RECIPROCATING PUMP

SELECTION AND APPLICATION INTO THE SYSTEM

CONTENT

I. GENERAL

1.1. Purpose of This Manual.

This article is a note or manual for mechanical engineer where work as rotating engineer or where concern to apply reciprocating 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.

1.2. Type and Construction Features of Reciprocating Pump.

Type and construction features of reciprocating pump :

1. Position
   - Vertical
   - Horizontal

2. Purpose
   - Metering Pump
   - Power Pump

3. Piston or Plunger acting : Single acting, Double acting

4. Number of Plunger in One Casing : Single, Duplex, Triplex, Multiplex

5. Liquid End Type : Direct exposed, Diaphragm

6. Plunger direction : Forward, Backward.

1.3. Components of Reciprocating Pump.

Main components of reciprocating pump :

- Reduction gear
- Coupling
- Casing and crankcase
- Crankshaft
- Connecting Rod
- Spacer rod
- Plunger
- Packing
- Check valves
- Bearings for crankshaft and connecting rod

Following figures show cross sectional drawing for typical of reciprocating pumps.

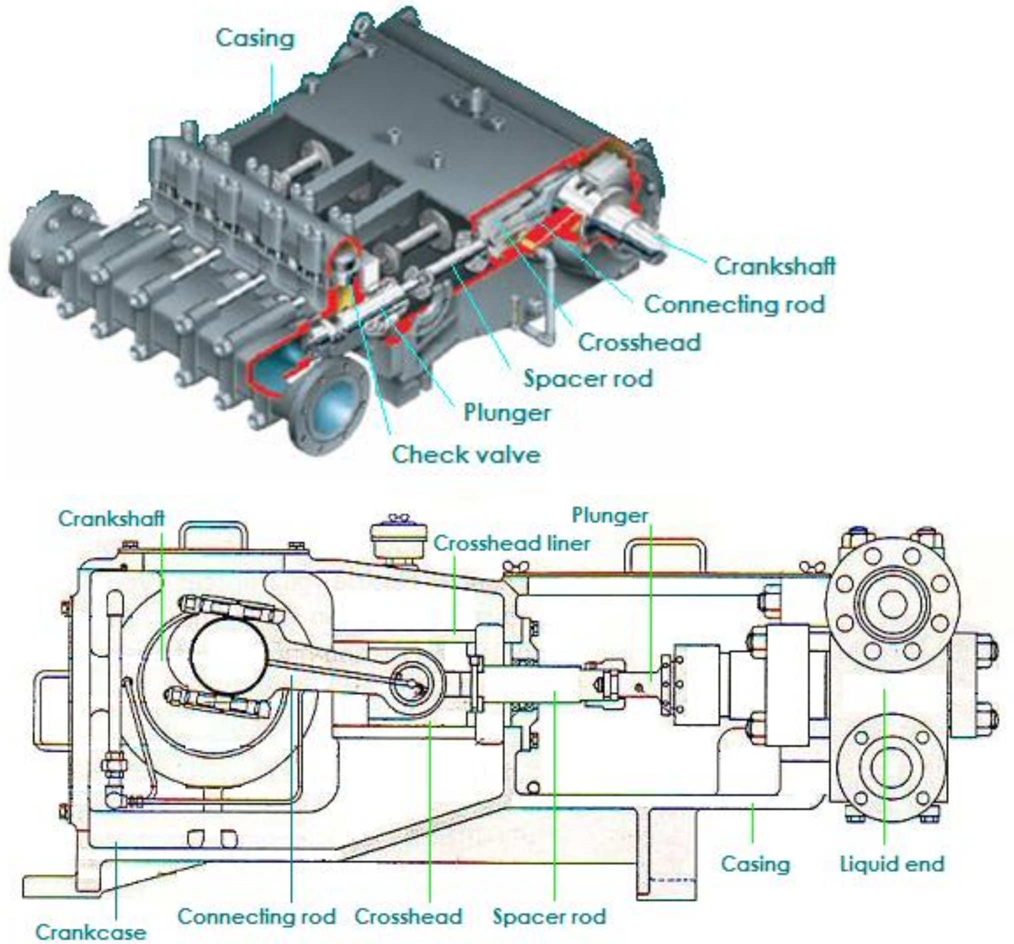
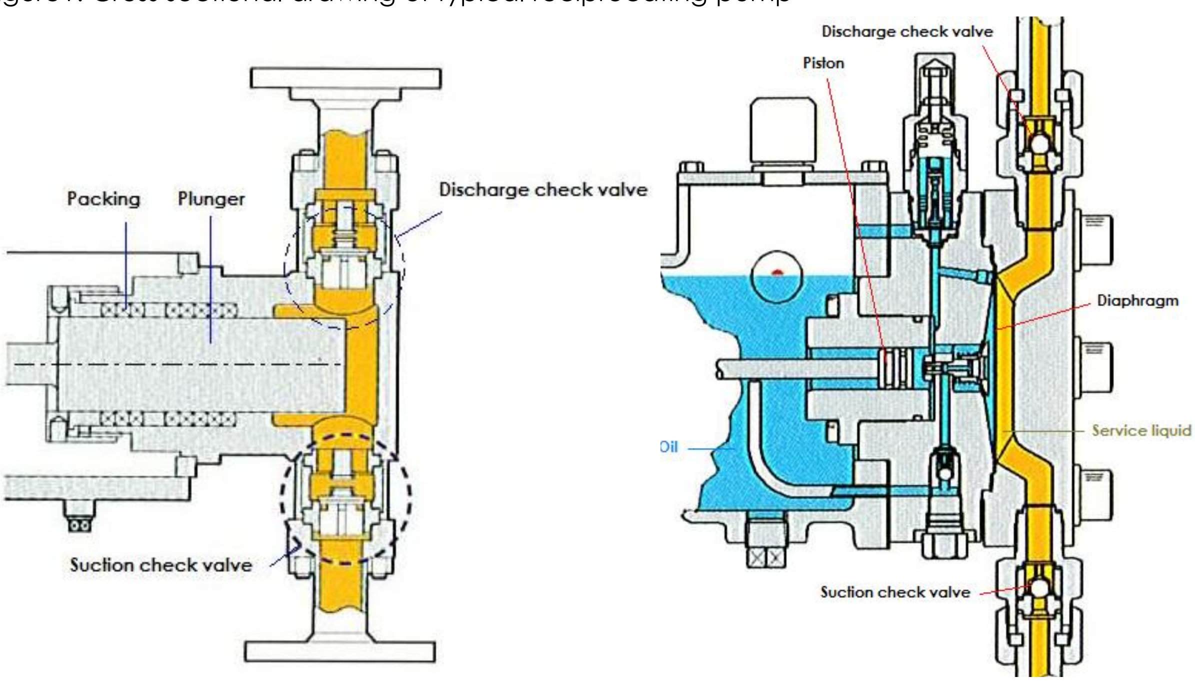


