Formulas for pump system and liquid flow analysis (Imperial units)

www.pumpfundamentals.com

J. Chaurette June 2016

Flow rate vs velocity for pipes

$$v\ (ft/s) = \frac{0.4085 \times q\ (gpm)}{(d(in))^2}$$

Pressure to head

$$h(ft) = 2.31 \times \frac{p\ (psi)}{SG}$$

Reynolds number

$$Re = 7746 \times \frac{v\ (ft/s) \times d\ (in)}{\nu (cSt)}$$

Friction parameter - turbulent flow (Swamee-Jain)

$$f = \frac{0.25}{\left(\log_{10}\left(\frac{\varepsilon\ (in)}{3.7 \times d\ (in)} + \frac{5.74}{Re^{0.9}}\right)\right)^2}$$

Friction parameter - laminar flow

$$f = \frac{64}{Re}$$

Pump power

$$P\ (hp) = SG \times \frac{q\ (gpm) \times \Delta H_P\ (ft)}{3960 \times \eta}$$

Pipe friction factor (Darcy-Weisbach)

$$\frac{\Delta h\ (ft)}{L\ (100\ ft\ pipe)} = 1200 \times f \times \frac{(v(ft/s))^2}{d\ (in) \times 2 \times g\ (ft/s^2)}$$

CONSTANTS AND DATA

typical discharge pump velocity - v = 9 to 12 ft/s

acceleration due to gravity - g = 32.17 (ft/s^2)

viscosity - ν = 1 cSt for water at 20 C

pipe roughness - ε = 0.00015 ft for steel

specific gravity - SG = 1 for water at 20 C

Reynolds number - Re < 2000 for laminar flow, Re > 4000 for turbulent flow

atmospheric pressure - p = 14.7 psia at sea level

pump efficiency - η from pump performance curve

Pump total head

total head = pipe friction loss + equipment friction loss + (outlet velocity head − inlet velocity head) + (discharge static head + outlet pressure head) − (suction static head + inlet pressure head)

$$\Delta H_P\ (ft) = \Delta H_{F1\text{-}2}\ (ft) + \Delta H_{EQ1\text{-}2}\ (ft) + \frac{(v_2(ft/s))^2 - (v_1(ft/s))^2}{2 \times g\ (ft/s^2)} + (z_2(ft) + H_2(ft)) - (z_1(ft) + H_1(ft))$$

Locations 1 and 2 identify the position of the liquid particles from the inlet to the outlet of the system

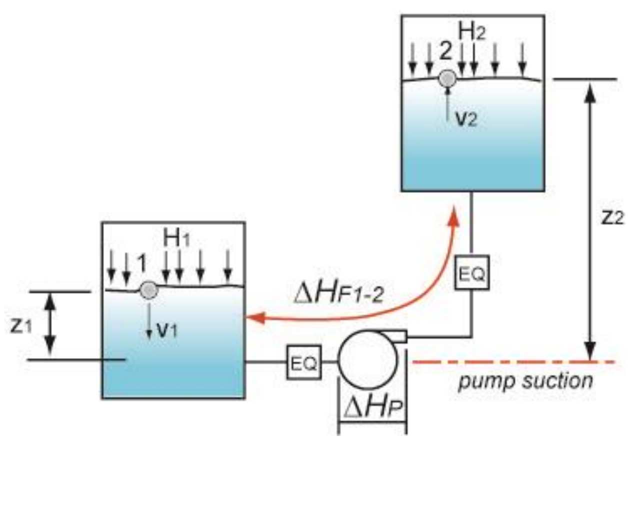
EQ equipment such as: fittings, manual valves, auto. valves, filters, etc.

H_1 and H_2 are the pressure heads on the liquid in their respective tanks, if the pressure head is atmospheric H_1 and $H_2 = 0$

