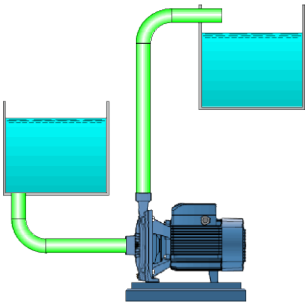
Pump Design
Suction head operation
(Free flow from the pipe ending above the fluid level)



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 above 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 (m^2):

- 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:

$$V_2 = \frac{Q}{A_2}$$

- Outlet of the discharge pipe:

$$V_3 = V_2$$

Reynolds number:

- Suction piping:

$$\mathrm{Re}_1 = \frac{V_1 \cdot D_1}{\nu}$$

- Discharge piping:

$$\mathrm{Re}_2 = \frac{V_2 \cdot D_2}{\nu}$$

Darcy friction factor:

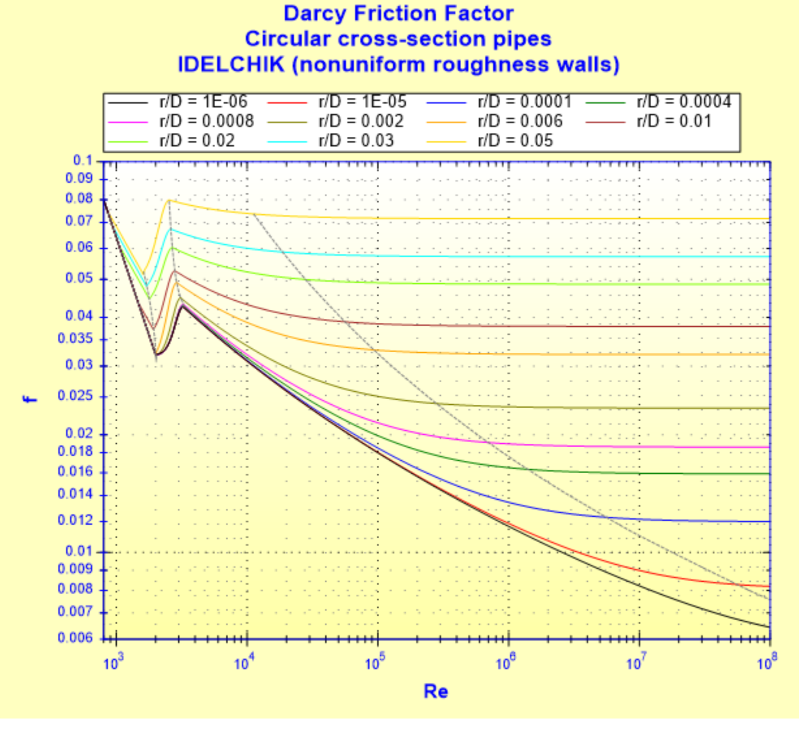
- Suction piping:

$$f_1 = f\left(\mathrm{Re}_1, \frac{r_1}{D_1}\right)$$

- Discharge piping:

$$f_2 = f\left(\mathrm{Re}_2, \frac{r_2}{D_2}\right)$$

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):

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

Total gage pressure at the discharge flange (Pa):

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

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)

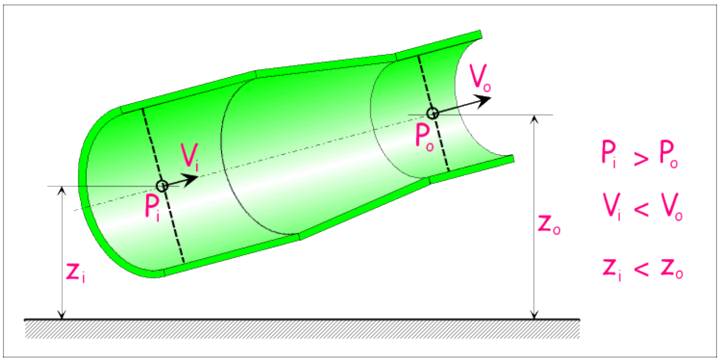


Illustration of Bernoulli's theorem

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)

