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Level : Master I
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Pumps & Pumping Stations Courses

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Sommaire

BIBLIOGRAPHICAL REFERENCES

I. GENERAL NOTIONS

I.1 Definition and areas of application of pumps

Pumps are devices that generate a pressure difference between the inlet and outlet pipes. Depending on the conditions of use, these machines communicate potential energy (by increasing the downstream pressure) or kinetic energy to the fluid by setting the fluid in motion.

Thus, we may want to increase the flow rate (increase in kinetic energy) and/or increase the pressure (increase in potential energy) for gaseous, liquid, viscous, very viscous fluids, etc. That's why the variety of pumps is so great.

There are two main categories of pumps:

I.1.1 Volumetric pumps

These are piston pumps, diaphragm pumps, plunger core pumps, etc. and rotary pumps such as screw, gear, vane and peristaltic pumps, etc. When the fluid conveyed is a gas, these pumps are called "compressors".

I.1.2 Turbopumps

They are all rotatable. These are centrifugal, propeller, helico-centrifugal pumps.

a) Radial turbomachines :

In this type of turbomachinery, the fluid passes through the impeller (rotor) perpendicular to the shaft axis of the machine.

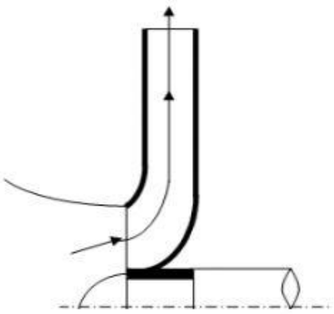


Fig. I.1 : Radial turbomachinery wheel

b) Axial turbomachines :

Here, the fluid flows through the machine wheel parallel to the axle.

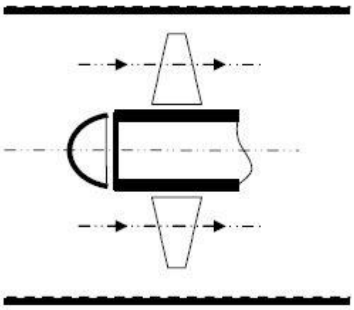


Fig. I.2 : Axial turbomachinery wheel

c) Semi-axial turbomachines :

These are machines where the fluid passes diagonally through the wheel. They are also called helicocentrifugal or helical machines.

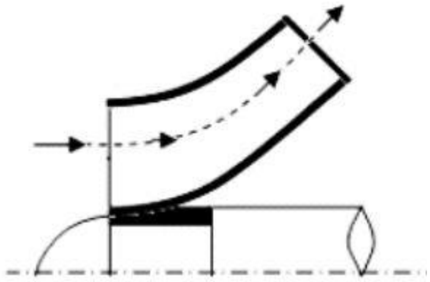


Fig. I.3 : Wheel of a semi-axial machine

The areas of use of these two broad categories are grouped together in the figure below:

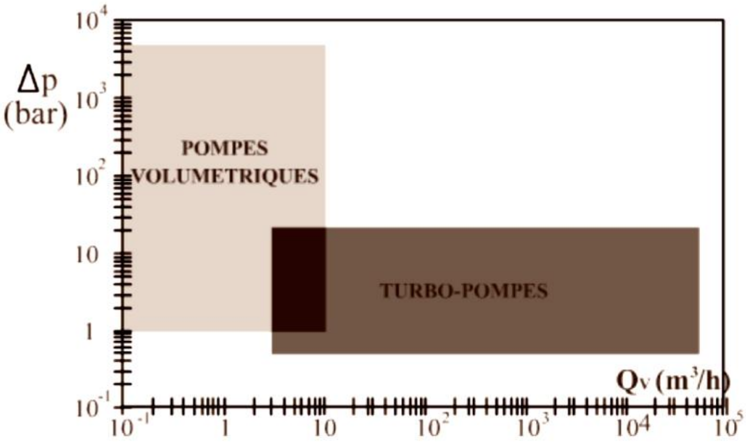


Fig. I.4 : Areas of application of the two main categories of pumps

I.2 Use of water resources from an energy perspective

Since ancient civilizations, different types of energy have been used by humans for pumping water, including :

Seghia : A kind of shallow gutter, while maintaining a certain slope so that the water can flow by gravity.

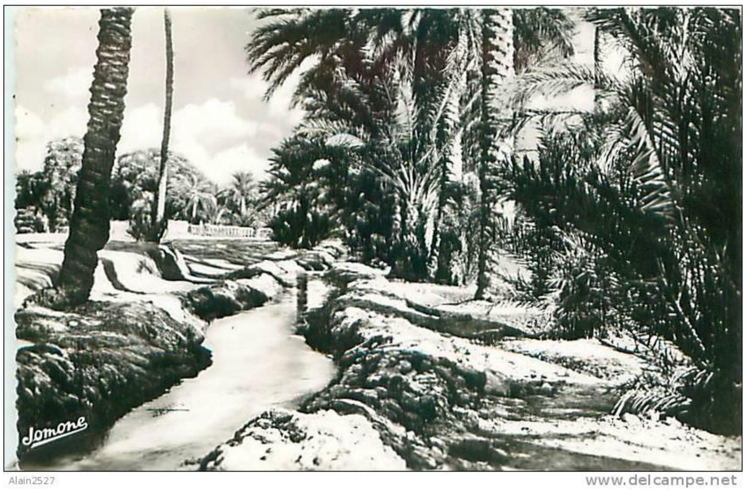


Fig. I.5 : Photo of a Seghia in the Algerian Sahara

Foggaras : A type of underground tunnel, they are generally found in Algeria at the level of Saharan oases.

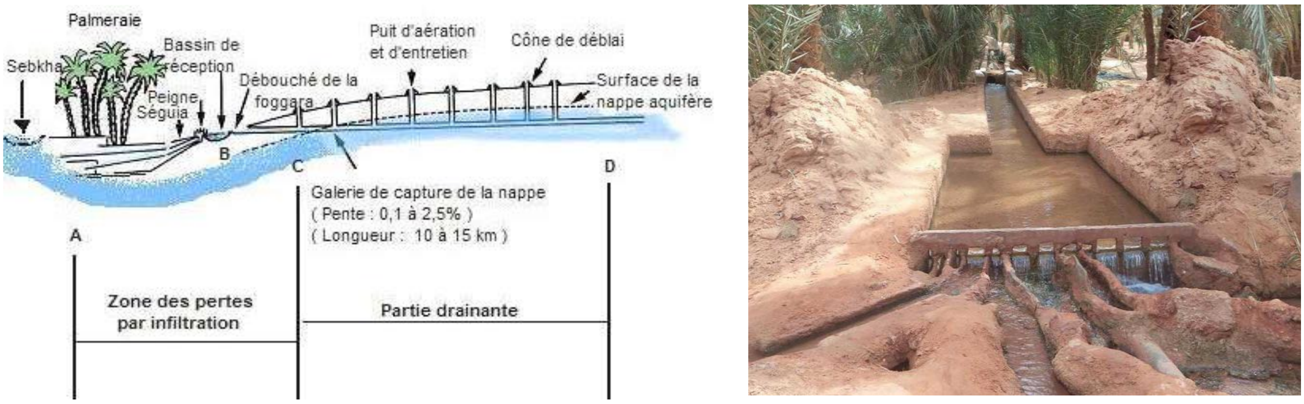
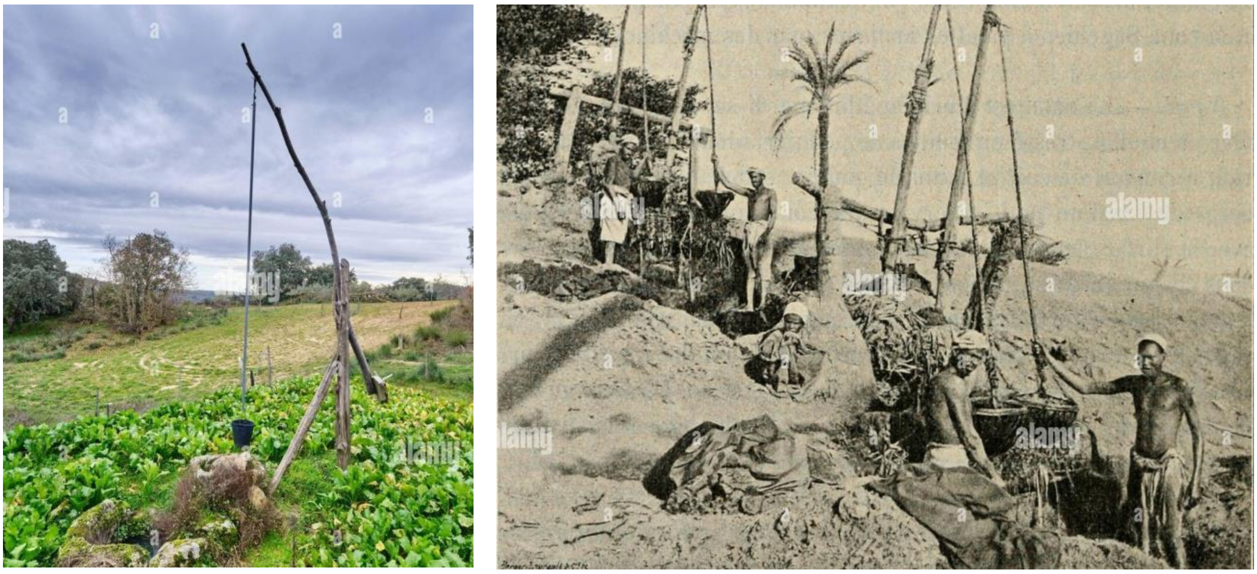


Fig. I.6 : Photo of a Foggara in the Algerian Sahara

Chadouf : Is a pendulum system with counterweights.



Chadouf from a well Chadouf by step

Fig. I.7 : Photo of a Chadouf in Egypt

Noria : Uses animals or humans to raise water by turning.

Fig. I.8 : Photo of a Noria in Egypt

Archimedean screw : a water elevation system with a constant flow of water, uses either human energy or other energies.

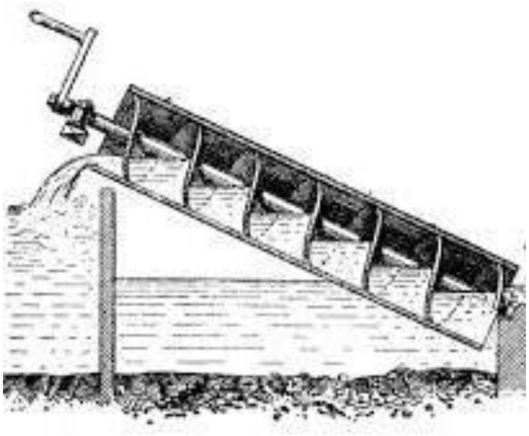


Fig. I.9 : Image of an Archimedean screw

I.3 Energy transformations

The energy chain of a pump is shown in the following diagram:

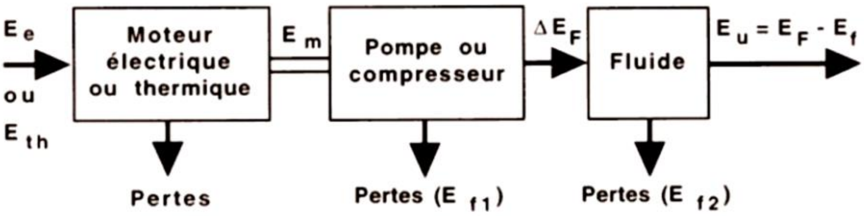


Fig. I.10 : Energy chain of a pump

Overall, 60 to 90% of the energy supplied by the engine is converted into mechanical energy. Only 50 to 80% of this mechanical energy will then be communicated to the fluid. Turbopumps are used to produce hydraulic energy from mechanical energy, often provided by an electric or combustion engine (e.g. diesel engine). The pump accelerates the fluid that passes through it by imparting a rotational movement, and therefore a certain hydraulic energy.

This hydraulic energy can be seen as the sum of kinetic energy determined by the liquid motion in the tube and potential energy stored either in the form of an increase in pressure or an increase in height (Bernoulli's theorem).

On the other hand, turbines produce mechanical energy (which will be transformed into electrical energy by an alternator) from the hydraulic energy of the different water flows (rivers, streams, waterfalls, sea currents, etc.).

I.4 Characteristic Parameters of the Operation of Hydraulic Machines

I.4.1 Manometric Total Head (HMT)

The manometric total head of a pump is the energy supplied by the pump to the unit weight of the liquid that passes through it. If HTA is the total fluid charge at the suction port and HTR is the total fluid charge at the discharge port, the pump head is:

$$\mathbf{HMT = HTR - HTA} \qquad \textbf{(I.1)}$$

The height varies with the flow rate and is represented by the characteristic curve H = f (qv) of the pump under consideration.

I.4.1.1 Suction height

This is the difference in altitude (height) between the suction point (the level from which a fluid is to be raised) and the axis of the hydraulic machine.

For centrifugal pumps this height is limited, since it is theoretically known that by creating a vacuum in a tube, it is impossible to raise the water to a height higher than atmospheric pressure.

When : H = 0.000 [NGA] So h = 10.33 m

For an altitude A then h = 10.33 - 0.0012 A m.

In reality, this height is significantly lower; Loss of head due to pressure drops and liquid velocity.

I.4.1.2 Discharge height

This is the difference in altitude between the point where the fluid to be pumped is to be brought back and the axis of the hydraulic machine.

I.4.2 Flow

This is the amount of fluid that passes through the hydraulic machine during the unit of time. A distinction is made between the mass flow rate q_m, which expresses the mass of the fluid during the unit of time (Kg/s), and the volume flow q_v given in (m^3/s).

$$q_m = \rho . v . S_1 = \rho . v . S_2 \qquad \textbf{(I.2)}$$

$$q_v = v . S_1 = v . S_2 \qquad \textbf{(I.3)}$$

- q_m: Mass flow rate (Kg/s);
- q_v: volumetric flow rate (m^3/s);
- v: Speed (m/s);
- S: Surface area (m^2).

I.4.3 Power and efficiency

Of course, the mechanical energy to be supplied to the machine is always greater than the hydraulic energy supplied to the liquid. Shaft power is the mechanical power required to operate the pump, it is given by:

$$P_{\text{to the tree}} = U\ I \cos \varphi \qquad \textbf{(I.4)}$$

With :

- U : voltage of the electric current;

- I: current intensity;
- cos φ: phase shift.

The hydraulic power supplied by the pump is given by the relation:

$$\mathbf{H_{hydraulic} = \rho\, g\, Q\, H} \qquad \textbf{(I.5)}$$

In which :

- $H_{hydraulic}$: is expressed in Watts;
- ρ : is the density of the liquid (kg/m^3) ;
- g : is the acceleration of gravity or 9,81 m/s^2 ;
- Q : is the volume flow rate of the liquid expressed as m^3/s ;
- H : is the head of the pump expressed in meters.

The η coefficient of proportionality between these two parameters is called pump efficiency. So we have the relationship:

$$\mathbf{\eta = P_{hydraulic} / P_{to\ the\ tree}} \qquad \textbf{(I.6)}$$

The efficiency varies depending on the operating point, and also depends on the machine. For conventional machines, it is usually between 70% and 90%.

I.5 Characteristic Parameter Measurements

For the measurement of flow rates, flow meters are used, while for pressures the following are used: pressure gauges for the measurement of overpressures and vacuum gauges for the measurement of depressions.

II. GENERAL TURBOMACHINERY RELATIONS

II.1 Definition and classifications

II.1.1 Definition

A turbomachine is a mechanical assembly of revolution comprising one or more movable wheels (rotors) equipped with vanes (blades, fins) which create channels between them through which the fluid flows.

The energy exchange takes place in the rotor and results from the work of aerodynamic forces on the blades produced by the flow of fluid around them, and which result mainly from the pressure difference between the two faces of the blades. It should be noted that, although the work is again produced by pressure constraints, it is simply done by rotating the blades.

II.1.2 Classifications

There are many criteria used to classify turbomachinery. The most important ones are :

- **The nature of the fluid** : A distinction is made between hydraulic machines with incompressible flows and machines with compressible flows ;
- **The function of the machine** : A distinction is made between the receiving machines that receive work and the driving machines that provide it. Receiving machines include turbopumps, fans, turbofans, turbochargers, and aerial and marine propellers. The main driving machines are steam and gas turbines, hydraulic turbines, as well as wind turbines;
- **The path of the fluid** : In some machines, the current tube running through the machine is essentially parallel to the axis of the machine, and so they are called axial machines. Both aerial and marine propellers fall into this category. In other machines, on the other hand, the current tube passing through the machine is essentially perpendicular to the axis, and the machine is said to be radial (centrifugal or centripetal). There are also intermediate, so-called mixed, configurations in which the flow has both axial and radial components ;
- **The mode of action of the fluid** : Action machines, in which the pressure remains constant through the rotor, and reaction machines in which it varies ;
- **The number of elements arranged in series** : a distinction is made between single-stage and multi-stage hydraulic machines.

II.2 Basic Theory of Turbomachine Operation – EULEUR Theory

To understand it, we need to imagine the energy balance between a fluid particle at the inlet of the wheel, and the same particle at the outlet. Since all the energy of the wheel's rotational motion is transferred to the liquid, the torque applied to the blades will be equal to the product of the flow of the liquid by the change in its momentum between its inlet and exit of the wheel. This requires an understanding of the wishbones at the wheel input and output.

II.2.1 Conservation of Mass

The equation for conservation of mass (continuity) expresses that the accumulation of matter in a control volume over time is equal to the sum of the mass fluxes that cross the boundaries of the volume (see Eq. I.2 and I.3 above).

II.2.2 Conservation of momentum

The principle of conservation of momentum states that the summation of forces is equal to the accumulation of momentum in a control volume over time plus the sum of momentum flows that cross the boundaries of volume…

$$F = \frac{d}{dt}\int_V \rho v dV + \int_s \rho v . v dS \tag{II.1}$$

With :

F : Summation of forces ;

- $d/dt\int \rho v dV$: Momentum Accumulation in a Control Volume Over Time;
- $\int \rho v . v dS$: Sum of momentum flows through both input and output surfaces.

Moment of momentum :

The angular moment of momentum is given by the following equation:

$$M = \frac{d}{dt}\int_V r.\rho v dV + \int_S r.\rho v . v dS \tag{II.2}$$

Stationary state :

$$\frac{d}{dt}\int_V r.\rho v dV = 0 \tag{II.3}$$

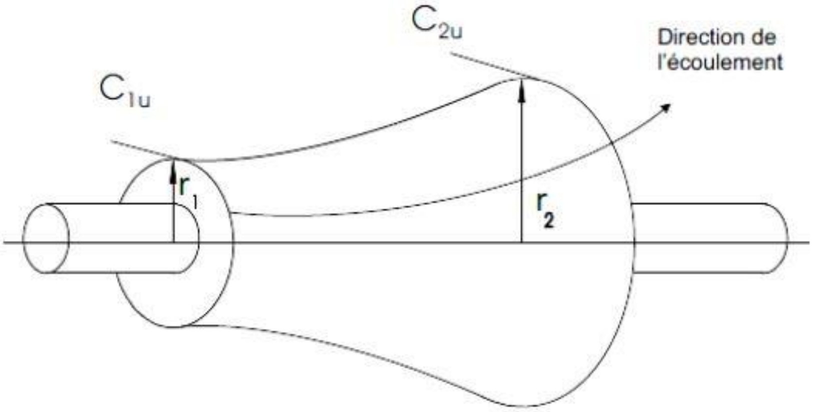


Fig. II.1 : Schematic rotor

$$M = \int_S (r.\rho v)v.dS = (r_2 . v_2)\rho_2 v_2 S_2 - (r_1 . v_1)\rho_1 v_1 S_1 \tag{II.4}$$

Using equation (I.2), equation (II.4) becomes:

$$M = Q_m\,(r_2 v_2 - r_1 v_1) \qquad \textbf{(II.5)}$$

II.2.3 Speed diagrams

The movement of the fluid within the channels of a paddle wheel is the result of two motions:

- The rotation of the wheel: represented by the speed tangential to the wheel $\vec{U}$ (also called peripheral velocity, circumferential velocity and drive speed). It is given by:

$$U = \pi D N / 60 = 2\pi r N / 60 \qquad \textbf{(II.6)}$$

With :

D : Wheel diameter;

N : Wheel rotation speed (rpm).

- Displacement relative to the blade: represented by the relative velocity $\vec{W}$ which is tangent to the dawn.

Figure II.1 shows a turbine wheel with the velocity vectors plotted (at the input "subscript 1" and at the output "subscript 2").

The velocity $\vec{C}$ is called the absolute velocity, which can be determined by: $\vec{C} = \vec{U} + \vec{W}$. In some reference documents, absolute velocity may be referred to as $\vec{V}$.

