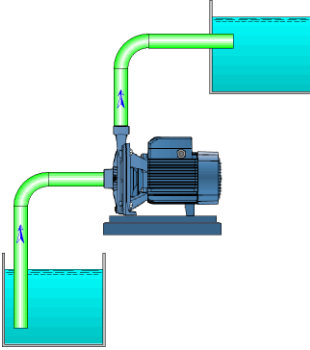




Pump Design

Suction lift operation

(Tank with pipe ending below the fluid level)



Model description:

This component model calculates the Total Dynamic Height (TDH) of a pump installed in a hydraulic installation. There is also an option to calculate the Net Positive Suction Head available (NPSHa) of the installation.

In this model,

- the pump is operating in suction mode (the level of the suction tank is located below the suction flange of the pump),
- the pump delivers into a tank whose pipe outlet is located below the fluid level of this tank and whose level is located above the pump discharge flange.

Model formulation:

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Cross-sectional area (m²):

- Suction piping:

$$A_1 = \pi \cdot \frac{D_1^2}{4}$$

- Discharge piping:

$$A_2 = \pi \cdot \frac{D_2^2}{4}$$

Mean velocity (m/s):

- Surface of the suction tank:

$$v_0 \approx 0$$

- Suction piping:

$$v_1 = \frac{Q}{A_1}$$

- Discharge piping:

$$v_2 = \frac{Q}{A_2}$$

- Surface of the discharge tank:

$$v_3 \approx 0$$

Reynolds number:

- Suction piping:

$$Re_1 = \frac{v_1 \cdot D_1}{\nu}$$

- Discharge piping:

$$Re_2 = \frac{v_2 \cdot D_2}{\nu}$$

Darcy friction factor:

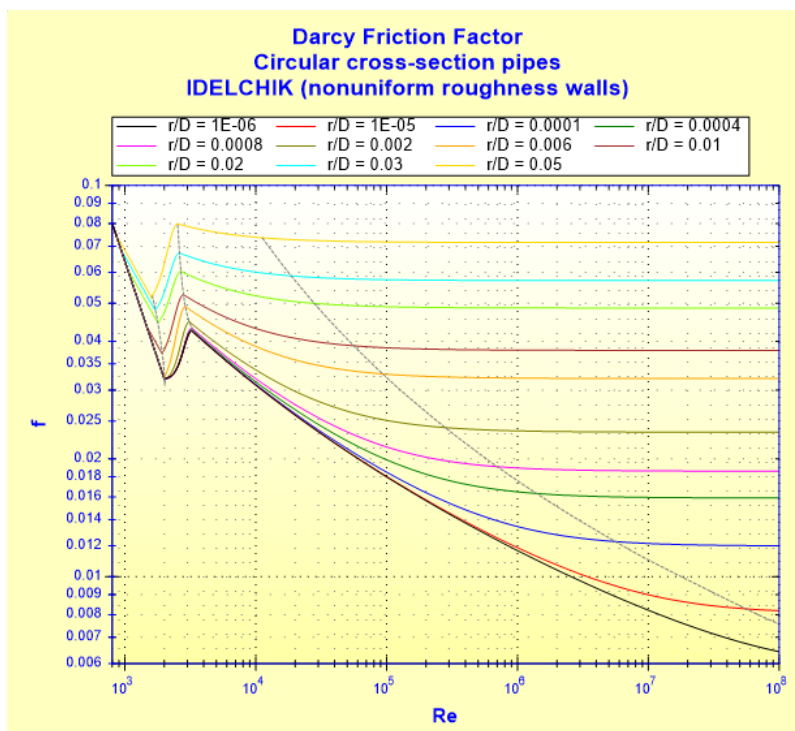
- Suction piping:

$$f_1 = f\left(Re_1, \frac{r_1}{D_1}\right)$$

- Discharge piping:

$$f_2 = f\left(Re_2, \frac{r_2}{D_2}\right)$$

See [Straight Pipe - Circular Cross-Section and Nonuniform Roughness Walls \(IDELCHIK\)](#)



Coefficient of major pressure losses (friction in pipes):

- Suction piping:

$$Kf_1 = f_1 \cdot \frac{L_1}{D_1}$$

- Discharge piping:

$$Kf_2 = f_2 \cdot \frac{L_2}{D_2}$$

Total pressure loss coefficient:

- Suction piping:

$$K_1 = Kf_1 + Ks_1$$

- Discharge piping:

$$K_2 = Kf_2 + Ks_1$$

Total pressure loss (Pa):

- Suction piping:

$$dP_{01} = K_1 \cdot \frac{\rho \cdot v_1^2}{2}$$

- Discharge piping:

$$dP_{23} = K_2 \cdot \frac{\rho \cdot v_2^2}{2}$$

Total head loss (m):

