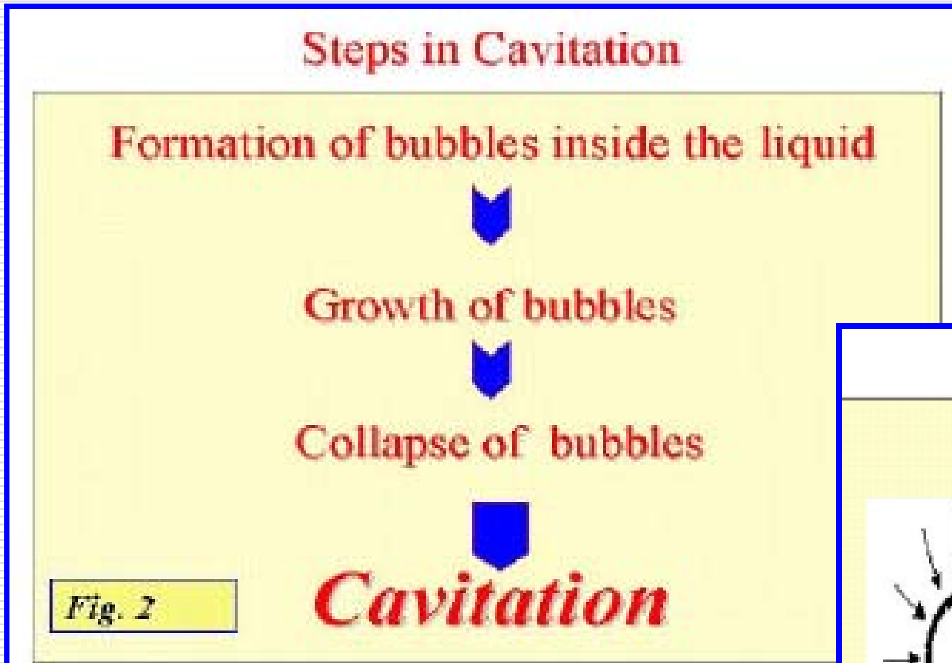


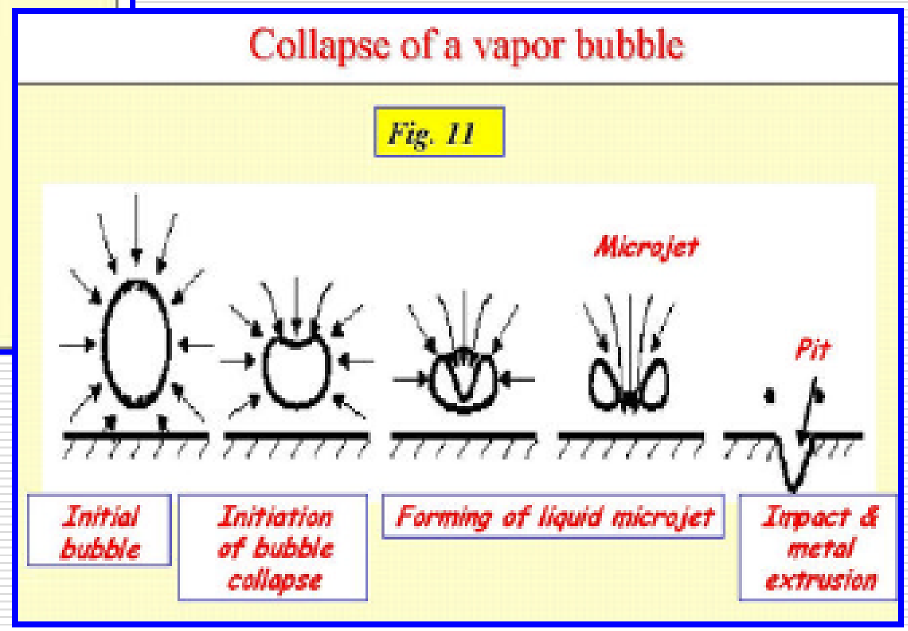


UNDERSTAND NPSH…

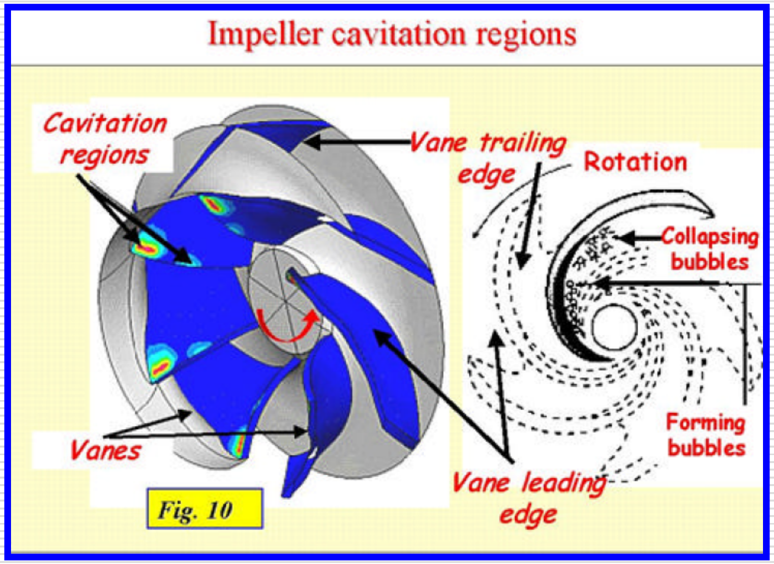
- It is impossible to design a centrifugal pump that exhibits absolutely no pressure drop between the suction inlet and its minimum pressure point, which normally occurs at the entrance to the impeller vanes.
- If the pressure is not sufficient, some of the water will change state (liquid to vapor) and cavitations occur.
- **It thus reflects the amount of head loss that the pump can sustain internally before the vapor pressure is reached.**

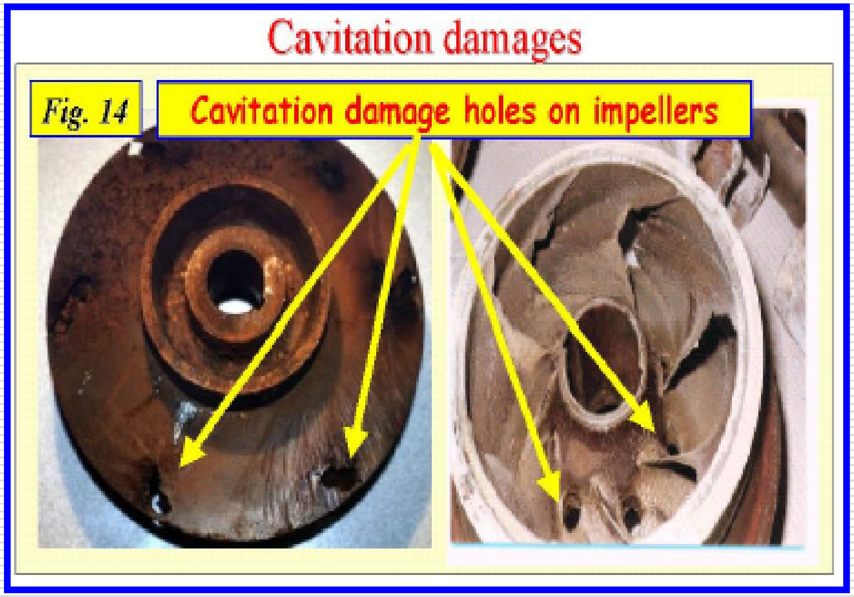
WHAT IS CAVITATION?