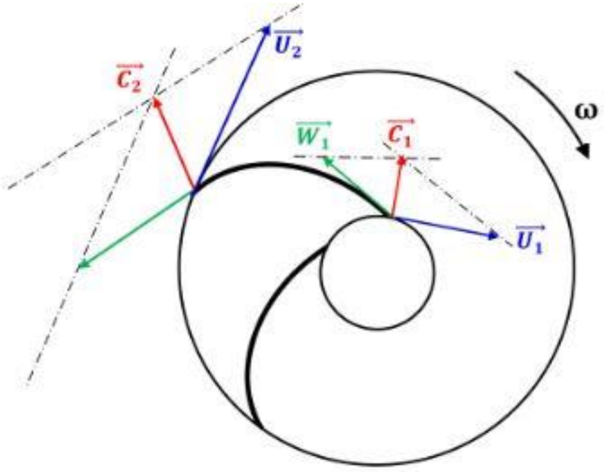


Fig. II.2 : Speed diagrams on a radial input wheel

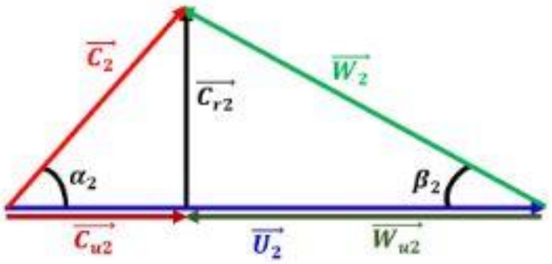


Fig. II.3 : Triangle of gears at the output of a radial turbomachinery

The angle α (shimming angle) is formed by the velocities $\vec{U}$ and $\vec{C}$ and the angle β (angle of construction) is formed by the velocities $\vec{U}$ and $\vec{W}$. It should be noted that the inclination of the blades does not depend on the operating speed.

In what follows, two more components of absolute velocity must be taken into account:

- A radial component :

$$C_r = C.\sin\alpha \tag{II.7}$$

- A circumferential component :

$$C_u = C.\cos\alpha \tag{II.8}$$

The C_r component can be determined using the continuity equation:

$$C_r = Q_v / S = Q_v / \pi D b \tag{II.9}$$

For a radial inlet turbomachine, the absolute velocity is perpendicular to the drive velocity and equal to its radial component since the tangential component is zero. ($C_1 = C_{r1}$, $\alpha_1 = 90°$).

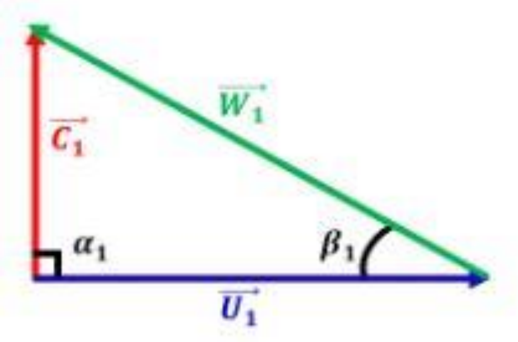


Fig. II.4 : Triangle of gears at the input of a radial turbomachinery

II.2.4 Euler’s Theorem

The starting point for the study of turbomachinery is Euler's equation. This can be easily deduced from the principle of conservation of angular impulse or moment of momentum. In particular, a one-dimensional steady-state flow in the rotor of a turbomachinery engine with uniform inlet and outlet conditions denoted by indices 1 and 2, respectively, is considered. Equation I.2 is then applied to a stream of fluid between its two points shown in figure II.1 and it becomes:

$$M = Q_m\,(r_2 v_2 - r_1 v_1) \tag{II.10}$$

Although this expression of Euler's equation is in an elegant mathematical form, it requires modifications to be easily usable.

In turbomachines ; $r.\,v = r.\,Cu$ (figure II.5).

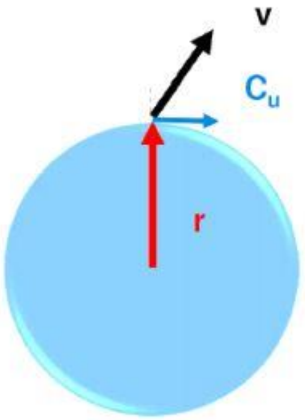


Fig. II.5 : Velocity Component Used to Calculate Angular Moment

Equation (II.5) becomes :

$$M = Q_m (r_2 C_{u2} - r_1 C_{u1}) \quad \textbf{(II.11)}$$

The power absorbed by the pump is determined by :

$$P = M.\,\omega = Q_m (r_2 C_{u2}\omega - r_1 C_{u1}\omega) \quad \textbf{(II.12)}$$

Where ω is the angular velocity of the wheel. Given that the tangential velocity U can be determined by: U=r.ω, equation (II.12) can be written as follows (efficiency equal to 1):

$$P = Q_m (C_{u2} U_2 - C_{u1} U_1) \quad \textbf{(II.13)}$$

The power consumption of the pump can also be determined as follows:

$$P = Q_m.\, g.\, H_{th} \quad \textbf{(II.14)}$$

Equalizing the two equations (II.13) and (II.14) gives Euler's equation:

$$H_{th} = (U_2 C_{u2} - U_1 C_{u1}) \,/\, g \quad \textbf{(II.15)}$$

For radial inlet turbomachinery, $C_{u1} = 0$ ($\alpha_1 = 90°$) is given. As a result, Euler's equation simplifies and becomes:

$$H_{th} = (U_2 C_{u2}) \,/\, g \quad \textbf{(II.16)}$$

On the other hand, assuming a perfect plane flow, the quantity $r_2\, C_2 \cos \alpha_2 - r_1\, C_1 \cos \alpha_1$ is proportional to the flow of liquid passing through the wheel, the coefficient being equal to the thickness of the fluid vein. As a result, Euler's theory provides for straight lines for characteristic curves.

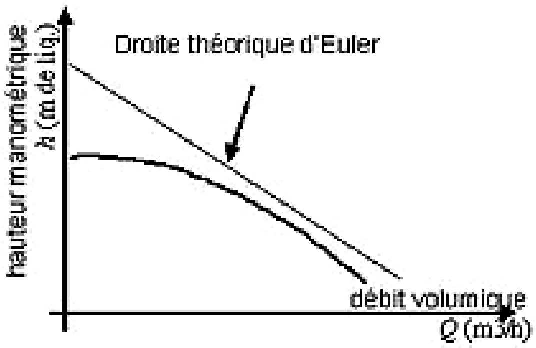


Fig. II.6 : The curve of the actual pump shows optimum efficiency where it best approximates the theoretical line

II.3 Bernoulli's theory in relative motion applied to the motion of the fluid within a turbomachinery wheel

II.3.1 Generalized Bernoulli Relation

If frictional forces occur (Pf dissipated power < 0) or when the fluid passes through a hydraulic machine, it exchanges energy with that machine. This exchanged power P is given by the generalized Bernoulli relation established between two points 1 and 2 (the fluid moving in the direction of 1 → 2) Under the form :

$$\frac{1}{2g}\left(v_2^2 - v_1^2\right) + (z_2 - z_1) + \frac{(p_2 - p_1)}{\rho g} = \frac{P}{\rho g q_v} \qquad \text{(II.17)}$$

- P > 0 if the energy is received by the fluid (e.g., pump P_G) ;
- P< 0 if the energy is supplied by the fluid (e.g., turbine P_R).

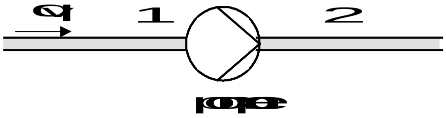


Fig. II.7 : Calculation scheme

$$\left(\rho\frac{v_2^2}{2} + \rho g z_2 + p_2\right) - \left(\rho\frac{v_1^2}{2} + \rho g z_1 + p_1\right) = \frac{P_f + P_R + P_G}{q_v} \qquad \text{(II.18)}$$

II.3.2 Case of an ideal pump

$$\frac{1}{2g}\left(v_2^2 - v_1^2\right) + (z_2 - z_1) + \frac{(p_2 - p_1)}{\rho g} = \frac{P}{\rho g q_v} \qquad \text{(II.19)}$$

For a pump, we call Net head or Manometric head the quantity H given by :

$$H_{Pompe} = \frac{P}{\rho g q_v} \quad \textbf{Ou} \quad H_{Pompe} = \frac{P}{g q_m} \qquad \text{(II.20)}$$

With :

- q_v : volume flow rate ;
- q_m : mass flow.

II.3.3 Case of a pump with friction

It now remains to establish the power dissipated by the frictional forces.

We use the relationship between two points 1 and 2 (the fluid moving in the direction 1→ 2) under the form :

$$\left(\frac{v_2^2}{2g}+\frac{p_2}{\rho g}+z_2\right)-\left(\frac{v_1^2}{2g}+\frac{p_1}{\rho g}+z_1\right)=H_{pompe}-\sum_i h_i$$

$$H_{T2}-H_{T1}=H_{Pompe}-\sum h_i \qquad \textbf{(II.20)}$$

$$\frac{v^2}{2g}+z+\frac{p}{\rho g}=H_T$$

$\Sigma\ h_i$ represents all pressure drops (mce) between 1 and 2.

III. DESCRIPTION AND OPERATION OF CENTRIFUGAL PUMPS

III.1 Description of a centrifugal pump

A centrifugal pump is a rotating machine designed to impart sufficient energy to the pumped liquid to cause it to move through a hydraulic network generally comprising a geometric height of level rise (Z), an increase in pressure (p) and always pressure drops.

A centrifugal pump consists mainly of a finned or vane impeller (rotor) that rotates inside a sealed housing called a pump casing.

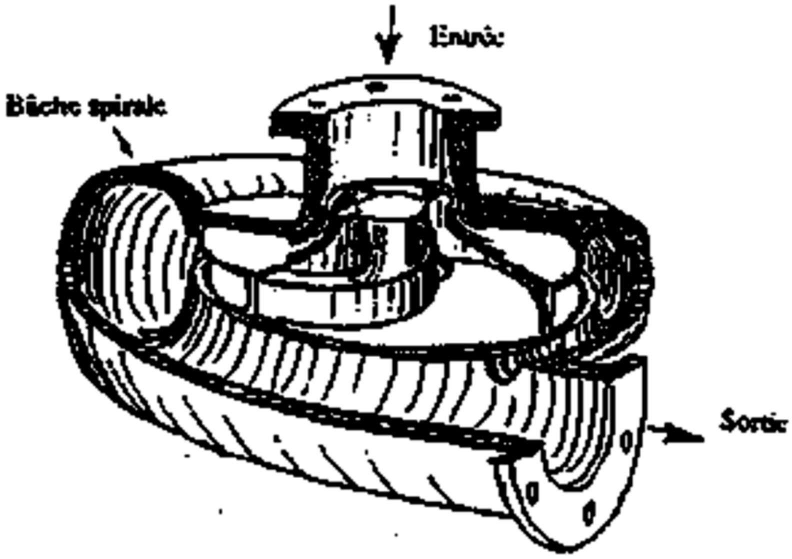


Fig. III.1 : Centrifugal pump

III.1.1 The ear

Together with the pump body, it forms the fixed element intended to direct the liquid to the inlet of the impeller, so that the speed is uniform at all points.

III.1.2 The impeller

The impeller (turbine, impelsor, rotor) which is the moving element of the pump communicates to the liquid part of the kinetic energy transmitted by the shaft through its blades (vanes).

There are three main shapes of wheels :

- Closed wheel;
- Semi-open wheel;
- Open Wheel.

The height generated by the wheel is a function of the square of the peripheral velocity. As a result, for a given height to be achieved, the greater the rotational speed, the smaller the diameter will be, and vice versa. The higher the flow rate, the larger the inlet section and outlet width.

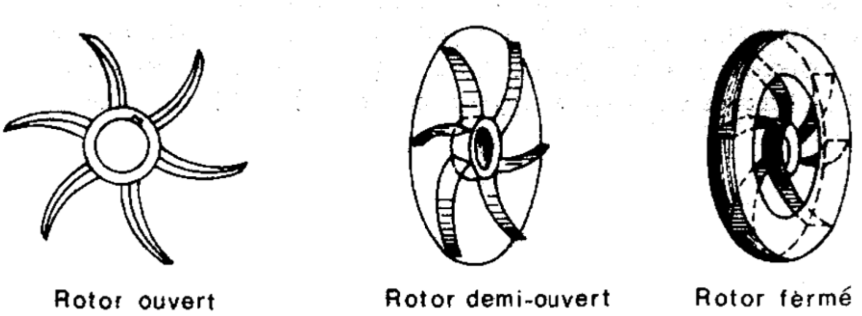


Fig. III.2 : Wheel types

III.1.3 The diffuser

It is the pump body, which constitutes the fixed element of the pump, is intended to collect the liquid that comes out of the impeller, and to direct it, either towards the volute or towards the inlet of the next impeller, depending on whether the pump is mono or multistage. It optimises the outgoing flow and thus limits energy losses. In addition, it transforms part of the speed into pressure. The main shape of the body depends on the type of pump (single or multistage).

III.1.4 The volute

The kinetic energy imparted to the fluid at the impeller by centrifugal force is converted into pressure energy in the volute. In addition, it acts as a manifold that directs the liquid to the discharge port.

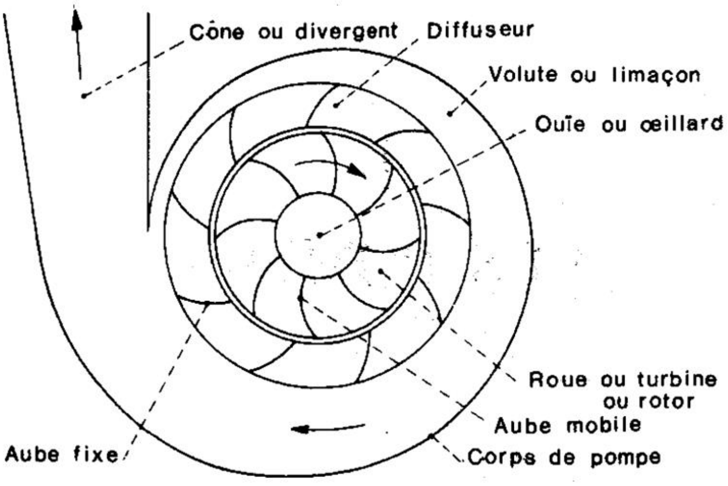


Fig. III.3 : Creation of a centrifugal pump

III.2 Drawing a centrifugal wheel

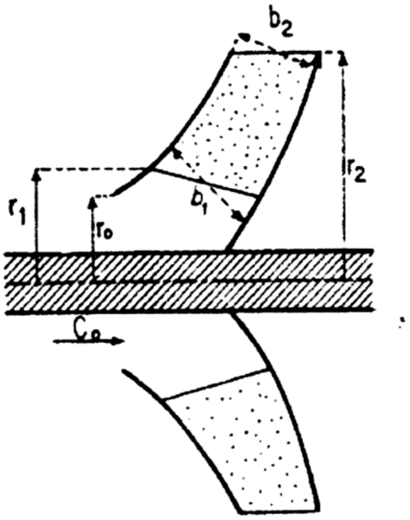


Fig. III.4 : Drawing a centrifugal wheel

The drawing of a wheel is generally done as follows :

- The input radius r_0 is determined by considering that the axial velocity C_0 must not exceed 2 to 6 m/s depending on the produced height of the wheel ;
- The radius r_1 is roughly 1 to 1.15 r_0 ;
- b1 deducted with C_1 greater than or equal to C_0 ;
- Flow rate taken into account = 1.03 to 1.1 qv because internal leaks are included ;
- b_1 and b_2 of the same order with $b_2 \leq b_1$;
- A ratio of $r_2/r_1 \leq 2$ is chosen unless the wheel is spinning slowly.

The wheels can be made of cast metal (cast iron, bronze, steel, stainless steel, etc.) or plastic. It is obvious that the choice of material will depend on the conditions of use and the nature of the fluid involved (corrosive fluid, high temperatures, etc.).

The blade is plotted from the angles β_1 and β_2 which have been calculated as a function of the fluid inlet and outlet velocities. Several methods exist to make the plot and are usually the result of empirical and experimental considerations and are part of the "trade secrets". Some consist of linearly evolving β_1 to β_2, others strive to achieve a continuous transfer of energy from the input to the output of the wheel (linear or parabolic growth of the power transmitted with the spoke).

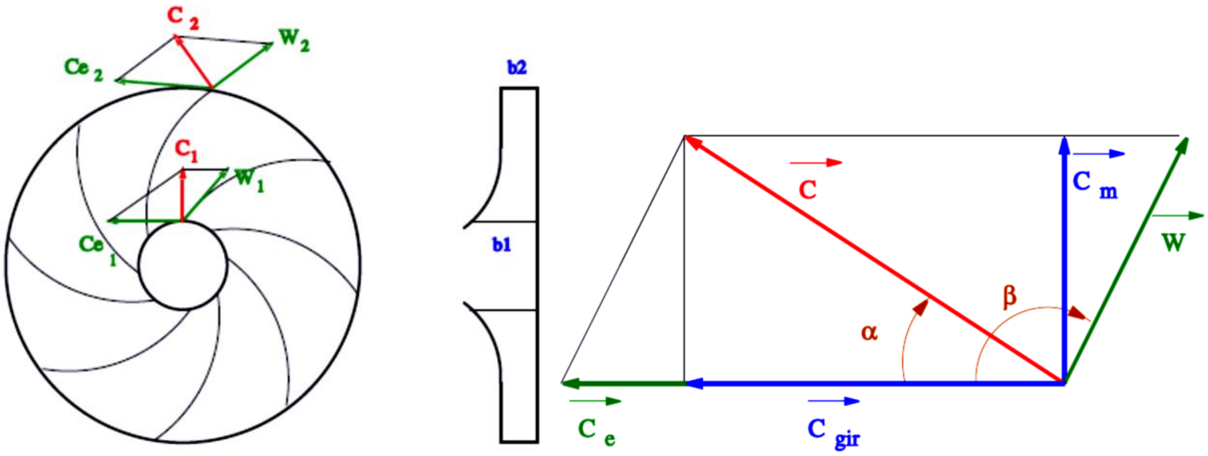


Fig. III.5 : Defining the Velocity Triangle Parameters

With :

- $\overrightarrow{C_{gır}}$ Roundabout speed ;
- $\overrightarrow{C_e}$ ou $\vec{u}$ Training speed ;
- $\overrightarrow{W}$ Relative speed ;
- $\overrightarrow{C_m}$ Meridian speed : $\vec{C} = \overrightarrow{C_{gır}} + \overrightarrow{C_m}$ ou $\vec{C} = \overrightarrow{C_e} + \overrightarrow{W}$;
- $\alpha = (\overrightarrow{C_e}, \vec{C})$ et $\beta = (\overrightarrow{C_e}, \overrightarrow{W})$.

III.3 Overall Pump Efficiency

The overall efficiency takes into account the energy losses in the pumps: hydraulic, volumetric and mechanical losses. It is given by the following relation :

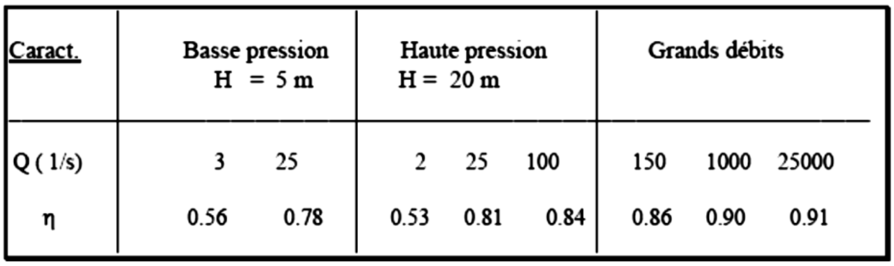
$$\boldsymbol{\eta_g = \eta_h\ \eta_t\ \eta_m} \qquad \textbf{(III.1)}$$

With :

- η_h : Hydraulic Pump Efficiency ;
- η_t : Transmission efficiency ;
- η_m : Motor efficiency.

Let's take a look at some efficiency values that are considered good for centrifugal pumps:

Table III.1: Efficiency values for different flow rates and elevation heights



Caract.	Basse pression H = 5 m		Haute pression H = 20 m			Grands débits		
Q (1/s)	3	25	2	25	100	150	1000	25000
η	0.56	0.78	0.53	0.81	0.84	0.86	0.90	0.91

III.4 Characteristic curves of a centrifugal pump

There are four main curves that characterize a pump. They are supplied by the manufacturer:

- Flow-head curve ;
- Yield curve ;
- Power curve ;
- NPSH Curve.

The first three characteristic curves are presented here, and the NPSH curve will be dealt with in Chapter VI.

III.4.1 Height-flow curve H (Q)

It shows the variations in the total head of head of elevation (HMT) that can be supplied by the pump as a function of the flow rate Q. They are essentially parables whose form :

$$H_p = a Q^2 + b Q + c \qquad \text{(III.2)}$$

III.4.2 Yield curve η (Q)

For each type of pump, it has a maximum in the vicinity of which the pump must be used. A dispersion of 25% around this point is however acceptable.

III.4.3 Power Curve P (Q)

This curve, which is a function of flow, is parabolic. For centrifugal pumps, the concavity of the dish is facing downwards. It differs for propeller pumps or helico-centrifugal pumps.

The power is equal to the work done during the unit of time to raise the corresponding flow rate to a height equal to the total head of the rise.

$$P = (\rho g Q H) / \eta \qquad \text{(III.3)}$$

With :

- P (Wh): total power consumed;
- ρ (kg/m3): density;
- Q (m3/s): flow rate;
- H (mce): head head;

- η: Total efficiency of the plant.

