Classification of Pumps and Turbines

1 Pumps

1.1 Positive displacement pumps

A positive displacement pump, see Fig. 1 makes a fluid move by trapping a fixed amount and forcing (displacing) that trapped volume into the discharge pipe.

Some positive displacement pumps use an expanding cavity on the suction side and a decreasing cavity on the discharge side. Liquid flows into the pump as the cavity on the suction side expands and the liquid flows out of the discharge as the cavity collapses. The volume is **CONSTANT** through each cycle of operation, see fig.

A positive displacement pump can be further classified according to the mechanism used to move the fluid:

- Rotary-type positive displacement:screw, Fig. 3, gear pump Fig. 4, lobe pump Fig. 2, Fig. 7
- Reciprocating-type positive displacement: move the fluid using one or more oscillating pistons Fig. 5, Fig. 6

Positive Displacement pumps do not use impellers, but rely on rotating or reciprocating parts to directly push the liquid in an enclosed cavity, until enough pressure is built up to move the liquid into the discharge system. The pump does not rely on raising the velocity of the fluid as the centrifugal pump does by moving the liquid through the impeller. Consequently, the fluid velocity inside a positive displacement pump is much lower than that of a centrifugal pump. This is often a desirable feature for certain applications, such as when needing to pump a media containing fragile solids.

1.2 Centrifugal pumps

General explanation: Like most pumps, a centrifugal pump converts rotational energy, often from a motor, to energy in a moving fluid. A portion of the energy goes into kinetic energy of the fluid. Fluid enters axially through eye of the casing, is caught up in the impeller blades, and is whirled tangentially and radially outward until it leaves through all circumferential parts of the impeller into the diffuser part of the casing. The fluid gains both velocity and pressure while passing through the impeller. The doughnut-shaped diffuser, or scroll, section of the casing decelerates the flow and further increases the pressure, see fig. **??**.