CAVITATION DAMAGE



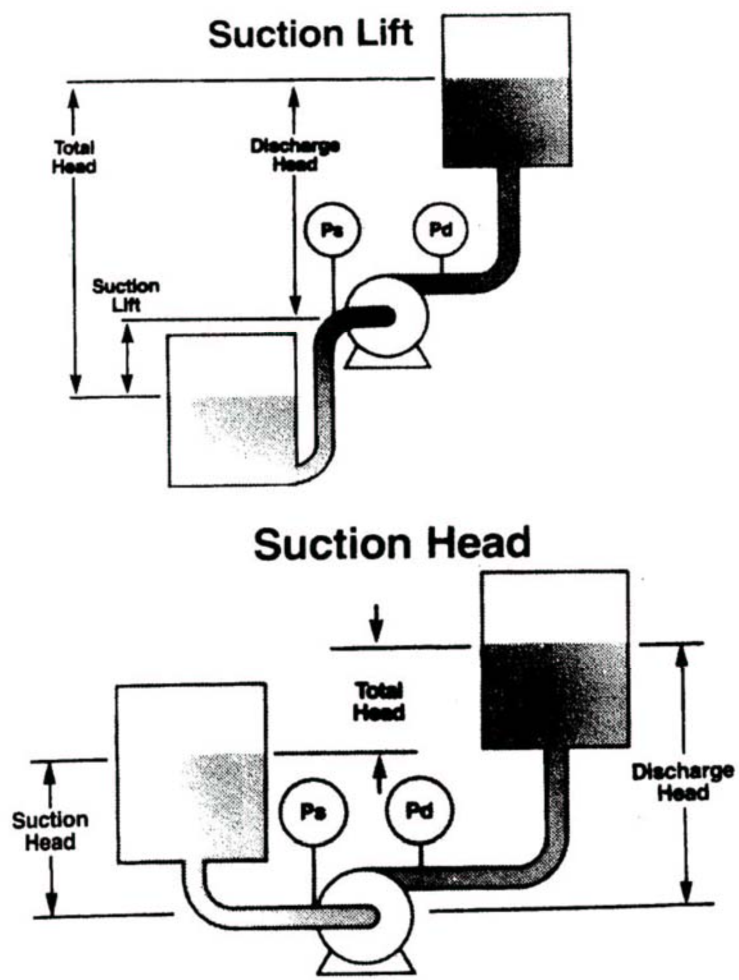


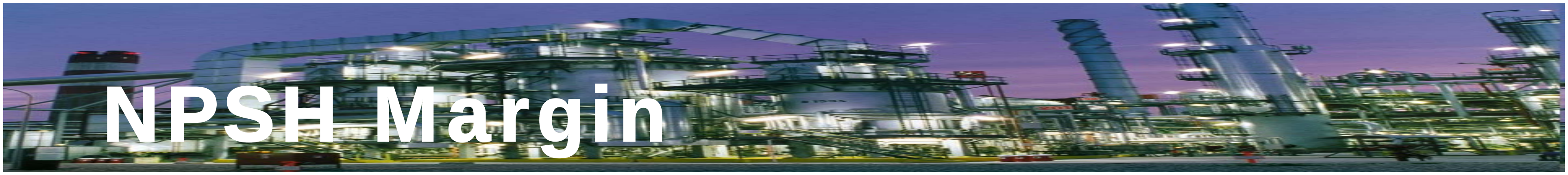
EFFECT ON NPSH

The N.P.S.H. available depends on:	Effect on N.P.S.H.A.
1. The friction loss in the pump suction line	The higher the friction loss, the lower the N.P.S.H.
2. The height of the suction tank fluid surface with respect to the pump suction	The lower the height of the fluid surface, the lower the N.P.S.H.
3. The pressure in the suction tank	This cannot be changed for atmospheric tanks. For tanks that are pressurized, the lower the pressure, the lower the N.P.S.H. available.
4. The atmospheric pressure	This cannot be changed. The lower the atmospheric pressure, the lower the N.P.S.H. available.
5. Fluid temperature	An increase in fluid temperature, increases the vapor pressure of the fluid which decreases the N.P.S.H. available.

NPSH CALCULATION

- NPSHa = Ha $\pm$ Hs - Hf – Hvp
  - Ha = atmospheric or vessel pressure (ft or m of liquid being pumped)
  - Hs = static lift or head
  - Hf = piping friction losses
  - Hvp = vapor pressure
  - All parameters should be in same unit.





NPSH Margin

- NPSH Safety margin = 10 % of Calculated or 1 meter minimum.
- **NPSHA > NPSHR**
- The NPSHA should normally be at least 0.6 m (2 ft) above the NPSHR in normal applications (stable operation with fluid at low vapor pressure).

NPSH CALCULATION

NPSHA CALCULATION									
ORIGIN P			kPag		81.50			81.50	
LIQUID HEAD		m	kPa	1.65	16.06		1.65	16.06	
SUCT. LINE LOSS			kPa		3.44			17.71	
SUCTION P			**kPag**		**94.12**			**79.86**	
VAPOR P @ P.T.			kPa		8.65			175	
NPSH CALC.		m	kPa	18.38	178.97		-0.17	-1.64	
SAFETY MARGIN	(2)	m		1.84			1.00		
$NPSH_A$		m	kPa	16.55	161.18		-1.17	-11.39	

1. Vessel Pressure = **81.5 kPag**
2. Liquid Level (From pump center line to LLLL) = 1750-1000+900 = 1650 mm Converting into pressure = 0.993 x 9.8 x 1.65 = **16.06 kPa** ***[Ref. Slide 16]***
3. Suction Line Loss = **3.44 kPa** ***[Ref. Slide 12-15]***
4. Suction Pressure at Pump Flange = **81.5 +16.06 – 3.44 = 94.12 kPag**
5. Vapor Pressure = **8.65 kPa**
6. NPSHa = Suction pressure – Vapor Pressure = (94.12 + 93.5) – 8.65 = **178.97 kPa**
7. Convert Pressure into head = 178.97 /(9.8 x 0.993) =**18.38 m**

$NPSH_A$

- NPSH calculated = 18.38 m
- Safety Margin = 10 % of Calculated or 1.0 m min = 1.84 m
- $NPSH_A$ = 18.38 – 1.84 = **16.54**

POWER CALCULATION

- Hydraulic horsepower (HHP) is the liquid horsepower delivered by the pump.
- **HHP (hp) =** $\mathbf{\dfrac{Q \times \Delta P}{1714}}$

Where

Q = Capacity, gpm

ΔP= Total Differential Pressure, psi

- **HHP (kW) =** $\mathbf{\dfrac{Q \times \Delta P}{3600}}$

Where

Q = Capacity, m^3 / h

ΔP= Total Differential Pressure, kPa

- Conversion from kW to hp

1 hp (British) = 0.7457 kW

POWER CALCULATION

- Brake Power is the actual horsepower delivered to the pump shaft.
- $$BHP = \frac{HHP}{Efficiency}$$
- Efficiency is product of pump and motor efficiency.
- 60 – 70% is a good assumption.