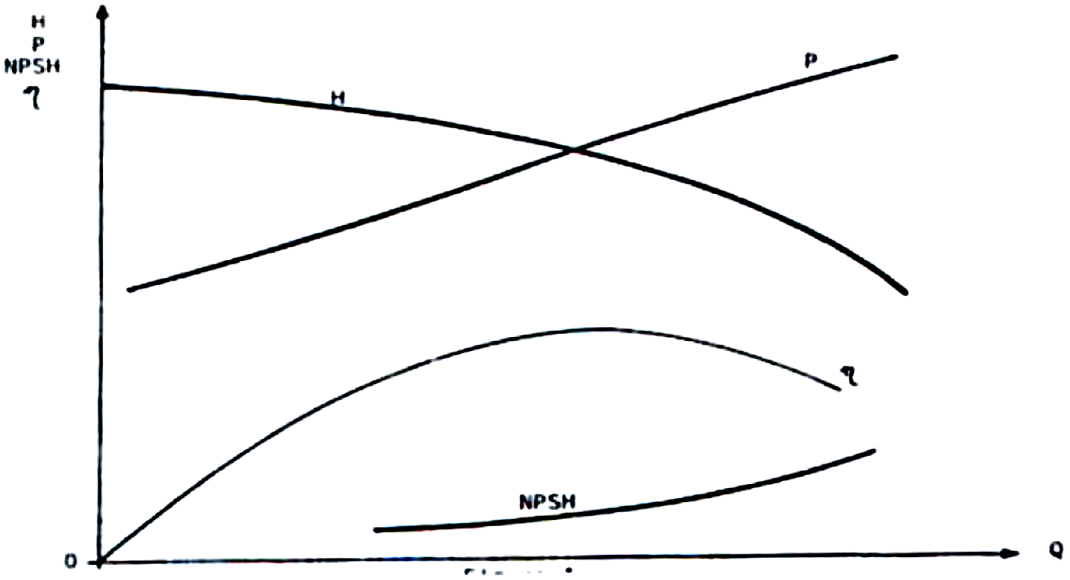


Fig. III.6 : Flow - height, efficiency and power curves

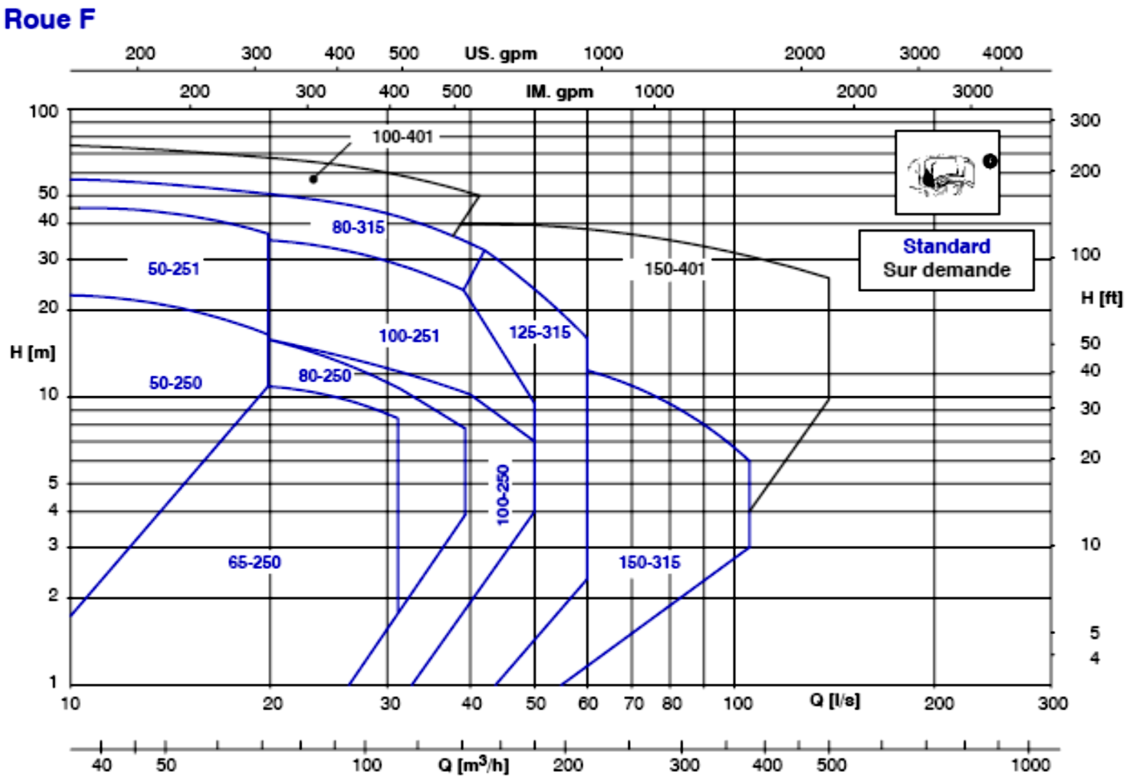


Fig. III.7 : Example of a KSB pump catalogue (Sewabloc F Dn Discharge Pump – Dn Impeller / 1 G V)

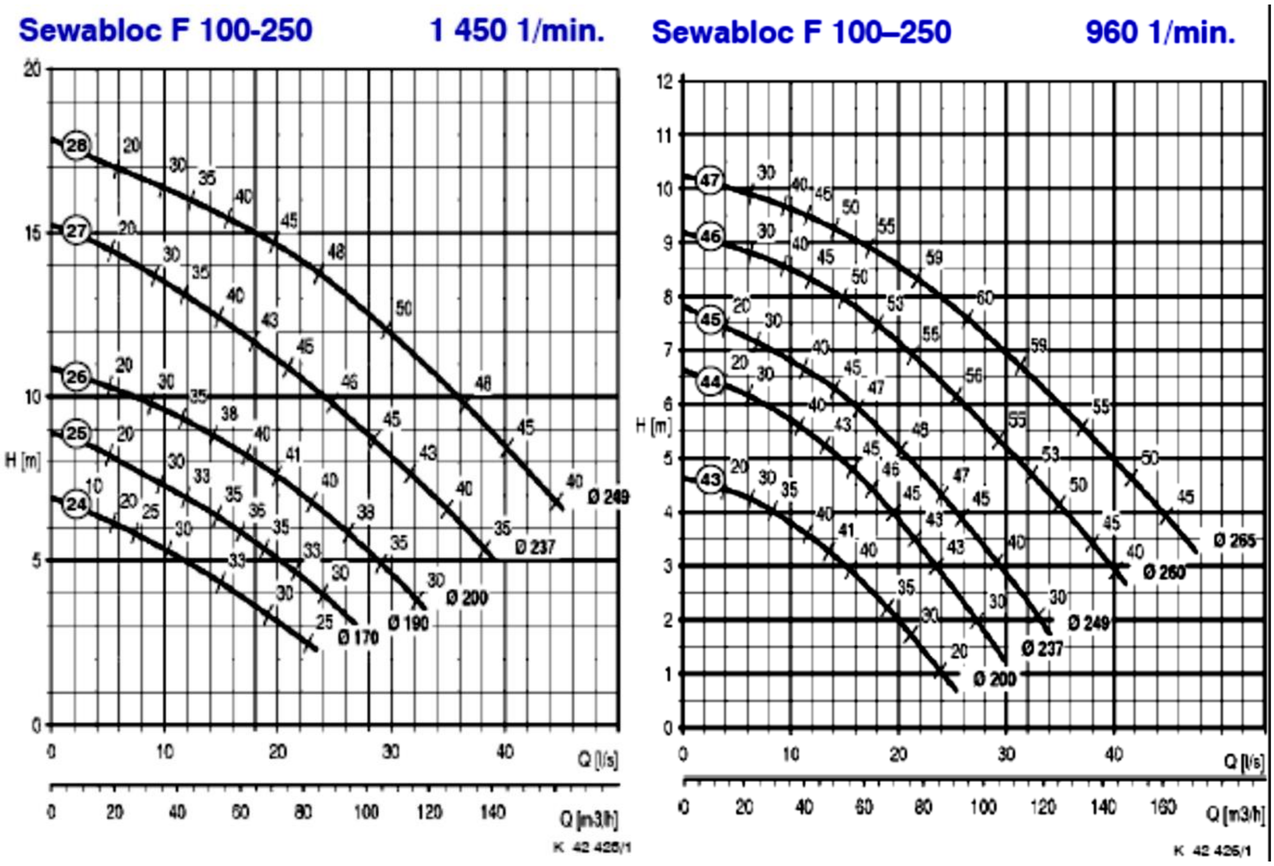


Fig. III.8 : Example of the characteristic curves of the Sewabloc F 100 – 250 pump for different speeds

III.5 Disc friction losses

Since friction in the wheel passage is considered similar to pipes with fully developed flow, the losses created by this friction are calculated according to the Blasius-Nikurrads law of pressure losses.

III.6 Leakage losses

Leakage or short circuit of liquid through the clearances between the stationary and moving parts of the machine.

The functional clearance between the moving organ and the machine body generates a fluid flow called q.

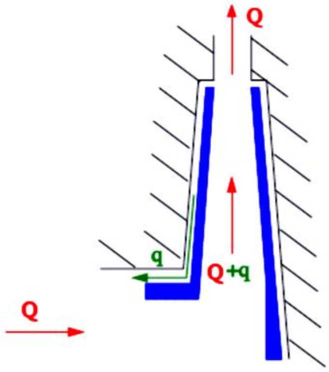


Fig. III.9 : Loss by leak

The conservation of the flow rate Q between the inlet and outlet of the impeller means that the impeller must give energy to the flow Q + q, to compensate for the leakage (q = f (p1, p2)).

III.7 Axial thrust

The forces resulting from the action of pressures on the front and rear flanges of different cross-sections of a wheel give rise to an axial thrust generally directed towards the suction.

III.8 Radial thrust

This thrust, perpendicular to the axis, results from a poor distribution of pressure around the impeller in volute pumps. The radial thrust maintains a fixed direction, changes direction around the nominal flow rate, cancelling out for the latter. It causes the shaft to flex and subject it to rotational bending.

IV. SIMILARITY THEORY APPLIED TO INCOMPRESSIBLE FLUID TURBOMACHINERY

IV.1 A Brief Reminder of the General Laws of Similarity

IV.1.1 Geometric similarity

Constant ratio between all geometrical elements of 2 pumps.

$L_1/L_2=K_L$ **(IV.1)**

With :

L: encompasses: length, width, and diameter;

K_L: Similarity Constant or Scale Factor.

IV.1.2 Kinematic similarity

Similar speed triangles between the 2 pumps.

$V_1/V_2=K_v$ ***et*** $A_1/A_2 = K_a$ **(IV.2)**

With :

V : Speed ;

A : acceleration.

IV.1.3 Dynamic similarity

Similar flow in the impellers of the 2 pumps in geometric and kinematic similarity.

$F_1/F_2=K_f$ ***et*** $I_1/I_2=K_m$ **(IV.3)**

With :

F: Force ;

I: Inertia.

IV.2 Similarity Theory

The laws of similarity of incompressible fluid turbomachinery result from the study of the following two questions :

- How does the operation of a pump vary when changing the rotational speed ?
- What are the characteristics of a pump or impeller that is geometrically similar to a given machine ?

The general conditions of similarities derive from fluid mechanics. The case of turbomachinery is only a special case. They can be deduced either from a direct study of the phenomena in question or from the general theorems relating to dimensional analysis.

IV.3 Quantities characterizing a class of similar turbomachinery

Rateau coefficients are dimensionless numbers that characterize a hydraulic machine. They are built from the geometrical and mechanical characteristics of the machine. For a given pump, the characteristic plotted using the Rateau coefficients is always the same regardless of the rotation speed and the fluid.

Flow Coefficient $\delta = Q/ \omega R^3$

Manometric Coefficient $\mu = H g/ \omega^2 R^2$

Power Coefficient $\tau = g P_u / \rho \omega^3 R^5$ **(IV.4)**

Efficiency $\eta = P_u / P_A$

With :

Q: Pump flow rate (m3/s);

ω : wheel rotation speed (rad/s);

R: wheel radius (m);

g: gravity (m/s2);

ρ: density (Kg/m3);

Pu: useful power (W);

Pa: power consumption (W).

Rateau coefficients are used to predict the behaviour of a pump (the characteristics) based on the characteristics of a pump of the same family operating at a different speed.

IV.4 Laws of proportionality in the case of turbopumps

Two pumps 1 and 2 designed on the same model but of different dimensions. From the characteristics of 1, those of 2 are given by :

$$\delta_1 = \delta_2 \qquad Q_2 = Q_1 \frac{\omega_2}{\omega_1} * \frac{R_2^3}{R_1^3}$$

$$\mu_1 = \mu_2 \qquad H_2 = H_1 \frac{\omega_2^2}{\omega_1^2} * \frac{R_2^2}{R_1^2} \tag{IV.5}$$

$$\tau_1 = \tau_2 \qquad P_2 = P_1 \frac{\omega_2^3}{\omega_1^3} * \frac{R_2^5}{R_1^5}$$

Thus, for a given pump (R1=R2), from a given characteristic and at a given speed, the characteristic of the same pump can be traced at any rotational speed (Figure 16). As a first approximation, it is assumed that the yield is not affected.

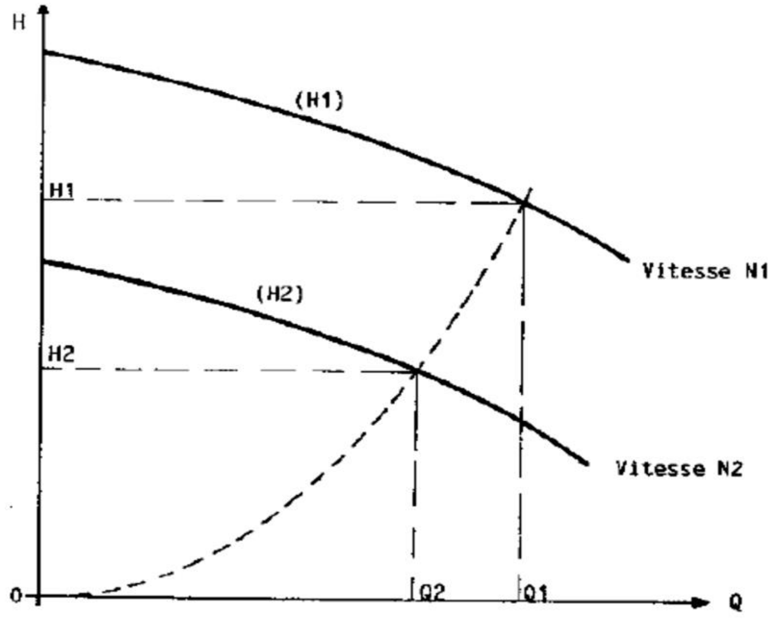


Fig. IV.1 : Characteristics of a pump operating at N1 and N2 speeds

It is noticeable that for a given wheel spoke :

- The flow rate Q increases with ω ;
- The manometric head H increases with ω^2 ;
- The power P increases with ω^3 ;
- The yield remains the same.

Rateau coefficients are useful for determining similarities between pumps. Indeed, from a given characteristic, it will be possible to determine the operation of the pump for other impeller speeds, other fluids or other impeller dimensions.

V. AXIAL TURBOMACHINES

V.1 Description of an axial pump

Figure V.1 shows that the blades of a pump can impose either radial, axial, or mixed flow.

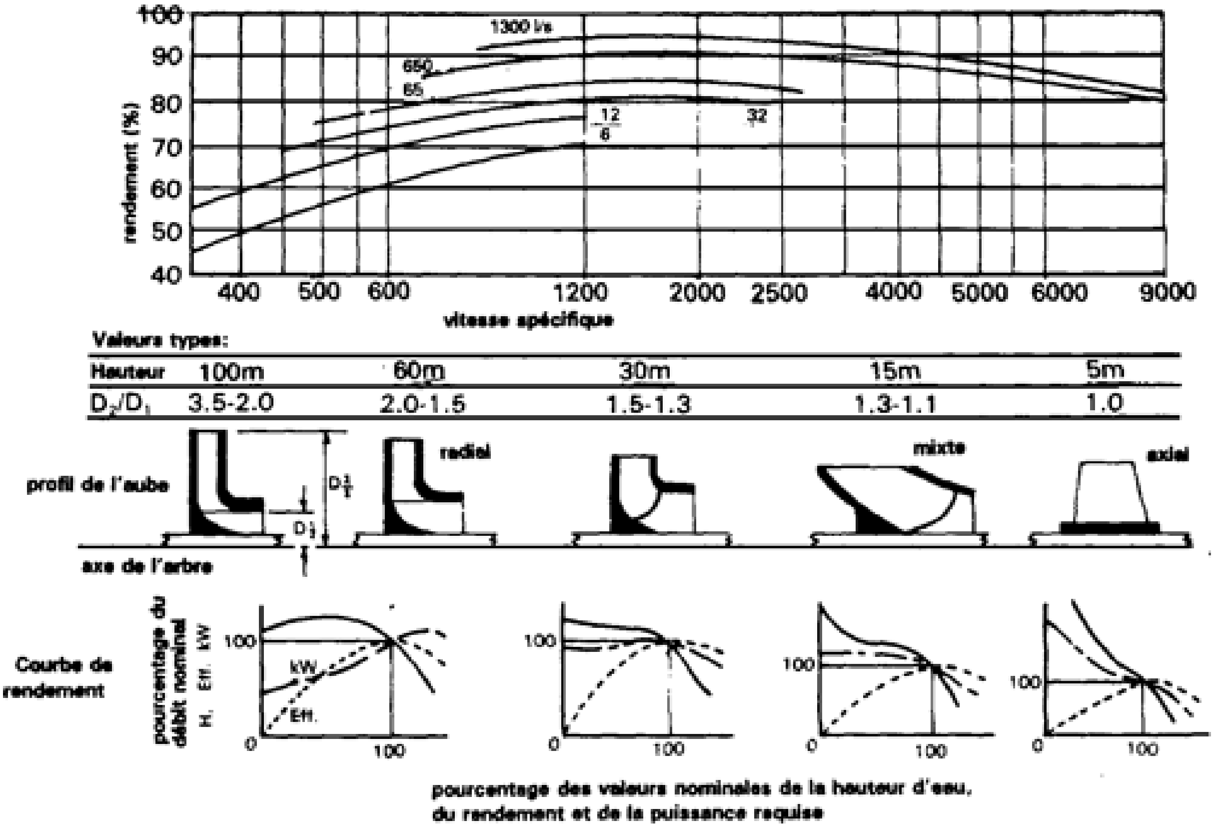


Fig. V.1 : Typical characteristics of turbomachinery

For pumping high flows at low water levels, which is very common in the case of pumped irrigation, the most efficient impeller is the axial flow impeller. The wheel is similar to a propeller installed in a pipe (Figure V.2).

As with a propeller, the rise in water is produced by the energy communicated by a well-profiled (aerodynamic) moving vane. As in the case of the pump, the propeller is mounted in a crankcase, the reaction sets the water in motion. On the other hand, for high water levels and low flow rates, the rotor must be centrifugal flow (radial flow). The rotor is typically characterized by a high ratio of inlet diameter to outlet diameter so that the flow is virtually radial and axial pumps are characterized by a low ratio of inlet-outlet diameter. Between these two extreme cases is the entire range of helico-centrifugal pumps.

V.2 Peculiarities of the flow through the impeller of an axial turbomachinery

We have already seen that most of the pressure exerted by the propeller pump is due to the propulsive action of its rotating blades on the water. This thrust has the effect of propelling the water towards the exit of the rotor or wheel, and it also imprints the water with a rotational motion (spin), which is a source of wasted energy. Indeed, the spin of the water would result in an increase in frictional forces and turbulence phenomena, without however having any positive effect on the discharge of water into the pipe. Propeller pumps are therefore equipped with guide vanes whose angle of inclination allows the flow to be straightened and the rotating component of the speed to be transformed into additional pressure, in much the same way as the diffuser of a centrifugal pump. The diagram in Figure 18 shows a typical example of a propeller pump with guide vanes mounted just above the rotor. These blades also have a secondary structural role since they have a large flat bearing that facilitates the centering of the shaft. This bearing is usually water-lubricated and has the same characteristics with the aft box of a boat's engine.

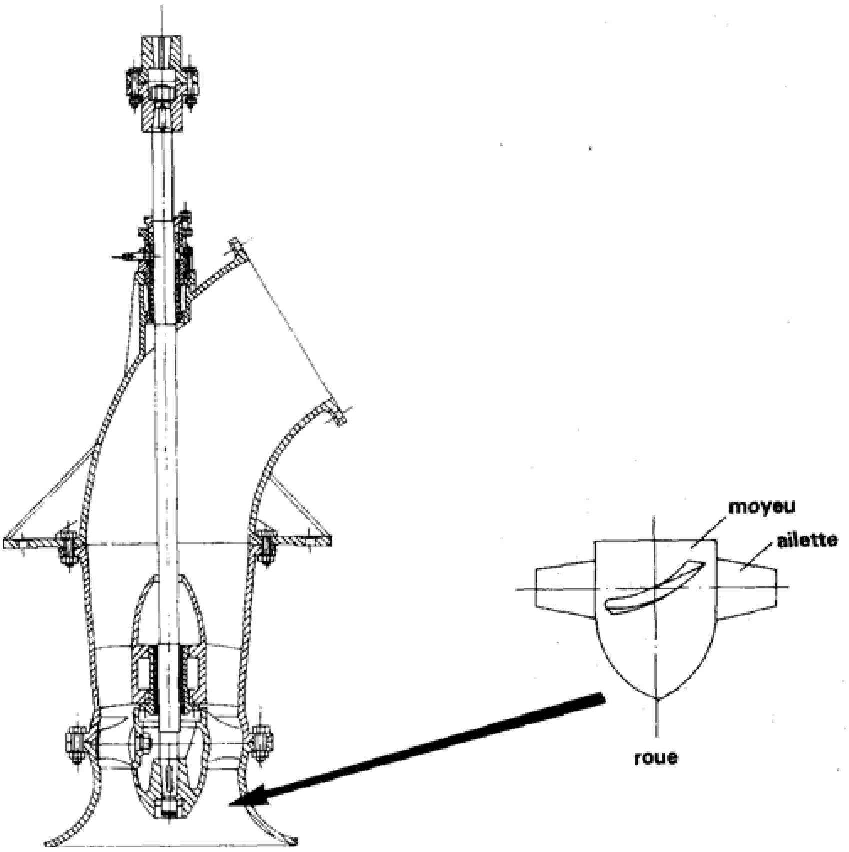


Fig. V.2 : Axial turbomachinery

Propeller pumps are typically manufactured for a flow rate range of 150 to 1500 m3/h. They have a vertical axis and their gauge heights vary from 1.5 to 3.0 m. Multi-stage propeller pumps (i.e. multiple impellers on the same shaft) can have discharge heads of about 10 m.