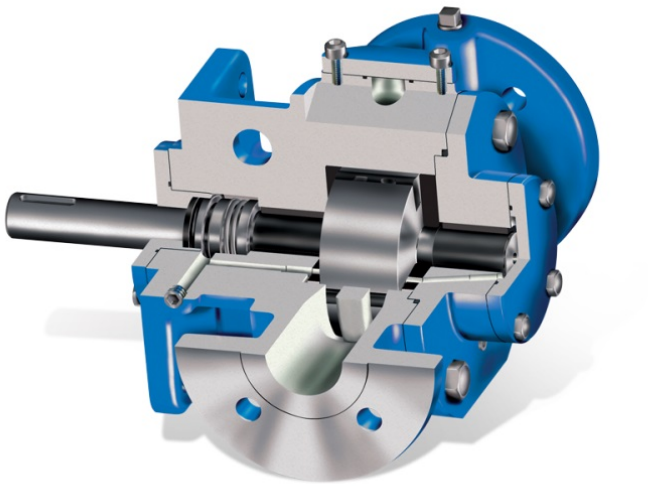

Figure 1: Positive displacement pump

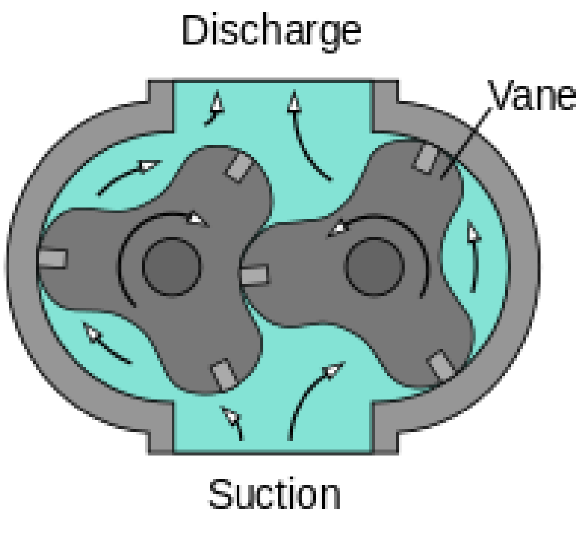

Figure 2: Lobe pump

Figure 3: Screw rotors

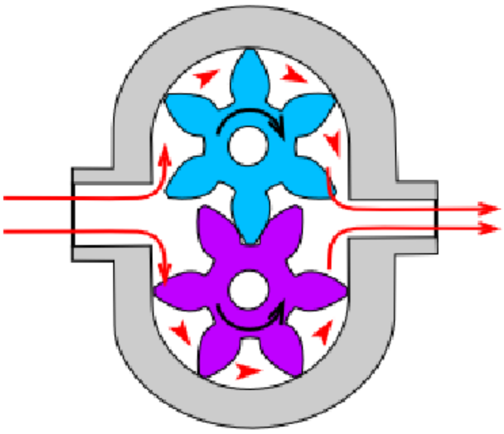

Figure 4: Gear pump

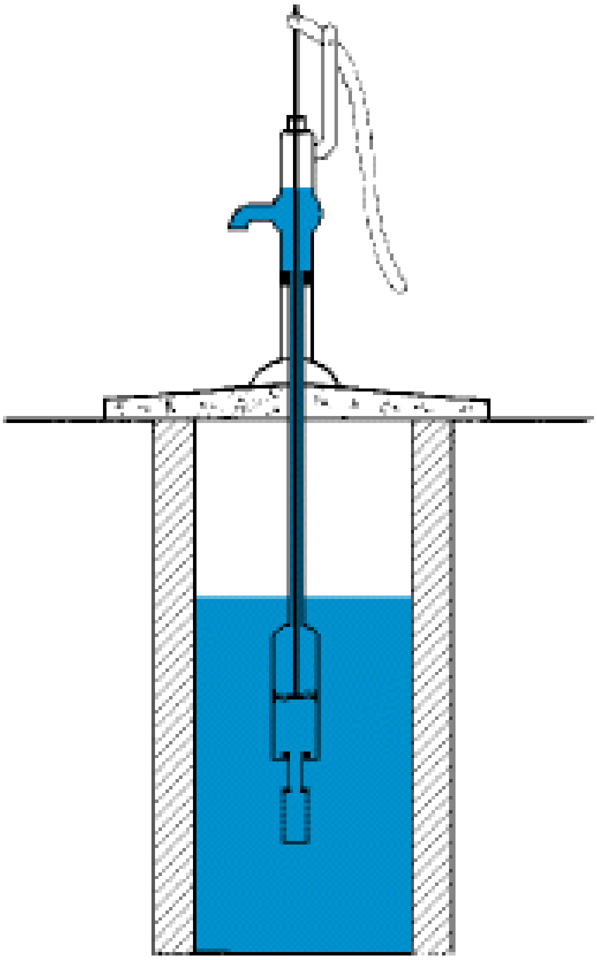

Figure 5: Hand pump

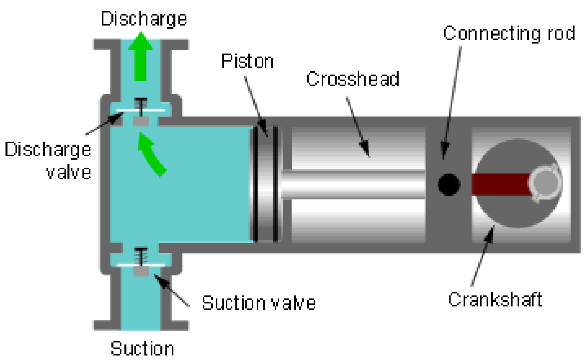

Figure 6: Piston

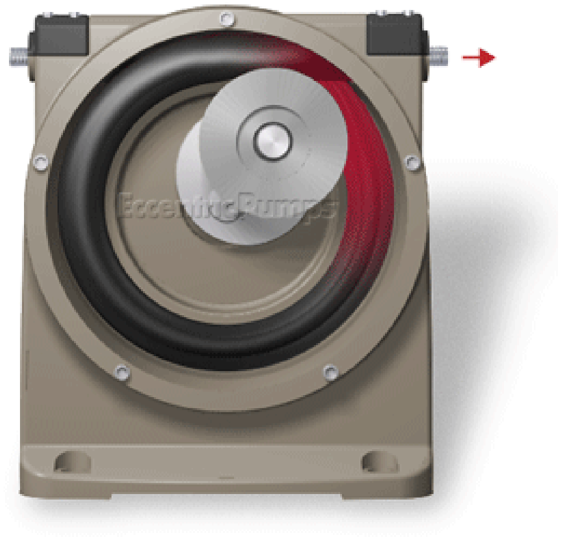

Figure 7: Eccentric

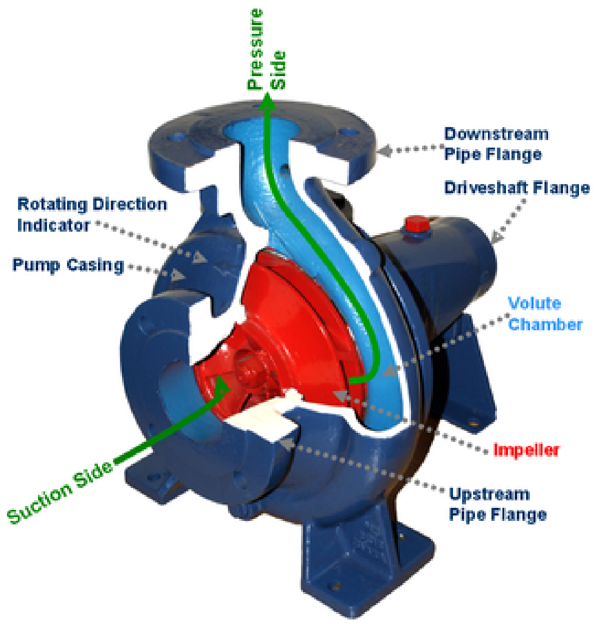

Figure 8: Centrifugal

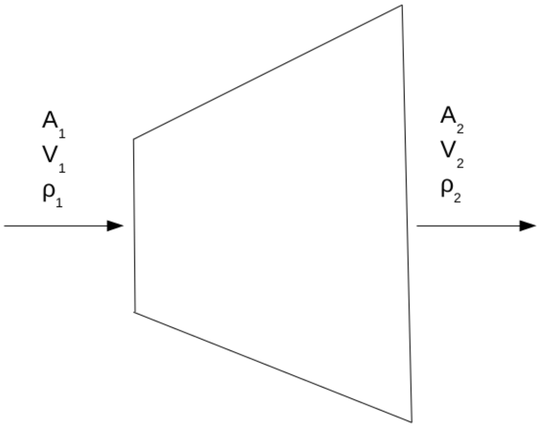

Figure 9: Continuity equation

1.3 Basics of Fluid Mechanics

1.3.1 Continuity equation

Mass conservation equation reads, see fig. 9:

$$\rho_1 \ * \ Area_1 * \ Velocity_1 = \rho_2 \ * \ Area_2 * \ Velocity_2 \tag{1}$$

1.3.2 Bernoulli equation

Bernoulli's principle can be derived from the principle of conservation of energy. This states that, in a steady flow, the sum of all forms of energy in a fluid along a streamline is the same at all points on that streamline. This requires that the sum of potential energy, dynamic pressure and static pressure remains constant, see fig. 10:

$$P_T = P_1 + \rho g z_1 + \frac{\rho u_1^2}{2} = P_2 + \rho g z_2 + \frac{\rho u_2^2}{2} = P_3 + \rho g z_3 + \frac{\rho u_3^2}{2} \tag{2}$$

In reality there are energy losses, due to the friction of fluid runnning through the pipe, expressed as pressure losses. These are proportional to the square of the fluid velocity. Bernoulli's equation for viscous flows reads

$$P_1 + \rho g z_1 + \frac{\rho u_1^2}{2} = P_2 + \rho g z_2 + \frac{\rho u_2^2}{2} + P_{losses12} \tag{3}$$

$$P_2 + \rho g z_2 + \frac{\rho u_2^2}{2} = P_3 + \rho g z_3 + \frac{\rho u_3^2}{2} + P_{losses23} \tag{4}$$

