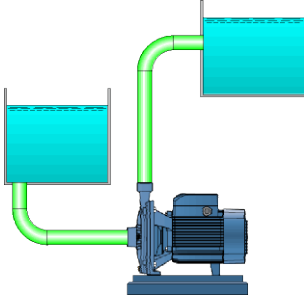




Pump Design

Suction head 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 head mode (the level of the suction tank is located above 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:

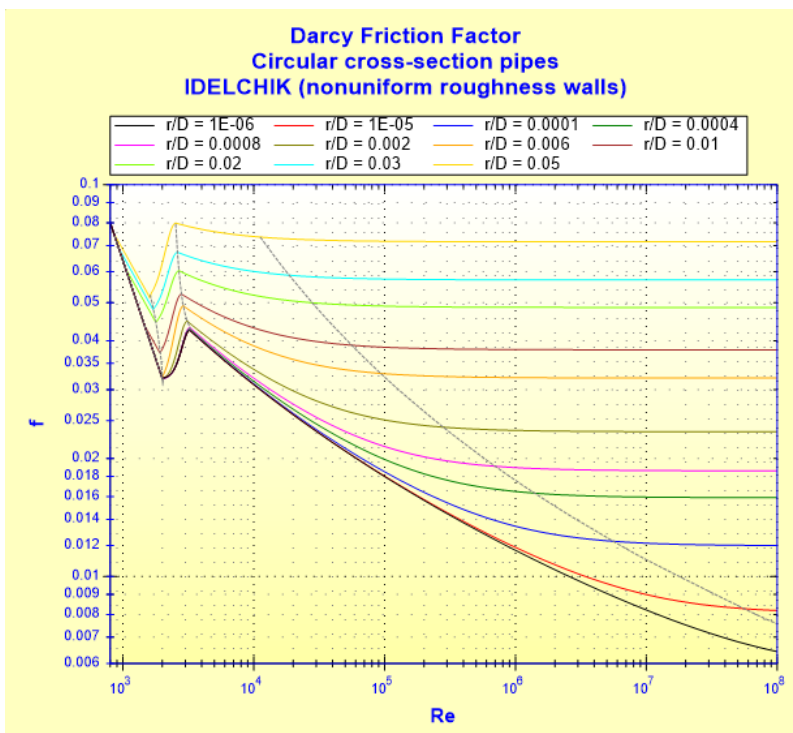
- Suction piping:

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

- 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:

$$K_2 = Kf_2 + Ks_2$$

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):

$$P_1 = P_0 + \frac{V_0^2 \cdot \rho}{2} + (H_0 - dH_{01}) \cdot \rho \cdot g$$

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)

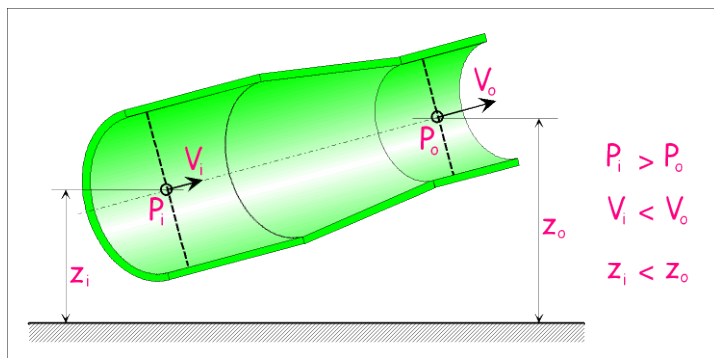


Illustration of Bernoulli's theorem

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

$$HMT = (H_3 - H_0) + \left(\frac{P_3 - P_0}{\rho \cdot g} \right) + \left(\frac{V_3^2 - V_0^2}{2 \cdot g} \right) + (dH_{01} + dH_{23})$$

([1] equation 5)