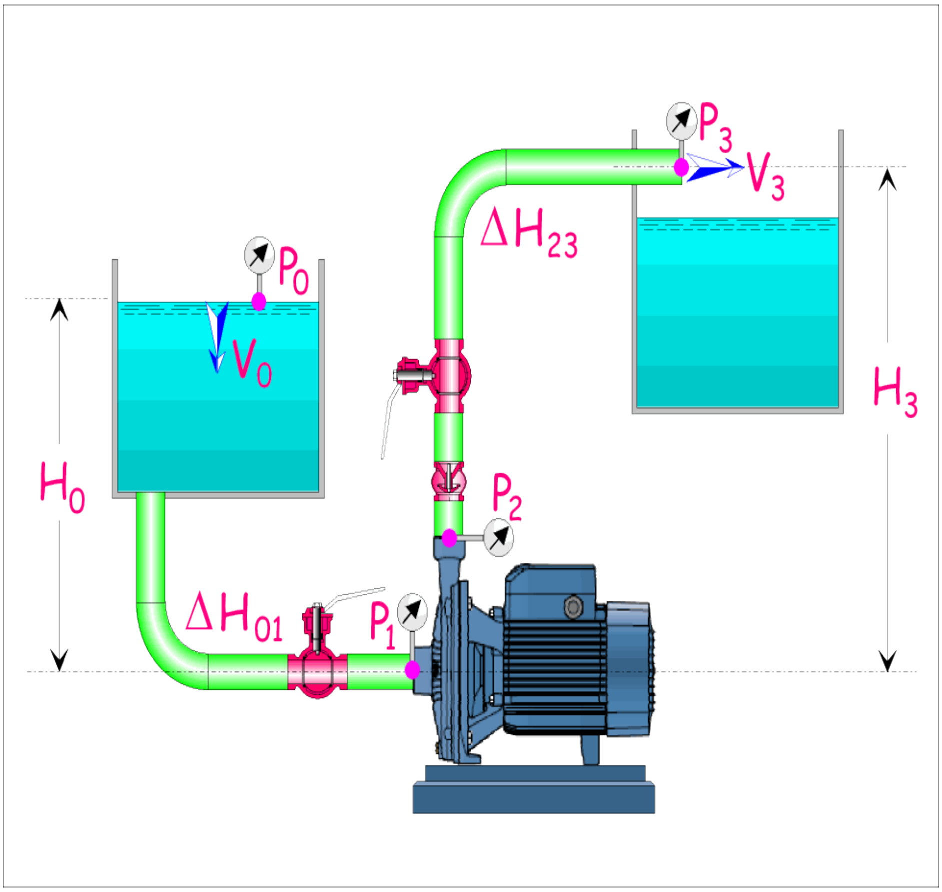


Illustration of the system

where:

$H_3 - H_0$ Total static head, this is the difference in height between the liquid level in the suction tank and the center of the exit plane (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:

$$NPSH_a = \frac{P_0 + P_{atm} - P_{vap}}{\rho \cdot g} + \frac{v_0^2}{2 \cdot g} - dH_{01} + H_0$$

([1] 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 at the outlet of the discharge pipe (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 center of the exit plane (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)
ηp	Pump efficiency ()
Wm	Input mechanical power taken by the pump (W)