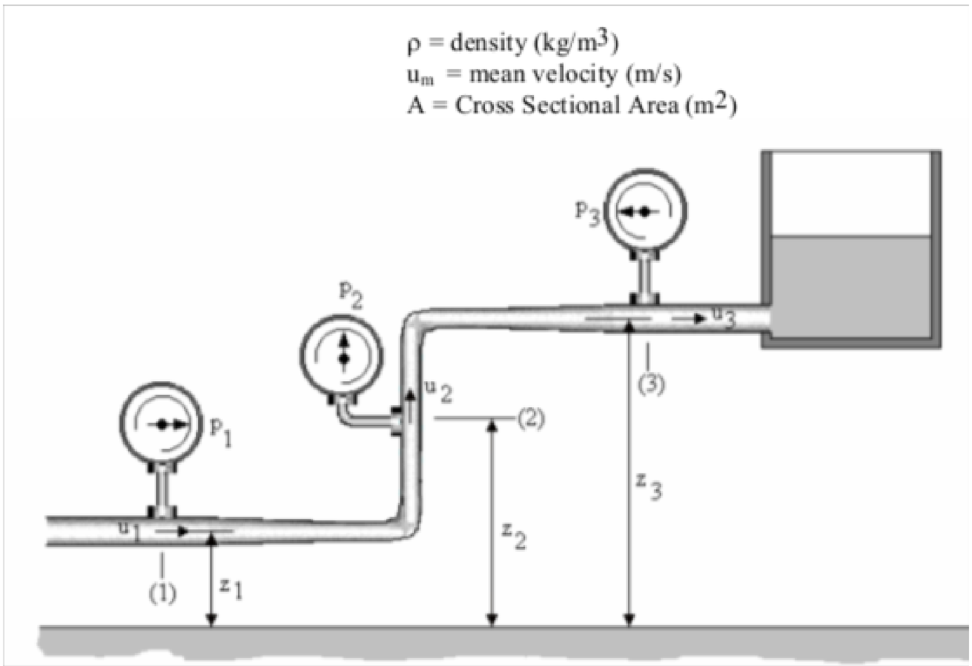

Figure 10: Flow in a pipe

1.3.3 Pumping station

We apply the bernoulli equation, see fig. 11, from points A to a and E to e, according to the following notations:

- **H** is pressure head. This is the internal energy of a fluid due to the pressure exerted on its container. It may also be called static pressure head or simply static head. It is mathematically expressed as:
  $\mathbf{H} = \frac{\mathbf{p}}{\rho\ \mathbf{g}}$ (length, typically in units of m)
- **p** is fluid pressure (force per unit area, often as Pa units)
- γ is the specific weight (force per unit volume, typically $\frac{Nt}{m^3}$ units)
- ρ is the density of the fluid (mass per unit volume, typically $\frac{kg}{m^3}$ units)
- **g** is acceleration due to gravity (rate of change of velocity, given in $\frac{m}{s^2}$ units)
- **c** velocity, given in $\frac{m}{s}$ units
- δh_f pressure losses, given in units of m
- H_B atmospheric pressure, given in units of m