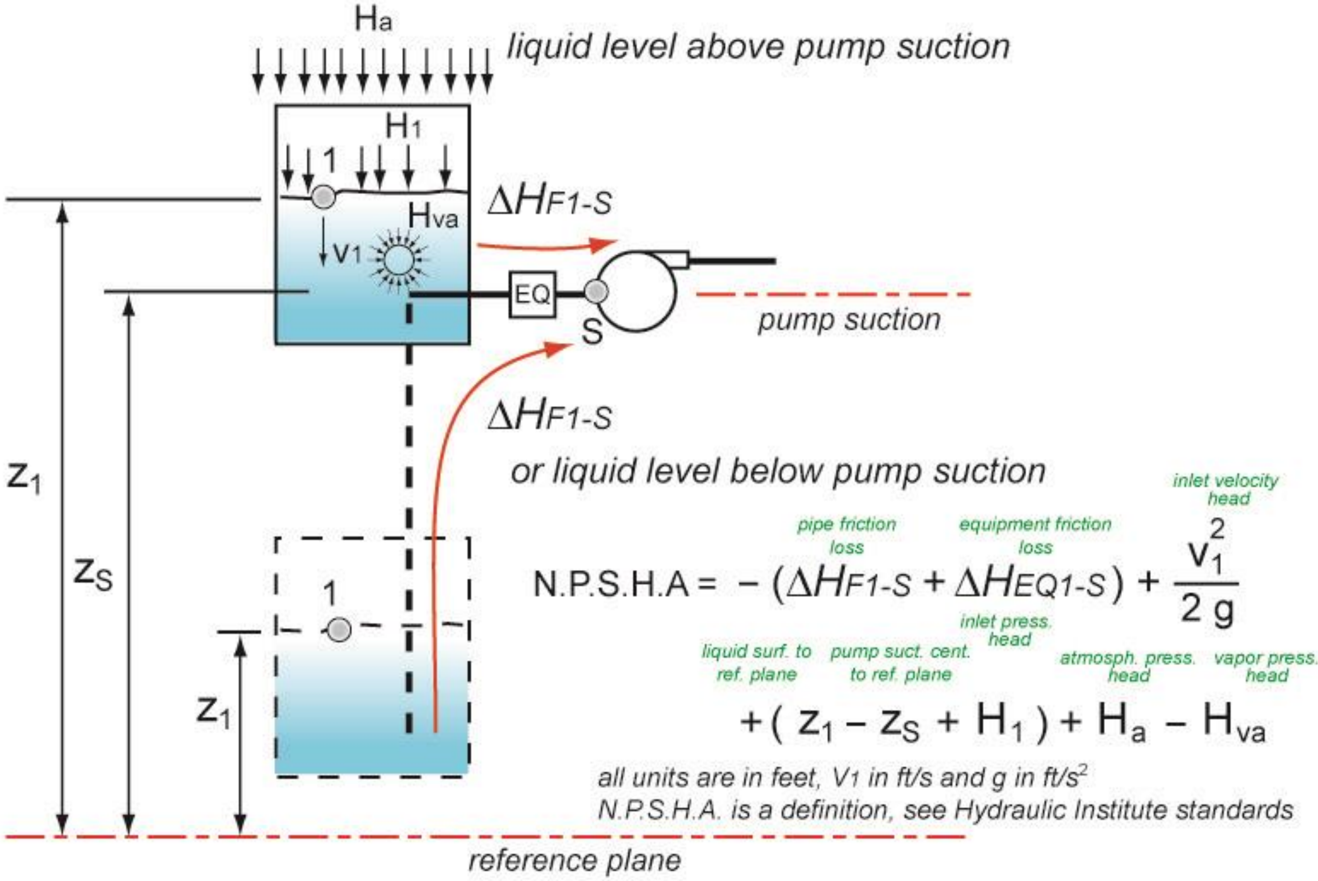
v_1 and v_2 are the liquid surface velocites in each tank, the velocity heads are small

If there is no equipment and fitting loss is negligable, tanks are atmospheric and we neglect the velocity heads, we have:

$$\Delta H_P\ (ft) = \Delta H_{F1\text{-}2}\ (ft) + z_2(ft) - z_1(ft)$$



Net positive suction head available (N.P.S.H.A.)



$$N.P.S.H.A = -\left(\Delta H_{F1\text{-}S} + \Delta H_{EQ1\text{-}S}\right) + \frac{v_1^2}{2\,g} + \left(z_1 - z_S + H_1\right) + H_a - H_{va}$$

all units are in feet, V_1 in ft/s and g in ft/s^2
N.P.S.H.A. is a definition, see Hydraulic Institute standards

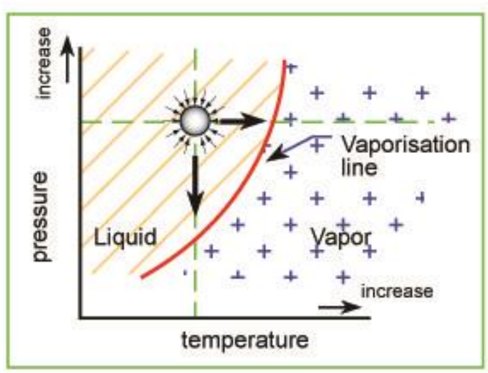
CONSTANTS AND DATA

typical suction pump velocity - v = 3 to 6 ft/s

atmospheric pressure - H_a = 14.7 psia at sea level, depends on elevation

vapor pressure - H_{va} depends on nature of liquid and temperature

vapor pressure varies with temperature and pressure, as pressure decreases at constant temperature vaporisation occurs, this is why vapor pressure is subtracted from all other pressure terms, to ensure that at a minimum the N.P.S.H.A. is above the vapor pressure



