Pump Curve Similarity Laws Model

1 OVERVIEW

The `*PumpCurveSimilarity*` component models a pump using manufacturer performance curves together with the pump affinity (similarity) laws. It allows computing the pump operating point in three possible modes:

- P_N: Given suction and discharge pressures and rotational speed, compute flow rate and shaft power.
- P_M: Given suction and discharge pressures and mass flow rate, compute the rotational speed and shaft power.
- M_N: Given suction conditions, mass flow rate and speed, compute exhaust pressure and shaft power.

The model uses four characteristics curves at rated speed:

- Head rise: $\Delta H = f(\dot{V})$
- Isentropic efficiency: $\varepsilon_{\mathrm{is}} = f(\dot{V})$
- Required NPSH: $\mathrm{NPSH_r} = f(\dot{V})$

The isentropic efficiency can be computed based on the power curve is not available in the datasheet of the manufacturer:

$$\varepsilon_{is} = \frac{\dot{W}_{hyd}}{\dot{W}_{shaft}} = \frac{\rho g \, \Delta H \, \dot{V}_{m^3/s}}{\dot{W}_{shaf}}$$

The curves are supplied at a rater speed (N_{rated}) and are scaled to other rotational speeds using similarity laws.

2 ASSUMPTIONS

- Steady–state operation

- The fluid is treated as incompressible for head calculations

- The manufacturer curves are provided at a reference speed

- Similarity laws are valid (geometric similarity with speed variation)

- Isentropic efficiency $\varepsilon_{\mathrm{is}} = f(\dot{V})$ is *assumed independent of speed* (standard pump affinity assumption)

3 FUNDAMENTAL PUMP RELATIONS

3.1 Head-Pressure relation

The relationship between pressure rise and pump head is:

$$\Delta H = \frac{P_{ex} - P_{su}}{\rho g}$$

Where:

- ΔH : head increase [m]

- $P_{ex} - P_{su}$: discharge and suction pressures [Pa]

- g : gravitational acceleration [m/s²]

- ρ: fluid density [kg/m³]

3.2 Hydraulic and Shaft Power

The ideal hydraulic power is:

$$\dot{W}_{\text{hyd}} = \rho g \, \Delta H \, \dot{V}_{m^3/s}$$

The real (shaft) power is:

$$\dot{W}_{shaft} = \dot{m} \cdot (h_{ex} - h_{su})$$

Where $h_{ex} = h_{su} + \frac{h_{ex,is} - h_{su}}{\varepsilon_{is}}$

4 SIMILARITY LAWS

The manufacturer curves are provided at rated speed (N_{rated}). When the pump rotates at speed N the similarity laws give:

Flow scaling:

$$\dot{V} = \dot{V}_{rated} \cdot \frac{N}{N_{rated}}$$

Head scaling:

$$\Delta H = \Delta H_{rated} \cdot \left(\frac{N}{N_{rated}}\right)^2$$

NPSH scaling:

$$\text{NPSH}_{\text{r}} = \text{NPSH}_{\text{r,rated}} \cdot \left(\frac{N}{N_{rated}}\right)^2$$

Efficiency is assumed constant with respect to speed:

$$\varepsilon_{is} = \varepsilon_{is,rated}$$

5 EXAMPLE

In Figure 2, the points taken from the characteristic curve are shown.

All of those points are for a speed reference of 2900 RPM and a water temperature of 20°C.

```
# Example characteristic curves and parameters
V_dot_curve = np.array([20, 30, 40, 50, 60, 70, 80])   # m3/h
Delta_H_curve = np.array([57, 55, 52, 49, 45, 42, 36])  # m (head falls with flow)
eta_is_curve = np.array([0.45, 0.59, 0.69, 0.75, 0.79, 0.79, 0.75])  # eff peaks near mid-flow
NPSH_r_curve = np.array([1.1, 1.1, 1.4, 1.8, 2, 3, 4.7])  # m, increases again near max flow
```

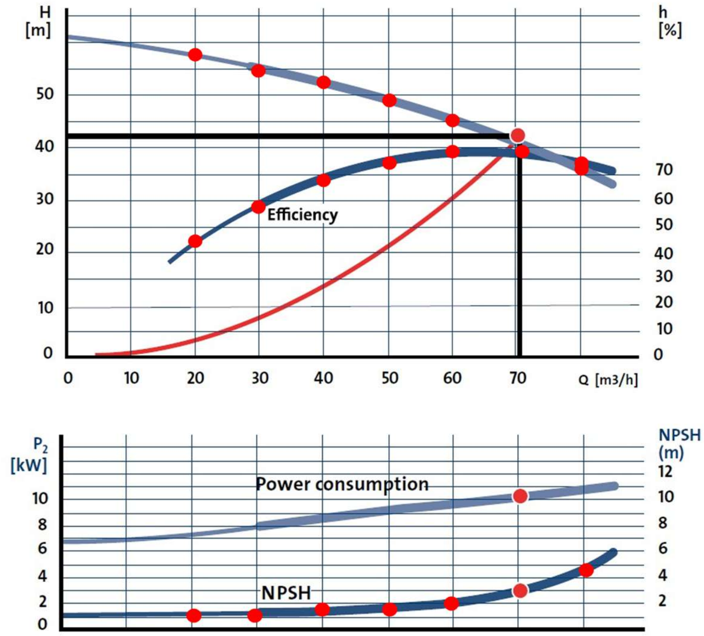

Figure 1: Example of a characteristic curve provided by the manufacturer.