# RECIPROCATING PUMP

## SELECTION AND APPLICATION INTO THE SYSTEM

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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


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.
Figure 1. Cross sectional drawing of typical reciprocating pump

Figure 2. Cross sectional drawing of liquid end of reciprocating 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 symbols and units are used in this manual

- **P**<sub>1</sub>: Suction Equipment Pressure (kg/cm² A)
- **H**<sub>1</sub>: 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
- **DP**<sub>1</sub>: Pressure loss in the suction line (kg/cm²)
- **PS**: Pump suction pressure (kg/cm² A)
- **H**: Pump total head (m)
- **PD**: Pump discharge pressure (kg/cm² A)
- **DP**<sub>2</sub>: Pressure loss in the discharge line (kg/cm²)
- **DIP**: Differential pressure = PD – PS (kg/cm²)
- **H**<sub>2</sub>: Discharge liquid head (m)
- **V**: Liquid average velocity at suction flange (m/s)
- **PV**: Vapor pressure of liquid at pumping temperature (kg/cm² A)
- **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, m³/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.

![System diagram around metering pump](image)

Figure 5. System diagram around metering pump
2.2. Mathematical Relations

1. Pump suction pressure,
   \[ PS = P1 - DP1 + 0.1(H1.SG) - \left(500.SG \cdot \frac{V^2}{98066.5}\right) \]  \((\text{kg/cm}^2\text{A})\) (1)

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

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

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

   When velocity \((V)\) is low or to be neglected, \(PS\) become
   \[ PS = P1 - DP1 + 0.1(H1.SG) \]  \((\text{kg/cm}^2\text{A})\) (3)

2. Pump discharge pressure,
   \[ PD = P2 + DP2 + 0.1(H2.SG) \]  \((\text{kg/cm}^2\text{A})\) (4)

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

3. Pump Differential Pressure,
   \[ DIP = PD - PS \]  \((\text{kg/cm}^2)\) (5)

Figure 6. System diagram around reciprocating pump
4. Pump total head,
\[ H = (H_2 - H_1) + 10\left(\frac{P_2 - P_1}{SG}\right) + 10\left(\frac{DP_2 + DP_1}{SG}\right) \]  
\[ = 10DP \frac{SG}{SG} \]  
\[ = 10DP \]  
(6)  
(7)

5. Net Positive Suction Head Available,
\[ NPSHA = \frac{10(PS - PV)}{SG} \]  
(8)

NPSHA should be greater than NPSHR

6. Liquid Horse Power (LHP),
\[ LHP = 0.0272\ PD\ Q \text{ (kW)} \]  
\[ = 0.0272\ (PS+DIP)Q \text{ (kW)} \]  
(9)  
(10)

7. Pump Brake Horse Power (BHP),
\[ BHP_{PUMP} = \frac{100(LHP)T_c}{\eta_V\eta_M} \]  
(11)

8. BHP driver
\[ BHP_{DRIVER} = \frac{BHP_{PUMP}}{\eta_{VAR}\eta_{GEAR}} \]  
(12)

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

- Water at above 1cP, \( \eta_V = 0.92 - 0.96 \)
- 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.
2.4. **Stroke Length, Speed and Plunger Diameter.**

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

\[ Qp1 = 4.721 D^2 L N \cdot 10^{-8} \quad (m^3/hr) \]  

(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,

\[ U_p = 3.333 L N \cdot 10^{-5} \quad (m/s) \]  

(14)

\( L \) is stroke length in mm and \( N \) in RPM. Literature gives \( U_p \) 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 8. Performance curve capacity against stroke length at constant speed

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

2.6. **Acceleration Head.**

Reciprocating pump has uncontinuous 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.](image)

Acceleration head shall be added to discharge pressure,

\[
Pad = \frac{SG \cdot Lpd \cdot L \cdot N^2 \cdot D^2 \cdot 10^{-7}}{K1d \cdot Dpd^2} \text{ (kg/cm}^2\text{)}
\]  \hspace{1cm} (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.