Figure1. Cross sectional drawing of typical reciprocating pump



Direct exposed Diaphragm

Figure 2. Cross sectional drawing of liquid end of reciprocating pump

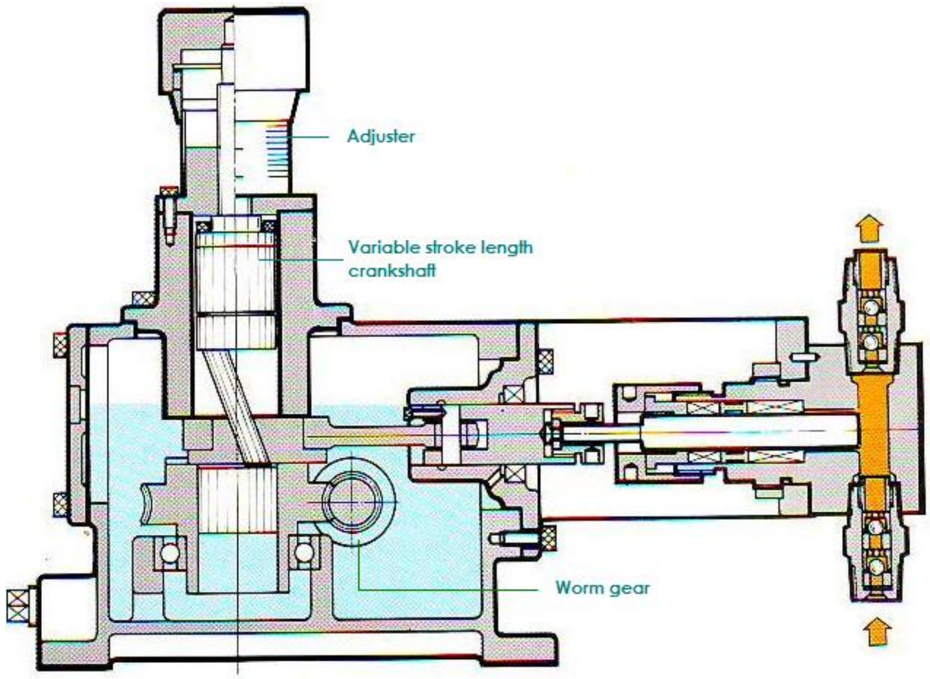


Figure 3. Cross sectional drawing of typical metering pump

1.4. Operating Range Of Reciprocating Pump.

Casing Pressure	: Up to about 600 kg/cm^2
Speed	: Low, up to 700 RPM after reducing gear
Capacity	: Up to about 500 m^3/hr.
Total head	: Up to about 5000 m

The following figure shows the operating range of reciprocating pumps.

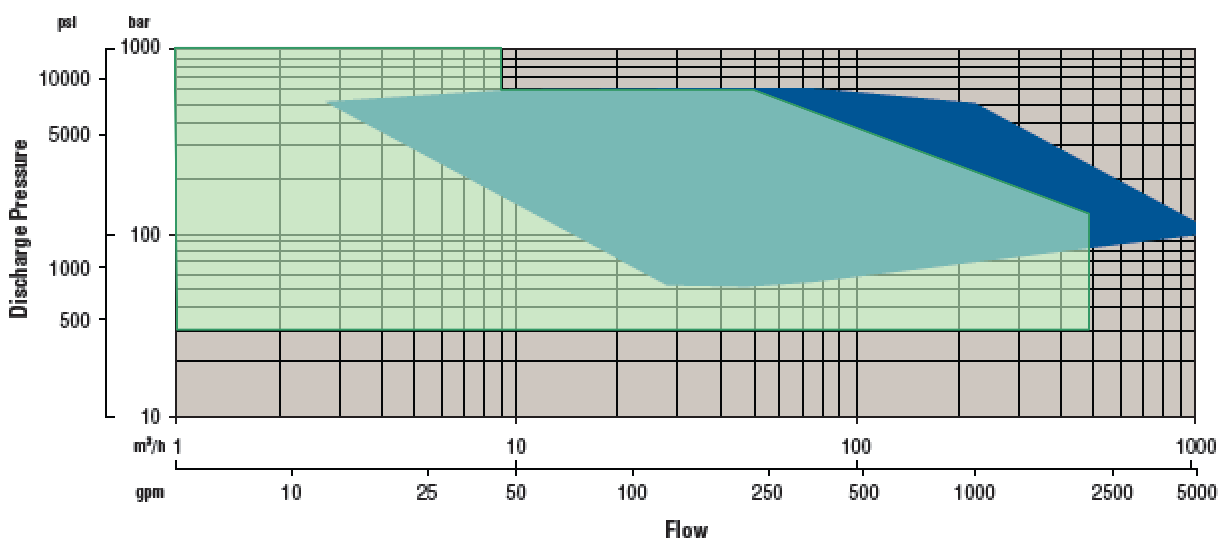


Figure 4. Operating range of reciprocating pump

1.5. Nomenclature

The following symbosl and units are used in this manual

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	: Plunger diameter (mm)
N	: Speed (RPM, rotary per minute)
L	: Stroke length (mm)
Dp	: Inside pipe diameter (mm)

II. PUMP SELECTION AND APPLICATION INTO THE SYSTEM

2.1. System

Following figures show system diagram around reciprocating pump.