- Suction piping:

$$dH_{01} = K_1 \cdot \frac{v_1^2}{2 \cdot g}$$

- Discharge piping:

$$dH_{23} = K_2 \cdot \frac{v_2^2}{2 \cdot g}$$

Total gage pressure at the suction flange (Pa):

$$P_1 = P_0 + \frac{v_0^2 \cdot \rho}{2} - (dH_{01} + H_0) \cdot \rho \cdot g$$

Total gage pressure at the discharge flange (Pa):

$$P_2 = P_3 + \frac{v_3^2 \cdot \rho}{2} + (dH_{23} + H_3) \cdot \rho \cdot g$$

Bernoulli's equation:

$$P_i + \frac{1}{2} \cdot \rho \cdot V_i^2 + \rho \cdot g \cdot z_i = P_o + \frac{1}{2} \cdot \rho \cdot V_o^2 + \rho \cdot g \cdot z_o$$

(Perfect fluid, incompressible, steady state flow)

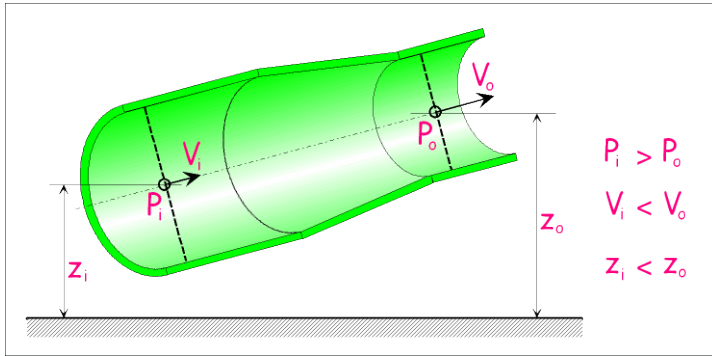


Illustration of Bernoulli's theorem

Pump Total Dynamic Head (application of the extended Bernoulli equation for a real fluid):

$$HMT = (H_o + H_3) + \left(\frac{P_3 - P_o}{\rho \cdot g} \right) + \left(\frac{v_3^2 - v_o^2}{2 \cdot g} \right) + (dH_{o1} + dH_{23})$$

([1] equation 5)

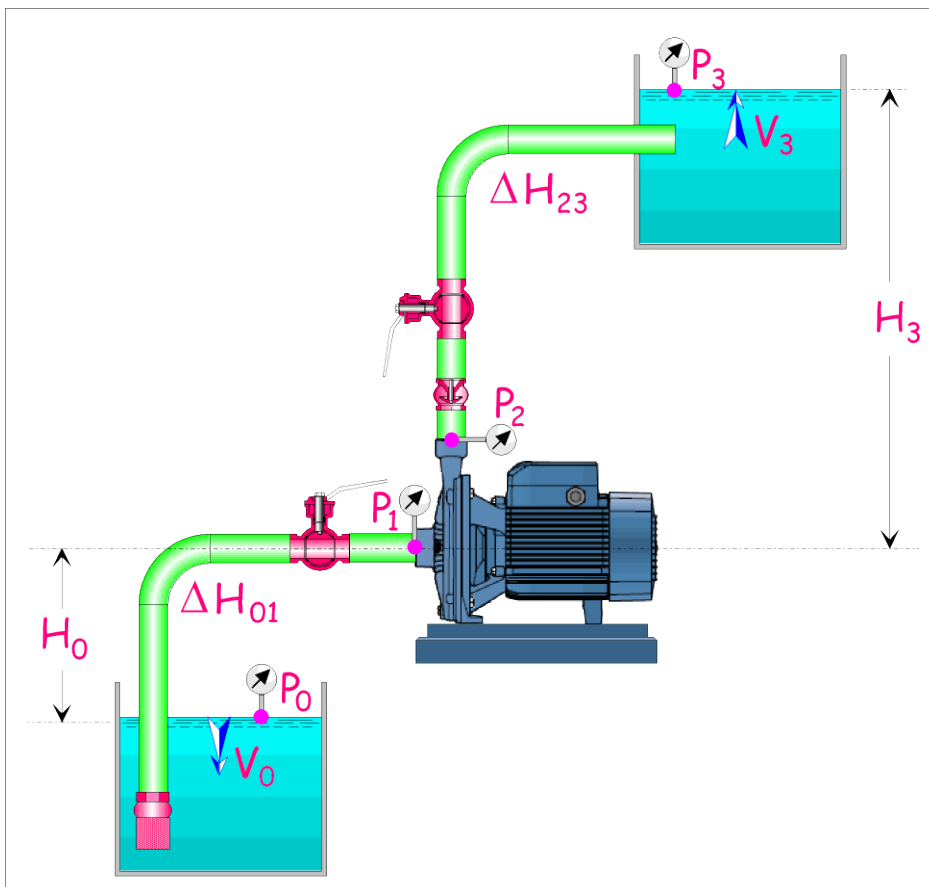


Illustration of the system

where:

$$H_o + H_3$$

Total static head, this is the difference in height between the liquid level on the inlet and discharge sides (geodetic head).

