Cours CIVIL 469 - Synthesis of the course, **week #06** (26.03.2025), 2h theoretical +2h exercises

1. Definitions

a. **Pump setting level,** as function of the

NPSH – net positive suction head, i.e. the required submergence of the suction side to prevent cavitation.

In general terms, in a hydraulic circuit the net positive suction head (NPSH) may refer to one of two quantities in the analysis of cavitation and definition of equipment setting levels (and therefore powerhouse and pumping station floor levels):

- The Available NPSH ($NPSH_A$): a measure of how close the fluid at a given point is to flashing, and so to cavitation. *Technically it is the absolute pressure head minus the vapour pressure of the liquid*.

- The Required NPSH ($NPSH_R$): the head value at the suction side (e.g. the inlet of a pump) required to keep the fluid away from cavitating (provided by the manufacturer).

NPSH is particularly relevant inside centrifugal pumps and reaction turbines, which are parts of a hydraulic system that are most vulnerable to cavitation.

If cavitation occurs, the drag coefficient of the impeller vanes will increase drastically - possibly stopping flow altogether - and prolonged exposure will damage the impeller.

$$NPSH_A = \left(\frac{p_i}{\rho g} + \frac{{V_i}^2}{2g}\right) - \frac{p_v}{\rho g}$$

z_i	the impeller axis level (or setting level)
$NPSH_A$	NPSH at the inlet of the impeller (suction side)
p_i	absolute pressure at the inlet
V_i	average velocity at the inlet
p_v	vapour pressure of the fluid at site conditions

One needs to compare the "Required NPSH" (provided by the manufacturer) with the "Available NPSH" provided by a baseline design (obtained with the expressions above).

Note that NPSH is equivalent to the sum of both the static and dynamic heads – that is, the stagnation head – minus the equilibrium vapor pressure head, hence "net positive suction head", assessed in absolute pressure terms.

Applying the Bernoulli's equation for the control volume enclosing the suction free surface "0" and the pump inlet "i", under the assumptions that the kinetic energy at "0" is negligible, that the fluid is inviscid, and that the fluid density is constant, leads to:

$$\frac{p_o}{\rho g} + z_o = \frac{p_i}{\rho g} + \frac{{V_i}^2}{2g} + \mathrm{z}_i + \mathrm{h}_f$$

Using the above application of Bernoulli to eliminate the velocity term and local pressure terms in the definition of $NPSH_A$:

$NPSH_A = \frac{p_0}{\rho g} - \frac{p_v}{\rho g} + (z_0 - z_i) - h_f$ [in meters]

Cavitation will occur when the available NPSH is less than the required by the manufacturer. In this case, designer must find ways either to lower the impeller level (and thus increase the available NPSH for the available impeller) or, if there is no means to change the structural part of the plant, select another pump with lower NPSH requirements.

b. Turbine setting level for a reaction turbine (e.g. Francis), as function of the required tailwater submergence

The minimum submergence for a Francis turbine is referred to as “maximum suction head” and can be related to the definition of the NPSH for pumps with some notable differences.

The calculation of NPSH in a reaction turbine is different to the calculation of NPSH in a pump, because the point at which cavitation will first occur is in a different place. In a reaction turbine, cavitation will first occur *at the outlet of the runner, at the entrance of the draft tube*.

Denoting the entrance of the draft tube by “e”, the $NPSH_A$ is defined in the same way as for pumps.

Applying Bernoulli's principle from the draft tube entrance e to the lower free surface 0, under the assumptions that the kinetic energy at 0 is negligible, that the fluid is inviscid, and that the fluid density is constant:

Using the above application of Bernoulli to eliminate the velocity term and local pressure terms in the definition of $NPSH_A$:

$NPSH_A = \frac{p_0}{\rho g} - \frac{p_v}{\rho g} - (z_e - z_o) + h_f$

Note that, in turbines, the minor friction losses on the draft tube (h_f) alleviate the effect of cavitation - opposite to what happens in pumps.

The minimum submergence is therefore

$h_{s,min} = (z_e - z_o) - h_f$

h_{s_min} – minimum submergence (or maximum suction head), i.e. the required tailwater backpressure required to prevent cavitation is

Combining the two above expression we can relate the submergence with NPSH provided by the manufacturer as function of the turbine characteristics:

$$h_{s\_min} = \frac{p_0}{\rho g} - \frac{p_v}{\rho g} - \sigma H$$

2. **Pumped storage cycle efficiency and equipment alternatives**

    a. Cycle efficiency (aka round-trip efficiency)
    b. Equipment alternatives
        i. With two machines, equipped with pump-turbines + motor/generators
        ii. With three machines, or ternary units, with separate mechanical runners for pumping and generation, sharing a common motor/generator
        iii. With four machines, also called “decoupled” systems, with separate mechanical runners for pumping and generation, each linked with its own motor or generator

3. **Pumped storage business case**

    a. Avoided costs => reduction of trade balance, replacing imported fossil fuels by domestic resources (water/wind/solar/geothermal)
    b. Electricity value gradient, for instance between peak and off-peak hours
    c. Capacity, for specific contributions for load balance, frequency control, voltage control etc.
    d. Facilitator, considering a lumped payment as provider of system stability based on benefits for total system costs

4. **Exercise 2**
    - Short-cycle, semi-open loop PSP scheme

5. **Design lessons**
    - Engineering design is always function of available data and resources.

    - Project definition level is in direct proportion to available data and resources (analogy with Spiderman sketches

    - Project definition advances per iterations, desirably incremental. At each stage the feasibility must be confirmed in view of justifying mobilising more resources (for investigations, for further engineering detailing)

    - **The designer must select methodology and assumptions according to each design stage, which means that they are also in direct proportion to available data and resources.**

    - Assumptions must be justified based on state-of-the-art good 8or best) practices and own experience.