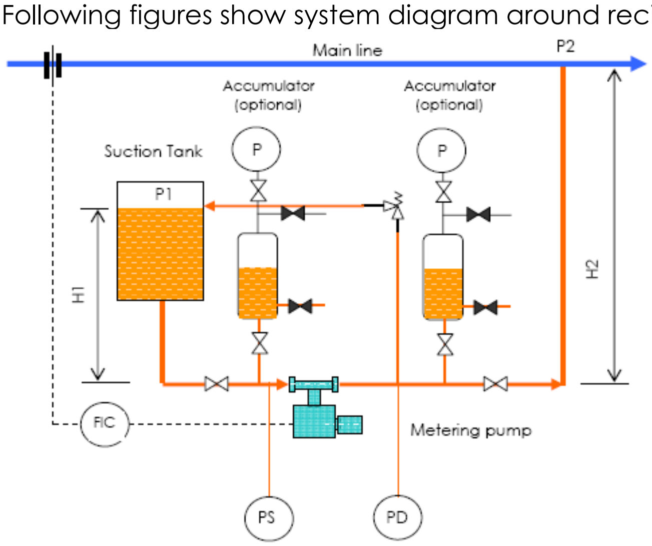


Figure 5. System diagram around metering pump

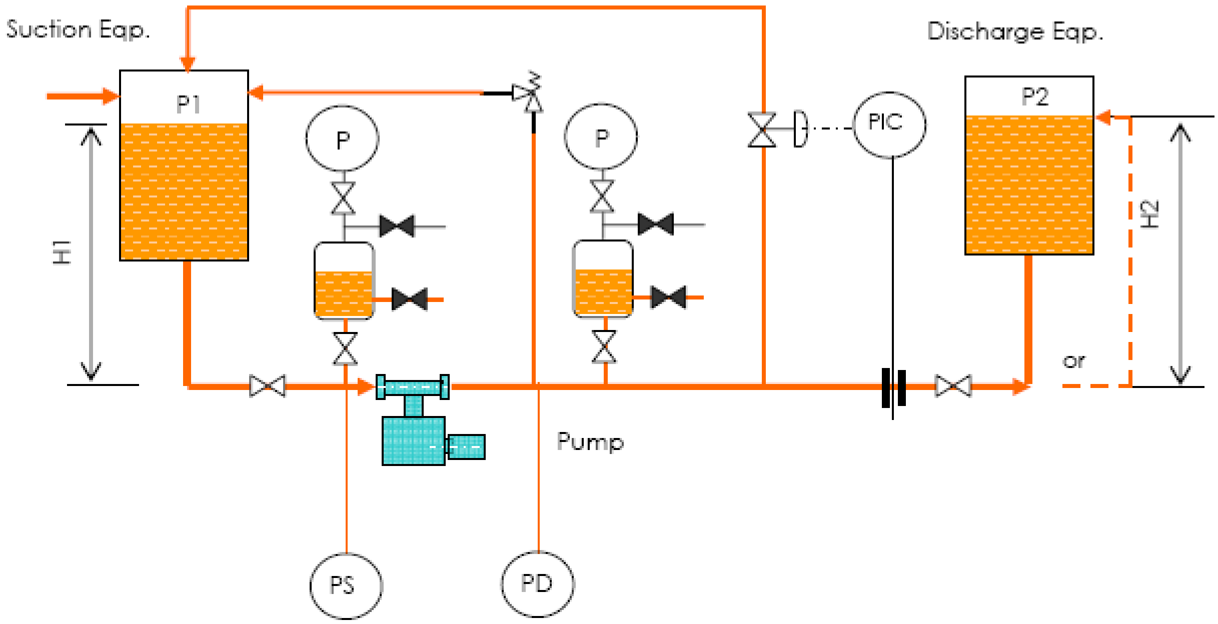


Figure 6. System diagram around reciprocating pump

2.2. Mathematical Relations

1. Pump suction pressure,

$$PS = P1 - DP1 + 0.1(H1.SG) - (500.SG.\frac{V^2}{98066.5}) \quad \text{(kg/cm}^2\text{A)} \qquad (1)$$

DP1 = Pressure drop from suction equipment to pump suction connection (kg/cm^2)
V = Liquid velocity at suction connection (m/s)
H1 = Suction side static head at minimum liquid level (m)

$$V = \frac{0.5481(Q)}{D^2}$$ if inside diameter of suction connection, D in inches, Q in m^3/hr

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

When velocity (V) is low or to be neglected, PS become

$$PS = P1 - DP1 + 0.1(H1.SG) \quad \text{(kg/cm}^2\text{A)} \qquad (3)$$

2. Pump discharge pressure,

$$PD = P2 + DP2 + 0.1(H2.SG) \quad \text{, (kg/cm}^2\text{A)} \qquad (4)$$

DP2 = Pressure drop from discharge connection to discharge equipment (kg/cm^2)
H2 = Discharge side static head at maximum level or end pipe (m)

3. Pump Differential Pressure,

$$DIP = PD - PS \quad \text{(kg/cm}^2\text{)} \qquad (5)$$

4. Pump total head,

$$H = (H2 - H1) + 10(\frac{P2 - P1}{SG}) + 10(\frac{DP2 + DP1}{SG}) \quad (6)$$

$$= \frac{10.DP}{SG} \quad (7)$$

5. Net Positive Suction Head Available,

$$NPSHA = \frac{10(PS - PV)}{SG} \quad (8)$$

NPSHA should be greater than NPSHR

6. Liquid Horse Power (LHP),

$LHP = 0.0272\ PD.\ Q$, (kW) (9)

$= 0.0272\ (PS+DIP).Q$, (kW) (10)

7. Pump Brake Horse Power (BHP),

$$BHP_{PUMP} = \frac{100(LHP).T_C}{\eta_V . \eta_M .} \quad (11)$$

8. BHP driver

$$BHP_{DRIVER} = \frac{BHP_{PUMP}}{\eta_{VAR} . \eta_{GEAR} .} \quad (12)$$

Where Tc is torque factor 1.05 for N>100 RPM and 1.08 for N<100 RPM, η_V is volumetric efficiency, η_M is pump mechanical efficiency (0.88), η_{VAR} is speed variator efficiency (for variable speed metering pump, 0.80-0.85), η_{GEAR} is reduction gear efficiency (0.93-0.95). Volumetric efficiency:

Water at above 1cP, η_V	= 0.92 – 0.96
Water at below 1 cP	= 0.94 – 0.98
Viscous slurry	= 0.90 – 0.95
If there is any slurry sediment	= 0.85 – 0.90

2.3. Reciprocating Pump Performance.

Typical reciprocating pump performance is shown in capacity against speed curve as figure 7 at constant discharge pressure, and capacity against stroke length as shown in figure 8.