Formulas for pump system and liquid flow analysis (metric units)

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J. Chaurette June 2016

Flow rate vs velocity for pipes

$$v\ (ft/s) = \frac{21.22 \times q\ (l/m)}{(d(mm))^2}$$

Pressure to head

$$h(ft) = 0.102 \times \frac{p\ (kPa)}{SG}$$

Reynolds number

$$Re = 1000 \times \frac{v\ (m/s) \times d\ (mm)}{\nu(cSt)}$$

Friction parameter - turbulent flow (Swamee-Jain)

$$f = \frac{0.25}{\left(\log_{10}\left(\frac{\varepsilon\ (in)}{3.7 \times d\ (in)} + \frac{5.74}{Re^{0.9}}\right)\right)^2}$$

Friction parameter - laminar flow

$$f = \frac{64}{Re}$$

Pipe friction factor (Darcy-Weisbach)

$$\frac{\Delta h\ (m)}{L\ (100\ m\ pipe)} = 10^5 \times f \times \frac{(v(m/s))^2}{d\ (m) \times 2 \times g\ (m/s^2)}$$

Pump power

$$P\ (kW) = SG \times \frac{q\ (l/min) \times \Delta H_P\ (m)}{6128 \times \eta}$$

CONSTANTS AND DATA

typical discharge pump velocity - v = 2.5 to 5 m/s
acceleration due to gravity - g = 9.81 (m/s^2)
viscosity - ν = 1 cSt for water at 20 C
pipe roughness - ε = 0.0457 mm for steel
specific gravity - SG = 1 for water at 20 C
Reynolds number - Re < 2000 for laminar flow, Re > 4000 for turbulent flow
atmospheric pressure - p = 101 psia at sea level
pump efficiency - η from pump performance curve

Pump total head

total head, pipe friction loss, equipment friction loss, outlet velocity head, inlet velocity head, discharge static head, outlet pressure head, suction static head, inlet pressure head

$$\Delta H_P\ (m) = \Delta H_{F1\text{-}2}\ (m) + \Delta H_{EQ1\text{-}2}\ (m) + \frac{(v_2(m/s))^2 - (v_1(m/s))^2}{2 \times g\ (m/s^2)} + (z_2(m) + H_2(m)) - (z_1(m) + H_1(m))$$

Locations 1 and 2 identify the position of the liquid particles from the inlet to the outlet of the system

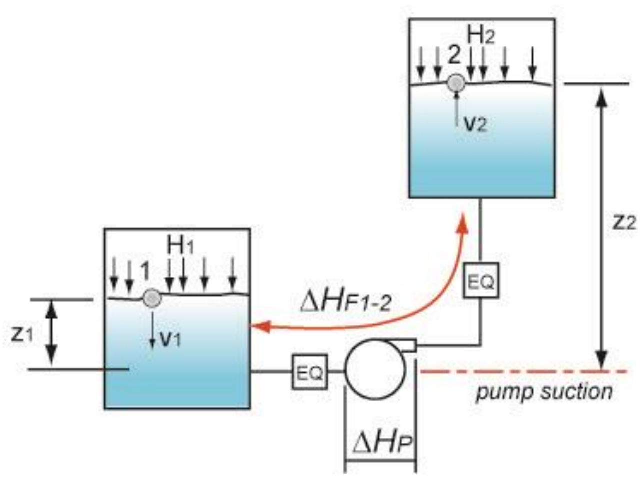
EQ equipment such as: fittings, manual valves, auto. valves, filters, etc.

H_1 and H_2 are the pressure heads on the liquid in their respective tanks, if the pressure head is atmospheric H_1 and H_2 = 0