EFFICIENCY ESTIMATION

The pump efficiency may be estimated by

$$\eta = 1 - [1.6/(GPM)^{0.27}]$$

where

η = pump efficiency expressed as a fraction

GPM = gallons per minute of fluid being pumped

POWER CALCULATION

POWER CALCULATION								
HYDRAULIC POWER	kW		0.53			1.59		
EST. EFFICIENCY	%		65			65		
EST. BRAKE POWER	kW	hp	0.81	1.09		2.44	3.28	
Est. Motor Size	kW	hp	0.90	1.21		2.70	3.62	

- Hydraulic Power = $\frac{6.60 \times 287.42}{3600}$ = 0.53 kW
- Brake Power = 0.53 / 0.65 = **0.81 kW**

STANDARD MOTOR SELECTION

- Select motor size close (upper side) to Brake power.

Power HP	Power kW	Motor Efficiency (%)
1	0.75	80
2	1.5	82
3	2.2	84
5	3.7	85
7.5	5.6	85
10	7.5	85
15	11.2	86
20	14.9	87
25	18.6	88
30	22.4	89
40	29.8	89
50	37.3	89
75	55.9	90
100	74.6	90
125	93.2	90
150	111.9	90
150	111.9	90
200	149.1	90
250	186.4	90
500	372.9	93
600	447.4	93
700	522.0	93
800	596.6	94
900	671.1	94
1000	745.7	94
1250	932.1	94
1500	1118.6	94
1750	1305.0	94
2000	1491.4	94
2250	1677.8	94
2500	1864.3	95
3000	2237.1	95
3500	2610.0	95
4000	2982.8	95
4500	3355.7	95
5000	3728.5	95

SHUT OFF HEAD ESTIMATION

- Shutoff head is the head produced when the pump operates with fluid but with no flow rate.
- Pump shut off head provided by the manufacturer.
- Rule of Thumb for estimation of shut off head is

(1.25 x Differential Head) + Max Suction Pressure at HHLL

PUMP CALCULATION SPREADSHEET

PUMP CALCULATION SHEET

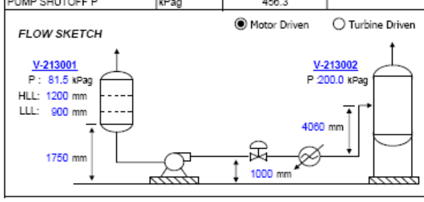
SI Units

Client: Tutorial
Item: P-1000
Description: UTILITY WATER PUMP
Job Number:

Rev.: A
Date: 5/5/2010
By:
Checked:

SUCTION LINE:	P-XX-001					DISCHARGE LINE:	P-XX-002	
			CASE 1		NOTES	CASE 2		NOTES
SUCTION LINE SIZE	inches		3			3		
DISCHARGE LINE SIZE	inches		2			2		
FLUID PROPERTIES & FLOW RATE								
FLUID PUMPED			WATER			WATER		
PUMPING TEMP. (P.T.)	°C		43			43		
S.G. @ P.T./15° C			0.993			0.993		
VISCOSITY AT P.T.	cP		0.65			0.65		
ATMOS. PRESS.	kPa abs		93.5			93.5		
NORMAL FLOW	m^3/h		6			15		
DESIGN FACTOR	%		10			10		
RATED FLOW	**m^3/h**		**6.60**			**16.50**		
NPSHA CALCULATION								
ORIGIN P		kPag		81.50			81.50	
LIQUID HEAD	m	kPa	1.65	16.06		1.65	16.06	
SUCT. LINE LOSS		kPa		3.44			17.71	
SUCTION P		**kPag**		**94.12**			**79.86**	
VAPOR P @ P.T.		kPa		8.65			175	
NPSH CALC.	m	kPa	18.38	178.97		-0.17	-1.64	
SAFETY MARGIN (2)	m		1.84			1.00		
$NPSH_A$	m	kPa	16.55	161.18		-1.17	-11.39	
DIFFERENTIAL HEAD CALCULATION								
DISCH. LINE LOSS		kPa		23.04			118.02	
HEAT EXCH. LOSS		kPa		50.00			0.00	
FIRED HEATER LOSS		kPa		0.00			0.00	
ORIFICE LOSS		kPa		0.00			0.00	
CONTINGENCY		kPa		0.00			0.00	
CONTROL VALVE LOSS (3)		kPa		68.95			68.95	
DISCH. STATIC HEAD	m	kPa	4.06	39.55		4.06	39.55	
TERMINAL P		kPag		200.00			200.00	
DISCHARGE P		**kPag**		**381.54**			**426.51**	
DIFFERENTIAL P	**m**	**kPa**	**29.52**	**287.42**		**35.61**	**346.66**	
POWER CALCULATION								
HYDRAULIC POWER	kW		0.53			1.59		
EST. EFFICIENCY	%		65			65		
EST. BRAKE POWER	kW	hp	0.81	1.09		2.44	3.28	
Est. Motor Size	kW	hp	0.90	1.21		2.70	3.62	
MAXIMUM SUCTION PRESSURE								
SUCT. VESSEL PSV SET P	kPag		100.0			100.0		
MAX. SUCTION P	kPag		97.0			82.8		
PUMP SHUTOFF PRESSURE								
PUMP SHUTOFF P	kPag		456.3			516.1		

