Hydraulic Dredging: horizontal transport Part 2: Dredging Process of dredged mixtures trough pipes (2009-2010)

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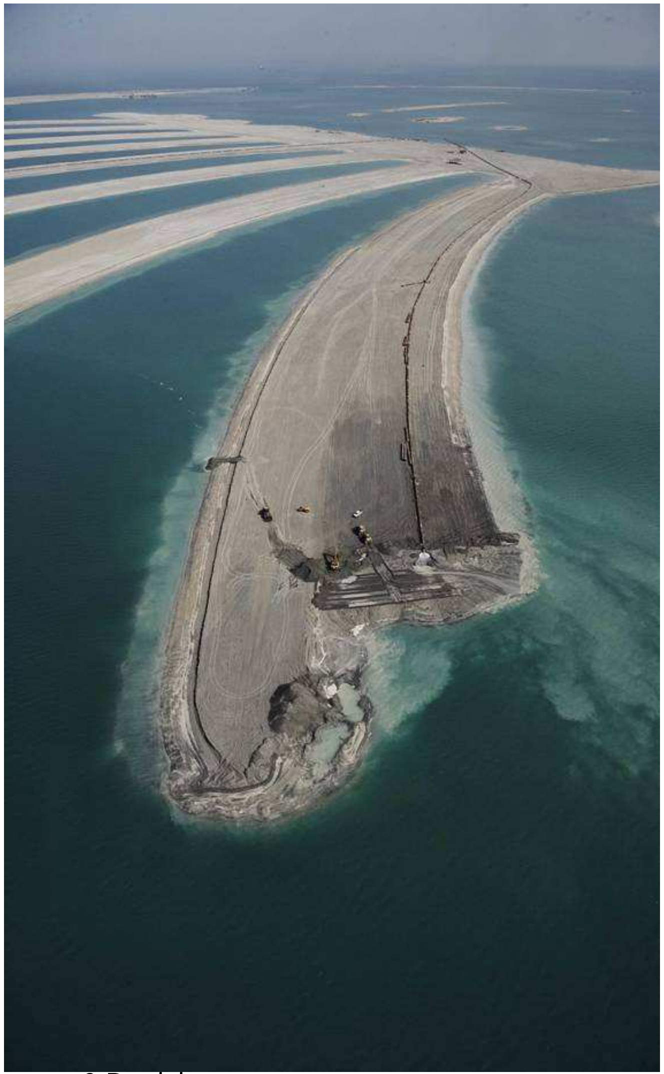
Hydraulic Dredging and Transport of soil particles

Dredging is a complete process-technology with following processes:

1. Breaking shear-resistance of in-situ underwater soils: mechanical cutting, ripping,… and/or hydraulic erosion-lifting of particles
2. Admixture of water with particles to get a hydraulically pumpable mixture
3. Creation of a vacuüm in suction-pipe in order to get hydraulic mixture into the dredge-pump: velocity and turbulence
4. Creation of sufficient head to pump the mixture as a turbulent suspension into the hopper or via pipelines down to the discharge point
5. Discharge of mixture in an area designed to allow settlement and separation of particles from water

The Energy for velocity/turbulence and Head is added to the mixture by the Pump-Drive Plant. The Pump-Drive Plant accelerates the fluid in order to give it a Dynamic Pressure or Head (velocity) and a Static Pressure or Head (pressure).