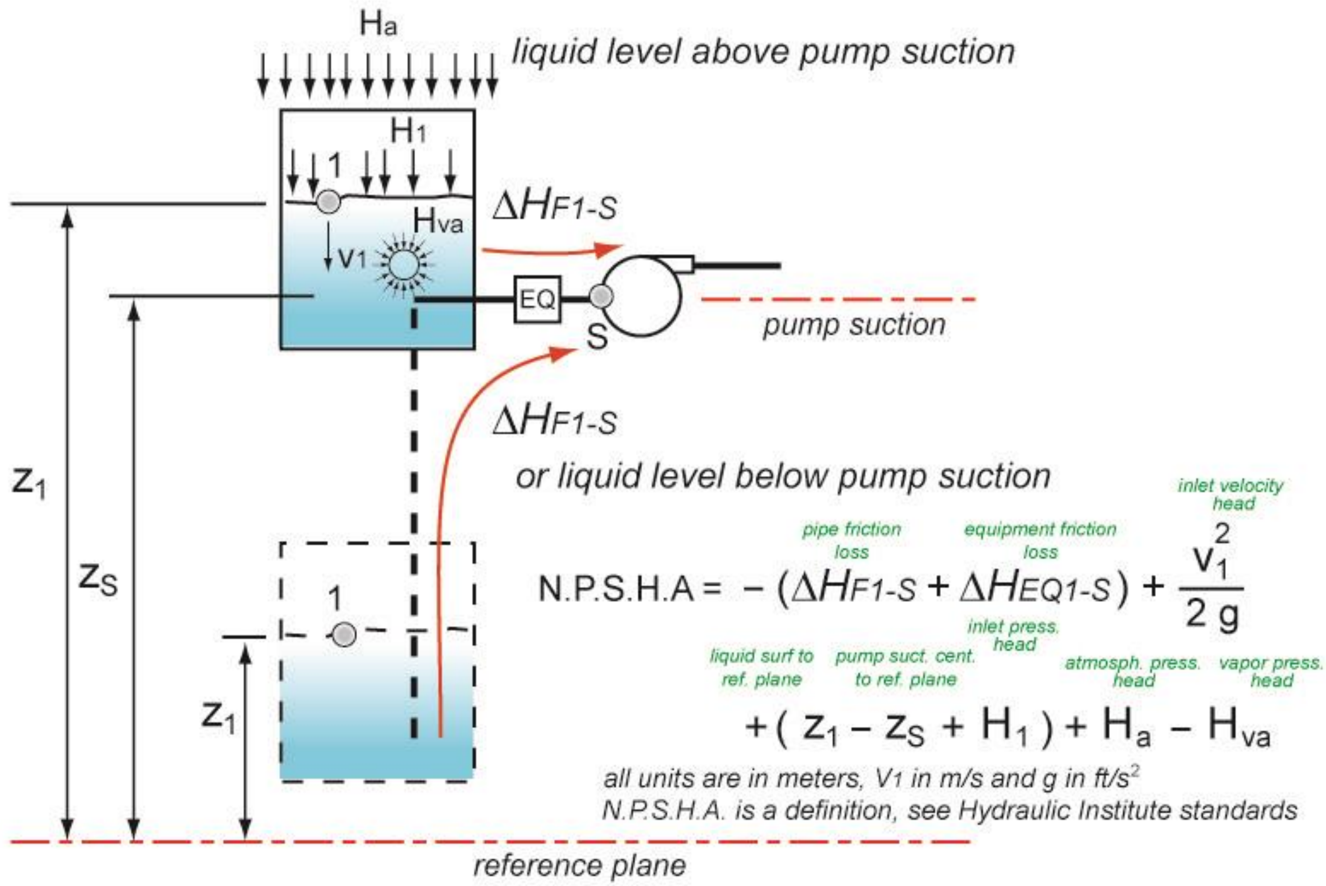
v_1 and v_2 are the liquid surface velocites in each tank, the velocity heads are small

If there is no equipment and fitting loss is negligable, tanks are atmospheric and we neglect the velocity heads, we have:

$$\Delta H_P\ (m) = \Delta H_{F1\text{-}2}\ (m) + z_2(m) - z_1(m)$$



Net positive suction head available (N.P.S.H.A.)



$$\text{N.P.S.H.A} = -\left(\Delta H_{F1\text{-}S} + \Delta H_{EQ1\text{-}S}\right) + \frac{V_1^2}{2\,g} + \left(z_1 - z_S + H_1\right) + H_a - H_{va}$$

(pipe friction loss: $\Delta H_{F1\text{-}S}$; equipment friction loss: $\Delta H_{EQ1\text{-}S}$; inlet velocity head: $\frac{V_1^2}{2g}$; liquid surf to ref. plane: z_1; pump suct. cent. to ref. plane: z_S; inlet press. head: H_1; atmosph. press. head: H_a; vapor press. head: H_{va})

all units are in meters, V_1 in m/s and g in ft/s²

N.P.S.H.A. is a definition, see Hydraulic Institute standards

CONSTANTS AND DATA

typical suction pump velocity - *v = 1 to 3.6 m/s*

atmospheric pressure - *H_a = 101 kPaa at sea level, depends on elevation*

vapor pressure - *H_{va} depends on nature of liquid and temperature*

vapor pressure varies with temperature and pressure, as pressure decreases at constant temperature vaporisation occurs, this is why vapor pressure is subtracted from all other pressure terms, to ensure that at a minimum the N.P.S.H.A. is above the vapor pressure