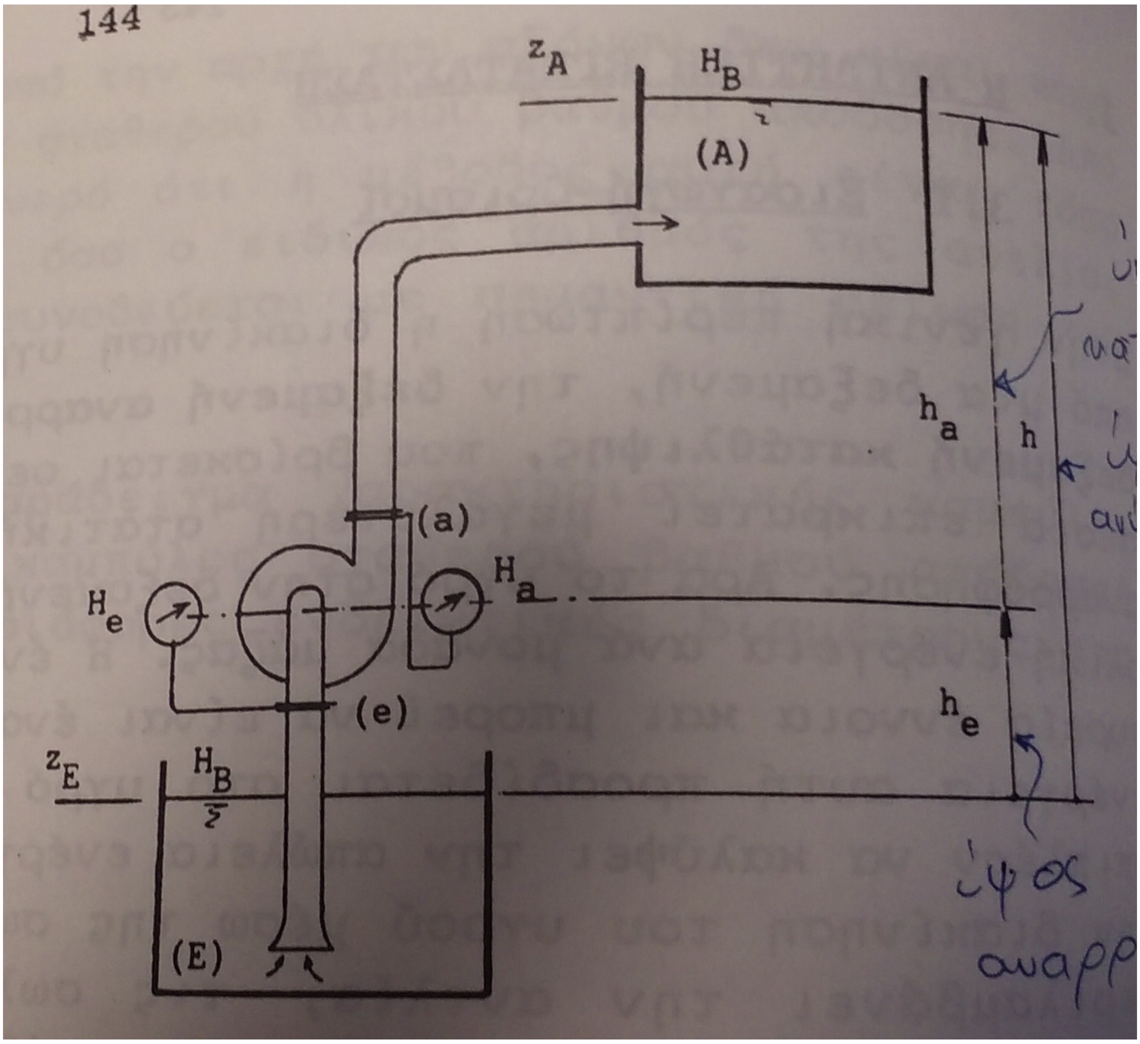

Figure 11: Pump station

$$\text{Bernoulli aA:}\quad H_{oa} = H_a + z_\alpha + \frac{c^2{}_a}{2g} = H_B + z_A + \delta h_{faA} \tag{5}$$

$$\text{Bernoulli eE:}\quad H_{oe} = H_e + z_\alpha + \frac{c^2{}_e}{2g} = H_B + z_E + \delta h_{fEe} \tag{6}$$

If we subtract eq. 9 from eq. 5 we have:

$$H = H_{oa} - H_{oe} = h + \delta h_{fEaA} \tag{7}$$

where H stands for the energy given from the pump, h for the energy taken by the fluid, and δh_{fEaA} are the pressure losses in the pipes.
The energy given from the pump to the fluid is given by:

$$N_i = Q(P_{oa} - P_{oe}) = Q(\rho g(H_{oa} - H_{oe}) = \gamma * Q * H \tag{8}$$

The efficiency of the pump is the fraction of the energy given by the pump and the power given by the power grid :

$$\eta = \frac{\gamma * Q * H}{V * I} \tag{9}$$

2 Lab Exercise No 1

Basic units

Atmospheric pressure (atm) is the force per unit area by the weight of air above that point. 1 atmosphere is about 101,325 pascals. Barometer is a device used to measure the atmospheric pressure.
Bar is the atmospheric pressure at the sea level, which is around 100 kilopascals. Since the difference between atm and bar is so small, in most applications bar unit is used.