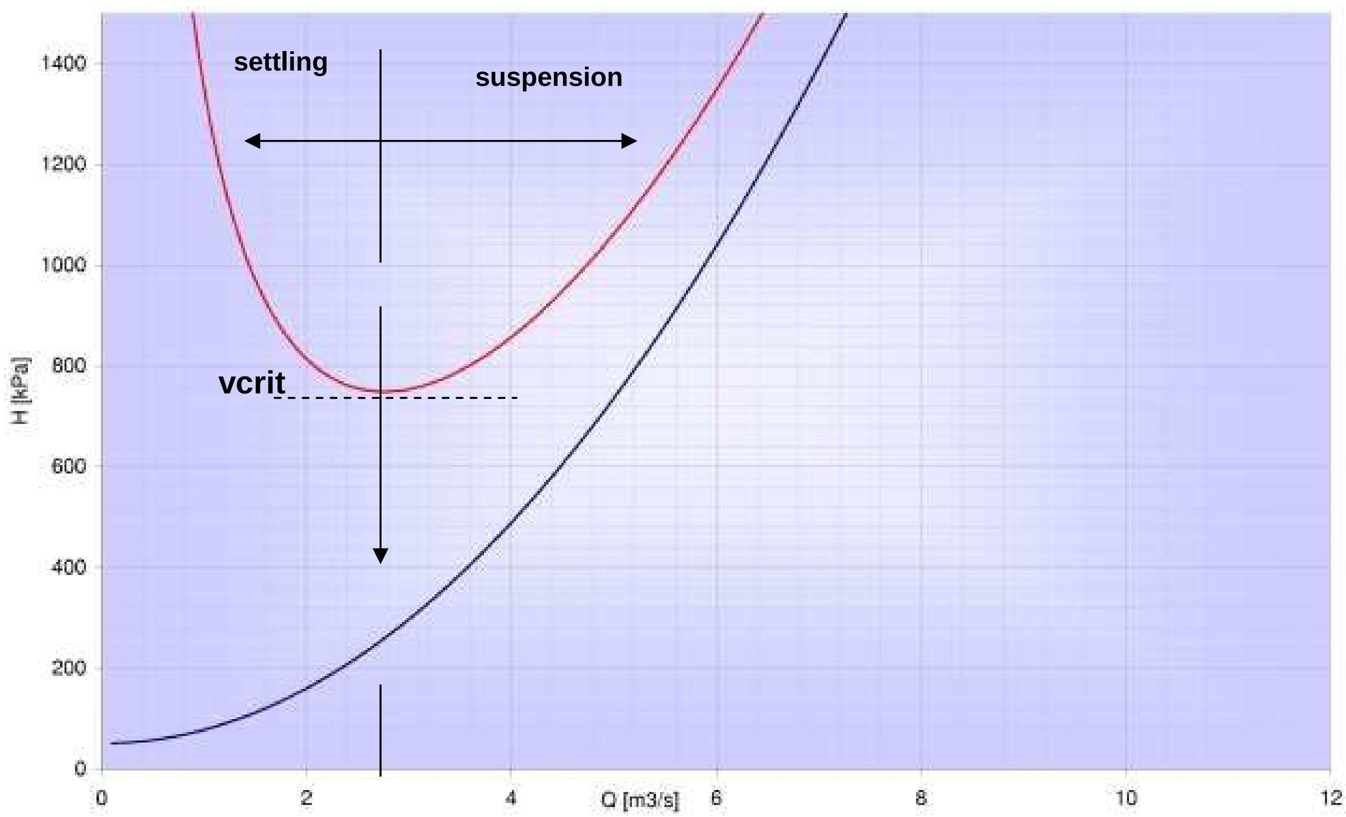


Hydraulic Process in Dredge-Pipe: Hydraulic characteristic of sand-water mixture

- **Relationship is of the following type:**

$$H = aQ^2 + \frac{b}{Q} + c$$

- **Minimum of curve: critical velocity/discharge**



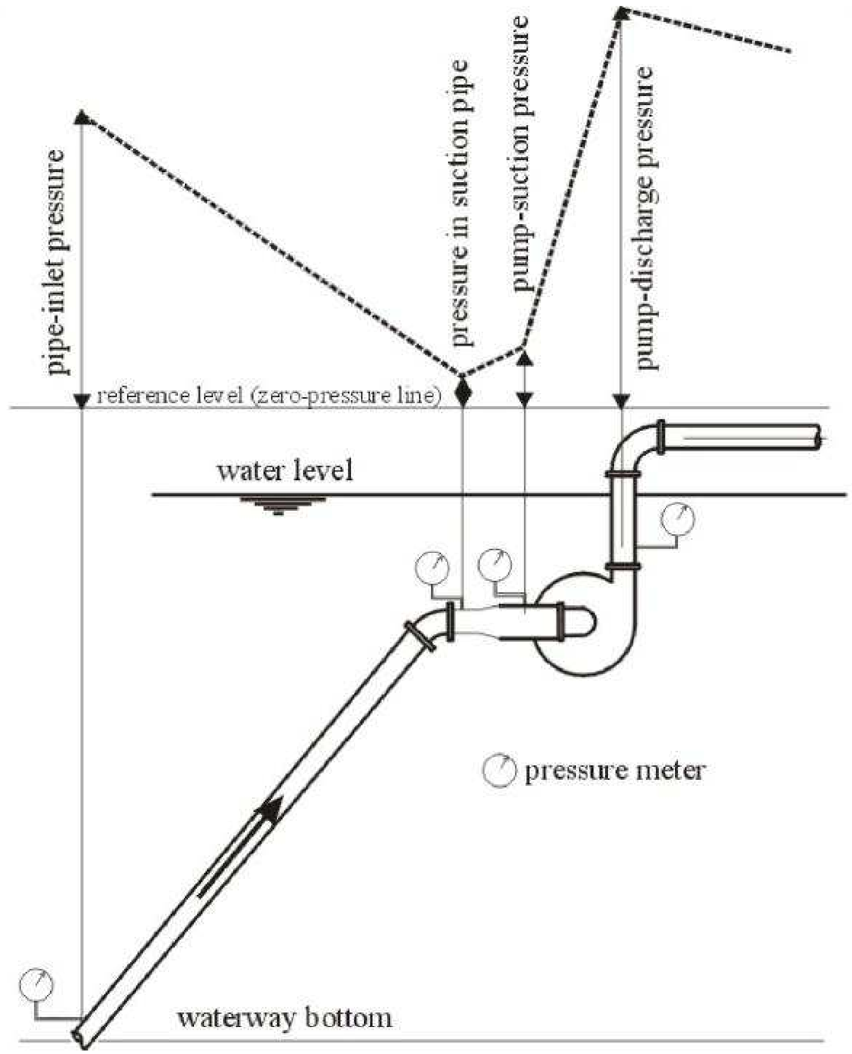
Hydraulic Process in Dredge-System

Governing elements in the dredging process

•Critical Velocity/Discharge
⇒ Control: delivered discharge/velocity

• Resistance in the total pressure line
⇒ Control: Hydraulic head delivered by pump & drive by Power

• Resistance in suction pipe
⇒ Control: Decisive vacuüm & position of pump



Dredge pumps

Specific requirements of dredge-pumps:

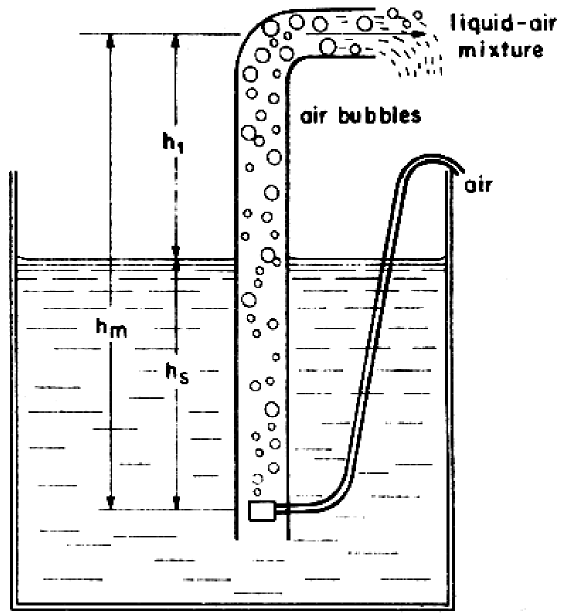
- **Large operational range: the same pump must be able to tackle a wide range in discharge, concentrations, soil-parameters**
- **Pump must compromise 2 requirements**
  - **dredging: high discharge, low pressure**
  - **reclamation:low discharge, high pressure**
- **Wear resistant**
- **Large opening preventing clogging by obstacles: cables, chains, debris,….**
- **High power**
- **Large efficiency**
- **Good decisive vacuüm (vacuüm as large possible before 5 % pressure-drop occurs in pressure-line)**

Dredge pumps

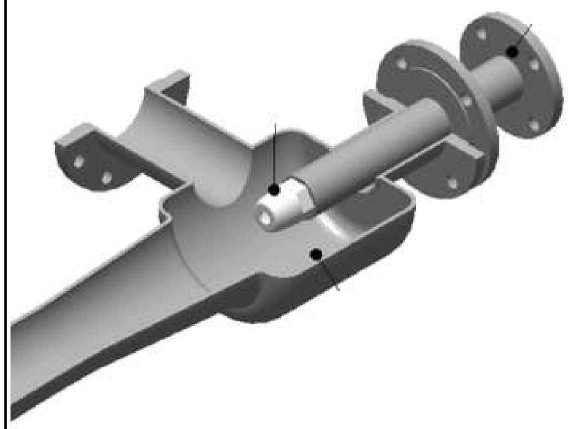
Pumps used sporadically in dredging works

Airlift-pump	Ejector-pump	Membrane-pump

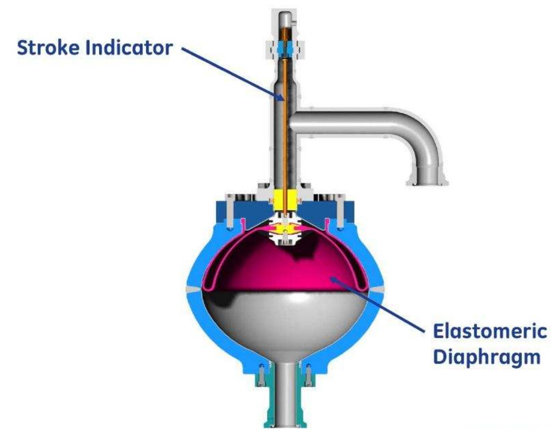
Airlift-pump



Ejector-pump



Membrane-pump



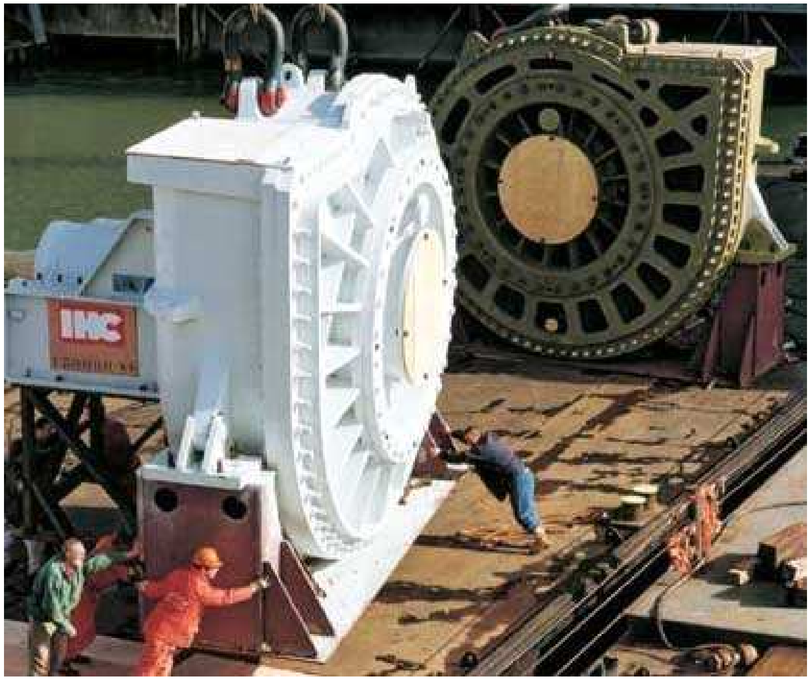
Centrifugal Dredge Pumps

Advantages

- continuous fluid-discharge.
- minimum moving parts
- cost-effective
- compact and light-weight.
- high efficiency (80% - 85%).
- large sphere-passage.
- allowed to be manufactured in wear-resistant materials
- possibility to be fail-safe conceived: double-walled pump