Propeller pumps are mostly too bulky, and their installation requires extensive civil engineering work. As a result, their area of use would be that of the largest farms. Typically, they are mostly used in open channel irrigation projects to raise large flows to heights of 2 to 3 m from a main channel to a supply or distribution channel.

VI. CAVITATION IN TURBOMACHINERY

VI.1 Some definitions

VI.1.1 Fluid Density

Density is an important factor to consider when sizing a pump. The density of a liquid can affect the pressure delivered by a pump. At the same vertical height, a liquid heavier than water requires a greater force to carry the fluid.

The graph below compares the liquid heights of liquids with different densities in liquid heights for the same pressure. A water column of 100 m (density of 1 or 1000 kg/m3) exerts a pressure of 9.81 bar, while a column of 83 m of brine (heavier liquid) and a column of 133 m of gasoline (lighter liquid) are required to exert the same pressure.

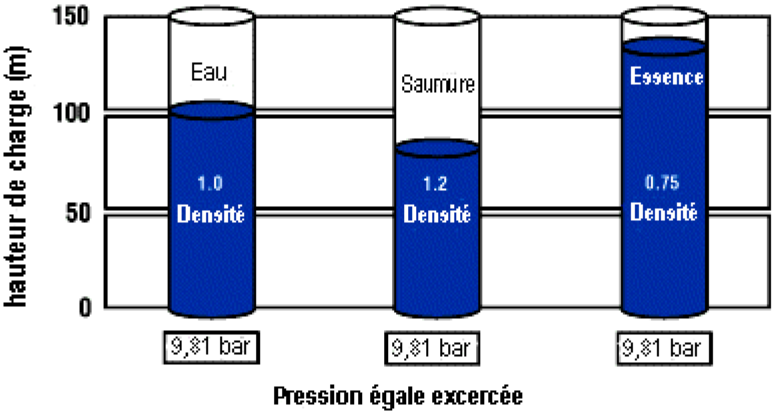


Fig. VI.1 : Liquid heights for the same pressure

VI.1.2 Atmospheric pressure (P_{atm})

In the same place, this atmospheric pressure of 1033 mbar at sea level can vary depending on the weather conditions. It is not uncommon to hear a low pressure of 960 mbar, which is a variation of 73 mbar from normal atmospheric pressure.

The generally adopted practical suction atmospheric pressure is a variation in less than 25 to 30 mbar, to be placed under unfavourable normal conditions, i.e. 1005 mbar.

VI.1.3 Saturation vapour pressure (P_v)

This is the maximum vapor pressure that the air can withstand at a given temperature. This is the case for air in contact with water. The saturation vapour pressure increases with temperature. At a given temperature, a liquid at a given boiling pressure corresponds to its vapour pressure. If the pressure at a point in this liquid falls below the vapour pressure, it comes to a boil.

For a mixture of liquids, the vapour pressure of the most volatile fraction, i.e. the highest vapour pressure, is taken as a value.

In a closed chamber, it vaporizes until the pressure is restored. In the open air, on the other hand, it vaporizes completely.

For pumping water at 20 °C, the vapour pressure is 2337 Pa (0.24 mce). For hot water, it can be several meters (101325 Pa or 10.33 mce at 100 °C).

VI.2 NPSH (Net Positive Suction Head)

A pump has a maximum suction capacity which is the value of the vacuum it can produce. This feature varies depending on the type and engineering design of the pump.

Theoretically, the maximum suction height in a cavity where there is an absolute vacuum is equal to the atmospheric pressure, i.e. 10.33 m of water at sea level. It gradually decreases as altitude increases.

In reality, this height is limited, not only by the pressure drops in the suction line but also by the physical properties of each type of liquid.

To remedy cavitation, sufficient pressure must always be provided to the suction of the pump. Only the machine manufacturer is in a position to determine by means of tests whether or not the head of the suction is sufficient. This essential feature of the machine is called its NPSH (Net Positive Suction Head). It is sometimes referred to as the "required NPSH" of the pump. For a given pump, the required NPSH increases with flow rate. Machine builders provide the required NPSH curves in addition to the characteristic curves mentioned above.

VI.2.1 Calculation of the NPSH available for a suction pump in an open water table

$NPSH_d$ (en Pa) = $P_{atm} - P_v - J_{asp} - H_h$ **(VI.1)**

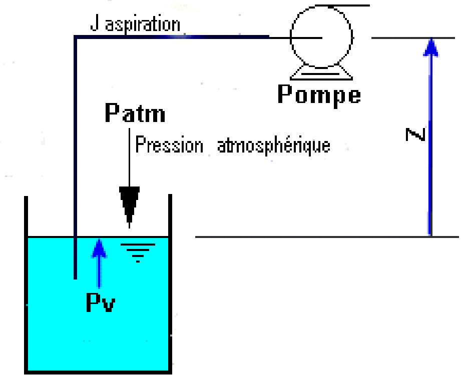


Fig. VI.2 : Suction pump

With :

- P_{atm} = Atmospheric pressure (depends on altitude) in Pa ;
- P_v = Absolute pressure (Pa) of vaporization of the fluid, see water table ;
- J_{asp} = Pressure losses of the suction line in Pa ;
- H_h = Hydraulic load of the fluid (H_h (in Pa) = $(9.81 * Z * \rho)$) ;
- ρ = density of the liquid in kg/m^3 ;
- 9.81 = Average intensity of gravity ;
- Z = Geometric (suction) height in meters of water, mCE.

To convert the NPSH expressed to Pa, to :

- NPSH in metres of water column = $(P_{atm} - P_v - J_{asp} - H_h) / 9810$;
- NPSH in Liquid meter = $((P_{atm} - P_v - J_{asp} - H_h) / \rho) / 9,81$.

VI.2.2 Calculation of the NPSH available for a loaded pump

NPSH (in Pa) = $P_{atm} - P_v - J_{asp} + H_h$ **(VI.2)**

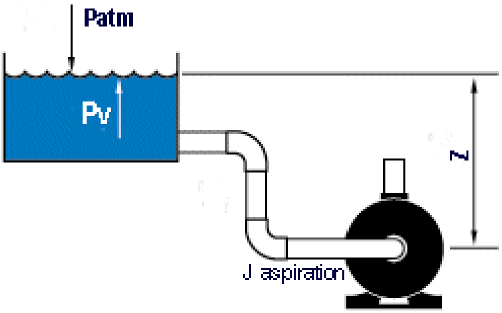


Fig. VI.3 : Pump on charge

VI.2.3 NPSH required

This is the minimum height of liquid (assumed at its boiling point), needed above the suction, to prevent cavitation.

It depends :

- The type of pump ;
- From the point of operation.

It is given by the pump manufacturer in the form of a curve giving the required NPSH (in meters of liquid) as a function of flow rate. Expressed in this way (in meters of liquid), the NPSH is independent of the nature of the liquid being pumped. It is always positive and usually a few meters (2 to 5 meters).

VI.3 Cavitation

Is a term used to describe the phenomenon that occurs in a pump when NPSH is insufficiently available. The pressure of the liquid is reduced to a value equal to or less than its vapour pressure where the small bubbles or pockets of vapour begin to form.

Accompanying noise is the easiest way to identify cavitation. Vibration and mechanical damage such as bearing failure can also occur due to operation in cavitation.

The only way to prevent the adverse effects of cavitation is to ensure that the NPSH available in the system is higher than the NPSH required by the pump. Generally, an additional margin of safety of 0.5 m. ($NPSH_r \leq NPSH_d - 0.5\ m$).

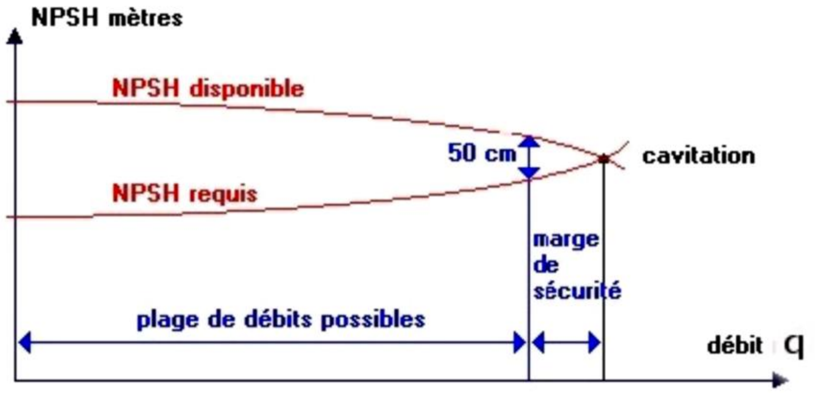


Fig. VI.4 : NPSH curves

VII. PUMP OPERATION IN A NETWORK

VII.1 Hydraulic pipelines and networks

VII.1.1 Type of pipes

VII.1.1.1 Cast iron pipes

A distinction is made between ductile iron pipes, which have a higher strength (42 daN/mm^2) and grey iron pipes (18 to 20 daN/mm^2). These pipes are generally manufactured in lengths of 6 m and externally coated with a coal pitch-based varnish. They often have one end interlocking and the other with a plain end.

VII.1.1.2 Steel pipes

Steel tubes are made from :

- Sheet metal or strip for welded pipes;
- From ingots, blooms or rounds for seamless tubes.

Various exterior coatings can be used for this type of pipe. Steel pipes have the following advantages :

- Lighter than cast iron pipes;
- High resistance to stress (shocks, crushing and ground displacement);
- Suitable for all operating conditions thanks to the possibility of changing the grade of the steel or the thickness of the sheet metal;
- Longer than other types, which reduces the number of connections and makes installation faster.

On the other hand, they have a very low resistance to corrosion.

VII.1.1.3 Polyvinyl chloride (PVC)

Polyvinyl chloride (PVC) pipes are available in different pressure classes with relatively small diameters. They are assembled by means of an elastomer seal.

PVC pipes behave well over time, provided that a certain number of conditions are met:

- Always store them away from UV rays and at a reasonable temperature before installation;
- Plan a particularly careful installation, especially without hard spots;
- Always keep them below their nominal pressure;
- Ensure that they are not subject to mechanical damage during their service life.

VII.1.1.4 High-density polyethylene (HDPE)

Over the past two decades, high-density polyethylene (HDPE) has made significant inroads in the field of water distribution. This material has all the qualities of PVC (insensitivity to chemical aggression and corrosion in particular), without having the main disadvantages (they are less fragile, and are more resistant to mechanical aggression).

In addition, their assembly by butt welding or electroweldable sleeve (or by screw fitting for smaller diameters) makes HDPE pipes self-stopping, which is an added advantage.

In addition, the low speed of HDPE pipes (300 m/s) compared to that of steel or cast iron (1000 to 1200 m/s), makes this material more viable. This advantage makes it possible, in the case of discharges with low HMT (<12 bar), to limit the volumes of the anti-ram tanks, or even the absence of the need for anti-hammer protection.

VII.1.1.5 Pipes with a mid-tube made of sheet steel and double lined with reinforced concrete

Pipes of this type consist of:

- A cylindrical liner made of sheet steel;
- An interior concrete cladding, reinforced or not;
- Reinforced concrete exterior cladding.

VII.1.1.6 Prestressed concrete pipes

The advantage of using prestressed concrete lies in the fact that, up to the limit of the test pressures, internal compressive forces are opposed to the tensile forces due to the loads, which prevents the cracking of the concrete. The tightness of the pipe is thus perfectly ensured and its resistance to external agents is considerably increased.

VII.1.1.7 Asbestos cement pipes

They are made from an intimate, homogeneous mixture in the presence of water, asbestos fibre and portland cement, excluding any metal reinforcement. Pipes have two plain ends or plain ends.

VII.1.2 Pipes corrosion

VII.1.2.1 Corrosion phenomenon

Corrosion refers to the alteration of a material by a chemical reaction with an oxidant (mainly oxygen and the H+ cation). A distinction is made between internal corrosion due to the quality of the water transported by the pipe and external corrosion due to the quality of the soil crossed and the presence of water in the soil.

Corrosion of metals is in the vast majority of cases an electrochemical reaction (redox) involving the manufactured part and the environment. It is therefore necessary to take into account :

The material :

- Chemical composition;
- Microstructure (size of crystallites, precipitates), and therefore thermomechanical treatments;
- Surface treatments.

The environment :

- Chemical composition;
- Pressure;
- Temperature.

This determines the type of corrosion and the rate of corrosion; In industrial plants, corrosion risk zones are defined as corrosion loops.

The shape of the part and the treatments it undergoes (shaping, welding, screwing) play a key role. Thus, an assembly of two different metals (e.g. two grades of steel, or the same steel treated differently) can create accelerated corrosion; You can often see traces of rust on the nuts. If the part has a gap (e.g. between two plates), this can form a confined environment that will evolve differently from the rest of the part and therefore lead to accelerated local corrosion. Any heterogeneity can lead to accelerated local corrosion, such as at weld seams. The heterogeneity of the environment to which a metal part of regular composition is subjected can lead to corrosion known as the 'concentration pile'. The same is true for a metal part located in a solution of identical composition but experiencing non-uniform agitation. A partially submerged metal plate will undergo localized corrosion known as "at the water line".

VII.1.2.2 Corrosion protection

There are two ways to prevent the chemical reaction from taking place :

First of all, the room can be isolated from the environment, by a coating using a layer of paint, plastic, or by a surface treatment: nitriding, chromization, plasma spraying.

It is also possible to introduce another part to slow down or prevent the reaction; This is the principle of cathodic protection which can be achieved by two means :

A first way to achieve this is to use a "sacrificial anode". This new part (often made of zinc or magnesium) lowers the electrochemical potential of the protected part below the potential where it can oxidize, and will corrode in place of the part to be protected. In an aqueous medium, it is sufficient to screw or contact the sacrificial anode on the part to be protected. However, if the part is large, such as a long pipe, it is necessary to take into account a loss of protection due to the ohmic drop. This is caused by the resistance to the passage of current through the surrounding environment, and it increases with the distance from the point of the protected part in contact with the sacrificial anode. Beyond a certain distance, which depends on the conductivity of the medium, the part is no longer protected. Therefore, the anodes must be positioned at regular distances so that any point is below the potential or the metal can corrode. These sacrificial anodes are consumed and therefore have a limited lifespan, and require periodic replacement. In the air, the part must be completely covered with zinc, this is the principle of galvanization.

A second way to achieve cathodic protection is to lower the potential of the metal with an external electrical source, by imposing a potential or current between the part and an external anode positioned with respect to the surface, but without direct contact with the metal. In this case, the anode does not consume itself and does not need to be replaced.

VII.2 Characteristic curves of pipes and networks

Determining the operating point of a pump makes it possible to know the flow rate and the head generated by a given pump flowing through a given network or pipe.

This determination is easily made by plotting on the same graph the characteristic curve of the pipe, which represents for each flow rate the sum of the geometric height and the pressure drops in the pipe according to the following equation :

$$\mathbf{H_R = H_g+\Delta h} \tag{VII.1}$$

The total pressure drop of a pipe, as a function of the liquid flow, will be plotted on a graph. This results in the characteristic curve of the pipe. It is also possible to represent the geometric height of the elevation as a function of the flow rate, which makes it possible to determine in a simple way, for each flow, the sum of $H_{\text{géom}}$ and Δh (J_a+J_r).

The pressure drop is proportional to the square of the flow rate, and the curve is a parabola of the following form :

$$\mathbf{H_{mt} = H_g+\Delta P+\Delta h = H_g+\Delta P+R\,Q^2} \tag{VII.2}$$

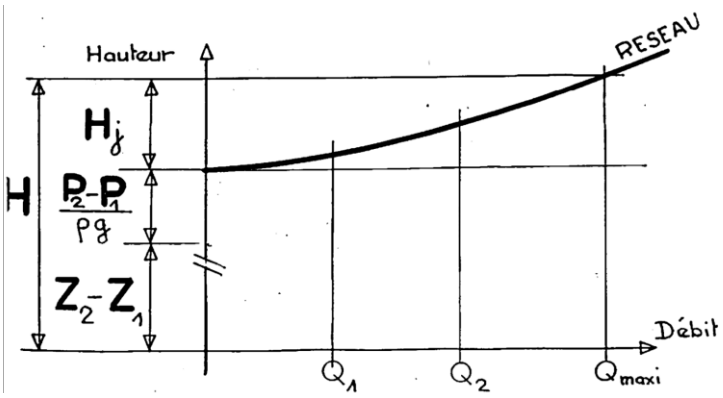


Fig. VII.1 : Characteristic curves of a network

At a given flow rate, a Pdc Δh corresponds to friction in the pipes and road accidents.

As the flow increases in the pipes, the more Pdc there is. The relationship expressing the evolution of Pdc as a function of volume flow is :

$$\Delta h_1 / Q_{v1}^2 = \Delta h_2 / Q_{v2}^2 \tag{VII.3}$$

It can be seen that the ratio of the PoCs varies with the square of the flow rate :

$$Q_{v1}^2 / Q_{v2}^2 = \Delta h_1 / \Delta h_2 \tag{VII.4}$$

VII.3 Point of operation of a flow pump in a discharge system

Determining the operating point of a pump makes it possible to know the flow rate and the head generated by a given pump flowing through a given network or pipe.

This determination is made either graphically by plotting on the same graph the characteristic curve of the pipe (which represents for each flow rate the sum of the geometric height and pressure drops in the pipe) and the characteristic curve (H-Q) of the pump. At the point of intersection of these two curves, the head of the pump will be equal to the sum of the total geometric height in the pipe. Therefore, this point is the operating point of the pump. Or mathematically if we have in hand the equation giving the head delivered by the pump as a function of the flow rate, while solving the following equation :

$$HMT = H_p \tag{VII.5}$$

Which give :

$$Hg + R\,Q^2 = a\,Q^2 + b\,Q + c \tag{VII.6}$$

Remarks :

- For a new pump, a new operating point must be determined;
- In order for this point to be rationally determined, it must be in line with the maximum efficiency of the pump.

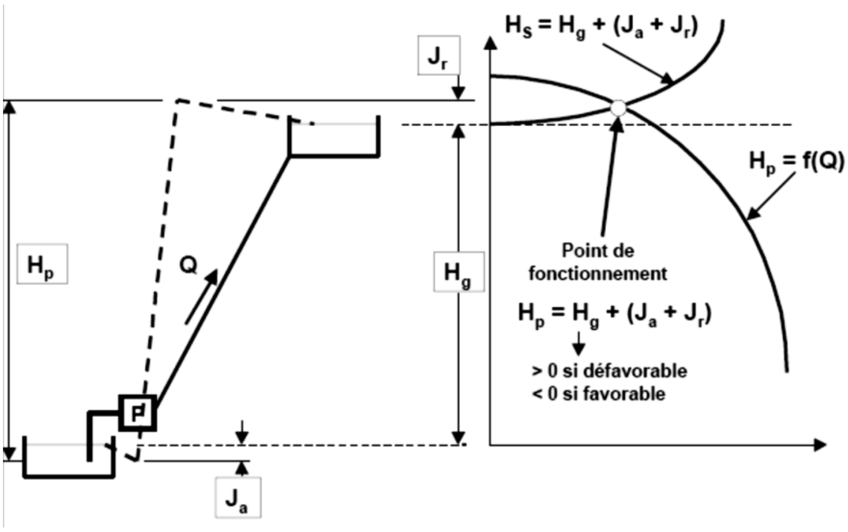


Fig. VII.2 : Operating point of a pump

VIII. HYDRAULIC EQUIPMENT FOR A PUMPING STATION

VIII.1 The pump

VIII.1.1 Rotational speed of a centrifugal pump

If the rotational speed of a centrifugal pump increases from n_1 to n_2 rpm, the flow rate Q, the total manometric head HMT and the power consumption P vary in the following ratios :

$$Q_2 = \frac{n_2}{n_1} \cdot Q_1 \qquad P_2 = \left(\frac{n_2}{n_1}\right)^3 \cdot P_1 \qquad H_2 = \left(\frac{n_2}{n_1}\right)^2 \cdot H_1 \qquad \text{(VIII.1)}$$

The speed of an electrical motor is given by the general relation :

$$n = \frac{f}{p} \cdot 60 \quad [\text{t/min}] \qquad \text{(VIII.2)}$$

With: f = frequency (50 Hertz) and p = number of pole pairs.

The following table gives the % variation in flows, heights and power as a function of the change in n (also in %):

Table VIII.1: Variation of Q, H, P as a function of n

n	0	5	10	15	20	25
Q	0	5	10	15	20	25
H	0	10	21	32	44	56
P	0	16	33	52	73	95

VIII.1.2 Specific speed n_s

This is the speed at which a standard pump would rotate and calculated to raise a flow rate of 1 m^3/s to a height of 1.0 m.