FLOW SKETCH

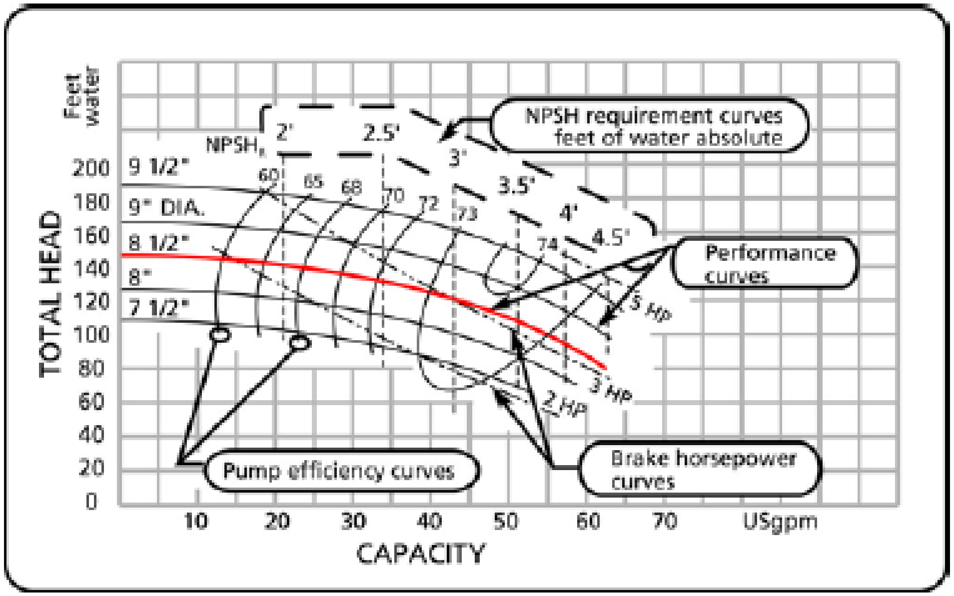


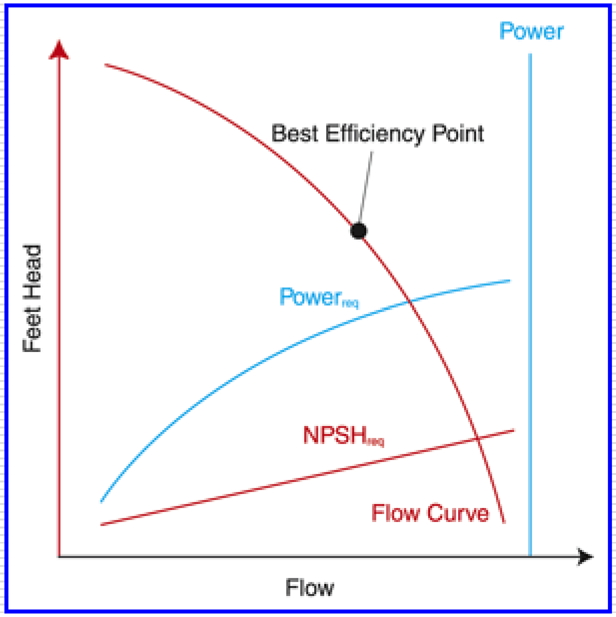
NOTES
(1) Skirt Height set by pump NPSH
(2) $NPSH_A$ Safety Margin
10% OF CALC. (min. 1m)
(3) ΔP = 15% OF DYNAMIC HEAD
(min. 68.95 kPa)

SI Units

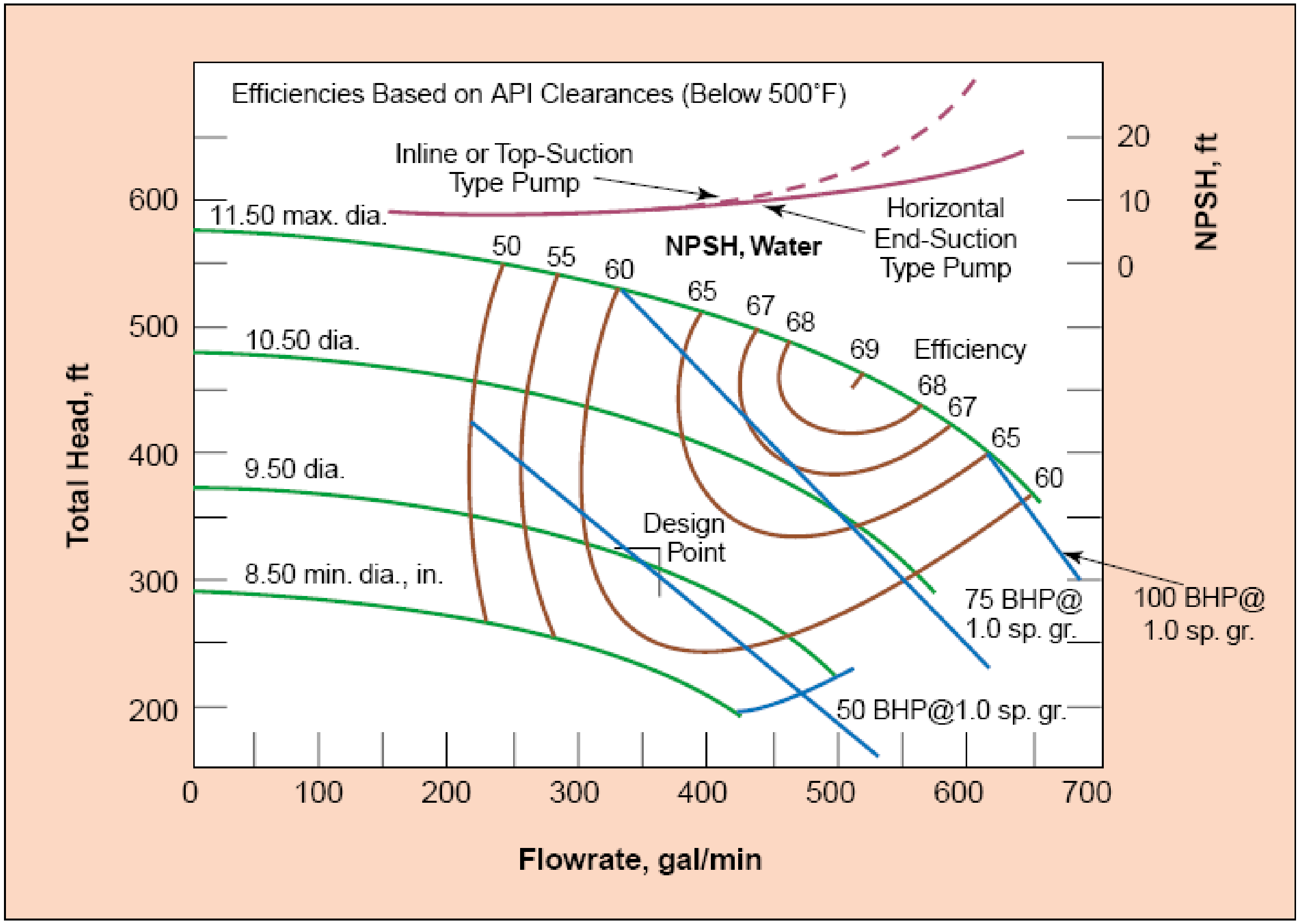
Pump Calc. Spreadsheet

PUMP CHARATERISTIC CURVE





PUMP CHARATERISTIC CURVE



UNSERSTAND PUMP CURVE

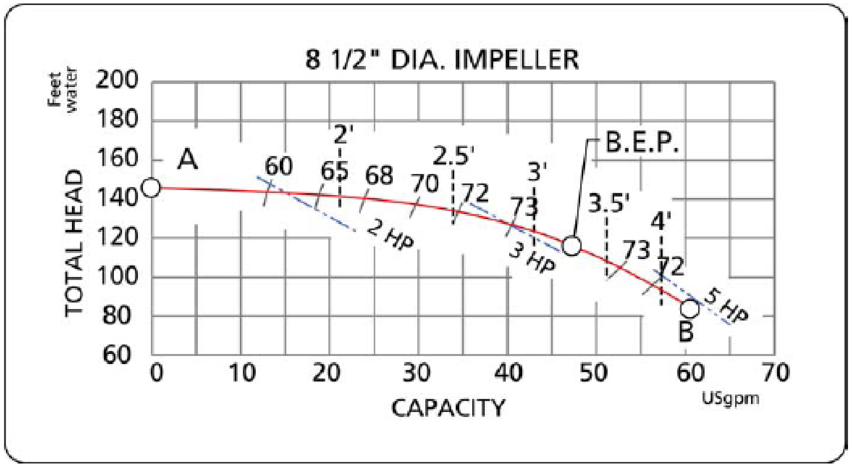
- A great deal of information is crammed into one chart and this can be confusing at first.
- The performance chart covers a range of impeller sizes, which are shown in increments.
- At some point in the pump selection process, the impeller diameter is selected. For an existing pump, the diameter of the impeller is known.
- For a new pump, our calculations of Total Head for a given flow rate will have determined the impeller diameter to select according to the performance curve.
- A performance curve is a plot of Total Head vs. flow rate for a specific impeller diameter and speed.