Drawbacks

- no self-priming
- sensitive to air-leaks, gas (on suction side)



Centrifugal Dredge Pumps

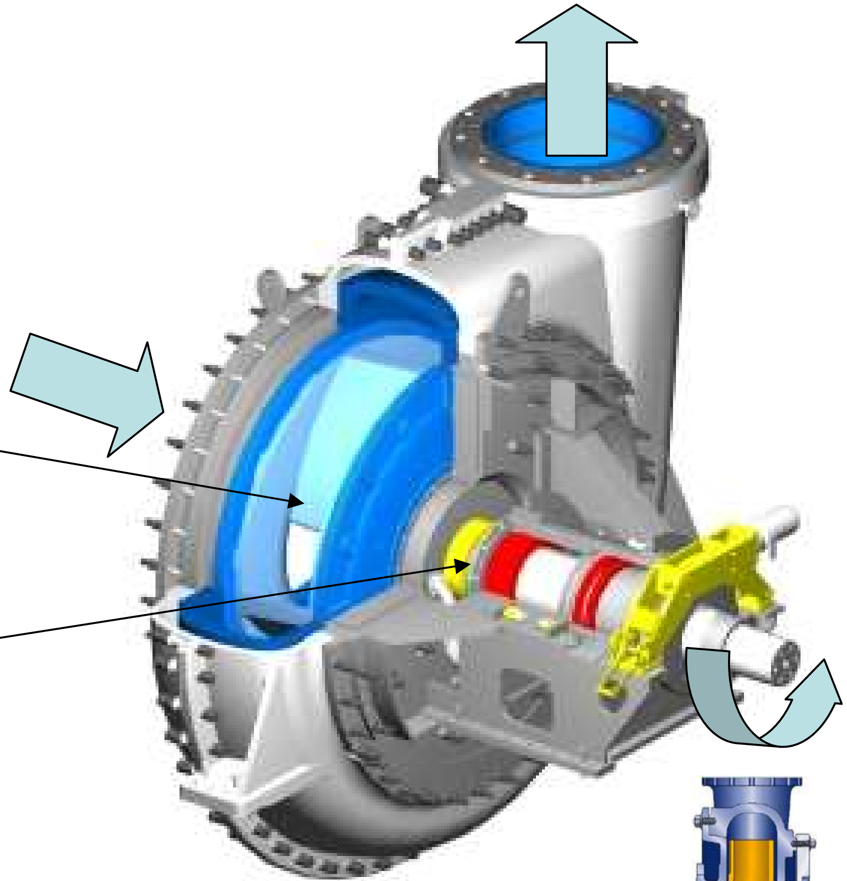
Specificities of pumps

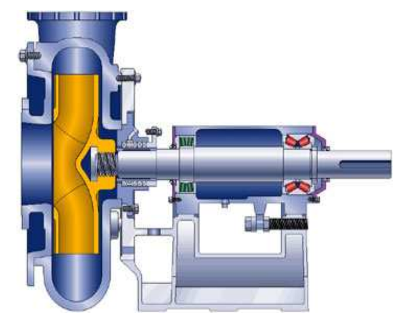
- Smallest aperture at inlet of rotor (no clogging in pressure line)
- Aperture is large: limitations to 3 to 5 blades
- Double walled stator
- Glandwater-flushing