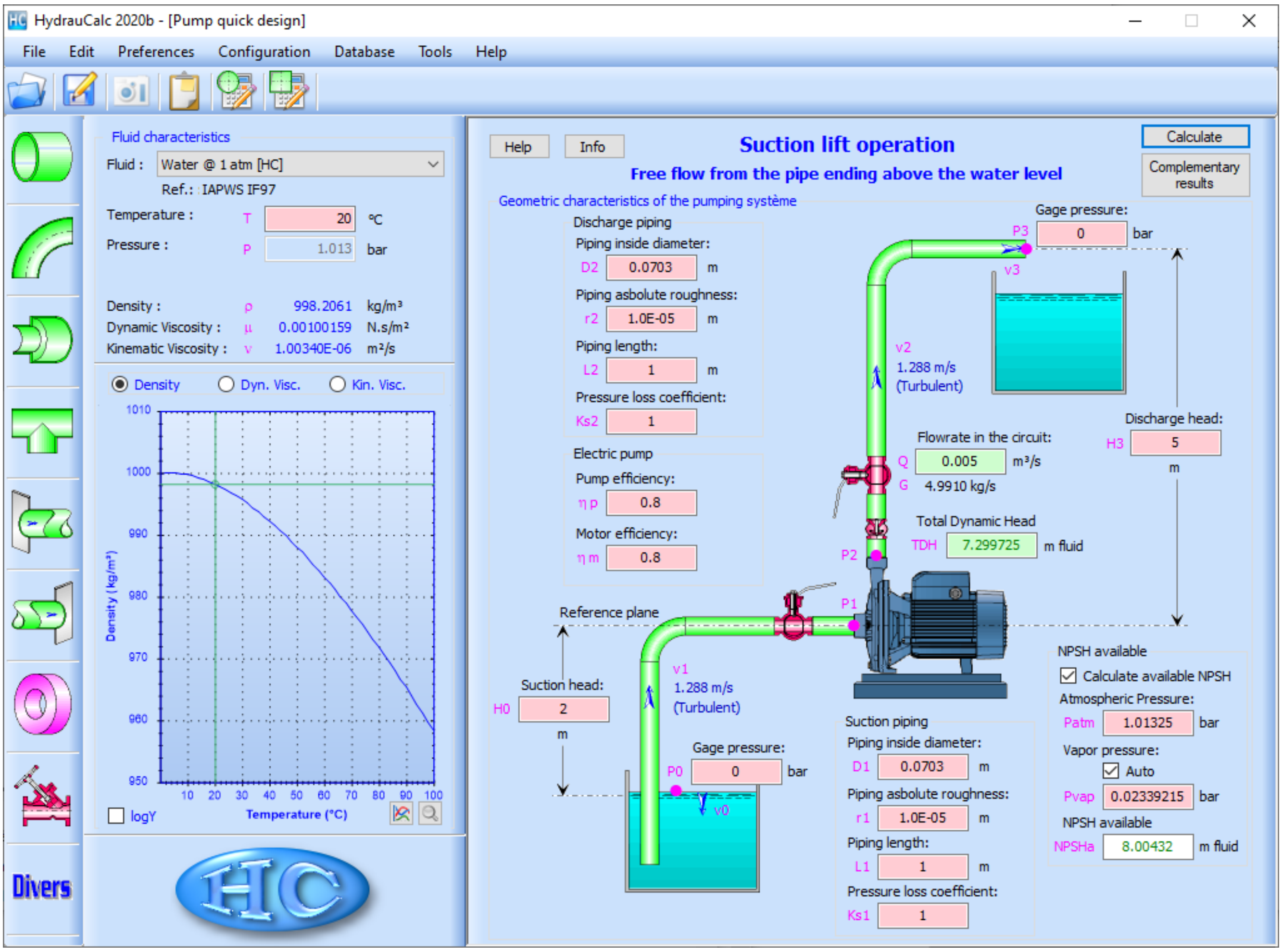
ηm Electrical motor efficiency ()
We Electric power absorbed by the electric motor (W)