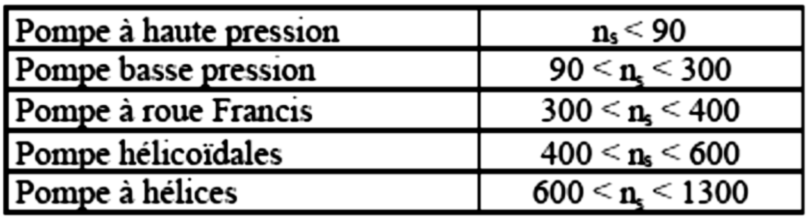
It is used to choose a type of pump. The specific velocity ns of a pump is :

$$n_s = n \cdot \left(\frac{Q^{1/2}}{H^{3/4}}\right) \qquad \text{(VIII.3)}$$

- *n*: rotational speed in rpm;
- *Q*: flow rate m^3/s;
- *H* : total head of elevation in m.

n_s is often referred to as the rotational speed of the pump. Some indicative values are summarized in the table below:

Table VIII.2: Rotational speeds of different pumps



Pompe à haute pression	$n_s < 90$
Pompe basse pression	$90 < n_s < 300$
Pompe à roue Francis	$300 < n_s < 400$
Pompe hélicoïdales	$400 < n_s < 600$
Pompe à hélices	$600 < n_s < 1300$

VIII.1.3 Choosing a pump type

The different criteria for choosing the most suitable pump for the intended function are :

VIII.1.3.1 Hydraulic characteristics

Depending on the hydraulic characteristics of the network to be carried out: flow rate and head of rise, which are the basis for choosing the most suitable pump for any network.

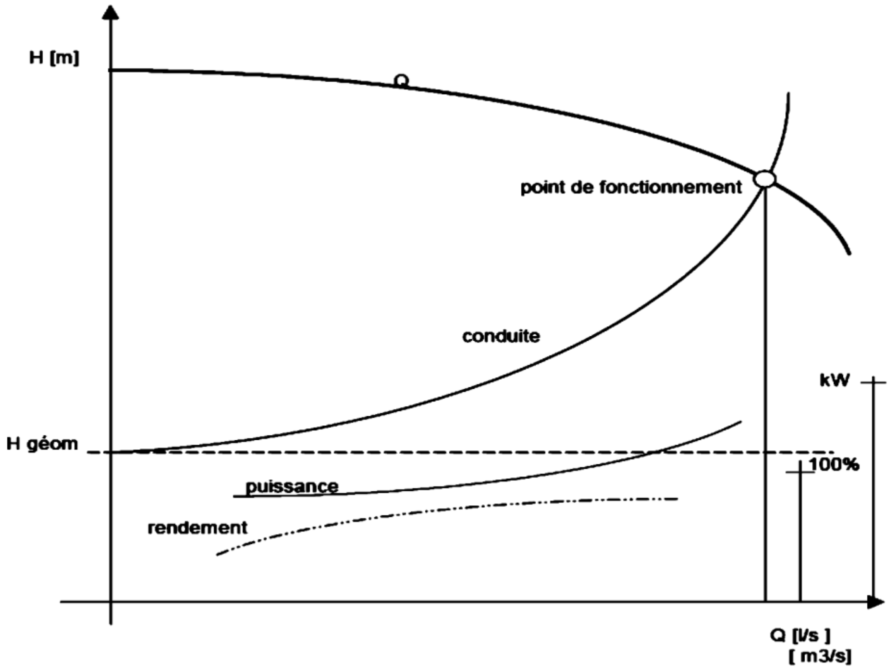


Fig. VIII.1 : Pump characteristic curves

VIII.1.3.2 Rotation speed

The cost of a centrifugal pump depends directly on its rotational speed. The slower it is, the higher the cost. As a first approximation, for an equal power consumption, and taking as a basis the price of a pump at 3,000 rpm, the prices will vary in the following proportions :

- 3 000 rpm = 100 ;
- 1 500 rpm = 150 ;
- 1 000 rpm = 300.

The advantages of reducing speed are:

- Noise reduction;
- Improved suction capacity;
- Reduced wear and tear.

The choice of pump speed will therefore be made after carrying out a technical and economic study.

VIII.1.3.3 Operating point

The operating point on the characteristic curve must be as close as possible to the point with the maximum efficiency (PRM), for obvious reasons of energy saving, but also for reasons of mechanical strength of the pump in order to avoid any cavitation phenomenon.

The selected flow rate Q must satisfy the following condition, 0.5QN < Q < 1.25QN, where QN is the flow rate corresponding to the maximum efficiency point (MRP) of the characteristic curve. This condition arises from variations in the radial force Fr acting on the pump motor (impeller – shaft), as shown in Figure VIII.2-a.

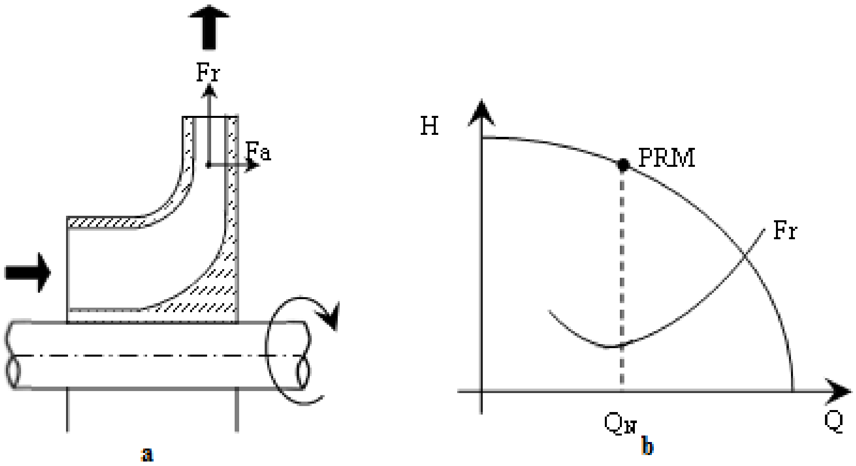


Fig. VIII.2 : a) Representation of axial and radial thrust; b) Operating point and radial thrust

Outside the prescribed operating area, the increase in radial force leads to fatigue of the pump mobile components (bearings, seal). The operating point of the pump should therefore be as close as possible to the point corresponding to the minimum value of the radial force, and should instead be located to the left of the curve (Figure VIII.2-b). In addition, the operation far to the right or far left of the pump's optimum operating point leads to variations in the axial thrust Fa, which generates vibrations. To the right of the curve there is a greater risk of cavitation that can lead to the destruction of the wheel.

VIII.1.3.4 Required NPSH

In general, the pump manufacturers' catalogues give the characteristic curve of the NPSHr (NPSHr = f(Q)) corresponding to the nominal diameter of the impeller (= maximum diameter). If the wheel is cropped, the NPSHr is changed. Its new value can be approximated graphically, as shown in Figure VIII.3.

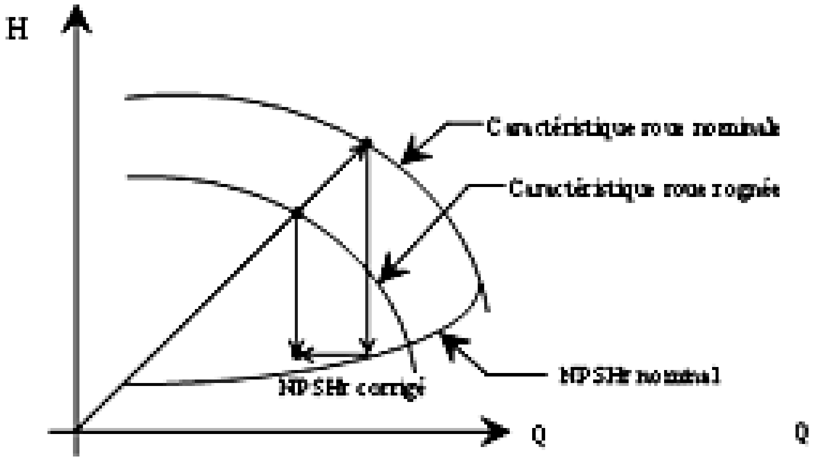


Fig. VIII.3 : Influence of wheel diameter on NPSHr

In addition, the selected pump must have an NPSHr value that is compatible with the available NPSH of the installation. In any case, the value of the NPSHd must be higher than that of the NPSHr, it should be remembered that the safety margin must be at least 0.5 m ($NPSH_r \leq NPSH_d - 0.5$ m).

VIII.1.3.5 Characteristic Curve Appearance

The search for the pump giving the desired characteristics (height-flow rate) in the manufacturers' catalogues can lead to finding several models corresponding to these characteristics. In addition to the conditions listed above, the pump with the steepest slope at the operating point should be chosen, so that any variation in height (a value not fully controlled by calculations and over time) will result in only a small variation in flow rate, as shown in Figure VIII.4.

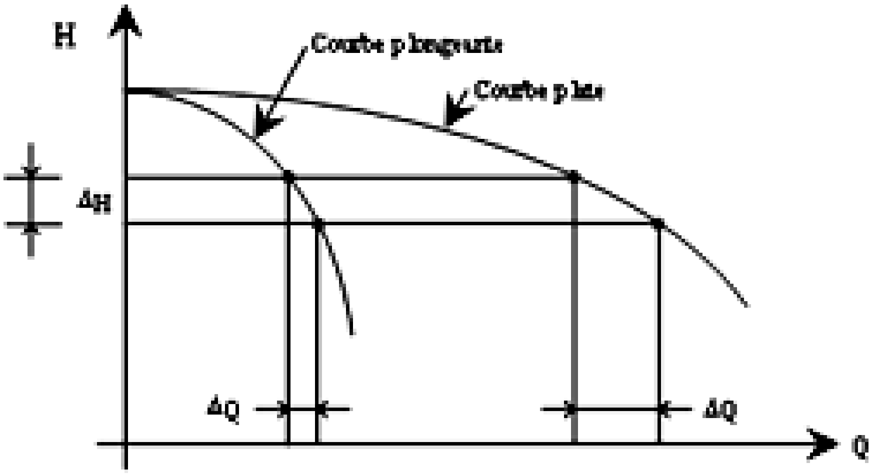


Fig. VIII.4 : Influence of curve shape on pump choice

VIII.1.3.6 Shaft sealing

Braids are a cost-effective sealing system, but require some attention at the operational level. Because they are in direct contact with the shaft, it is necessary to create a leak to lubricate and cool them. There is therefore a compromise to be found between an operation that favours lubrication, and an operation that limits leaks to the detriment of the braid hold. If the pumped fluid is incompatible with the lubrication function, an auxiliary fluid (in the case of sludge or abrasive water) must be provided. The use of braids requires lining the shafts in line with the waterproofing system. This type of sealing is not suitable for high rotational speeds.

Mechanical seals provide a high-performance seal and are suitable for most applications (however, care must be taken to avoid any depression that could cause their degradation). They are more expensive than braided trimmings.

VIII.1.3.7 Construction materials

En fonction des caractéristiques du fluide à pomper on peut choisir :

For fresh water :

- Cast iron;
- Steel (for high pressures).

For brackish water or seawater:

- Stainless steel;
- Bronze or brass;
- Copper-aluminium.

For Chemicals :

- Stainless steel ;
- Synthetic materials (PVC, PP).

For abrasive products :

- Alloy cast iron;
- Coated cast iron.

The choice of materials also depends on the trade-off between price and pump life.

VIII.1.3.8 Depending on the particular conditions of use

Piston pump and centrifugal pump with hydro-ejector :

Use: Pumping water into deep wells with a low flow rate.

Example :

- Hand or foot pumps in the Sahel;
- Garden Pump.

Single-stage and multi-stage centrifugal pumps :

The discharge head of a pump varies with its rotational speed. For single-stage pumps:

- 1450 rpm h elevation about 60 m;
- 2900 rpm elevation approx. 100 m.

To achieve higher elevation heights, multistage pumps (= several mono pumps in series) will need to be used.

Generally speaking :

- $H < 60$ m single-stage pump;
- $60 < H < 90$ m possibility between a single-stage pump (electric motor) at high speed (2900 rpm) and a multistage pump at low speed (1450 rpm) – economic study required;
- $H > 90$ m multistage pump.

Horizontal Shaft Pumps or Vertical Shaft Pumps :

- Horizontal pump for $H_{asp} < 6 - 7$ m or load feed;
- Vertical Shaft Pump for Wells and Boreholes.

Shaft Line Pumps - Submersible Unit :

- Spindle line pumps: the motor is installed at ground level;
- Submerged unit: directly in the borehole or well.

When a multistage pump is not required, the following types of pump should generally be chosen :

- $H < 15$ m and $Q > 100$ l/s: propeller or helicopter-centrifugal pumps;
- $H > 15$ m and Q all: centrifugal pump.

VIII.1.3.9 Conclusion

After correctly defining the operating characteristics of the pump, i.e. the flow rate and the corresponding rise height, as well as those of its suction system (NPSH available), it is necessary to select the pump and its drive motor in such a way as to obtain a correct and long-lasting operation of the electric pump unit, which implies a perfect knowledge of the operating principles of the pumps and the variations of their characteristics according to the different parameters (wheel diameter, rotation speed, etc.).

Remark :

The optimum economic time in terms of daily pumping time is at least 20 hours.

It is prudent to provide an extra group at a station for safety reasons.

Example :

- 1 or 2 electricals pumps ;

- 1 diesel engine pump in case of power failure.

VIII.1.4 Finding the optimal diet

In practice, it is necessary to look for the type of pump that gives the best economic performance, by varying the speed of the pump.

This speed is related to that of the electric drive motor, which is 3000, 1500, 1000 or 750 rpm, for a number of corresponding pole pairs of 1, 2, 3, 4, and a frequency of 50 Hz.

Builders make a whole series of more or less similar groups and give for each of them only the portion of the plan in the diagram (H, Q) where the efficiency is acceptable.

The choice of a pump is made from a catalogue of pumps available from suppliers. We use the operating points to choose a pump that satisfies them while having the best possible efficiency.

VIII.1.5 Performance Guarantee & Standard Testing

The performance of the pump shall be in accordance with ISO 2548 - Approval Test Code - Class C (1973). The purpose of the tests is to confirm the performance of the pump and compare it with the manufacturer's warranty. The performance test of the pump(s) shall provide the performance of the pump in terms of discharge rate, total head head, energy input, etc. For a combination of motor and drive unit (e.g., a submersible pump; or a separate pump and motor with a guarantee of total efficiency), the warranty encompasses the efficiency of the entire unit.

Before shipping, the pump must be tested to ensure that it is in good electromechanical condition and that it is operating at electrical service ratings according to ISO 2548 - Class C (1973) standards.

Upon request, the pump supplier must provide the test results listed below :

- Hydraulic test curve to prove that the pump meets the operating conditions specified in ISO 2548 - Class C (1973);
- Electrical current consumption during the test;
- Megger test - verification of electrical resistance to grounding;
- Wet test - submerged operation test and electrical verification of rated voltage;
- Dry test - test of at least 15 seconds in dry conditions with verification that the voltage and power consumption does not exceed the nominal value in dry conditions;
- Water infiltration and oil checking;
- Verification of monitoring units - including, but not limited to, engine temperature sensors and leak detectors;
- A hydrostatic test of the volute of the pump or the complete pump unit and a vibration test, will be carried out at the express request of the buyer.

VIII.1.6 Experience acquired

The pump manufacturer must have installed several pump units of a similar type, which have operated for at least five years. Preference is given to a supplier who, at short notice, is able to temporarily replace a pump from a rental fleet with an adequate inventory of pumps and accessories. Preference is also given to the supplier who, locally, can supply parts and labour with factory-trained technicians.

VIII.1.7 Pump coupling

It can be done in series or in parallel. Within a network, pumps can be coupled in such a way as to obtain a gain in flow rate or head.

If the flow range to be pumped is wide enough, it is better to use a group of pumps in parallel. On the other hand, if the loads are large, pumps installed in series can be used. The following diagrams depict these installations on the principle of common load and sum of flow rates for parallel aggregation, and common flow rate and sum of loads for a series system.

VIII.1.7.1 Series coupling

The discharge of the first pump leads to the suction of the second, and so on. The same flow flow flows through all pumps and the elevation heights produced by each group are added. So we have :

$$H_{mt} = \sum_{pompes} H_{mt,i}(q_v) \qquad \textbf{(VIII.4)}$$

The series coupling therefore makes it possible to obtain a very high head head. However, it is more interesting to use multi-stage pumps for which the series coupling is carried out inside the same pump housing (up to several dozen impellers). This minimizes pressure drops that occur when fluid passes from one pump to another.

Identical pumps can be coupled or different pumps, in which case care must be taken to ensure that the flow rate does not exceed the maximum flow rate of one of them. A pump used beyond its maximum flow rate would act as a turbine and absorb some of the energy provided by the other pumps.

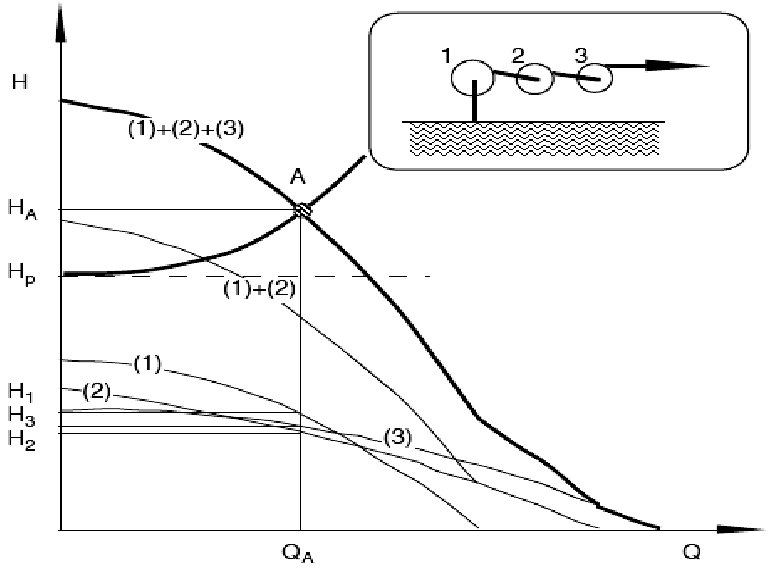


Fig. VIII.4 : Pumps in series

Remark :

In all cases, the height resulting from the coupling is less than the sum of the heights created for each pump operating alone on the same pipeline.

VIII.1.7.2 Parallel coupling

Each forcemain terminates in a common general manifold.

The common manifold flow rate will be made up of the sum of the flow rates of each pump.

The characteristic of all the groups will be obtained by summing the abscissa flows of each group for the same ordinate H.

Parallel-coupled pumps each contribute to the overall flow rate while operating at the same head head. So here we have :

$$q_v = \sum_{pompes} q_{v,i}(H_{mt}) \qquad \textbf{(VIII.5)}$$

This type of coupling is interesting if you need too much flow to be obtained by a single pump. It is also interesting to couple pumps in parallel so that they can be controlled in cascade if a variable flow rate is required. You can also try to alternate between a large or low flow pump. In the case of the use of different pumps, care must be taken to ensure that the required head is not higher than the maximum head of one of the pumps. Otherwise, its contribution to throughput would be negligible.

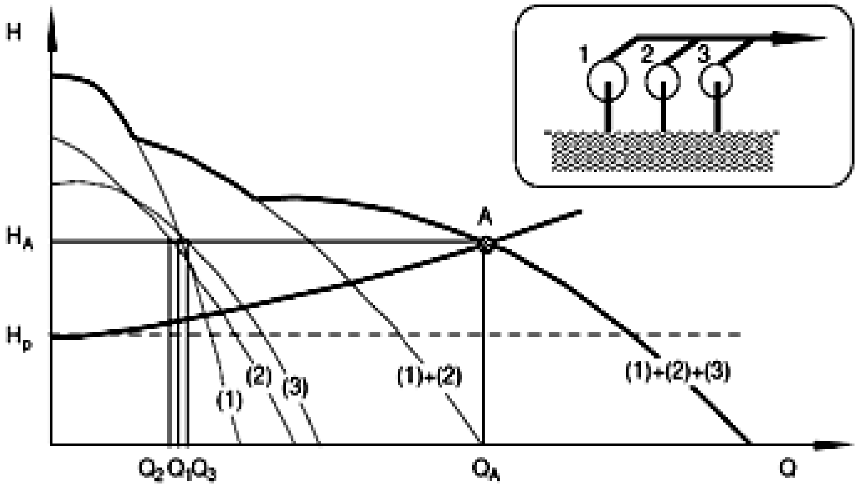


Fig. VIII.5 : parallel pumps

Remark : the sum of the actual partial flows < Q_{Tot}. Theoretical

VIII.1.7.3 Choice of pump coupling

The coupling of pumps for installation in a network must allow for the maximization of the flow rate or head of the system. For a network with little resistance, requiring a high or variable flow rate, parallel coupling is preferred, while for a highly resistant network, serial coupling is mandatory.

In any case, unlike the free association of pumps, coupling within a network will not provide the exact sum of either flow rates or gauge heads, but will provide a lower value. This is due to the convex nature of the characteristic of a network.

VIII.1.8 Flow adjustment

In order to compensate for a possible underestimation of pressure losses in the network, or to compensate for the ageing of the elements, the pump chosen is generally oversized in relation to the desired flow rate in the network. In this case, the flow rate initially obtained should be reduced to the desired one.

VIII.1.8.1 Valve-Network Association

A control valve can be used in series or in parallel with the network. This imposes an adjustable singular pressure drop, such as :

$$J_{vanne} = R_{vanne} q_v^2, \qquad \textbf{(VIII.6)}$$

For a given opening.