$$\frac{P_3 - P_0}{\rho \cdot g}$$

Static pressure head, this is the pressure head difference between the inlet and outlet tank.

In the case of open boxes at atmospheric pressure, the pressures P_0 and P_3 are equal and the static pressure head is zero.

$$\frac{v_3^2 - v_0^2}{2 \cdot g}$$

Dynamic head, this is the dynamic height due to the vertical speed difference in the two tanks.

In general, the liquid surface flow velocities v_0 and v_3 of tanks are very low and the dynamic head is considered to be zero (negligible).

$$dH_{01} + dH_{23}$$

Pressure loss head, this is the sum of all the head losses of the installation, suction and discharge piping.

(= resistance to flow in the pipes, valves, strainer, piping inlet and outlet, etc.).

NPSH Available of the system:

$$NPSH_a = P_1 - P_{vap}$$

By applying the extended Bernoulli equation for a real fluid, between the tank level and the pump suction flange, we obtain the following equation:

$$NPSH_a = \frac{P_0 + P_{atm} - P_{vap}}{\rho \cdot g} + \frac{v_0^2}{2 \cdot g} - dH_{01} - H_0 \quad ([1] \text{ equation } 29)$$

where (as for the TDH):

$$\frac{P_0 + P_{atm} - P_{vap}}{\rho \cdot g}$$

Static pressure head.

$$\frac{v_0^2}{2 \cdot g}$$

Dynamic head.

$$dH_{01}$$

Pressure loss head.

$$H_0$$

Total static head.

Hydraulic power supplied to the fluid by the pump (W):

$$Wh = TDH \cdot \rho \cdot g \cdot Q$$

Input mechanical power taken by the pump (W):

$$Wm = \frac{Wh}{\eta p}$$

Note: Pumping media which are more viscous than water will require a higher input power.

Electric power absorbed by the electric motor (W):

$$W_e = \frac{W_m}{\eta_m}$$

Symbols, Definitions, SI Units:

Q	Volume flow rate (m ³ /s)
G	Mass flow rate (kg/s)
D ₁	Suction piping diameter (m)
D ₂	Discharge piping diameter (m)
A ₁	Suction piping cross-sectional area (m ²)
A ₂	Discharge piping cross-sectional area (m ²)
v ₀	Flow velocity of the liquid surface of the suction tank (m/s)
v ₁	Mean velocity in suction piping (m/s)
v ₂	Mean velocity in discharge piping (m/s)
v ₃	Flow velocity of the liquid surface of the discharge tank (m/s)
Re ₁	Reynolds number in suction piping ()
Re ₂	Reynolds number in discharge piping ()
r ₁	Suction piping absolute roughness (m)
r ₂	Discharge piping absolute roughness (m)
f ₁	Darcy friction factor of the suction piping ()
f ₂	Darcy friction factor of the discharge piping ()
L ₁	Length of the suction pipe (m)
L ₂	Length of the discharge pipe (m)
Kf ₁	Coefficient of friction resistance of the suction piping ()
Kf ₂	Coefficient of friction resistance of the discharge piping ()
Ks ₁	Resistance coefficient of the singularities of the suction piping ()
Ks ₂	Resistance coefficient of the singularities of the discharge piping ()
K ₁	Total pressure loss coefficient of the suction piping ()
K ₂	Total pressure loss coefficient of the discharge piping ()
dP ₀₁	Total pressure loss of the suction piping (Pa)
dP ₂₃	Total pressure loss of the discharge piping (Pa)
dH ₀₁	Total head loss of the suction piping (Pa)
dH ₂₃	Total head loss of the discharge piping (Pa)
P ₀	Relative pressure on the surface of the suction tank (Pa)
P ₁	Total relative pressure at the suction flange (Pa)
P ₂	Total relative pressure at the discharge flange (Pa)
P ₃	Relative pressure on the surface of the discharge tank (Pa)
H ₁	Height difference between the fluid level of the suction tank and the suction flange (m)
H ₃	Height difference between the suction flange and the fluid level of the discharge tank (m)
TDH	Pump Total Dynamic Head (m)
P _{atm}	Atmospheric pressure (Pa)