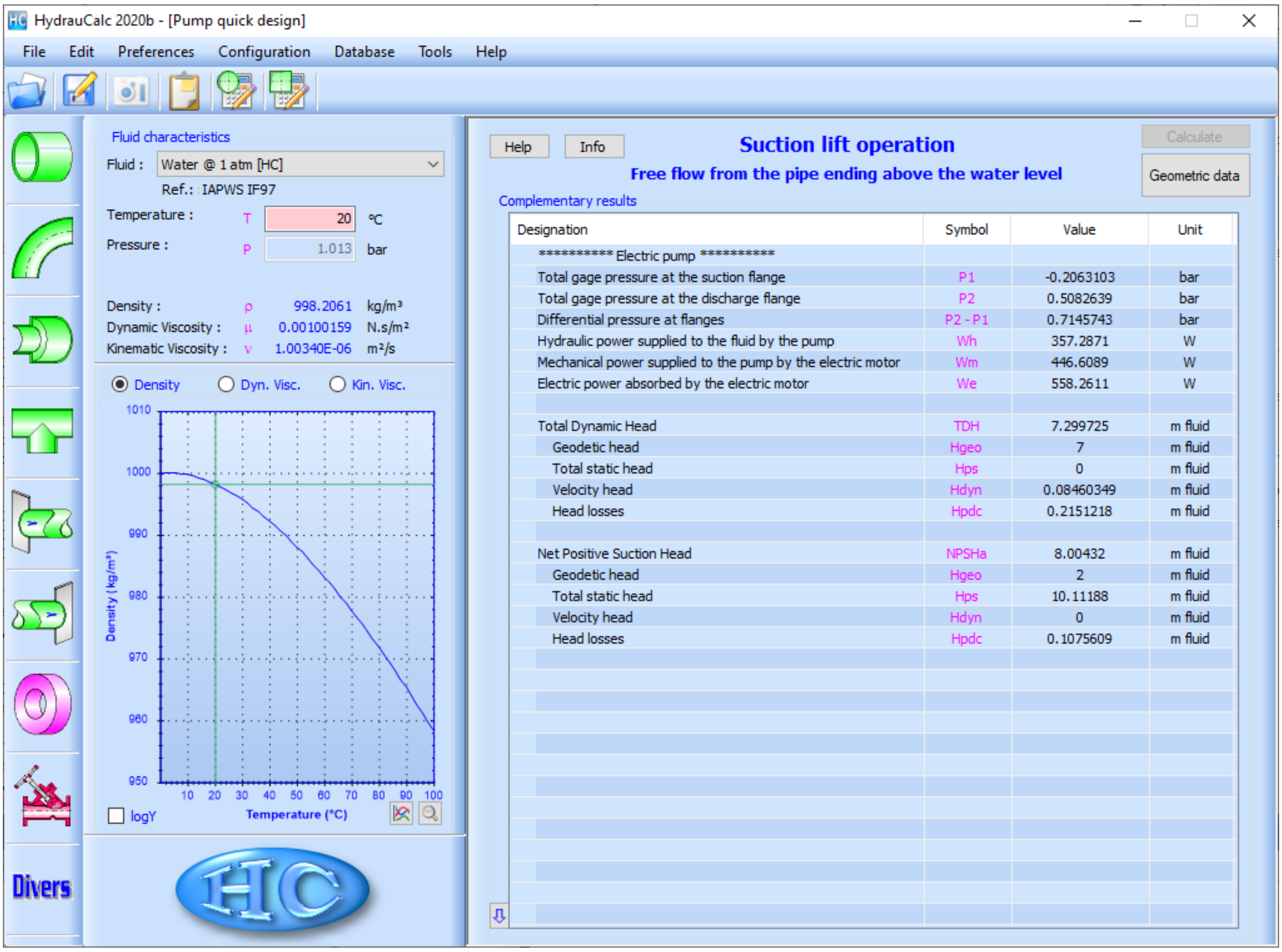
ρ Fluid density (kg/m^3)
ν Fluid kinematic viscosity (m^2/s)
g Gravitational acceleration (9.80665 m/s^2)

Validity range:

- turbulent flow regime

Example of application:





References:

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