In the case of a series connection with the network, the pressure drop due to the pump is added to that of the network, so a valve is chosen that allows a new operating point to be obtained at the desired flow rate and we have the relationship :

$$J_{vanne}(q_{v\,souhaité}) = H_{mt}(q_{v\,souhaité}) - J_{réseau}(q_{v\,souhaité}) \tag{VIII.7}$$

As $q_{v\ souhaité} < q_{v\ pf}$, there is a higher head than at the initial operating point and a lower network pressure drop than at the initial operating point.

The addition of the pressure drop due to the valve therefore logically increases the resistance of the network in order to artificially reduce the flow rate. The power consumed by the pump increases with the flow rate, so the addition of a valve can significantly reduce the power consumed, despite the increase in resistance.

It can also be considered that the valve transforms the pump into an equivalent pump with a reduced head of J_{valve}.

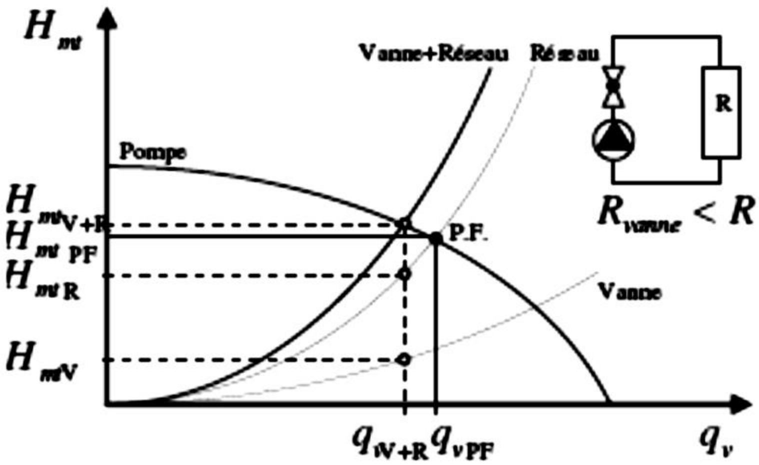


Fig. VIII.6 : Characteristic of a Valve-Network Association in Series

In the case of parallel mounting where the valve is in an additional branch, it is said to double pass the superfluous flow. The head of the gauge is therefore equal to the pressure drop of the network and the pressure drop of the valve, because these three branches are then mounted in parallel. This possibility of additional passage tends to reduce the initial pressure drop and therefore to push the pump towards an operating point with a higher flow rate. The power consumed by the pump is therefore higher than that at the initial operating point in the case of parallel valve assembly.

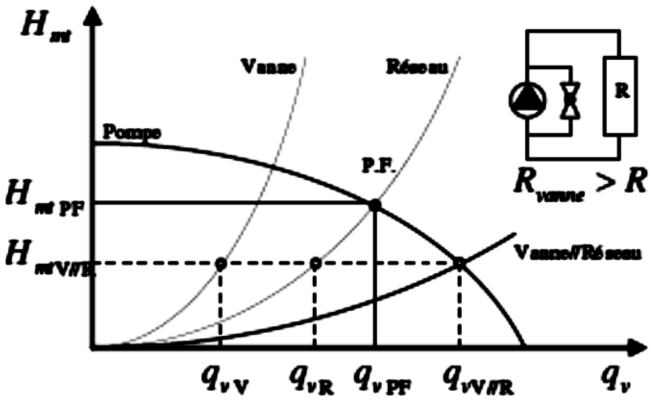


Fig. VIII.7 : Characteristic of a valve-network association in parallel

VIII.1.8.2 Variable pump speed

It is logical to obtain a flow rate lower than the flow rate at the initial operating point by reducing the rotational speed of the pump, since it has been shown that the flow rate and the head are proportional to the rotational speed and its square, respectively.

The variation in the rotational speed of a pump is therefore characterized by a simple deformation of its characteristic curve along the qv and Hmt axes, which makes it possible to find a new operating point, at the desired flow rate.

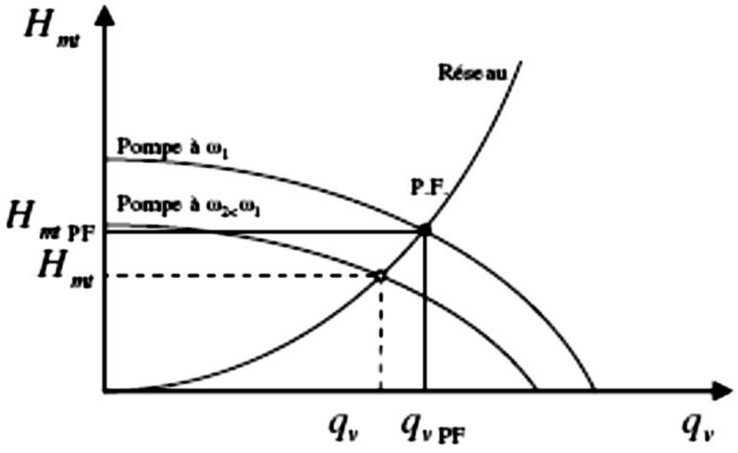


Fig. VIII.8 : Flow rate adjustment by variable rotation speed

If it is assumed that the efficiency of the pump is practically constant over the range of flow rates considered, the power consumed by the pump will be significantly reduced, this being proportional to the cube of the rotational speed.

Most motors and many circulators now have a high number of windings, which allows access to several predefined speed speeds by switching. Circulators often offer two to five possible speeds, with the lowest being around 70% of the highest.

Motors equipped with or associated with a variable frequency variable speed drive are more expensive, and are generally used in control, when a gradual adjustment of the flow rate is desired. Again, a cost study may be necessary.

VIII.1.8.3 Wheel trimming

Impeller trimming is the process of reducing the outside diameter of the impeller without changing the pump housing. This practice allows the characteristic of the pump to be lowered in order to best adapt it to specific load and flow conditions. The blades must be re-sharpened to regain a proper trailing edge profile.

In theory, the flow rate and head vary in proportion to the square of the wheel diameter. We then have :

$$\frac{q_v}{q_{v0}} = \frac{H_{mt}}{H_{mt0}} = \left(\frac{D}{D_0}\right)^2 . \qquad \textbf{(VIII.8)}$$

The error made is small as the trimming does not exceed 15% of the initial diameter.

VIII.2 Accessories

VIII.2.1 Upstream and downstream equipment of the pumps

The hydraulic equipment of a pumping station includes apart from the pumps themselves :

- **Suction equipment**: grille, suction cover, strainer, valve, seal, valve, convergent, anti-vortex device, anti-hammer protection devices, pipe and pump priming circuit. This equipment differs depending on whether the suction is done in a tarpaulin or on a pipe;
- **Discharge equipment**: seal, diverging, non-return valve, valve, various devices.

VIII.2.1.1 Upstream equipment: suction

The pumps of a station can be suctioned either in a suction tank or in a pipe.

VIII.2.1.1.1 Tarpaulin suction

The water to be raised is stored in a tarpaulin or suction tank.

- **Grids :**

These devices are only used for pumping raw water in order to prevent the entry of solids into the pumps.

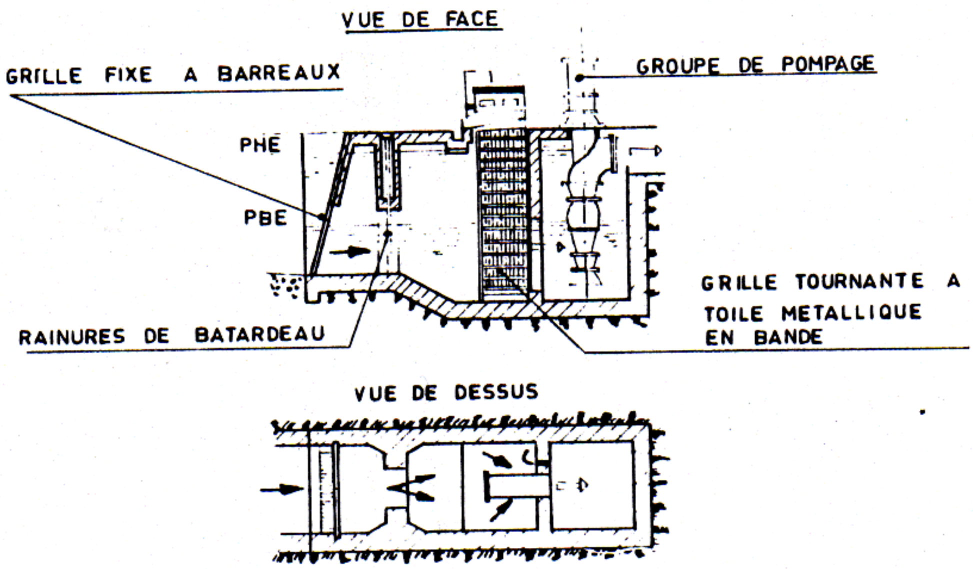


Fig. VIII.9 : Suction equipment for a raw water pumping station

- **Tulip :**

The need for the socket depends mainly on the speed at which the water enters the suction line.

For values not exceeding 0.8 m/s, it is possible not to provide a tulip. However, its use makes it possible to reduce pressure drops. Therefore, it is recommended to provide them as soon as the speed reaches 0.5 m/s.

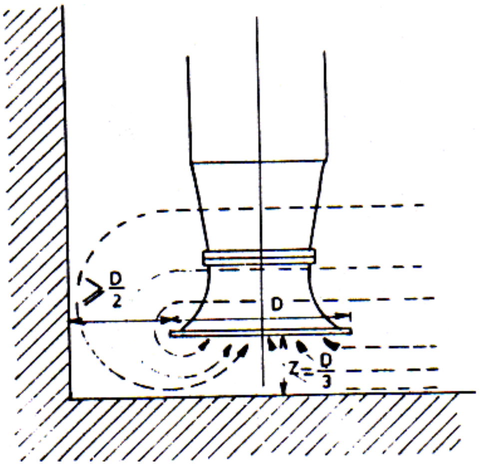


Fig. VIII.10 : Suction Socket Position

- **Strainer :**

Just like the screen, the strainer prevents the accidental entry of solids into the pump. It consists of a perforated cylinder that refuses to allow objects much smaller than the grid to pass through.

It should be noted that a strainer should always be fully immersed to prevent air ingress (sufficient margin must be provided for the vortex) and about 0.5 m away from the bottom of the sump.

- **Suction valve or strainer valve :**

A non-return valve placed on the suction line prevents a backflow of water when the pump is shut down if the non-return valve normally placed at the discharge closes poorly.

VIII.2.1.1.2 Suction on pipe

The water to be raised arrives at the plant through a pipe that is connected directly to the suction manifold of the pumping station from which the suction of the pumps starts; There are no tarpaulins at the station.

- **Suction on pipe :**

On the pipe, avoid any formation of air pockets. The horizontal parts will have a slight slope (2%) going up towards the pump.

The velocity of water circulation in the suction pipe will be in the range of 0.8 to 1.2 m/s, in order to limit pressure drops, particularly at the right of the taps to the pumps. These taps should preferably be made in a Y shape unless the suction manifold is supplied at both ends. In this case, it will be wise to provide a so-called partition valve in the middle of the collector.

- **Seals :**

If the suction line is in a vacuum, special attention will be paid to the seals in order to eliminate any possibility of air entry and possibly the entry of polluting agent. Therefore, soldered joints are preferred to lead and wire socket joints, and threaded sleeve joints.

For connection to switchgear, strainers, valves, valves, pumps, flanged gaskets should be used.

VIII.2.1.1.3 Organs common to both cases of aspiration

The main idea that will govern the study of common intake oranges is the limitation of pressure drops on the one hand, and the elimination of any device that may generate air inlets on the other hand.

- **Elbows, anti-vortex device :**

The bends should be as few as possible, and with a large radius of curvature. Avoid mounting an elbow just upstream of the suction flange; If this is not possible, the elbow should be improved by installing an anti-vortex bulkhead or brace.

- **Suction valve :**

Une vanne montée à l’aspiration de la pompe permet d’isoler la pompe pour les travaux d’entretien ou de démontage sans pour autant arrêter toute la station.

- **Suction convergent :**

In order to limit pressure losses when suction of the pumps, the suction line often has a large diameter giving a circulation velocity of 0.8 to 1.2 m/s.

This speed is lower than the speed at the inlet of the pump flange (in the range of 2 to 5 m/s). The pipe is then connected to the pump by a convergent, which allows for a gradual acceleration of the flow, favouring the proper distribution of velocities just upstream of the pump.

- **Priming :**

When a centrifugal pump is not loaded at suction, priming the pump must be provided before the unit is switched on.

VIII.2.1.2 Downstream equipment: discharge

- **Connection joint :**

The discharge line shall be connected to the pump in such a way as not to transmit any parasitic stress to the pump. This is ensured by the use of a suitable seal, which will also facilitate the dismantling of the pump or downstream devices.

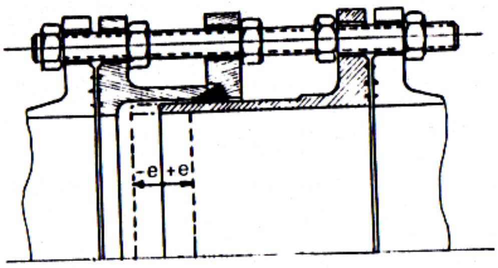


Fig. VIII.11 : Self-bumping disassembly joint

- **Divergent :**

At the outlet of the pump, the water velocity can be from 3 to 7 m/s. In discharge pipes, it is necessary to slow down this speed to keep it within a range of 1.2 to 1.5 m/s.

- **Discharge valve :**

At the outlet of the pump, a valve can be placed whose role will be to prevent the reversal of the water flow when the pump is stopped. The most commonly used valves are flapper valves installed on horizontal pipes. Other types can be used :

- Multi-flap valves to reduce closing time;

- Nozzle-shaped body valve with spring-loaded valve;
- Rubber diaphragm valve (hydro-stop);
- Low-inertia valve.

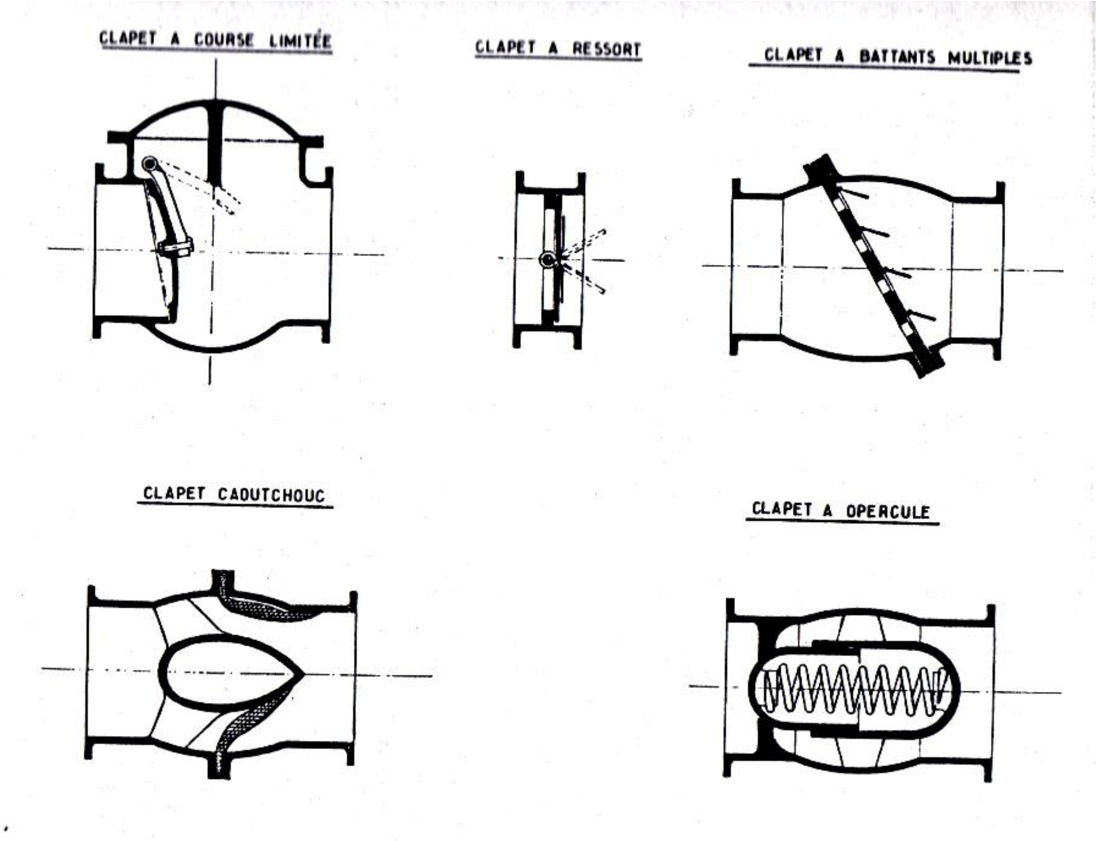


Fig. VIII.12 : Quick-close valves

- **Discharge valve :**

The discharge valve placed after the pump and the non-return valve can have several roles. This valve will first of all make it possible to isolate the pump during maintenance and disassembly. The valve can also be used when the pump is switched on and off in the case of centrifugal pumps. For these, in fact, the power consumption curve shows that the power is minimal when the discharge valve is closed. It will therefore be interesting, in the event that large powers are involved, to start the pump valve closed to limit the starting time. The gradual operation of the discharge valve will also make it possible, when starting and stopping the unit, to limit water hammer due to sudden variations in the speed of the water in the discharge pipe.

- **Discharge line or manifold :**

The velocity of water circulation in the pressure main of a pumping station will be in the range of 1.2 to 1.5 m/s. In fact, along this pipe or manifold are the bypasses or taps for the connection of the pump discharge. These taps should preferably be oblique. However, for safety reasons, the station may be connected to the distribution network at both ends. In this case, the taps can be either Y-shaped or 90° made. Too much speed in the manifold increases turbulence and the resulting pressure drops.

VIII.2.1.3 Particular case

- **Auxiliary circuits :**

Throughout a pumping station, there may be a need to provide various auxiliary pressurized water circuits for the following uses :

- Coolant of pump seals;
- Cooling of pump and motor bearings;
- Cooling of the electric motors used to drive the groups;
- Cooling of diesel engines;
- Cooling of slip rheostats;
- Feeding of automatic ignition circuits either by hydroejector or vacuum pump;
- Washing water supply to the grates;
- Cooling of air compressors for feeding anti-ram tanks;
- Power supply for the station's sanitary facilities.
- **Flowmeters :**

Point devices giving the flow rate by measuring the velocity at a point in the pipe can be used especially for large diameters, while Woltmann or similar type meters are interesting for small diameters. Finally, electromagnetic and ultrasonic flow meters, which are more expensive, allow measurements to be accurate enough for pumping stations.

- **Manometers :**

These devices are used to monitor the operation of the pump.

It must be provided for :

- A pressure gauge or vacuum gauge for suction; It will be placed on the suction flange of the pump (location provided by the manufacturer) or on the suction line ;
- An identically placed discharge pressure gauge.