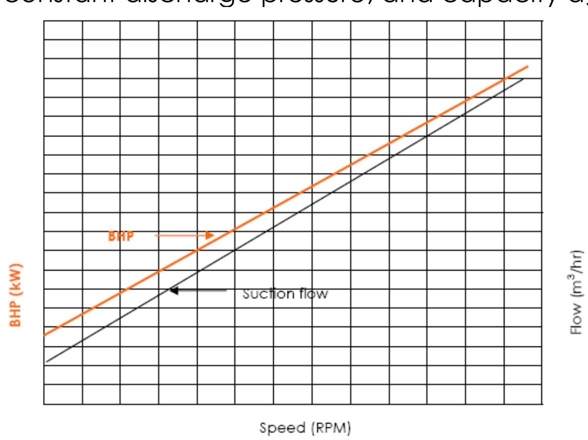


Figure 7. Typical Reciprocating Pump Performance Curve.

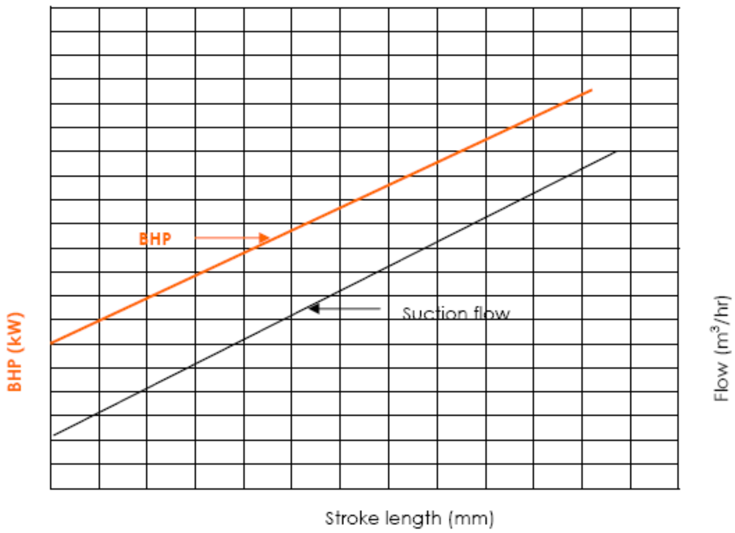


Figure 8. Performance curve capacity against stroke length at constant speed

2.4. Stroke Length, Speed and Plunger Diameter.

Stroke length, speed, plunger diameter has relation with plunger displacement capacity shown as the following equation

$$Qp1 = 4.721\, D^2\ L\ N.10^{-8} \qquad (\text{m}^3/\text{hr}) \qquad (13)$$

Qp1 is piston displacement capacity of each plunger. *L* is stroke length in mm, *D* is plunger diameter in mm, and *N* is crankshaft speed in RPM.

Average plunger speed,

$$Up = 3.333\, L.N.10^{-5} \qquad (\text{m/s}) \qquad (14)$$

L is stroke length in mm and *N* in RPM. Literatures give U_p within the range of 0.7 up to 2 m/s for high power pump and 0.1 up to 0.4 m/s for metering pumps, see figure 9.