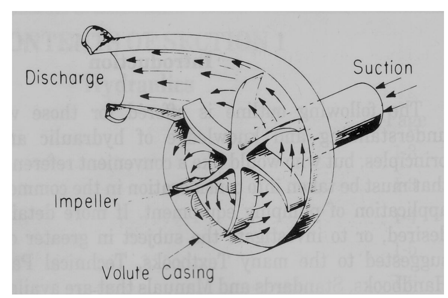
•Maximal rotor-tip velocity: 40-45 m/s

•Design pressure: 6 to 10 Bar

• Design discharge: 1 tot 10 m³/s



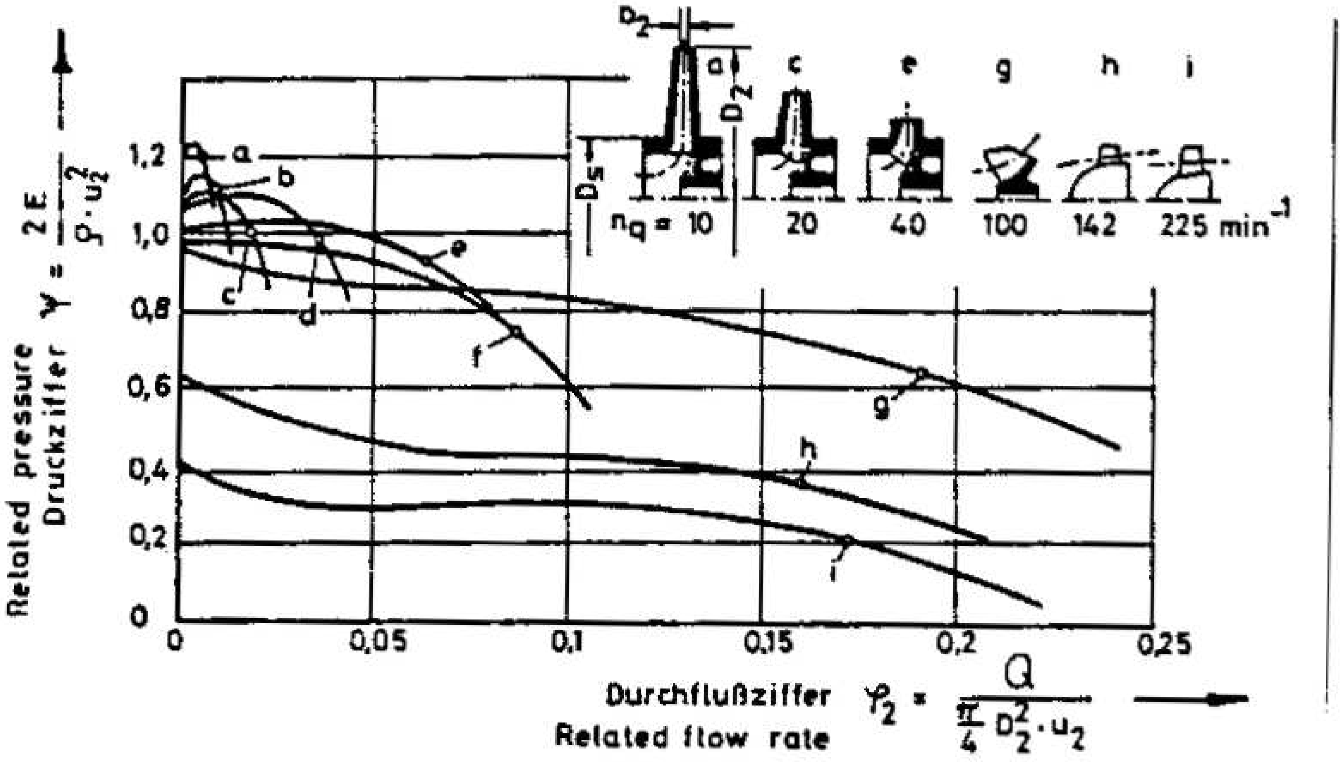




Centrifugal Dredge-Pump

A centrifugal dredge-pump is in fact a radial turbo-pump, in which:

- The diameter and the rpm will determine the pressure head, H
- The width determines the working area: the discharges where the best efficiencies are achieved
- Blade-form determine the Q/H characteristic



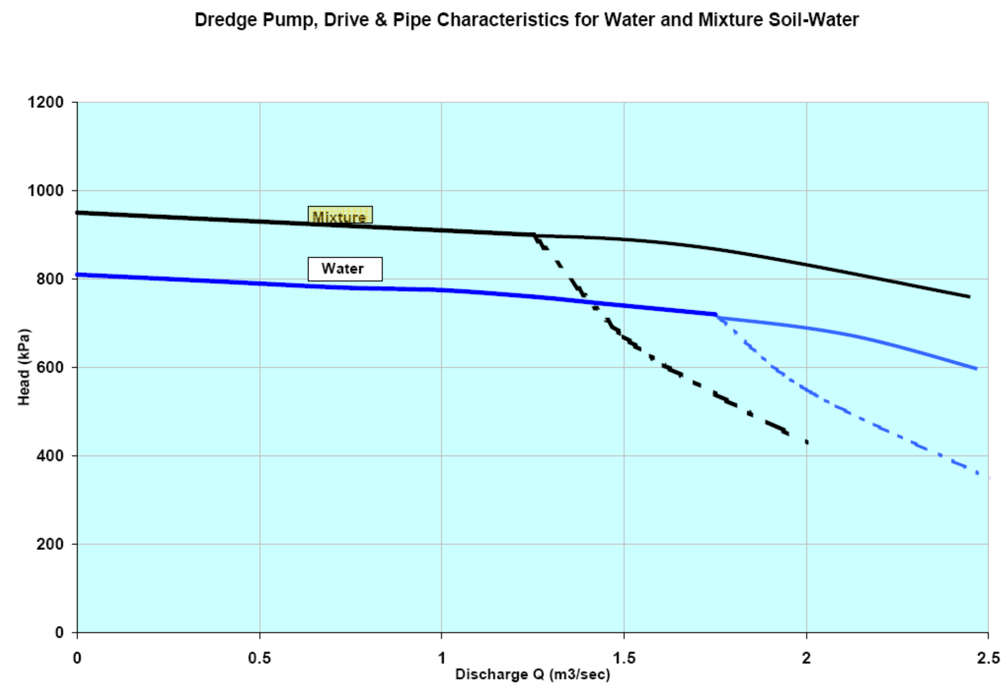
Centrifugal Dredge-Pumps

The pump's discharge is determined by the flow-resistance in the whole circuit: before and after the pump. And this is independently of her design discharge and manometric pressure-head.