- 1 bar = 100,000 Pascal = 10.199 meters head
- 1 atm (standard atmosphere) = 101,325 Pascal = 10.33 meters head
- 1 Atm = 1.01325 Bars

Plot performance curve (H,Q), Power curve (N,Q) (power required on the shaft), efficiency curve (η,Q), see fig. 13. Mind the position of the pump suction side (0.6 m above the lower tank). The absolute static pressure at inlet $P_{Suction}$, $H_{Suction}$ reads:

$$H_{Suction} = H_{atm} - 0.6m \tag{10}$$

$$P_{Suction}(bar) = P_{atm} - (0.6 * (1000*9.81)) = P_{atm} - 5886\ Pa = P_{atm} - 0.05886\ bar \tag{11}$$

Therefore, the manometric pressure differential reads:

$$\delta p = P_{Discharge_{absolute}} - P_{Suction absolute} = \tag{12}$$

$$P_{Discharge_{manometric}} + 1bar - (1bar - 0.05886) = P_{Discharge_{manometric}} + 0.05886\ (bars) \tag{13}$$

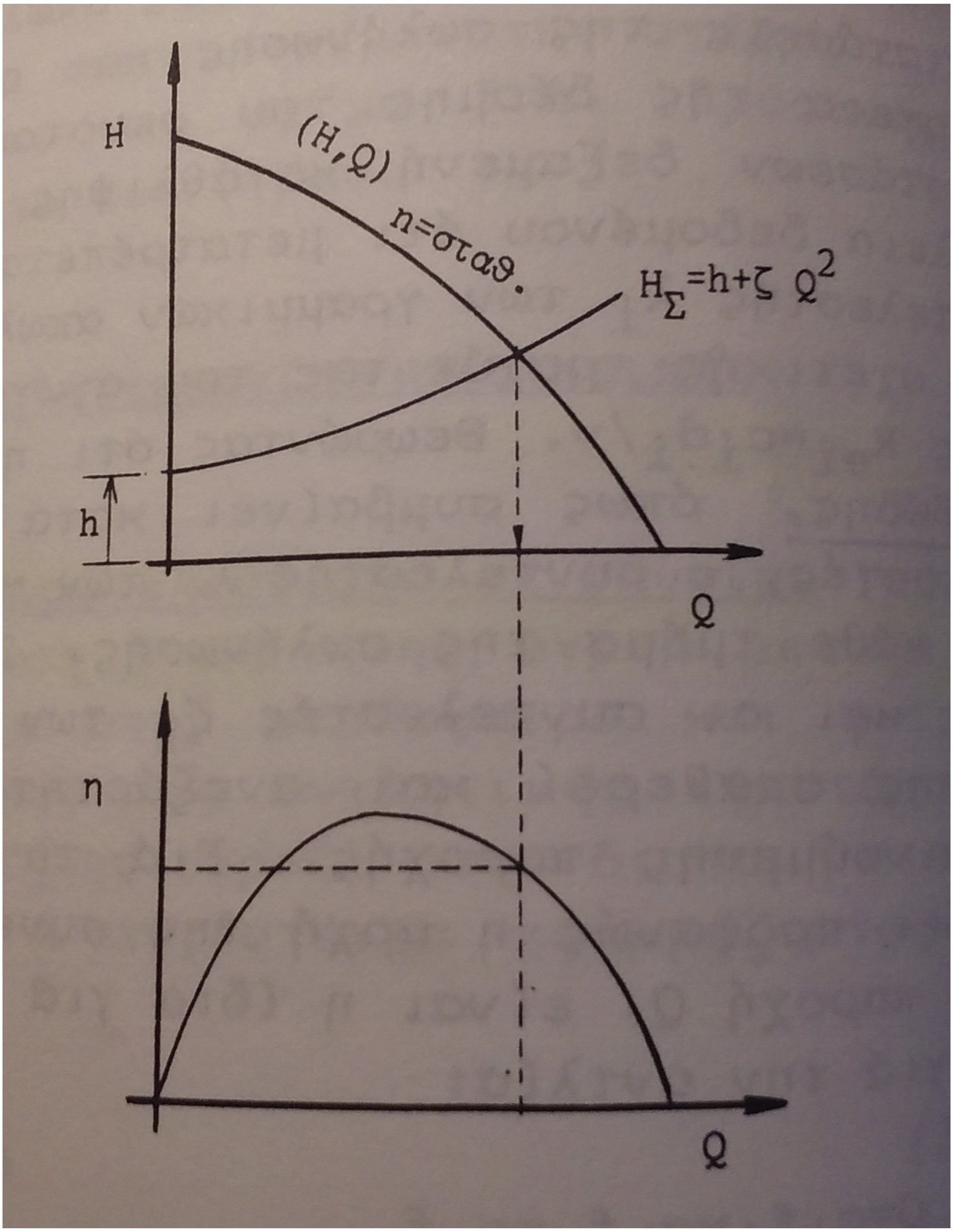

Figure 12: Operation point of pump

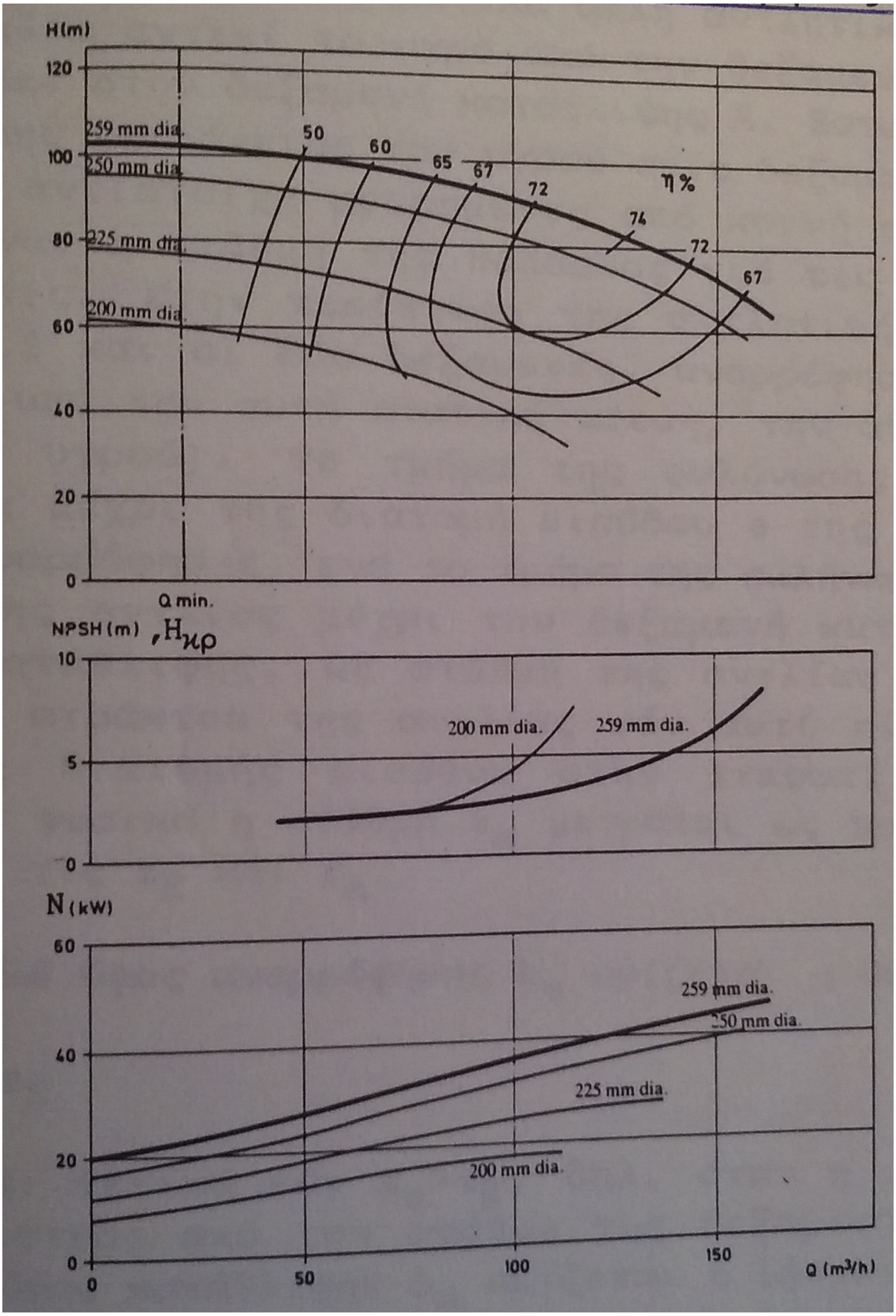

Figure 13: Pump curves

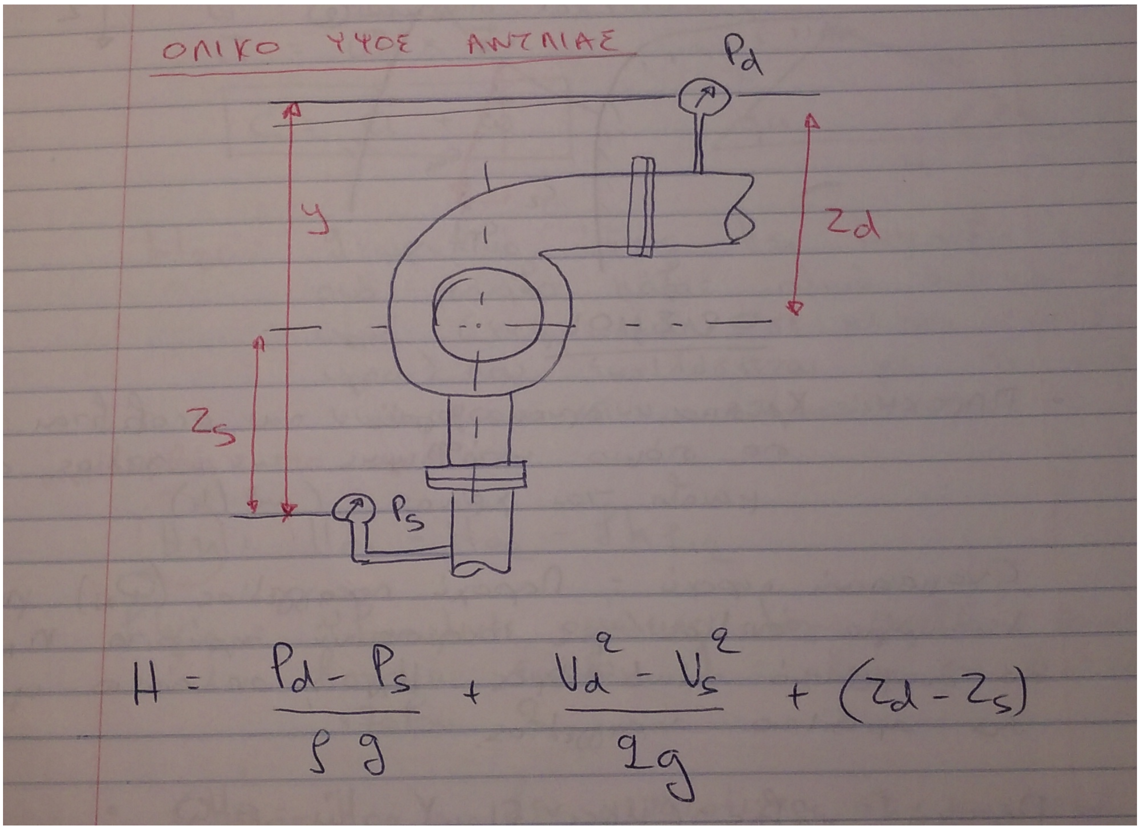

Figure 14: Pump total head