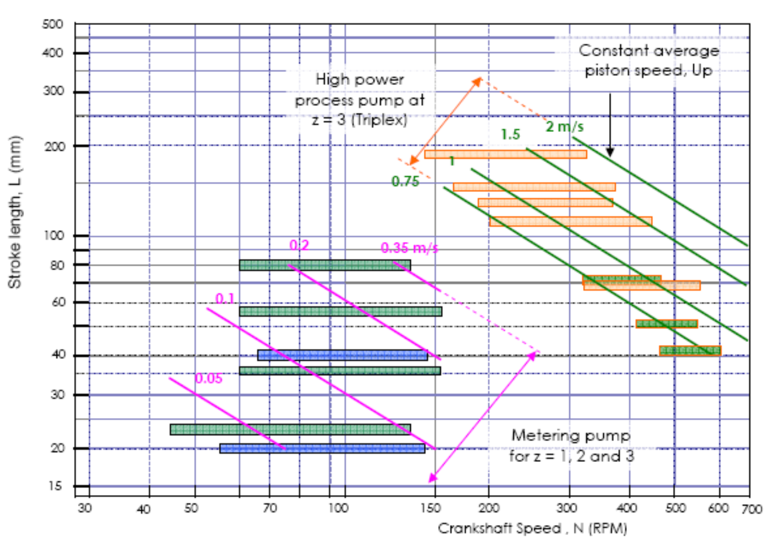


Figure 9. Stroke length at several average piston speed of reciprocating pump

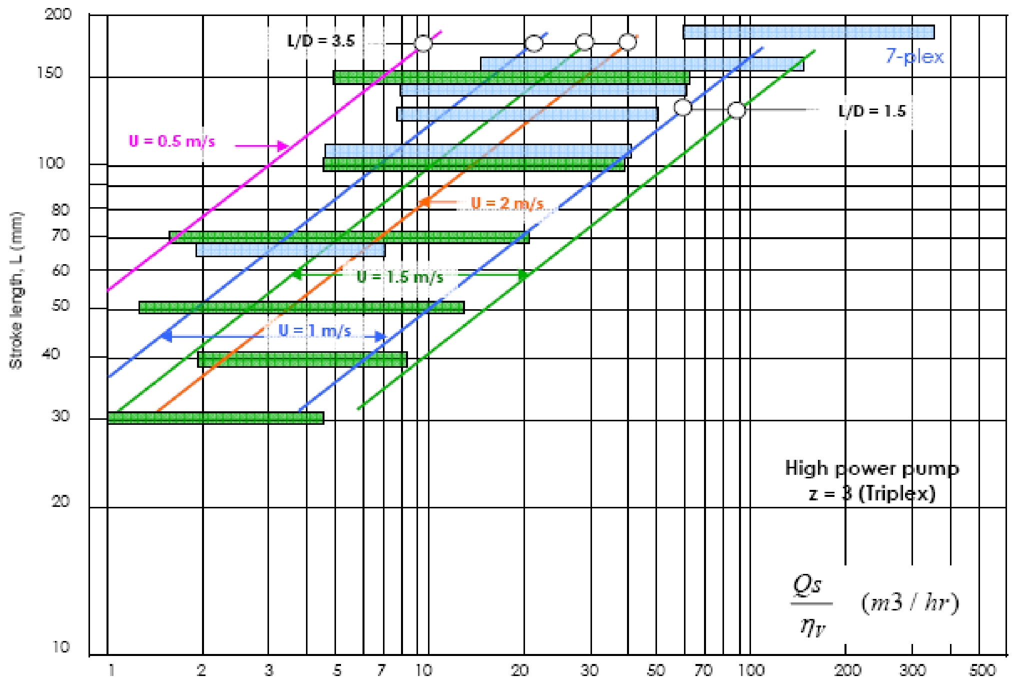


Figure 10. Stroke length of triplex (except noted) of high power reciprocating pump

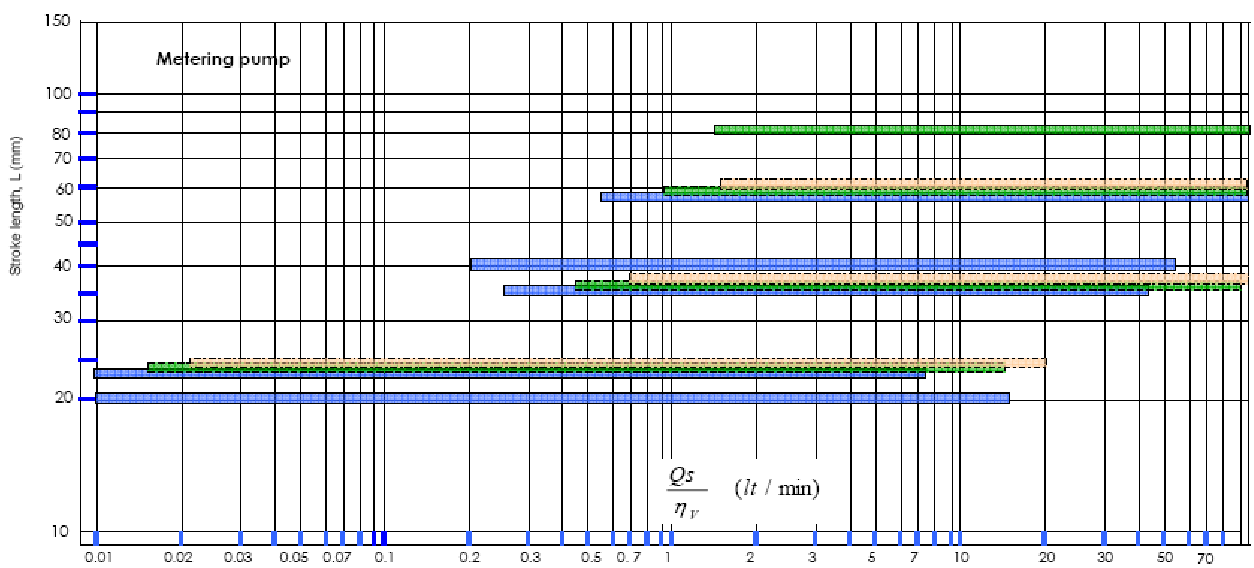


Figure 11. Stroke length at several number of plunger and plunger speed of metering pump

2.5. Number of Plunger.

In achieving liquid capacity and efficiency in space, pump are designed with more than one plunger for each casing. More number of plunger also reduce pulsation in each rotation of crankshaft. Figure 10 and figure 11 shows relation between capacity and stroke length for several number of plunger (z) and plunger speed (Up).

2.6. Acceleration Head.

Reciprocating pump has uncontinous flow to deliver the liquid. Liquid at discharge line shall be accelerated from low velocity to higher velocity. This process will effect in pressure loss, where reciprocating pump has higher pressure loss compared with continuous flow in each circle of crankshaft rotation, see figure 12.

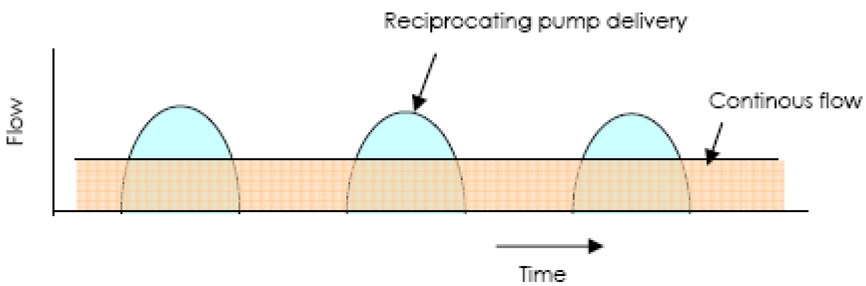


Figure 12. Flow fluctuation of simplex reciprocating pump.

Acceleration head shall be added to discharge pressure,

$$Pad = \frac{SG.Lpd.L.N^2.D^2.10^{-7}}{K1d.Dpd^2} \quad \text{(kg/cm2)} \qquad (15)$$

SG is specific gravity of liquid, *Lpd* discharge pipe length in meter (m), *L* is stroke length in mm, *N* is crankshaft speed in RPM, *D* is plunger diameter in mm, *Dpd* is inside pipe diameter in mm, *K1d* is number of plunger factor. K1d = 3 for triplex, 2 for duplex and simplex.