\[
PD' = PD + Pad \quad \text{(kg/cm}^2\text{)} \quad \text{and} \quad DP = PD' - PS \quad \text{(kg/cm}^2\text{)}
\]  \hspace{1cm} (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.

\[
Vp = \frac{\alpha \cdot D^2 \cdot L \cdot PD^2}{60 \cdot \eta_p \cdot DPr^2} \text{ (liter)}
\]  \hspace{1cm} (17)

\(\alpha = 1.1 \times 10^{-5}\) for simplex and \(0.42 \times 10^{-5}\) for duplex. Following figures show Vp for liquid SG=1, viscosity = 1 cP, PD = 10 and 100 kg/cm2, DPr2 is calculated at liquid velocity = 2 m/s for metering pump and 3 m/s for high power pump, \(\eta_p = 20\%\) 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,

\[ DP_{or} = 0.01 \eta P D_{P2} \]  \hspace{1cm} (18)

If pulsation dampener eliminate acceleration head, discharge pressure become,

\[ PD' = PD + DP_{or} \quad (kg/cm^2A) \quad \text{and} \quad DP = PD' - PS \quad (kg/cm^2) \]  \hspace{1cm} (19)

![Figure 15. Pulsation dampener arrangement, install as close as available to discharge nozzle](image)

2.8. **NPSHR**

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

\[ NPSHR = \frac{L_{ps}.L.N^2.D^2.10^{-6}}{K_1.D_{ps}^2} + K_2 \quad (m) \]  \hspace{1cm} (20)

\( L_{ps} \) is suction pipe length in m, \( D_{ps} \) is inside diameter of suction pipe in mm, \( K_1 = 4 \) for triplex and 1.5 for duplex or simplex, \( K_2 \) is pump valve loss in kg/cm2. \( K_2 \) 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.

![Positive pressure or atmospheric pressure](image)

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. **TURBINE DRIVER**

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.

<table>
<thead>
<tr>
<th>Dmin (mm)</th>
<th>Dmax (mm)</th>
<th>L (mm)</th>
<th>z-min</th>
<th>z-max</th>
<th>Nmin (RPM)</th>
<th>Nmax (m³/hr)</th>
<th>Qmin (m³/hr)</th>
<th>Qmax (m³/hr)</th>
<th>Qmin (L/min)</th>
<th>Qmax (L/min)</th>
<th>dps (mm)</th>
<th>dpd (mm)</th>
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</thead>
<tbody>
<tr>
<td>3.2</td>
<td>58</td>
<td>22</td>
<td>1</td>
<td>3</td>
<td>45</td>
<td>130</td>
<td>0.00048</td>
<td>1.36</td>
<td>0.0080</td>
<td>22.7</td>
<td>See note 1</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>105</td>
<td>35</td>
<td>1</td>
<td>3</td>
<td>60</td>
<td>160</td>
<td>0.0194</td>
<td>8.73</td>
<td>0.32</td>
<td>145.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>120</td>
<td>55</td>
<td>1</td>
<td>3</td>
<td>60</td>
<td>160</td>
<td>0.03046</td>
<td>17.92</td>
<td>0.51</td>
<td>298.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>120</td>
<td>60</td>
<td>1</td>
<td>3</td>
<td>60</td>
<td>160</td>
<td>0.09049</td>
<td>21.17</td>
<td>1.51</td>
<td>352.9</td>
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<tr>
<td>4</td>
<td>84</td>
<td>20</td>
<td>1</td>
<td>1</td>
<td>56</td>
<td>140</td>
<td>0.00084</td>
<td>0.93</td>
<td>0.01</td>
<td>15.5</td>
<td></td>
<td></td>
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<tr>
<td>10</td>
<td>111</td>
<td>40</td>
<td>1</td>
<td>1</td>
<td>56</td>
<td>140</td>
<td>0.01056</td>
<td>3.25</td>
<td>0.18</td>
<td>54.20</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### METERING PUMP/CONTROLLED VOLUME