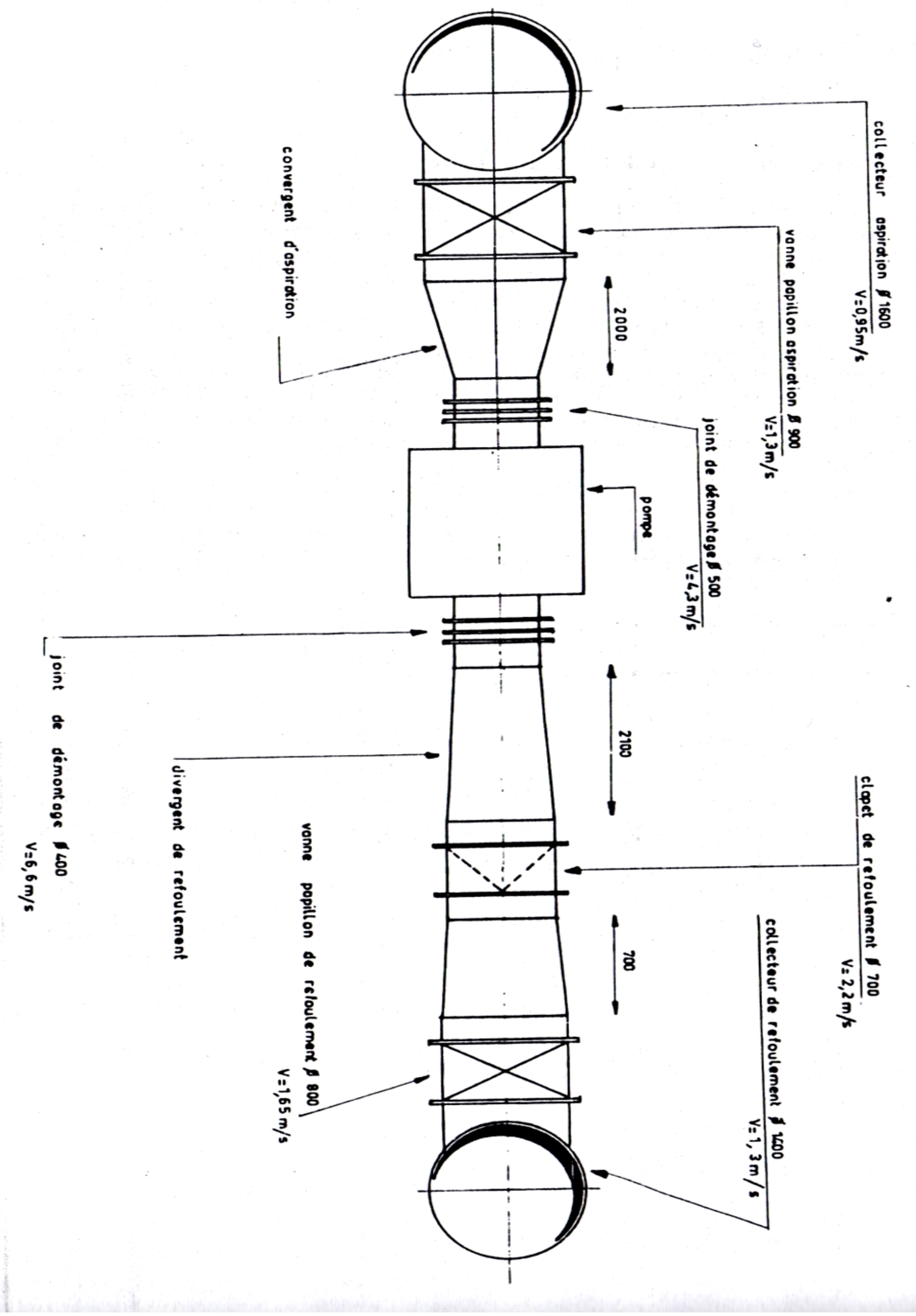


Fig. VIII.13 : Example of upstream and downstream equipment for a pump

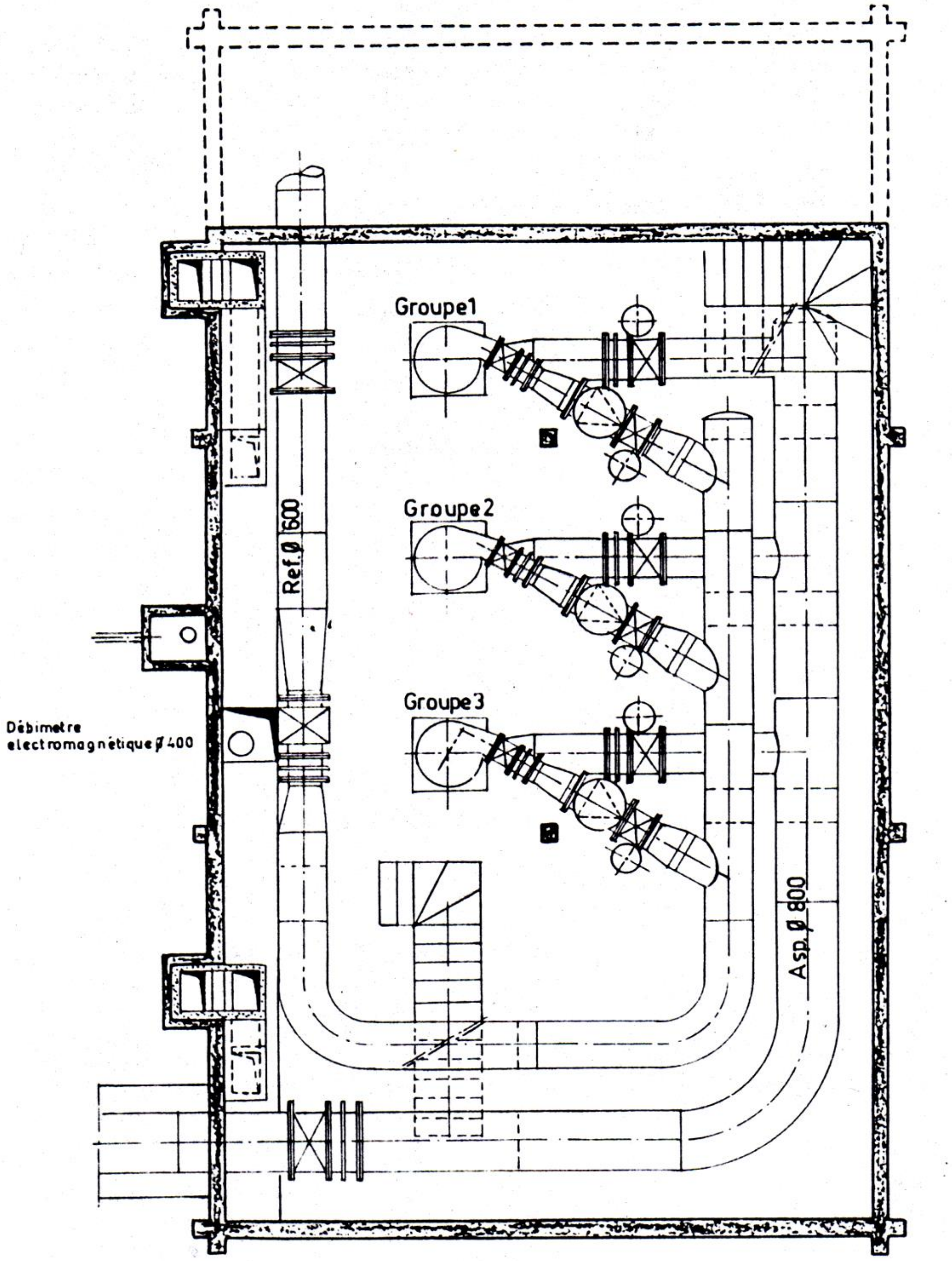


Fig. VIII.14 : Example of a pumping station layout

VIII.2.2 Auxiliary equipment of the station

To ensure the proper functioning of pumping stations, auxiliary equipment must be installed.

VIII.2.2.1 The anti-ram air tank

The number depends on the number of discharge manifolds.

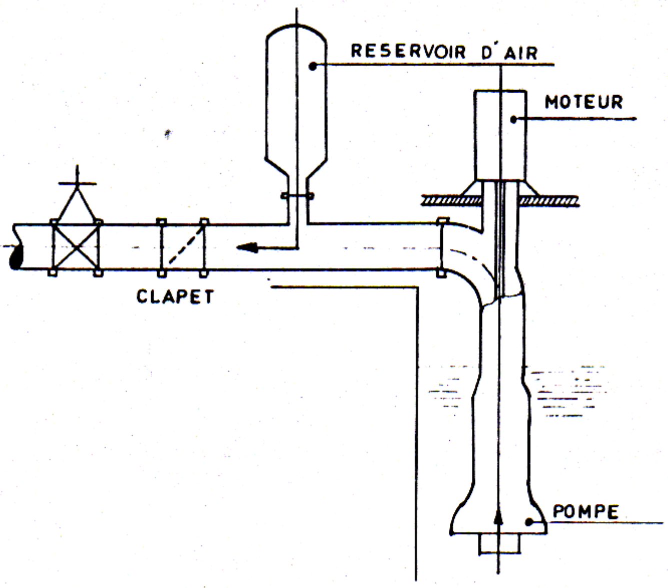


Fig. VIII.15 : Air tank at the discharge of a vertical unit with a flooded pump

VIII.2.2.2 Lifting system

There are two processes, hoist and overhead crane :

VIII.2.2.2.1 The hoist

Is a lifting device that can bear high weight, it occupies the length of the pumping station.

VIII.2.2.2.2 The overhead crane

A lifting device that only supports about 1 ton of weight.

The choice depends on the weight of the heaviest equipment (pump or motor) +20%, the span, and the energy consumption :

- If p<1T manual or electric overhead crane ;
- Si p>1T electric overhead hoist.

VIII.2.2.3 Drainage system

Water drainage through gutters if the pumping station is close to the wadi.

Evacuation of water by a drainage pump, from a sump for pumping stations far from the wadi.

Drainage systems are installed to evacuate leakage and cooling rates.

VIII.2.2.4 Fire pump

For the pumping station building, either a hydrant or a fire pump is used. They will be used to fight fires that may start inside the pumping station.

VIII.2.2.5 Ventilation system

Grilles are placed on the walls to allow air to enter the pumping station, these components can be equipped with ventilation fans. Devices that require cooling are those in motion such as the electric motor which has a self-contained cooling and ventilation system.

VIII.2.2.6 Lighting

To better maintain the pumping station, it is necessary to have good surface lighting, which is of the order of 12.5%.

IX. ELECTRICAL EQUIPMENT OF A PUMPING STATION

IX.1 Inventory of energy requirements and power balance

Prior to the study of the station's energy supply, an inventory of the needs should be drawn up.

A distinction should be made between electromechanical uses (pump drives), which account for most of the energy consumed by the station, and ancillary uses (lighting, heating, etc.).

IX.1.1 Electromechanical uses

The following information should be obtained :

- The net power across the motors, taking into account different efficiencies (pump, coupling, motor) and their power factors;
- The operating program of these motors (number of hours of operation during the day, and possible simultaneity of operation);
- The supply voltage of the electric motors;
- The starting conditions of electric motors: frequency, starting current value, etc.

IX.1.2 Other uses

These energy uses represent low powers, marginal compared to the values mentioned above, such as :

- Lighting;
- Electric heating;
- Auxiliaries (sterilization plant, sensors and measurement chains (level, flow, pressure), remote transmission devices, etc.).

IX.1.3 Power balance

When we have all these elements, we will calculate :

- The net sum of these powers, which is the installed capacity ;
- The sum of the powers of the devices likely to operate simultaneously, which will be the maximum power subscribed to from the electricity distributor, and will be used to set the power of the transformers.

IX.2 Delivery of electrical energy

IX.2.1 Low-voltage power delivery

It is difficult to give a power limit below which the distributor will offer a low-voltage delivery solution (220 – 380 V). In urban or suburban areas where the grid is particularly powerful, it can sometimes be as high as 150 Kw.

IX.2.2 Medium-voltage power delivery

"Medium voltage" means delivery from 3 to 30 Kv. This delivery involves greater investments, but energy is cheaper. Where the choice between LV and MV delivery is possible, an economic comparison will be necessary.

The location of the delivery station is determined in agreement with the distributor from the ground plan of the pumping station. It is most often placed on the side of the public road to facilitate access by the distributor. The different types of substations can be classified according to the technology used, the type of connection to the public grid, the power and the number of transformers.

IX.3 Transformers

When the station is supplied with medium voltage, it is necessary to lower the voltage by means of transformers in order to use the energy under acceptable conditions of safety and economy.

IX.4 The emergency generator

In water pumping stations, safety is an absolute principle. The use of the internal combustion engine can provide a solution to this problem. The combustion engine drives a power generator capable of compensating for failures in the public electricity distribution network.

Normal-backup coupling is the most common solution in which the combustion engine drives a low-voltage alternator supplying the low-voltage pumping station installation as a backup.

A normal-emergency inverter switches the electrical installation to the generator when the power from the public grid disappears and conversely switches the power supply to the installations to the grid as soon as the grid is energized again.

X. ELECTRIC AND CONVENTIONAL MOTORS

X.1 Electric motors

X.1.1 Different types of motors

We distinguish :

- AC motors that include three-phase asynchronous and synchronous motors, single-phase motors, and manifold motors are very little used in industrial applications;
- DC motors (separately excited, shunt, series, compound motors). The separate excitation motor is most widely used for variable speed pump drive where the speed variation covers a range of a few revolutions per minute at full speed.

X.1.2 Criteria for choosing the type of motor

- Network power and startup issues;
- Motor supply voltage.

X.1.3 Motor Connection Gear

The electrical equipment must be able to perform three specific functions :

- Ordering equipment;
- Severing circuits and devices;
- Circuit & Device Protection.

X.2 Diesel motors

X.2.1 Generals

The combustion engines used in pumping stations to drive an emergency generator and sometimes the pumps directly, are mostly diesel engines using diesel or fuel oil as fuel.

These are internal combustion engines, usually four-strokes. The combustion is gradual, being injected directly into the cylinder for the duration of combustion. The fuel injected in very fine mist ignites spontaneously by self-ignition in heated highly compressed oxidizing air.

X.2.2 Selection criteria

- Rotational speed;
- Number of cylinders;
- One-hour surcharge;
- Climatic conditions.

X.2.3 Type of use

The diesel engine can be used in pumping stations to drive either a generator or directly the pumps. A hybrid solution exists which consists of the drive of a pump by an electric or diesel motor on the same shaft, the diesel is coupled to the pump shaft in the absence of a power supply.

XI. PUMPING STATION BUILDING

He will inhabit all of the station's facilities :

- Hydraulic, hydromechanical, hydroenergetic equipment:
- Suction and discharge manifold, pump, motor, overhead hoist, vacuum pump, drainage pump;
- Ancillary equipment;
- Electrical equipment; Staff Quarters.

The type of building chosen must first satisfy the following factors :

- Purpose of the pumping station (water supply, irrigation, industry, first elevation, reclamation, etc.) etc.) ;
- Type of main equipment and their dimensions;
- Natural conditions (climate, relief, geology of the terrain);
- Available building materials;
- Connection system from the water intake to the building;
- Variation of the water body in the Wadi in the case of a first elevation station.

XI.1 Types of Pump Station Buildings

The buildings of the pump stations differ from each other according to the parameters mentioned in the previous paragraph. These types include :

- Surface type building;
- Block type building;
- Wet tarpaulin-type building with flooded pumps;
- Wet tarpaulin-type building with dewatered pumps;
- Block shaft type building;
- Dry tarpaulin type building;
- Dry tarpaulin well type building.

The following table gives some of the conditions for choosing the type of pumping station.

Table XI.1: Pump station type selection parameter

Parameters	*Pump Station Building Type*			
	Surface type	*Block type*	*Dry tarpaulin*	*Wet tarpaulin*
Q (m^3/s)	< 1.5	> 2	< 2	< 6
Pump type	*Centrifugal*	*Axial vertical*	*Centrifugal*	*Axial vertical centrifugal*
Alimentation	*On suction*	*In charge*	*Both*	*In charge*
ΔH	$< h^{adm}$	*Important*	/	/

In Algeria, the most widely used type of building is the surface building type. Which is best suited for good quality soils, i.e. all the structure of the pumping station is aboveground. For this purpose this type will be developed in this course.

XI.2 Surface type building

- Horizontal shaft pumps are usually projected;
- The construction does not require extensive foundation work, except in the case of a seismic zone where the foundations need to be deepened;
- It is mandatory to carry out the drainage system to avoid any risk of filtration;
- If the subsoil is wet, a layer of gravel is provided in the first place;
- The shape of the building is usually rectangular.

XI.2.1 How the building is constructed

For the design of the pumping station, it is necessary to take into consideration all the elements that are inside and in the vicinity of the pumping station, such as the water tank, the suction and discharge pipes.

The essential element for the sizing of the pumping station is the size of the units and pipes, as well as the special parts, the number of pumps, and the emergency pump that must be installed.

The units are often installed in a row, if the number of pumps exceeds 6, the pumps will be installed in parallel. The contact between the ground and the foundation must not present deformations, or defects in the construction, the concreting work must be done carefully and carefully.

XI.2.2 Upper part of the building

The building is generally constructed in a rectangular shape and includes a machine room, an assembly and dismantling platform, an annex room (for the operating offices, toilet, storage room, electrical cabinet room).

It is recommended to take standard dimensions :

- The height of the pumping station Hb = 3.5 m, 4.2 m, 4.8 m, 5.4 m, 6 m....) ;
- The length of the building L_b = 3, 6, 18, 21, 24 ... m ;
- The distance between the posts d_p = 3, 6 m.

If the length of the building exceeds 18 m, two exits are provided. The mounting platform should be designed right at the entrance to the building.

For large pumping stations, whose length exceeds 18 m, it is preferable to build two assembly platforms, it should also be noted that during construction, certain distances must be respected to facilitate the movement of personnel as well as for safety reasons.

We give some standards to be respected in the construction of the building :

- Distance between pumps between 0.8 et 1,5 m ;
- Distance between the electrical units and the control windows must be between (0.8 – 2) m ;
- Door dimensions 3×3, 3.6×3.6, 4×3, 4.2×4, 4.8×5.4 ;
- The surface area of the windows is taken up between 10 and 15% of the surface area of the machines room.

XI.2.3 Building sizing

a. The height of the building

The height is normalized (3.5, 4.2, 4.8, 5.4, 6) m according to the span of the crane, it is given as follows:

$$\mathbf{H_b = H_1 + H_2 + H_3 + H_4 + H_5} \qquad \textbf{(XI.1)}$$

Such as :

- H_1 : Reinforced concrete base : 0.2 à 0.6 m ;
- H_2 : 3 times the maximum height of the pump unit ;
- H_3 : Overhead crane height ;
- H_4 : height of the T (trail) : 0.1 à 0.3 m ;
- H_5 : safety height : 0.5 à 1.8 m.

b. The width of the building

The width of the building is determined according to the upstream and downstream equipment of the pump, it is calculated by the following formula :

$$\mathbf{l_b = l_r + L_p + L_{asp\ et/ou\ ref}} \qquad \textbf{(XI.2)}$$

With :

- l_r : Reserve (0.8 – 2) m ;
- L_p : Length of the pump unit.

To determine the suction or discharge length, it is first necessary to determine the lengths of the parts used (section, converge, diverge, disassembly joint, valve, valve, strainer).

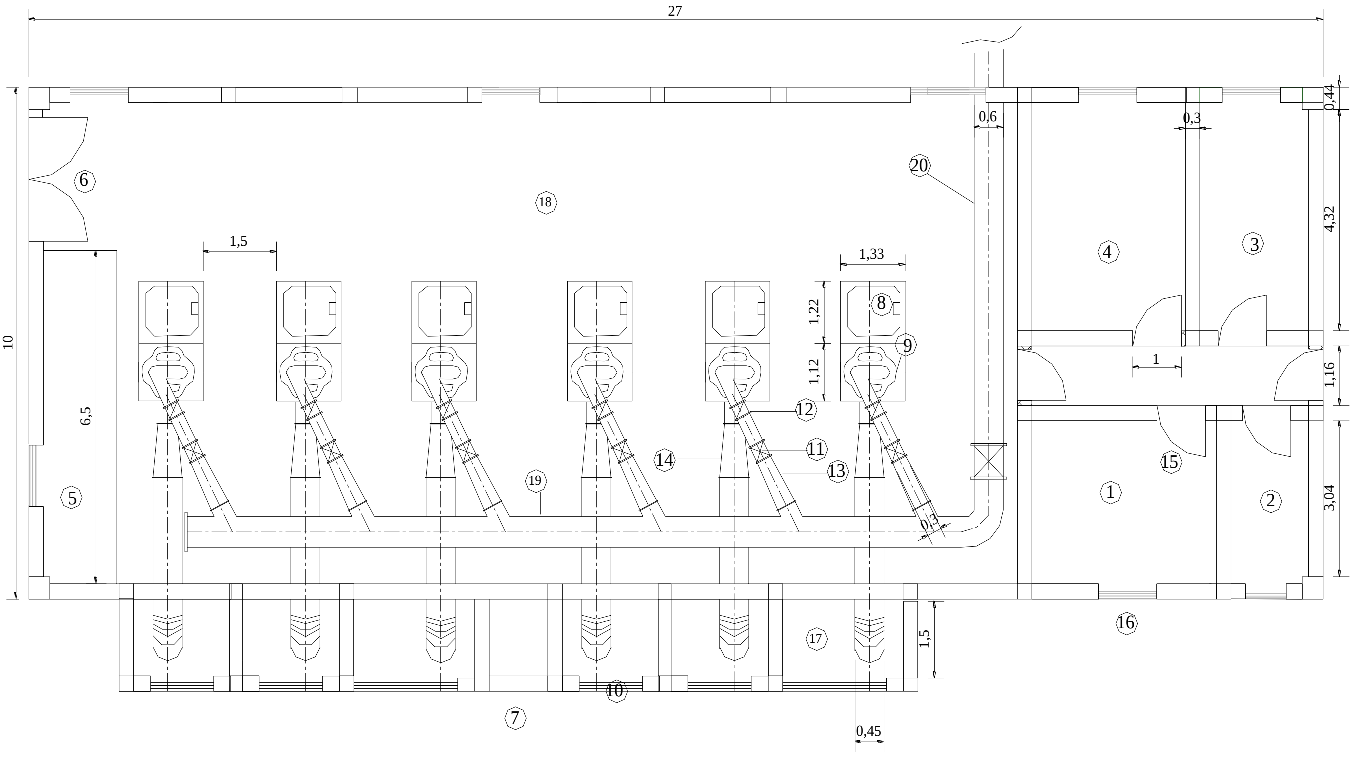
c. The length of the building

The length is determined according to the number of pumps, and the dimensions of the staff desks, it is calculated as follows :

$$\mathbf{L_b = n_p.l_p + (n_p + 1) L_{int} + L_{p.f} + L_{bp}} \qquad \textbf{(XI.3)}$$

With :

- n_p : number of pumps ;
- l_p : Width of the pump unit;
- L_{int} : Distance between two neighbouring pump sets (0.8 – 1.5) m ;
- $L_{p.f}$: Platform width ;
- L_{bp} : Length of staff desks.



LEGENDE

① Bureau du chef d'exploitation
② Toilette
③ Poste de garde
④ Salle d'équipements et commande
⑤ Plate forme (atelier)
⑥ Porte principale
⑦ Prise d'eau
⑧ Moteur électrique
⑨ Pompe centrifuge
⑩ Réinure de batardeau et grille
⑪ Robinet vanne à cache oval
⑫ Clapet anti-retour
⑬ Dévergent de refoulement
⑭ Convergent d'aspiration
⑮ Porte secondaire
⑯ Fenêtres pour l'aération
⑰ Compartiments (prise d'eau)
⑱ Salle machines
⑲ Collecteur de refoulement
⑳ Conduite de refoulement

Fig. XI.1 : Example of design and sizing of a water pumping station

XII. AUTOMATING THE OPERATION OF A PUMPING STATION

XII.1 DEFINITION

An automated system is a set of specific technical means connected to command and control means ensuring its autonomous operation.

An automated system is made up of subsystems belonging to various technological fields such as mechanics, hydraulics, electronics, etc. An automated system must operate autonomously, without human intervention (except for maintenance or special causes). Automation is the discipline concerned with the analysis and design of automated systems.