PD' = PD + Pad (kg/cm2A) and DP = PD'-PS (kg/cm2) (16)

PD in equation 4 is average pressure. Selection of reciprocating pump shall be based on PD'

2.7. Pulsation Dampener.

Pulsation dampener can be designed and supplied by pump manufacturer if required by purchaser. The following equation is method to calculate pulsation dampener volume at discharge side of the pump. Due to restriction orifice at main line, there is additional pressure drop at discharge line.

$$Vp = \frac{\alpha.D^2.L.PD^2}{60.\eta_p.DPt2} \quad \text{(liter)} \qquad (17)$$

α = 1.1 x 10^{-5} for simplex and 0.42 x 10^{-5} for duplex. Following figures show Vp for liquid SG=1, viscosity = 1 cP, PD = 10 and 100 kg/cm2, DPt2 is calculated at liquid velocity = 2 m/s for metering pump and 3 m/s for high power pump, η_P = 20 % is orifice pressure drop/discharge line pressure drop.

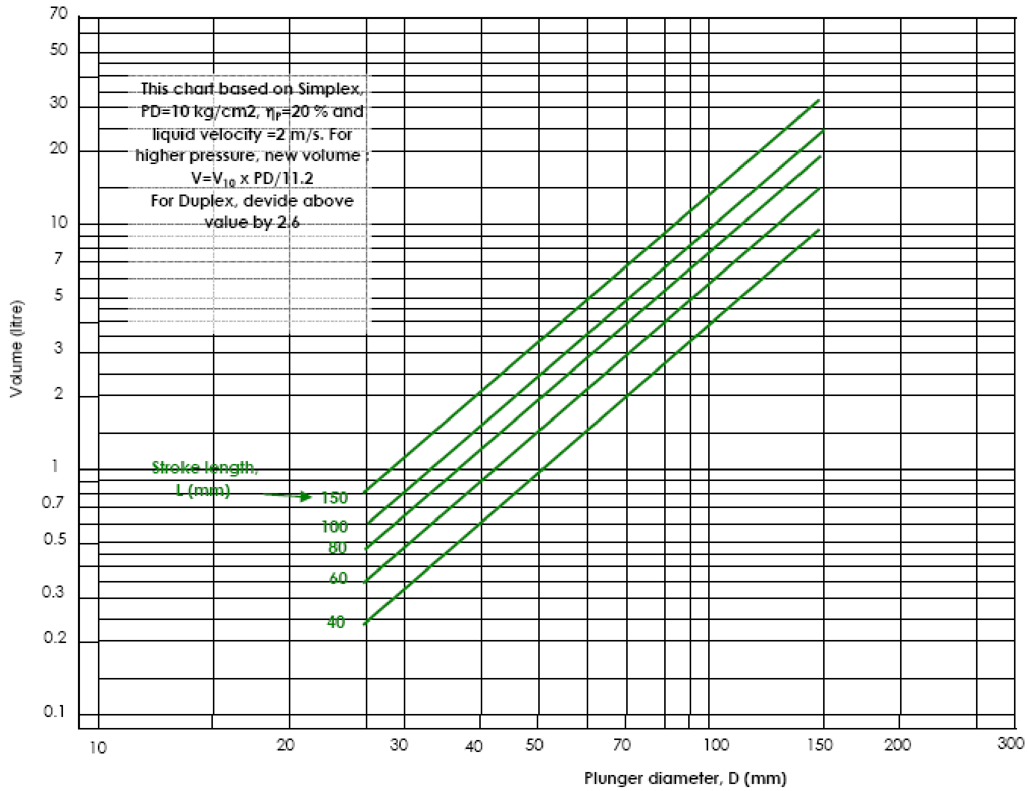


Figure 13. Typical pulsation dampener volume for small pump.

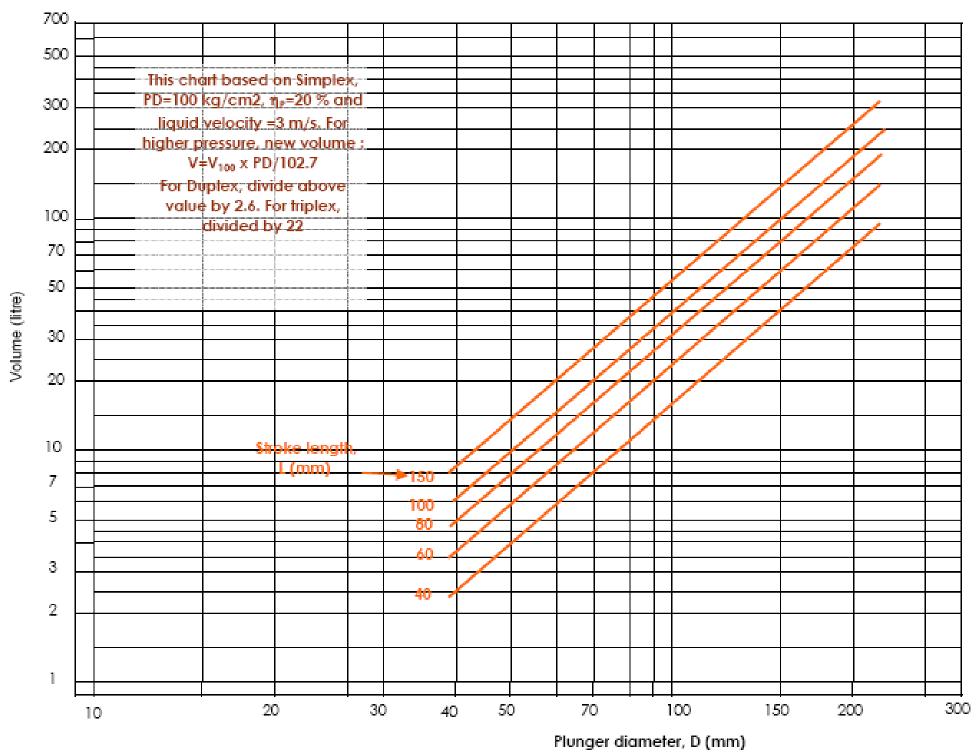


Figure 14. Typical pulsation dampener volume for high power pump.