| 20 | 20 | 20 | 3 | 3 | 600 | 1.77 | 1.77 | 29.6 | 29.6 |
| 20 | 40 | 30 | 3 | 3 | 600 | 1.12 | 4.40 | 18.7 | 74.7 |
| 24 | 50 | 40 | 3 | 3 | 600 | 1.95 | 6.48 | 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 |
| 25 | 38 | 111| 3 | 3 | 450 | 4.41 | 10.2 | 73.6 | 170.0 |
| 32 | 48 | 140| 3 | 3 | 380 | 7.70 | 17.3 | 128.4 | 288.8 |
| 35 | 76 | 111| 3 | 3 | 450 | 8.65 | 40.8 | 144.2 | 679.9 |
| 44 | 69 | 140| 3 | 3 | 380 | 14.56 | 59.6 | 242.7 | 993.0 |
| 35 | 48 | 127| 3 | 3 | 360 | 7.92 | 14.9 | 132.0 | 240.2 |
| 61 | 69 | 127| 3 | 3 | 360 | 16.8 | 51.2 | 280.2 | 653.4 |
| 45 | 133| 152| 3 | 3 | 360 | 15.7 | 136.9 | 261.1 | 2281.0 |
| 57 | 133| 178| 7 | 7 | 327 | 62.4 | 339.7 | 1039.8 | 5661.3 |

#### PROCESS PUMP

Symbols

- **D**: Plunger diameter
- **L**: Stroke length
- **z**: Number of plunger
- **N**: Crankshaft speed
- **Q**: Plunger displacement capacity
- **dps**: Suction pipe diameter
- **dpd**: Discharge pipe diameter

**Note 1)**

Suction nozzle diameter

Minimum nozzle diameter = \( \frac{Q}{112} \) (inches), \( Q \) in L/min. Used diameter 3/8, 1/2, 1, 1.5 2.5 and 3

Discharge nozzle diameter

Minimum nozzle diameter = \( \frac{Q}{4.225} \) (mm), \( Q \) in L/min. Used diameter 15, 20, 25, 40, 50 65, 80

Minimum nozzle diameter = \( \frac{Q}{135} \) (inches), \( Q \) in L/min. Used diameter 3/8, 1/2, 1, 1.5 2.5 and 3

Minimum nozzle diameter = \( \frac{Q}{5.2} \) (mm), \( Q \) in L/min. Used diameter 15, 20, 25, 40 65, 80
## APPENDIX B. UNIT CONVERSION

### UNIT CAPACITY OR VOLUME FLOW

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<th>To unit</th>
<th>Conversion factor</th>
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<tr>
<td>US GPM</td>
<td>m³/hr</td>
<td>0.2271</td>
</tr>
<tr>
<td>l/s</td>
<td>m³/hr</td>
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</tr>
<tr>
<td>Barrel / day</td>
<td>m³/hr</td>
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### UNIT PRESSURE

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<tr>
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<td>1.02 x 10⁻⁵</td>
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<tr>
<td>Psi</td>
<td>kg/cm²</td>
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<tr>
<td>Bar</td>
<td>kg/cm²</td>
<td>1.0197</td>
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<tr>
<td>inch H2O</td>
<td>kg/cm²</td>
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### UNIT POWER

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### UNIT DENSITY

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<td>kg/m³</td>
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</tr>
<tr>
<td>kg/ft³</td>
<td>kg/m³</td>
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### UNIT VISCOSITY

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<td>m²/s</td>
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### UNIT LENGTH

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<tr>
<td>mile</td>
<td>m</td>
<td>1609</td>
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**Example:**

120 GPM = 120 x 0.2271 m³/hr

= 27.252 m³/hr

25 psi = 25 x 0.0703 kg/cm²

= 1.758 kg/cm²

50 m³/hr = 50 / 0.2271 GPM

= 220.17 GPM

3 kg/cm² = 3 / 0.0703 psi

= 42.67 psi