The pump is the slave of the system

With a high resistance, one gets
•Low discharge
• Heigh pressure

With a low resistance
• High discharge
• Low pressure



Centrifugal Pump: Characteristic H /Q

characteristics
(deduced from Euler's equations)

Manometric Pressure Head for rpm n0:

$$H_w = aQ^2 + bQ + c$$

Efficiency for rpm n0:

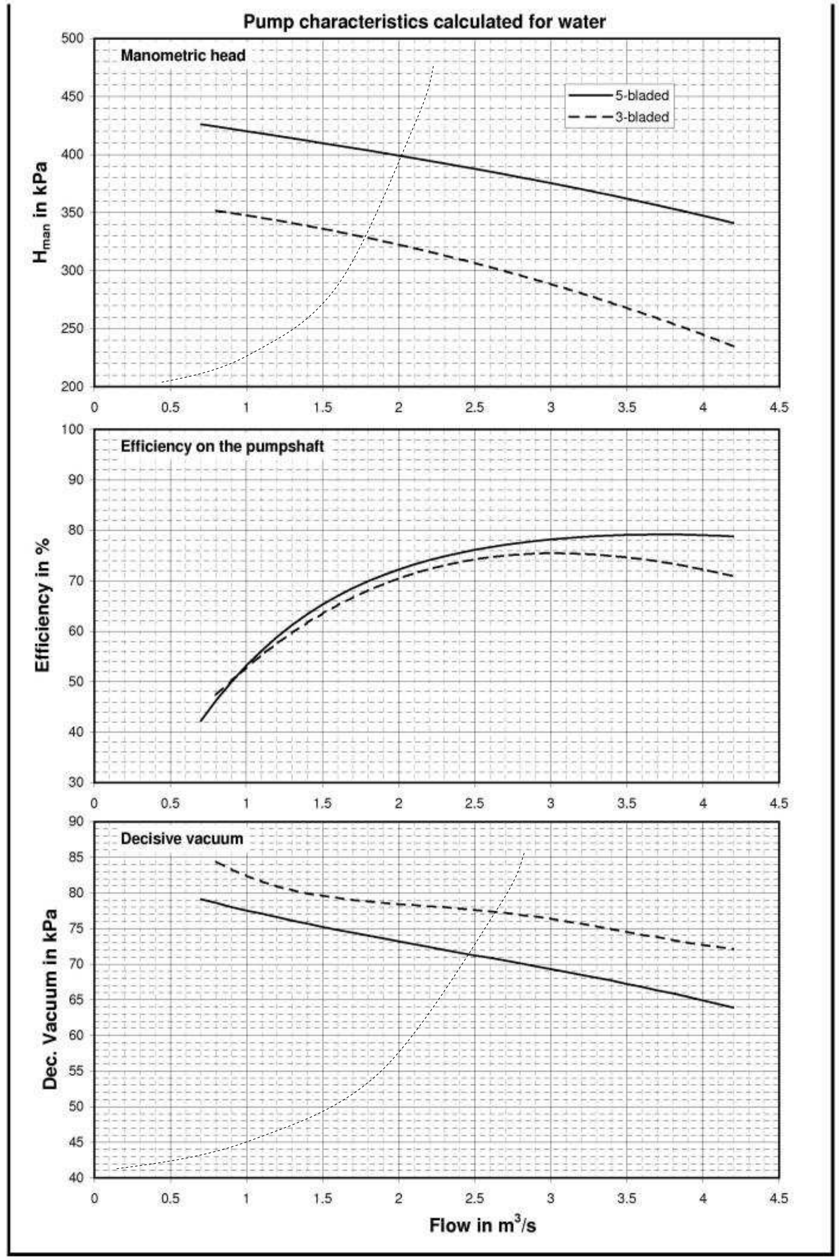
$$\eta_w = a'Q^2 + b'Q + c'$$

Power:

$$P = \frac{QH}{\eta}$$

Decisive Vacuüm:max Vac for max 5 % H drop

$$Vac_m = p_{atm} - NPSHR - p_d + \rho_m .v2/2$$



Centrifugal Pumps: Geometry

Slim & High pump

- Heigh pressure
- Low discharge

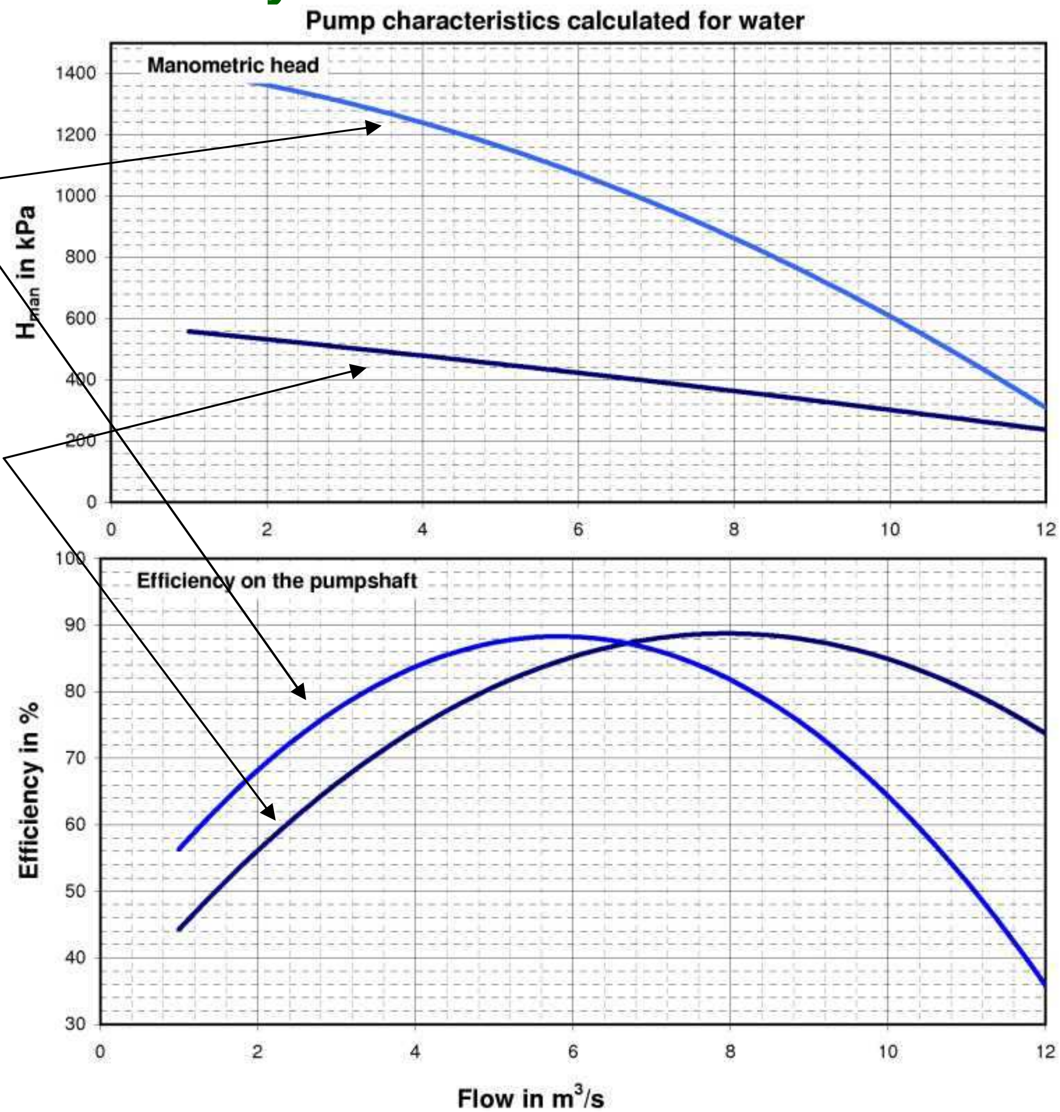
Wide & Short pump

- Low pressure
- High discharge

Manometric Pressure ~ diameter

Discharge ~ Width

Slope Q/H line ~blade-form

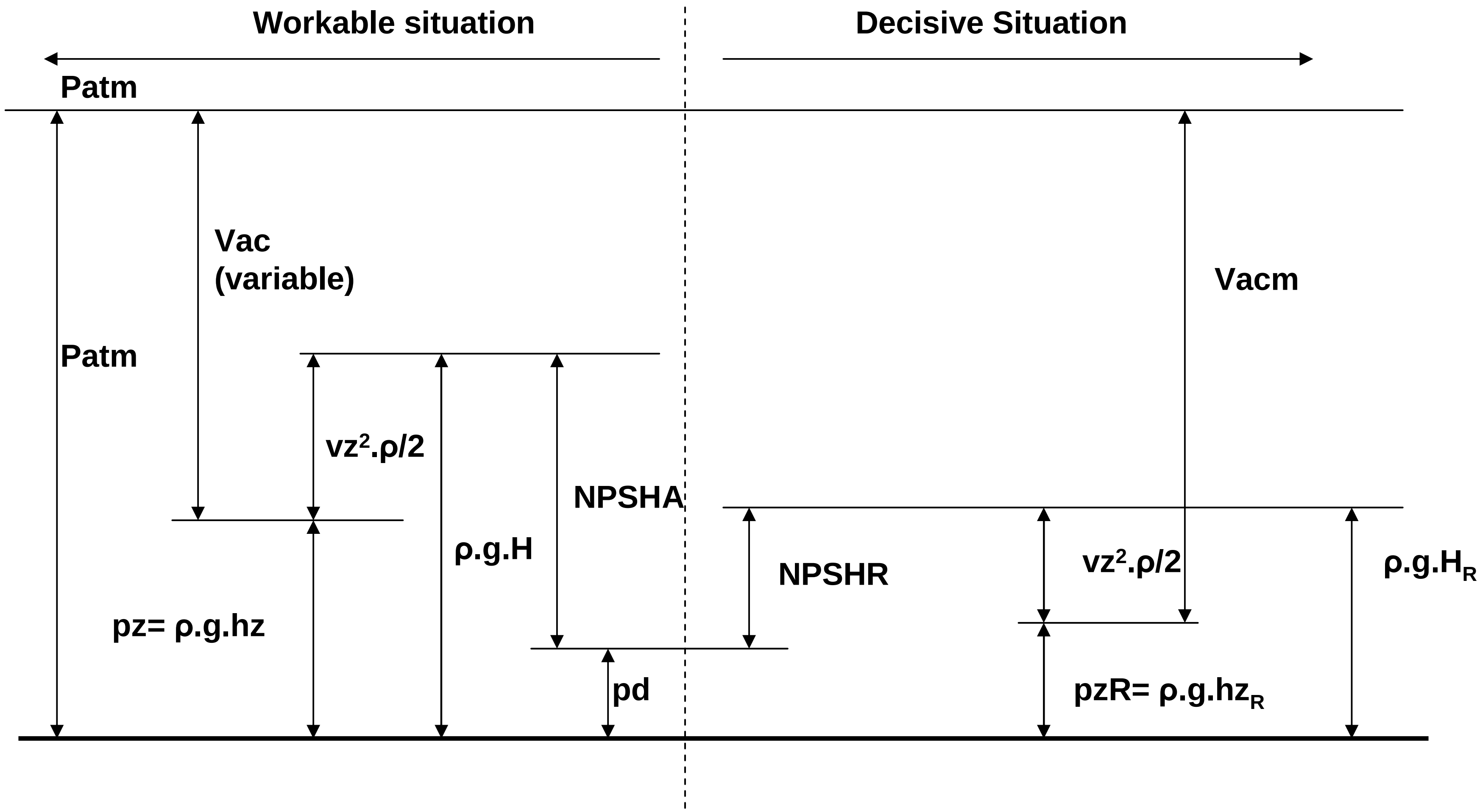