Due to restriction orifice, additional pressure for this purpose is,

$DP_{OR} = 0.01\ \eta_P \times DPt2$ (18)

If pulsation dampener eliminate acceleration head, discharge pressure become,

$PD' = PD + DP_{OR}$ (kg/cm2A) and DP = PD'-PS (kg/cm2) (19)

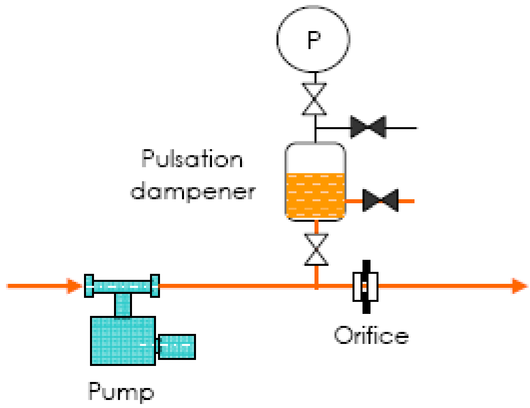


Figure 15. Pulsation dampener arrangement, install as close as available to discharge nozzle

2.8. NPSHR

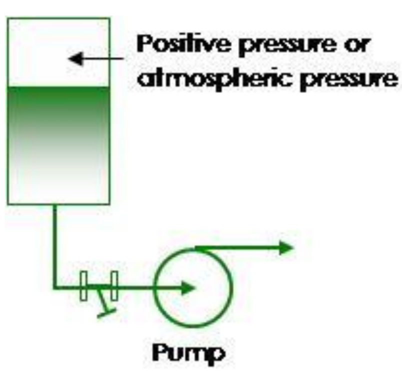
Net positive suction head required (NPSHR) of reciprocating pump can be calculated as following equation,

$$NPSHR = \frac{Lps.L.N^2.D^2.10^{-6}}{K1.Dps^2} + K2 \quad \text{(m)} \qquad (20)$$

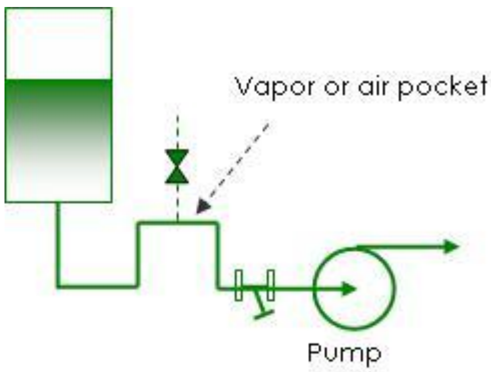
Lps is suction pipe length in m, *Dps* is inside diameter of suction pipe in mm, K1 = 4 for triplex and 1.5 for duplex or simplex, *K2* is pump valve loss in kg/cm2. K2 is approximately = 1m for direct exposed, 1.5 m for mechanical flexed diaphragm type, 1.5m for hydraulically flexed diaphragm type if vapor pressure < 0.3 kg/cm2A and 3.5 m if vapor pressure > 0.3 kg/cm2A.

2.9. Suction Piping System

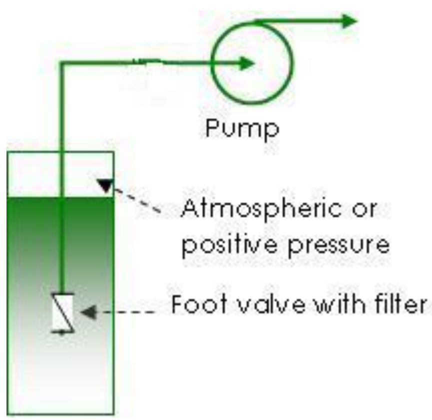
Suction pipe shall be planned to provide enough NPSHA and no vapor or air pocket. Suction pipe shall be design as short as possible. The following figures show the recommended suction piping.



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



Generally not accepted even there is vent line.



Accepted when suction equipment pressure is enough to give NPSHA higher than NPSHR

Figure 16. Suction piping for Reciprocating Pump.

III. LUBRICATION, SEAL OIL AND FLUSHING SYSTEM

Lubrication is required for parts in crankcase to prevent parts from wear. Sealing is required to prevent toxic or harmful liquid for leakage to ambient. Flushing is required to remove crystallized liquid from plunger and packing. For relatively low plunger force and short stroke length, lubrication is oil bath type. Other type is force lubrication. Figure 17 and 18 shows typical forced lubrication, sealing and flushing system.

IV. DRIVER

1. MOTOR DRIVER

When API-675 is specified for controlled volume pump, power rating on motor nameplate shall be at least 110 % of greatest horse power including gear and coupling losses, excluding service factor of motor. Including service factor, nameplate horse power rating shall be 10 % higher than horse power at relieve valve setting.