UNSERSTAND PUMP CURVE

- The pump performance curves are based on data generated in a test rig using water as the fluid. These curves are sometimes referred to as water performance curves.
- The use of these curves for fluids with a different viscosity than water can lead to error if the proper correction factors are not applied.

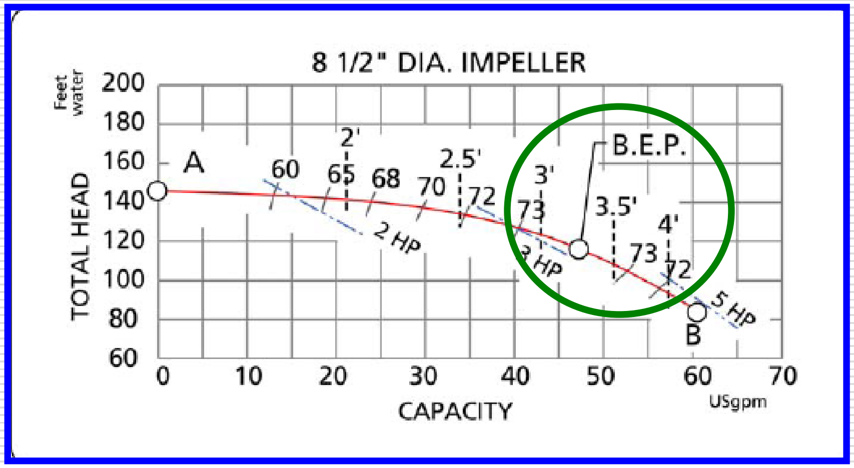
HEAD vs. CAPACITY CURVES

- The plot starts at zero flow. The head at this point corresponds to the shut-off head of the pump, point A in Figure.
- Starting at this point, the head decreases until it reaches its minimum at point B.
- This point is sometimes called the run-out point and represents the maximum flow of the pump.
- Beyond this, the pump cannot operate.
- The pump's range of operation is from point A to B.
- On every *Q–H* curve, a small triangle is plotted to indicate the *rated* point of operation. The pump manufacturer guarantees this flow and the corresponding differential head.
- API recommends that the curve from BEP to shut-off should rise by at least 10% for single-stage, single pump operation.



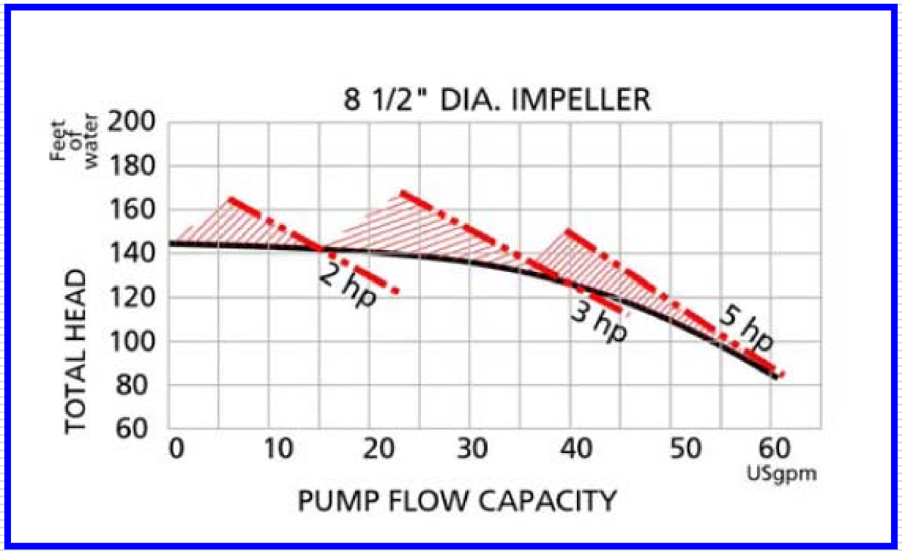
EFFICIENCY CURVES

- The *Q* vs. pump efficiency of the pump is an inverted ‘U’ shaped curve.
- The pump's efficiency varies throughout its operating range.
- At no flow, the efficiency is zero and then rises to a maximum value at a flow rate, which is termed as the BEP. Beyond this, the curve again drops.
- The B.E.P. (best efficiency point) is the point of highest efficiency of the pump.
- The pumps operate in a range of flows but it has to be kept in mind that they are designed only for one flow rate point.



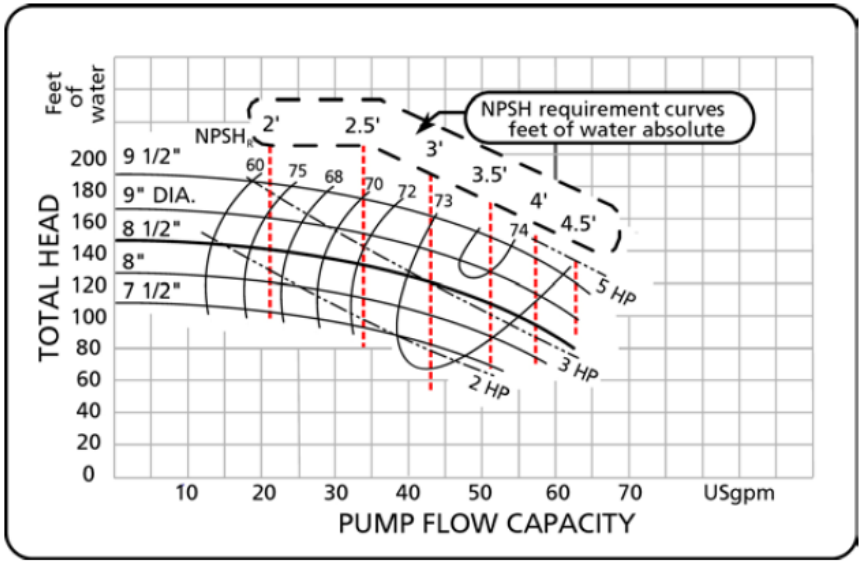
HORSEPOWER CURVES

- The horsepower can be calculated with the Total Head, flow and efficiency at the operating point.
- All points on the performance curve to the left of the 2 hp curve will be attainable with a 2 hp motor.
- The horsepower curves shown on the performance curves are valid for water only.
- Power obtained is for water and can be easily extrapolated for the liquid by multiplying it with the specific gravity of the service liquid.



NPSH REQUIREMENT CURVES

- The pump Manufacturer specifies a minimum requirement on the NPSH in order for the pump to operate at its design capacity.
- These are the vertical dashed lines in Figure.
- The NPSH required becomes higher as flow increases.
- This essentially means that more pressure head is required at the pump suction for high flows than low flows.



Pump Selection

- In selecting a pump, one of the concerns is to optimize pumping efficiency. It is good practice to examine several performance charts at different speeds to see if one model satisfies the requirements more efficiently than another.
- Whenever possible the lowest pump speed should be selected, as this will save wear and tear on the rotating parts.