XII.2 NECESSITIES AND PROBLEMS

Automation in water pumping stations is a necessity. It depends on the size of the installation. It contributes to :

- Improving operating conditions: Automation takes care of many of the tedious tasks that were previously carried out by manual by operators, such as cleaning filters;
- Improve the performance of the installation: the implementation of additional measures and regulations makes it possible to improve quality. Automatic degraded walking modes can be set up;
- Increase productivity: Energy costs can be optimized based on hourly electricity rates. Since pumping is the most energy-consuming operation, intermediate tanks are used to buffer;
- Assist with monitoring: Data acquisition and information transmission systems now make it possible to monitor operations remotely and act remotely in the event of a problem. Remote monitoring and remote control are booming. While the control changes, the tasks to be performed for water pumping remain the same;
- With remote management, the monitoring and central control of decentralised processes over long distances is becoming common;
- Service personnel can be informed early and timely of a defect and maintenance interval;
- Current system features can simply be transferred from sub-items to a control position;
- On-site troubleshooting time is significantly reduced, as a result of the possibility of remote programming.

XII.3 GENERAL STRUCTURE

The structure of an automated system can always be divided into two parts: one part that manages the tasks requested, that exchanges information and that gives orders to the second part that executes the tasks and acts directly on the work material. The first is called the control part (PC), the second operative part (PO).

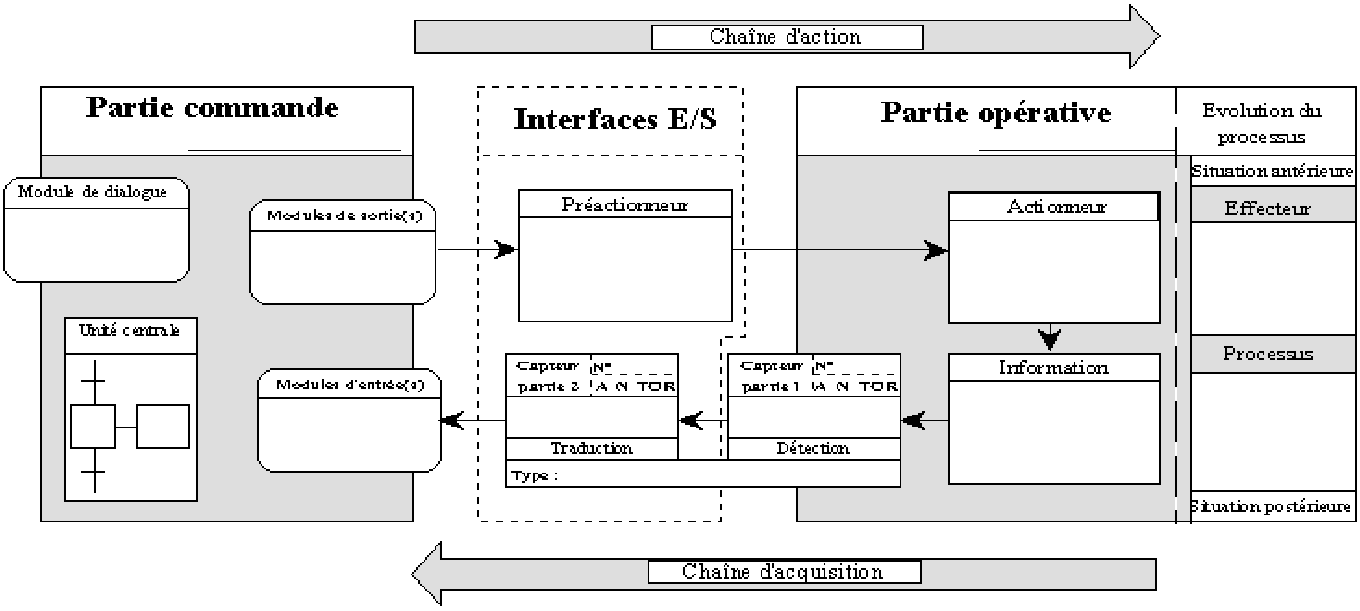


Fig. XII.1 : General structure of an automated system

XII.4 COMMAND HIERARCHY

Pumping station automation makes it possible to remotely monitor and manage a set of technical installations at the same station or a network of stations spread over several sites.

Beyond its remote control functions, automation aims to optimize the operation of a network of equipment.

Automation is therefore about :

- ACQUIRE technical information (alarms, signals, measurements, counting, etc.) ;
- PROCESS them locally by electronic equipment (local station) ;
- To TRANSMIT them to a central control point (central station) ;
- Who EXPLOITS them with the help of software (automation, calculations, spreadsheets, etc.);
- Then REPRODUCES them in various forms (synoptics, screen, printer, etc.) ;
- In order to ALERT people (postponement of on-call duty) ;
- And to ACT remotely (remote controls, remote adjustments, etc.).

XII.5 ENUMERATION OF THE FUNCTIONS TO BE PERFORMED

Automation is divided into telemetry, remote control, remote signalling and remote alarm.

XII.5.1 Concept of telemetry

Telemetry is a technique that allows the values of measurements made in technical installations to be obtained remotely. By extension, telemetry refers to one of these remote measurements.

Measurements made in a facility are routed on-site to a transmitting device, usually a remote terminal or programmable logic controller. This device transmits, usually in real time, to a remote control center. Telemetry is then taken care of by a remote management system.

Example :

- Temperature measurement;
- Level measurement;
- Pressure measurement;
- Flow Measurement.

XII.5.2 Concept of remote controls

A remote control is a device, usually small, used to manipulate another remotely, by cable, infrared or radio waves.

Example :

- Pump on/off control;
- Valve opening/closing control.

XII.5.3 Remote signaling

Telesignaling is characterized by information of a logical nature, also known as all or nothing (TOR). Depending on their origin, a distinction is made between :

- Physical remote signalling: this generally indicates operating states (pump on or off, valve open or closed, etc.) ;
- Logical remote signalling: correspond to thresholds on measurements or counts; They are generally used to issue alarms or trigger commands (high threshold on a level measurement, threshold on a temperature measurement, etc.).

XII.5.4 Concept of remote alarms

Remote alarms have the same physical nature as remote signals (logical information or all or nothing), but differ from them in their emergency nature. A remote alarm is in fact only a priority remote signalling, the degree of urgency of which is usually determined by software.

Example :

- Fault in power supply;
- Transmission fault;
- Exceedance of pressure threshold;
- Level Threshold Exceeded.

XII.6 CAPTURING INFORMATION (SENSORS)

Sensors are components of the acquisition chain in a functional chain. The sensors take information about the behavior of the operating part and transform it into information that can be used by the control part. A piece of information is an abstract quantity that specifies a particular event among a set of possible events. In order to be processed, this information will be carried by a physical medium (energy), which is referred to as a signal. The signals are usually electrical or pneumatic in nature.

In sequential automated systems, the control part deals with logical or numeric variables. The information delivered by a sensor can be logical (2 states), digital (discrete value), analog (in this case it will be necessary to add an analog-to-digital conversion module to the control part).

Sensors can be characterized according to two criteria :

- Depending on the quantity measured; This is referred to as a position, temperature, speed, force, pressure, etc. ;
- Depending on the nature of the information provided; these are called logic sensors, also known as all-or-nothing (TOR) sensors, analog or digital sensors.

XII.7 TRANSMISSION OF INFORMATION

Remote transmission means any transmission, transmission and reception at a distance of signs, signals, writings, images, sounds or information of any kind, by electric wire, radioelectricity, optical link, or other electromagnetic systems.

Automation systems use all means of communication, which make it possible to transmit data, such as for example :

- Dedicated lines: networking of automation stations dispersed on private dedicated lines;
- SMS: very easy remote maintenance and remote diagnosis with mobile phone, for maintenance cases via SMS with integrated process values;
- Via mobile phone (GPRS): mobile phone provider with a network that can be used worldwide. GPRS ensures short transfer times, only the volume of data transferred is calculated.

XII.8 THE COMMAND CENTER

The command center of an automated system, as its name suggests, controls the operational part in order to accomplish the requested objectives, giving orders that are a function of the information available at a given moment, the instructions and the model used. As we said before, the command center can also communicate with the user via an interface, or with other systems. The command center manages a flow of information and its main functions are as follows :

- Inform the user of the status of the system;
- Exchange information with other systems;
- Command the operative part;
- Receive data and information;
- Process data and information;

- Coordinate the execution of tasks.

A command center can generally be organized as follows :

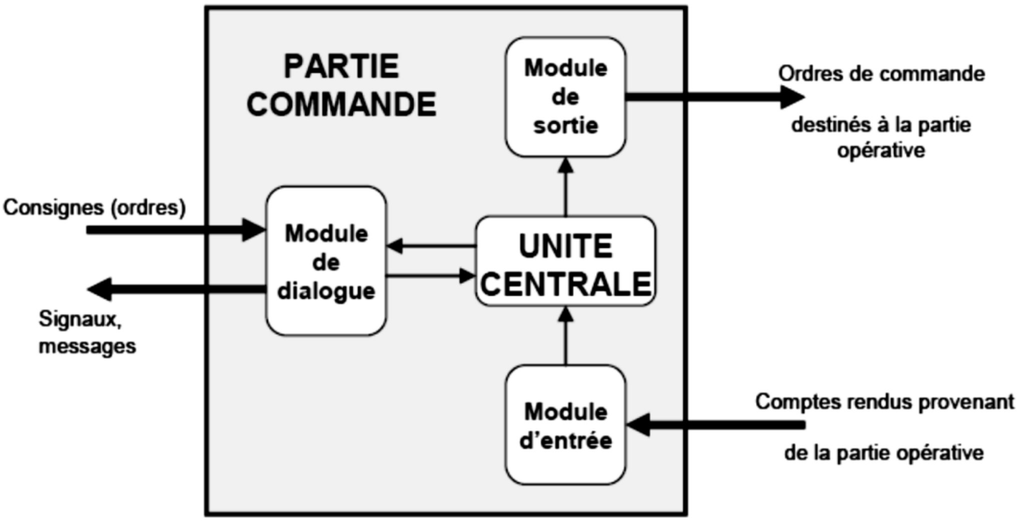


Fig. XII.2 : General structure of a command center

The functions mentioned above can be grouped according to the module that concerns them:

- The purpose of the central unit is to PROCESS the information exchanged between the other modules;
- The purpose of the output module is to COMMUNICATE, i.e. to adapt and then transmit the control orders to the operating party;
- The purpose of the input module is to COMMUNICATE, i.e. to adapt and transmit the orders of the reports (information) coming from the operational part;
- The dialog module, on the other hand, must ACQUIRE the instructions (or commands) given by a related system or by a user and COMMUNICATE information between the central unit and the environment.

The nature of the components of a command center varies according to the nature of the information processed, which can be logical (all or nothing) or analog (continuous), the mode of implementation (wired or programmed logic).

XII.9 EXAMPLE OF AN AUTOMATED NETWORK

The system presented below is that of supplying a municipality with water from groundwater:

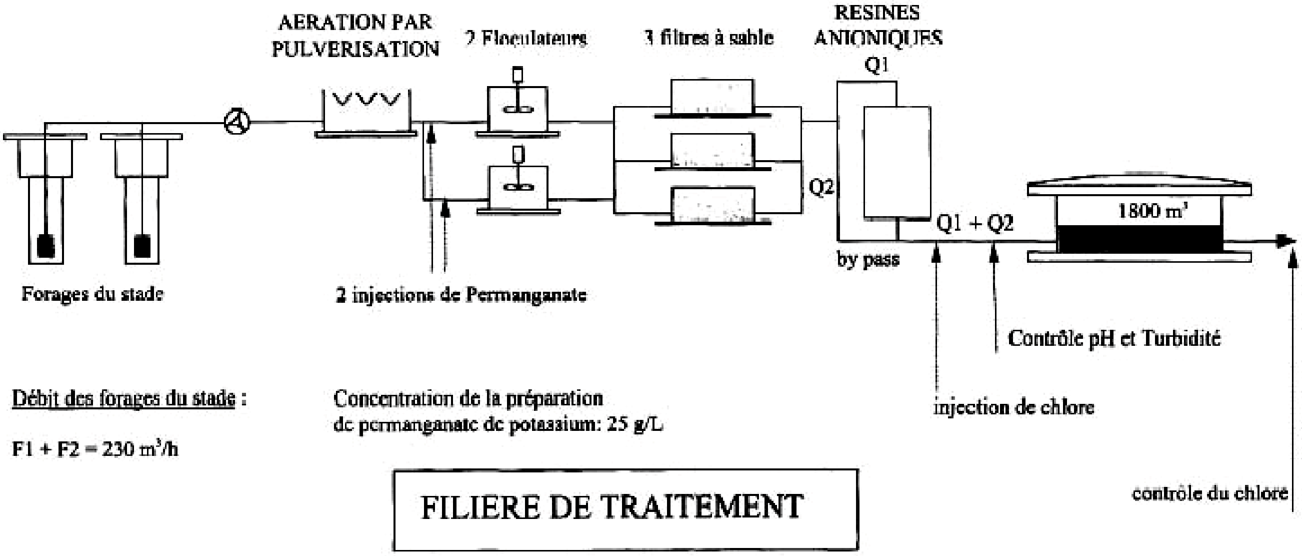


Fig. XII.3 : General diagram of the network to be automated

The water is extracted by means of two borehole pumps. It follows a treatment circuit to be stored in a 1800 m^3 tank at the end.

The two borehole pumps are controlled at the 1800 m3 reservoir levels. The outlet flow rate of the tank is always lower than the flow rate of the pump. This tank has 3 levels (NB, NTB and NH) corresponding to low, very low and high levels. Both boreholes are equipped with two sensors and a pump each :

- Borehole1: NBF1 (low level borehole 1) and NHF1 (high level borehole 1) and P1 pump
- Borehole 2: NBF2 (low level borehole 2) and NHF2 (high level borehole 2) and P2 pump

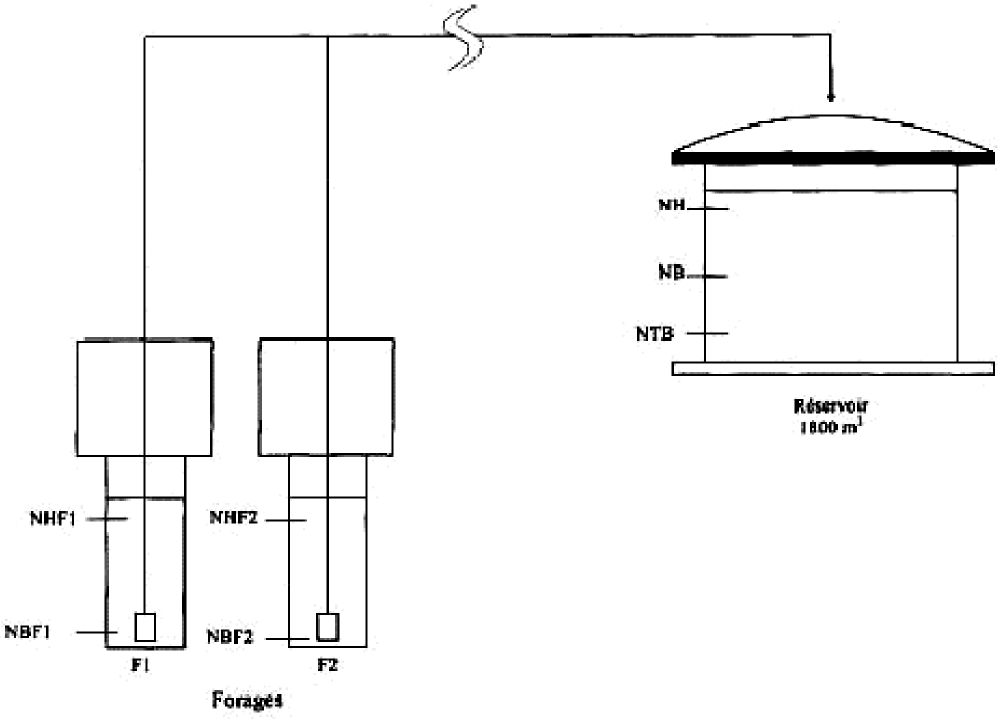


Fig. XII.4 : Diagramming of different levels for operating automation

The automatic operation is linked to the water level in the tank. The filling is done as follows:

- Water level above NH: no pump in operation ;
- Water level between NH and NB: P1 or P2 pump by permutation ;
- Water level below NB: P1 and P2 pumps in operation.

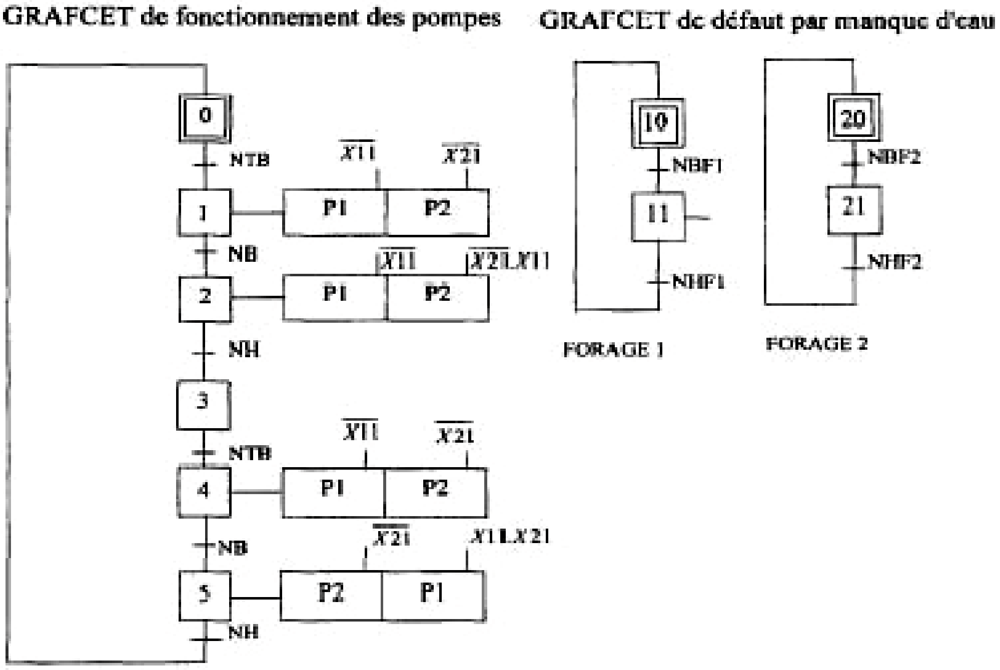


Fig. XII.5 : GRAFCET pump operation

To achieve the desired level, the pump is controlled. The diagram of the servo is given below:

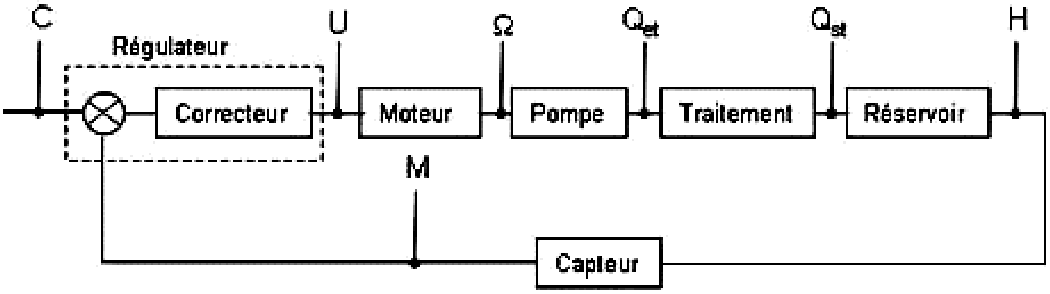


Figure XII.6 : Boucle de régulation de niveau

With :

- C: Control Instruction ;
- U : Motor set voltage in V ;
- Ω : Motor rotation speed in rad/s ;
- Q_{et}: Processing input flow ;
- Q_{st}: Processing output flow ;
- H : Tank height ;
- M: Measurement Signal.

For an on/off control with a set signal of 47%, the evolution of the tank height is given by the curve below :

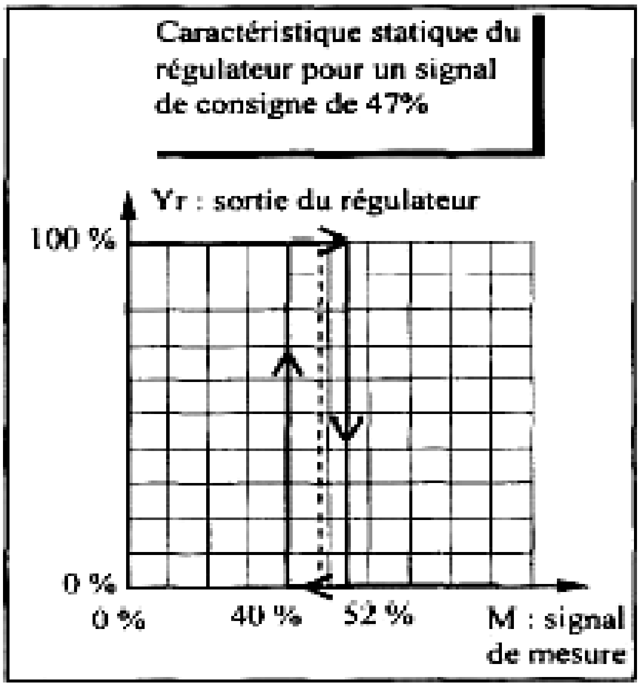


Fig. XII.7 : Regulation curve

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