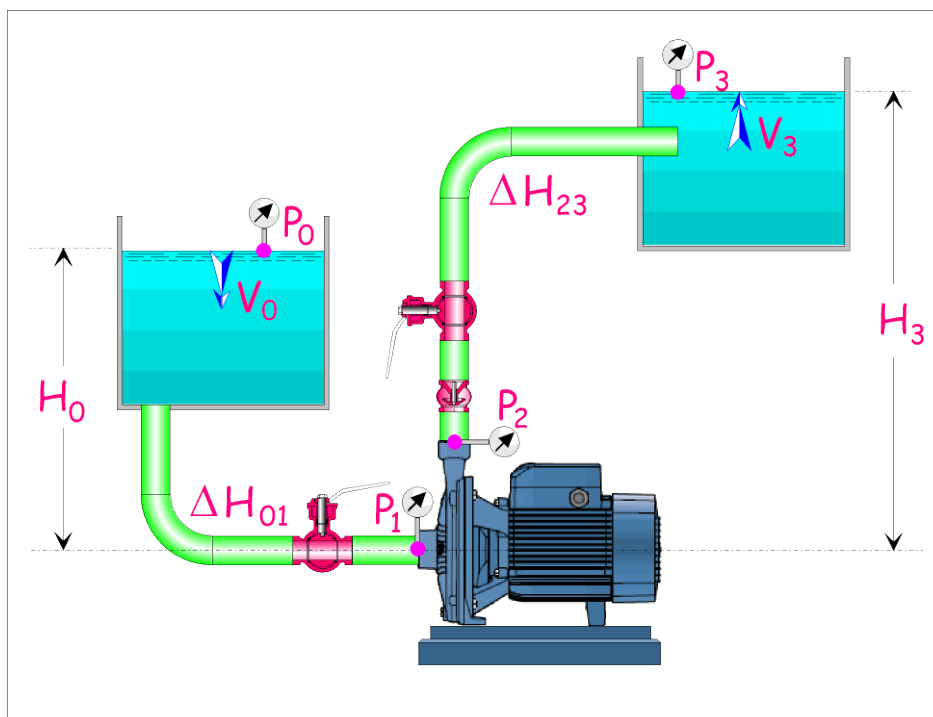


Illustration of the system

where:

$$H_3 - H_0$$

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:

$$NPSH_a = \frac{P_0 + P_{atm} - P_{vap}}{\rho \cdot g} + \frac{v_0^2}{2 \cdot g} - dH_{01} + H_0 \quad ([1] \text{ equation 31})$$

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):

$$We = \frac{Wm}{\eta m}$$

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)
Wh	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 interface for a pump quick design. The software is set to calculate the performance of a pump system under suction head operation, where the tank's pipe end is below the fluid level.

Fluid characteristics:

- Fluid: Water @ 1 atm [HC]
- Temperature: 20 °C
- Pressure: 1.013 bar
- Density: 998.2061 kg/m^3
- Dynamic Viscosity: 0.00100159 N.s/m^2
- Kinematic Viscosity: 1.00340E-06 m^2/s

Geometric characteristics of the pumping system:

- Electric pump:**
 - Pump efficiency: $\eta_p = 0.8$
 - Motor efficiency: $\eta_m = 0.8$
- Discharge piping:**
 - Piping inside diameter: $D_2 = 0.0703 \text{ m}$
 - Piping absolute roughness: $r_2 = 1.0\text{E-}05 \text{ m}$
 - Piping length: $L_2 = 1 \text{ m}$
 - Pressure loss coefficient: $K_{s2} = 1$
- Suction piping:**
 - Piping inside diameter: $D_1 = 0.0703 \text{ m}$
 - Piping absolute roughness: $r_1 = 1.0\text{E-}05 \text{ m}$
 - Piping length: $L_1 = 1 \text{ m}$
 - Pressure loss coefficient: $K_{s1} = 1$
- NPSH available:**
 - Calculate NPSH available:
 - Atmospheric Pressure: $P_{atm} = 1.01325 \text{ bar}$
 - Vapor pressure: $P_{vap} = 0.02339215 \text{ bar}$
 - NPSH available: $NPSH_a = 12.00432 \text{ m fluid}$

System Diagram and Results:

- The diagram shows a pump connected to a suction tank (P0) and a discharge tank (P3).
- Suction tank: Gage pressure = 0 bar, velocity $v_0 = 1.288 \text{ m/s}$ (Turbulent).
- Discharge tank: Gage pressure = 0 bar, velocity $v_3 = 1.288 \text{ m/s}$ (Turbulent).
- Flowrate in the circuit: $Q = 0.005 \text{ m}^3/\text{s}$, $G = 4.9910 \text{ kg/s}$.
- Discharge head: $H_3 = 5 \text{ m}$.
- Suction head: $H_0 = 2 \text{ m}$.
- Total Dynamic Head (TDH): 3.215122 m fluid .

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.

HC
Divers

Suction head 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	0.185252	bar
Total gage pressure at the discharge flange	P2	0.4999821	bar
Differential pressure at flanges	P2 - P1	0.3147301	bar
Hydraulic power supplied to the fluid by the pump	Wh	157.3651	W
Mechanical power supplied to the pump by the electric motor	Wm	196.7063	W
Electric power absorbed by the electric motor	We	245.8829	W
Total Dynamic Head	TDH	3.215122	m fluid
Geodetic head	Hgeo	3	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	12.00432	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)