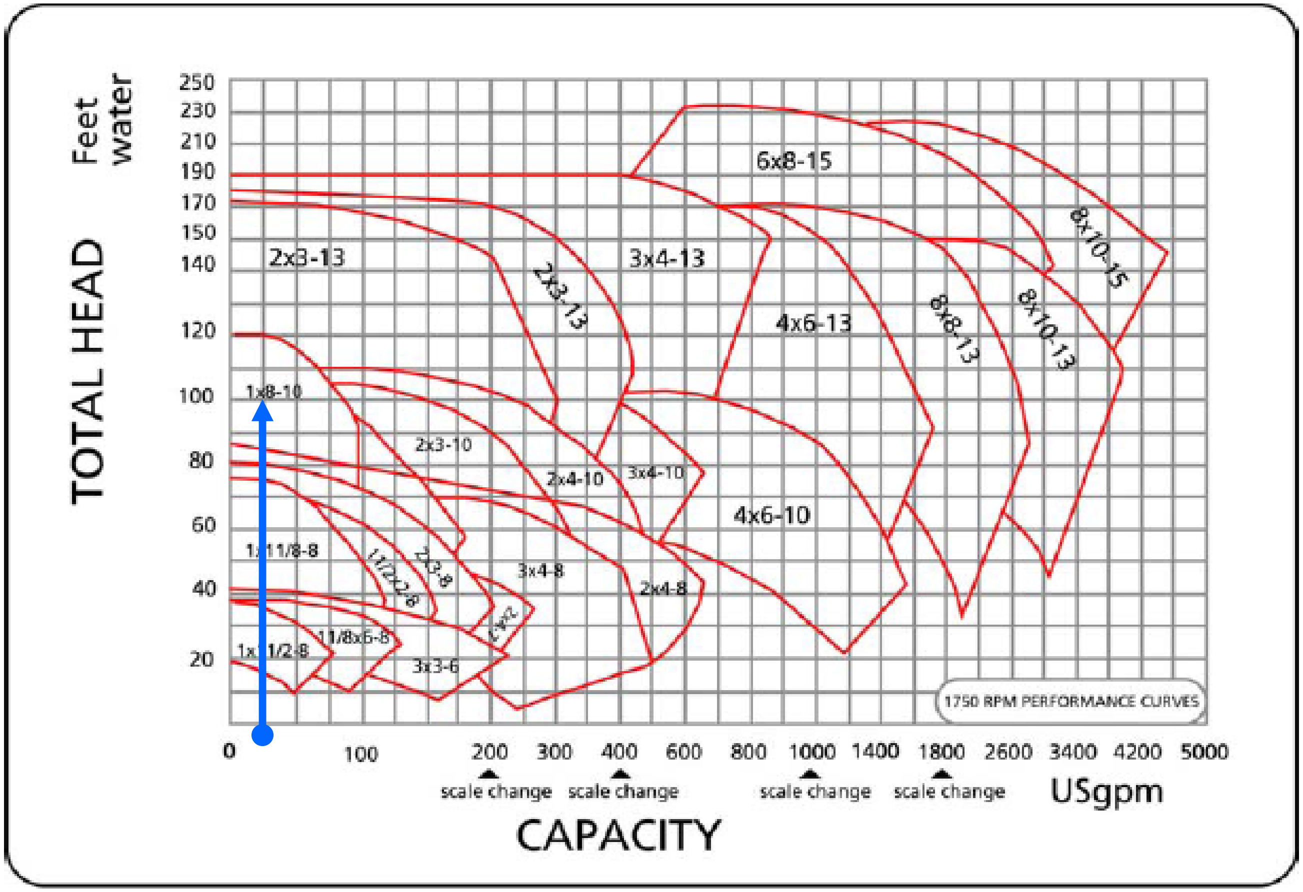
Pump Selection Rules-of-Thumb

- Select the pump based on rated conditions.
- The BEP should be between the rated point and the normal operating point.
- The head/capacity characteristic-curve should continuously rise as flow is reduced to shutoff (or zero flow).
- The pump should be capable of a head increase at rated conditions by installing a larger impeller.
- The pump should not be operated below the manufacturer’s minimum continuous flow rate.

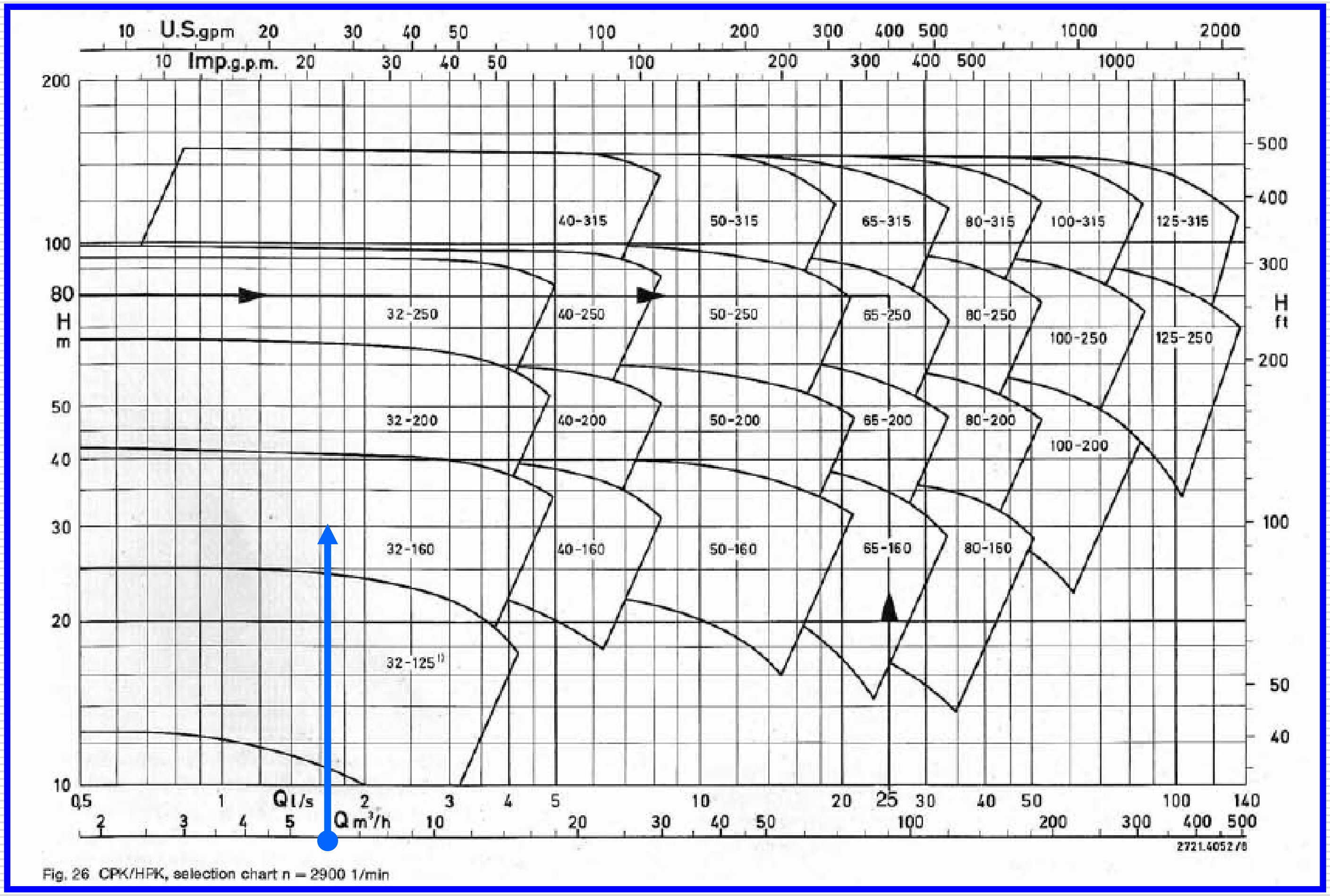
PUMP SPECIFICATIONS

- Flow Rate : 6 m^3/h = 26.42 gpm
- Differential Head : 29.5 m = 96.8 ft
- NPSHa = 16.54 m = 54.26 ft
- Brake Power = 0.81 kW = 1.10 hp
- Rated Motor = 1.12 kW = 1.5 hp
- Shut-off Head = 458.3 kPa