P_{vap} Vapour pressure of liquid at suction flange temperature (Pa)
 $NPSH_a$ Net Positive Suction Head available of the system (m)
 W_h Hydraulic power supplied to the fluid by the pump (W)
 η_p Pump efficiency (%)
 W_m Input mechanical power taken by the pump (W)
 η_m Electrical motor efficiency (%)
 W_e Electric power absorbed by the electric motor (W)

ρ Fluid density (kg/m^3)
 ν Fluid kinematic viscosity (m^2/s)
 g Gravitational acceleration (9.80665 m/s^2)

Validity range:

- turbulent flow regime

Example of application:

The screenshot displays the HydraulCalc 2020b software interface for a pump system simulation. The main window is titled "Suction lift operation" and "Tank with pipe ending below the fluid level".

Fluid characteristics (left panel):

- Fluid: Water @ 1 atm [HC]
- Ref.: IAPWS IF97
- Temperature: $T = 20$ °C
- Pressure: $P = 1.013$ bar
- Density: $\rho = 998.2061$ kg/m^3
- Dynamic Viscosity: $\mu = 0.00100159$ N.s/m^2
- Kinematic Viscosity: $\nu = 1.00340E-06$ m^2/s

Geometric characteristics of the pumping system (center panel):

- Discharge piping:
 - Piping inside diameter: $D2 = 0.0703$ m
 - Piping absolute roughness: $r2 = 1.0E-05$ m
 - Piping length: $L2 = 1$ m
 - Pressure loss coefficient: $Ks2 = 1$
- Electric pump:
 - Pump efficiency: $\eta_p = 0.8$
 - Motor efficiency: $\eta_m = 0.8$

Flow parameters (center panel):

- Flowrate in the circuit: $Q = 0.005$ m^3/s ($G = 4.9910$ kg/s)
- Total Dynamic Head: $TDH = 7.215122$ m fluid
- Velocity in discharge pipe: $v2 = 1.288$ m/s (Turbulent)
- Velocity in suction pipe: $v1 = 1.288$ m/s (Turbulent)

Head and pressure parameters (center panel):

- Suction head: $H0 = 2$ m
- Discharge head: $H3 = 5$ m
- Gage pressure at suction: $P1 = 0$ bar
- Gage pressure at discharge: $P3 = 0$ bar

NPSH available (right panel):

- Calculate NPSH available
- Atmospheric Pressure: $P_{atm} = 1.01325$ bar
- Vapor pressure: $P_{vap} = 0.02339215$ bar
- NPSH available: $NPSH_a = 8.00432$ m fluid

Graph (left panel):

A graph showing Density (kg/m^3) versus Temperature ($^{\circ}\text{C}$). The density decreases from approximately 998 kg/m^3 at 20 $^{\circ}\text{C}$ to about 970 kg/m^3 at 100 $^{\circ}\text{C}$.

HydrauCalc 2020b - [Pump quick design]

File Edit Preferences Configuration Database Tools Help

Fluid characteristics
 Fluid : Water @ 1 atm [HC]
 Ref.: IAPWS IF97

Temperature : T 20 °C
 Pressure : P 1.013 bar

Density : ρ 998.2061 kg/m³
 Dynamic Viscosity : μ 0.00100159 N.s/m²
 Kinematic Viscosity : ν 1.00340E-06 m²/s

Density Dyn. Visc. Kin. Visc.

logY

Divers HC

Suction lift operation
 Tank with pipe ending below the fluid level

Calculate
 Geometric data

Complementary results

Designation	Symbol	Value	Unit
***** Electric pump *****			
Total gage pressure at the suction flange	P1	-0.2063103	bar
Total gage pressure at the discharge flange	P2	0.4999821	bar
Differential pressure at flanges	P2 - P1	0.7062925	bar
Hydraulic power supplied to the fluid by the pump	Wh	353.1462	W
Mechanical power supplied to the pump by the electric motor	Wm	441.4328	W
Electric power absorbed by the electric motor	We	551.791	W
Total Dynamic Head	TDH	7.215122	m fluid
Geodetic head	Hgeo	7	m fluid
Total static head	Hps	0	m fluid
Velocity head	Hdyn	0	m fluid
Head losses	Hpdc	0.2151218	m fluid
Net Positive Suction Head	NPSHa	8.00432	m fluid
Geodetic head	Hgeo	2	m fluid
Total static head	Hps	10.11188	m fluid
Velocity head	Hdyn	0	m fluid
Head losses	Hpdc	0.1075609	m fluid

References:

[1] KSB - Selecting Centrifugal Pumps - 4th Edition (2005)