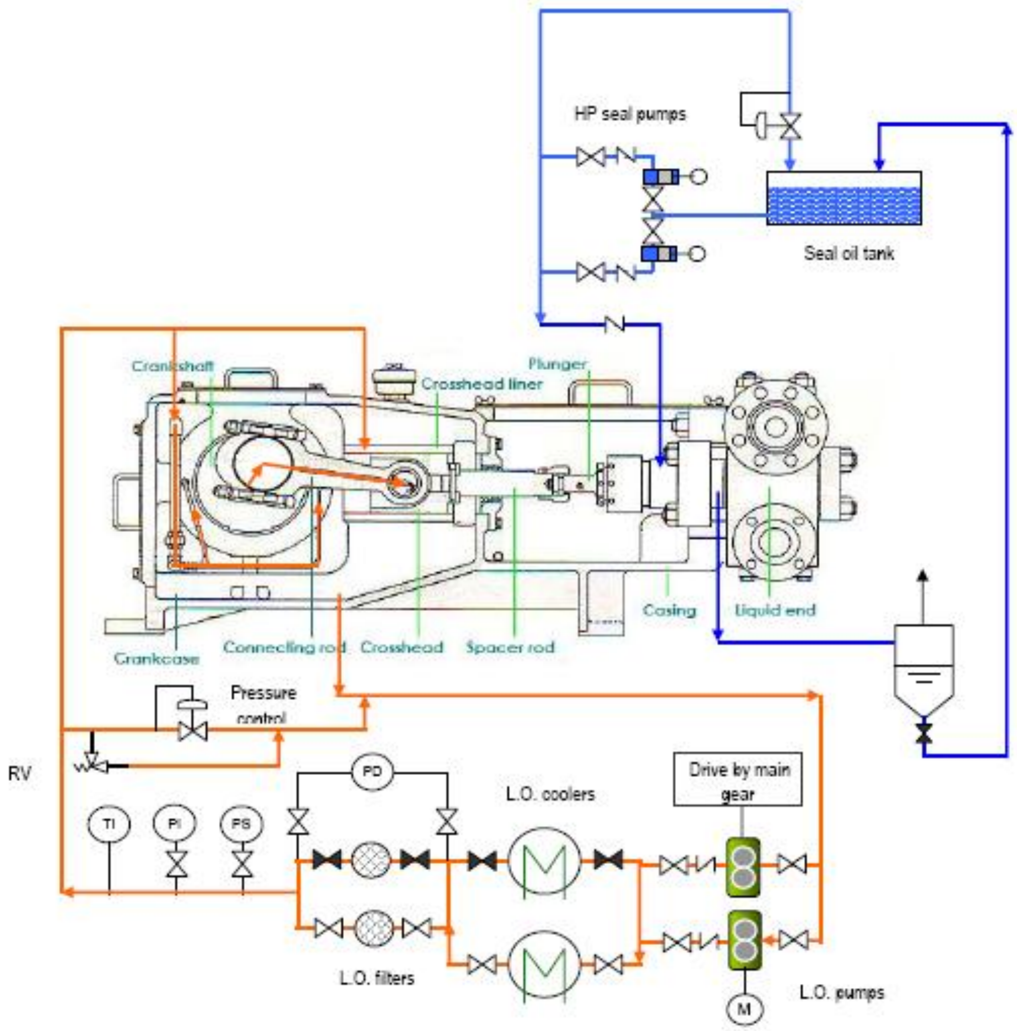


Figure 17. Typical lubrication and sealing system diagram for reciprocating Pump.

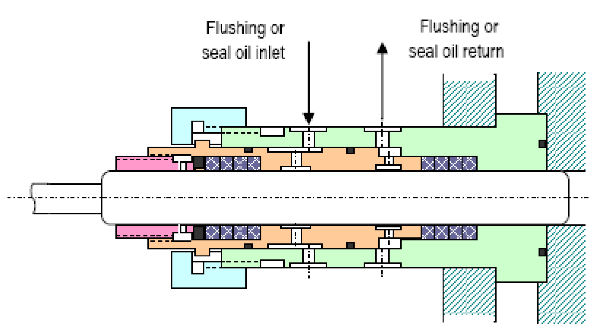


Figure 18. Typical sealing and flushing arrangement on stuffing box

2. <u>TURBINE DRIVER</u>

Power rating of steam turbine driver shall be > Pump rated BHP including power transmission equipment losses such as reduction gear, coupling and torque converter.

3. REDUCTION GEAR AND TORQUE CONVERTER

Power rating and torque of reduction gear shall be > driver nameplate or rated BHP and torque. When torque converter is used, efficiency of torque converter shall be near best efficiency at normal operation point.

APPENDIX A. NOZZLE SIZE

Following table presents typical nozzle sizes. Nozzle size is required for calculation of acceleration head, calculation of NPSH and to be required in piping design.

Dmin (mm)	Dmax (mm)	L (mm)	z-min	z-max	Nmin	Nmax (RPM)	Qmin (m^3/hr)	Qmax (m^3/hr)	Qmin (Lt/min)	Qmax (Lt/min)	dps (mm)	dpd (mm)
METERING PUMP/CONTROLLED VOLUME												
3.2	58	22	1	3	45	130	0.00048	1.36	0.0080	22.7	See note 1)	
14	105	35	1	3	60	160	0.0194	8.73	0.32	145.5		
14	120	55	1	3	60	160	0.03048	17.92	0.51	298.6		
20	120	80	1	3	60	130	0.09049	21.17	1.51	352.9		
4	84	20	1	1	56	140	0.00084	0.93	0.01	15.5		
10	111	40	1	1	56	140	0.01056	3.25	0.18	54.20		
PROCESS PUMP												
28	28	20	3	3		800	1.77	1.77	29.6	29.6		
20	40	30	3	3		660	1.12	4.48	18.7	74.7		
24	50	40	3	3		600	1.95	8.48	32.6	141.4		
18	58	50	3	3		540	1.24	12.84	20.6	214.0		
20	68	70	3	3		450	1.78	20.6	29.7	343.2		
32	85	100	3	3		330	4.78	33.7	79.6	561.8		
32	85	150	3	3		230	5.00	35.2	83.3	587.4		
44	115	150	3	3		230	9.44	64.5	157.4	1075.2		
50	160	150	3	3		180	9.54	97.7	159.1	1628.8		
19	38	64	3	3		550	1.80	7.2	29.9	119.8	38.1	38.1
25	38	111	3	3		450	4.41	10.2	73.6	170.0	49.3	38.1
32	48	140	3	3		380	7.70	17.3	128.4	288.8	73.7	49.3
35	76	111	3	3		450	8.65	40.8	144.2	679.9	97.2	73.7
44	89	140	3	3		380	14.56	59.6	242.7	993.0	146.3	73.7
35	48	127	3	3		360	7.92	14.9	132.0	248.2	73.7	49.3
51	89	127	3	3		360	16.8	51.2	280.2	853.4	146.3	73.7
45	133	152	3	3		360	15.7	136.9	261.1	2281.0	193.7	146.3
57	133	178	7	7		327	62.4	339.7	1039.8	5661.3	193.7	146.3

Symbols	D	Plunger diameter	Q	Plunger displacement capacity
	L	Stroke length	dps	Suction pipe diameter
	z	Number of plunger	dpd	Discharge pipe diameter
	N	Crankshaft speed	Subscrip	min. = minimum, max. = maximum

Note 1) Suction nozzle diameter

Minimum nozzle diameter = Q / 112 (inches), Q in Lt/min. Used diameter 3/8, 1/2, 1, 1.5 2.5 and 3

Minimum nozzle diameter = Q / 4.225 (mm), Q in Lt/min. Used diameter 15, 20, 25, 40, 50 65, 80

Discharge nozzle diameter

Minimum nozzle diameter = Q / 135 (inches), Q in Lt/min. Used diameter 3/8, 1/2, 1, 1.5 2.5 and 3

Minimum nozzle diameter = Q / 5.2 (mm), Q in Lt/min. Used diameter 15, 20, 25, 40, 50 65, 80

APPENDIX B. 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

Example :

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