PUMP SLECTION CHART



PUMP SLECTION CHART 2



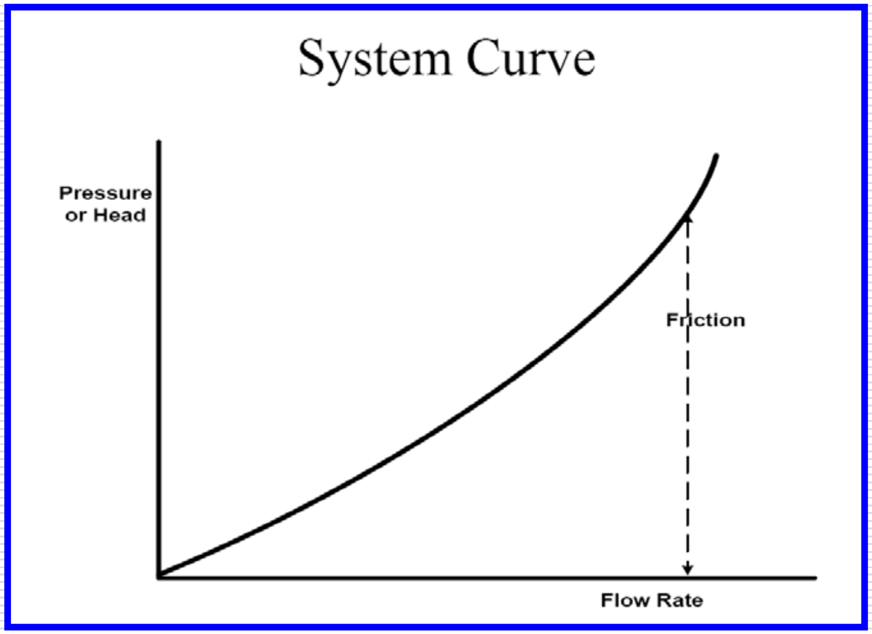
ΔP Rule of Thumb

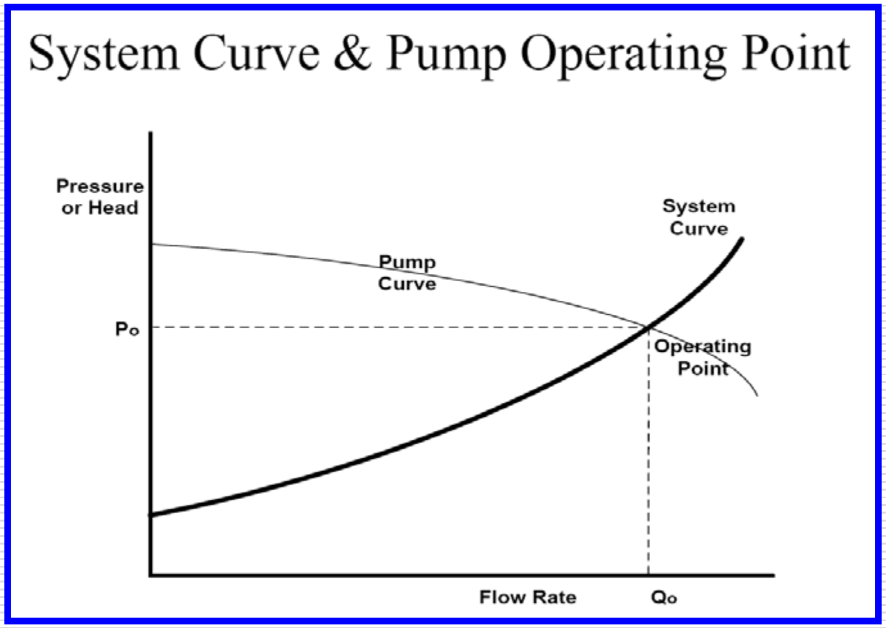
Equipment	Pressure Drop (kPa)
Heat Exchangers	50 - 100
Strainers	2 - 10
Pressure Filters	200 - 500
Spray Nozzles	-
(Coarse)	10 - 50
(Fine)	50 - 500
Washing Sprays	275 - 350
Orifice Flow Meter	10 - 20
In-Line Mixers	20 - 35

Understand System Curve

- A system head curve or system curve for a piping shows the variation of pressure required with flow rate.
- As the flow rate increases, the head required increases.
- The pump operating point is the point where the pump head curve meets the system head curve.

System Curve





Pump Curve Corrections

- The pump curves are generated while testing the pump using cold water as the liquid. The curve is fixed for a particular speed, impeller diameter, and water.
- When any of these change, the pump flow and head generated will differ.
- the curves can be corrected to obtain a performance map without retesting pump with modified conditions.

Viscosity Correction

- viscosity as a property of any fluid that is measure of its resistance to flow.
- As the liquid flows through the pump, hydrodynamic losses are increased due to higher viscosity, as a result it is observed that when a viscous fluid is handled by a centrifugal pump:
  - The brake horsepower requirement increases.
  - There is a reduction in the head generated by the pump.
  - Capacity reduction occurs with moderate and high viscosities.
  - There is a decrease in the pump efficiency.

Viscosity Correction

- Usually fluids more than 2 cP should be considered for viscosity correction.
- A viscosity correction chart from the Hydraulic Institute (as shown in Figure 3.4) provides coefficients for flow *C*q, head *C*h, and efficiency *C*η.
- These coefficients are used to modify the values of flow, head, and efficiency from the original curve

$$Q_{\mathrm{vis}} = C_{\mathrm{q}} \times Q_{\mathrm{w}}$$

$$H_{\mathrm{vis}} = C_{\mathrm{h}} \times H_{\mathrm{w}}$$

$$\eta_{\mathrm{vis}} = C_{\eta} \times \eta_{\mathrm{w}}$$

Viscosity Conversion

Some other common viscosity units and conversion factor is listed below:

Kinematic Viscosity	×	Specific Gravity	Absolute Viscosity
Centistokes	×	S.G.	Centipoise
SSU × 0.2198 – *	×	S.G.	Centipoise

SSU – *	×	0.2198	=	Centistokes
Degree Engler – *	×	7.45	=	Centistokes
Seconds Redwood – *	×	0.2469	=	Centistokes

* For centistokes greater than 50.

Viscosity Correction Chart

$Q = 500$ US-gpm, $H = 80$ ft, Viscosity = 1000 SSU.

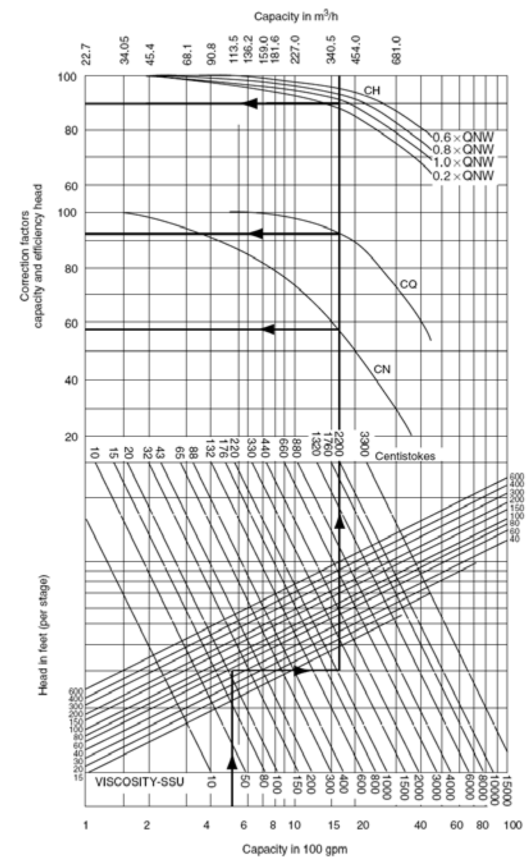


Figure 3.4
Viscosity correction charts – correction factors, Hydraulic Institute

Affinity Laws

- The 'Affinity laws' are mathematical expressions that best define changes in pump capacity, head, and power absorbed by the pump when a change is made to pump speed, with all else remaining constant.
- The Affinity laws are valid only under conditions of constant efficiency.
- The pump affinity laws mentioned above maybe utilized to determine the relationship between flow '*Q*' and impeller diameter as well as to predict Head '*H*' and Power '*P*' values with change in impeller diameter, whilst speed is kept constant.

Capacity Q changes in direct proportion to the change in pump speed N ratio:

$$Q_2 = Q_1 \times \left(\frac{N_2}{N_1}\right)$$

Head H changes in direct proportion to the square of the speed N ratio:

$$H_2 = H_1 \times \left(\frac{N_2}{N_1}\right)^2$$

Power P changes in direct proportion to the cube of the speed N ratio:

$$P_2 = P_1 \times \left(\frac{N_2}{N_1}\right)^3$$

Where the subscript 1 refers to initial condition and 2 refers to new condition.

$$Q_2 = Q_1 \times \left(\frac{D_2}{D_1}\right) \qquad H_2 = H_1 \times \left(\frac{D_2}{D_1}\right)^2 \qquad P_2 = P_1 \times \left(\frac{N_2}{N_1}\right)^3$$

Temperature Rise Due to Pumping

Basic Equation

$$T_r = \left(\frac{H}{Cp \times 778}\right)\left(\frac{1}{e} - 1\right) \text{[British System]}$$

$$T_r = \left(\frac{H}{Cp \times 427}\right)\left(\frac{1}{e} - 1\right) \text{[Metric System]}$$

where

Cp - specific heat of the liquid (BTU/lb/°F or kCal/kg °C)

Rule of Thumb: Generally 1.00 for water and 0.5 for hydrocarbons

H = differential head (feet or meter)

e = pump efficiency in decimal (i.e. 78 % = 0.78)

Tr = Temperature Rise, °F or °C

Minimum Flow in a Pump

- There are at least four (4) main factors possibly determining pump **MINIMUM RECYCLE** flow. They are:

  a) Fluid temperature rise
  b) Minimum stable flow
  c) Internal recirculation
  d) Thrust capacity

Minimum Flow – Rule of Thumb

- Percentage can ranged from 10% to 50% of Pump Flow may be considered during design phase.
- Recommendation is 30 – 40 %.
- However, this figure shall always be checked & confirmed with actual selected pump when they are manufactured.

Fluid Temp. Rise at Shut-off

- When a pump operates near shut-off (low flow) capacity and head, or is handling a hot material at suction, it may become overheated and create serious suction as well as mechanical problems.

- At shutoff condition, majority of transmitted energy is converted into heat going into liquid.

- To avoid overheating due to low flow, a minimum rate should be recognized as necessary for proper heat dissipation.

- **The maximum temperature rise recommended for any fluid is 15°F (8°C)** except when handling cold fluids or using a special pump designed to handle hot fluid, such as a boiler feed water pump of several manufacturers.

Temp. Rise Calc. at Shut off

$$t = (14.3)\frac{BHP_{SO}}{WCp}$$ (for metric system)

$$t = (42.4)\frac{BHP_{SO}}{WCp}$$ (for British system)

where:

t = temperature rise	(°C/min)	(°F/min)
BHP_{SO} = brake horsepower at shut-off	(kw)	(HP)
C_p = specific heat of pumped liquid	(kcal/kg°C)	(Btu/lb°F)
W = liquid weight in pump	(kg)	(lb)

Minimum Flow Calculation

- If a temperature rise of 15 °F is accepted in the casing - minimum flow through a centrifugal pump can be calculated as

$$\mathbf{Q = BHP\ /\ 2.95\ Cp\ SG}$$

where

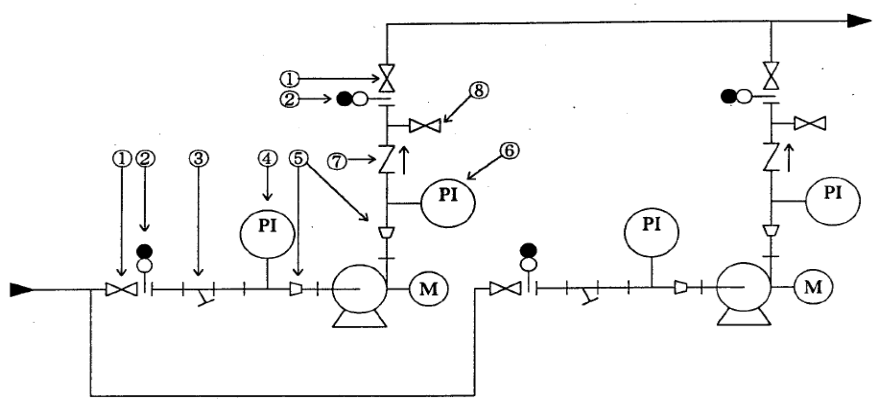
Q = minimum flow rate (gpm)

BHP = power input, hp

cp = specific heat capacity (Btu/lb °F)

SG = specific gravity of the fluid

Basic Arrangement



Ref. No.	Item Name	Purposes
①	Gate valve	Isolation for maintenance
②	Spectacle Blind (Option)	Isolation for on-stream maintenance. This should be installed, when spare pump is installed and client requests
③	Suction Strainer	To prevent mechanical damage of pump. Type of Strainer (1) "Y" type strainer : 2" and less size (2) "T" type strainer : 3" and larger size (3) Bucket type strainer : This type shall be applied to the dirty liquid service such as the crude charge and bottom's pump in crude distillation unit, bottom's pump in vacuum unit, etc.
④	Local Pressure Gauge (Option)	To check strainer pressure drop and pump suction pressure. This is not necessary, if flow rate measurement is provided at the discharge of pump. In such case approach of cavitation can be checked by decrease of flow rate.
⑤	Reducer (Option)	To adjust line size and pump nozzle size.
⑥	Local Pressure Gauge	To check pump performance.
⑦	Check Valve	To prevent pump mechanical damage due to reverse flow.
⑧	Drain Connection	Line drain

QUESTIONS