Suction Pipe in Dredger: relationship between Vacuüm, NPSH en Pressures

H= head at suction of pump

pd= vapour pressure

NPSH: Net Positive Suction Head

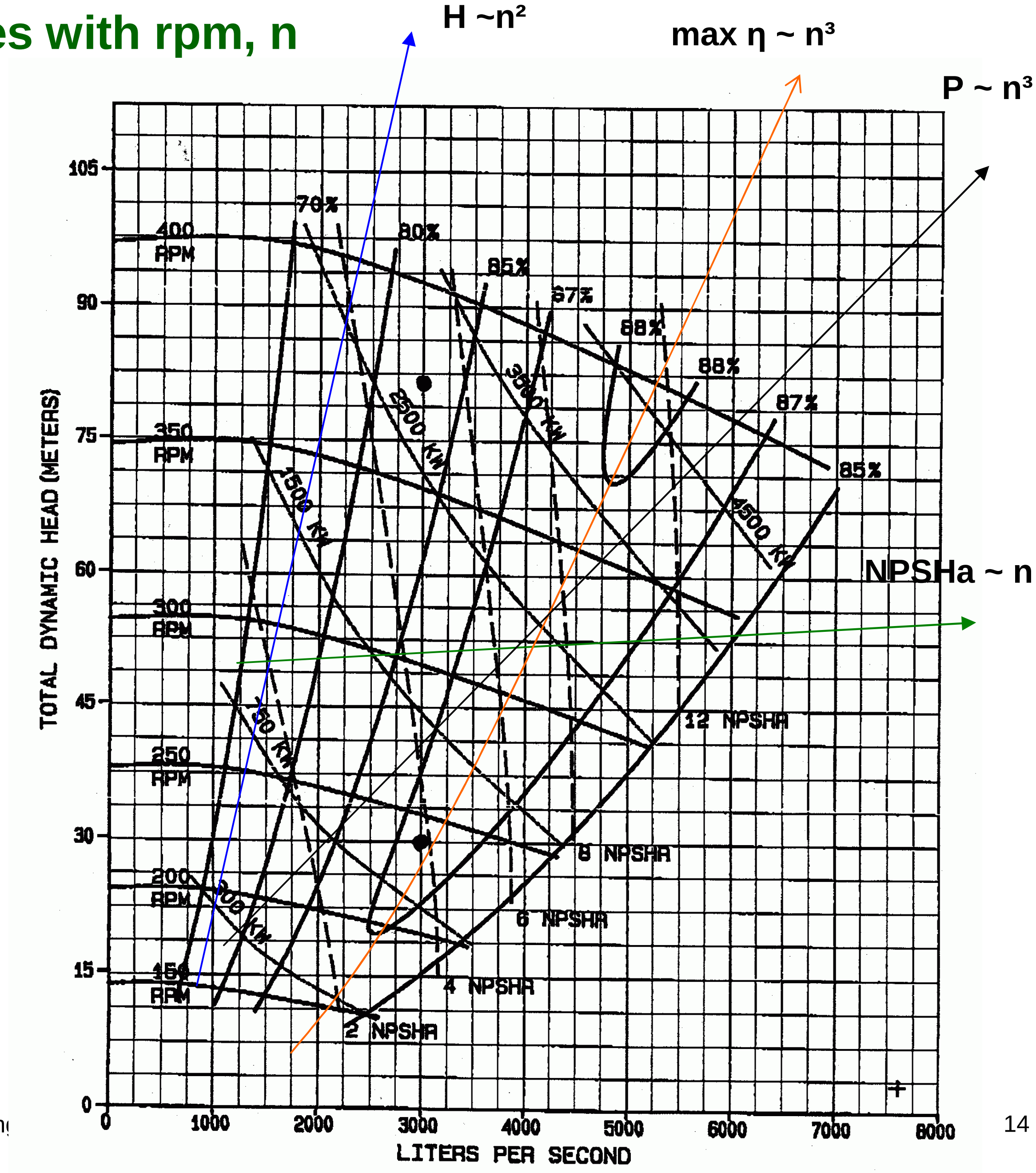


Centrifugal Pumps: Affinities with rpm, n

Discharge: $Q \sim n$

Manometric Pressure Head: $H \sim n^2$

Power: $P \sim n^3$



Centrifugal Pumps: Affinities with n

Affinity -laws

(Deduced from Euler's equations)

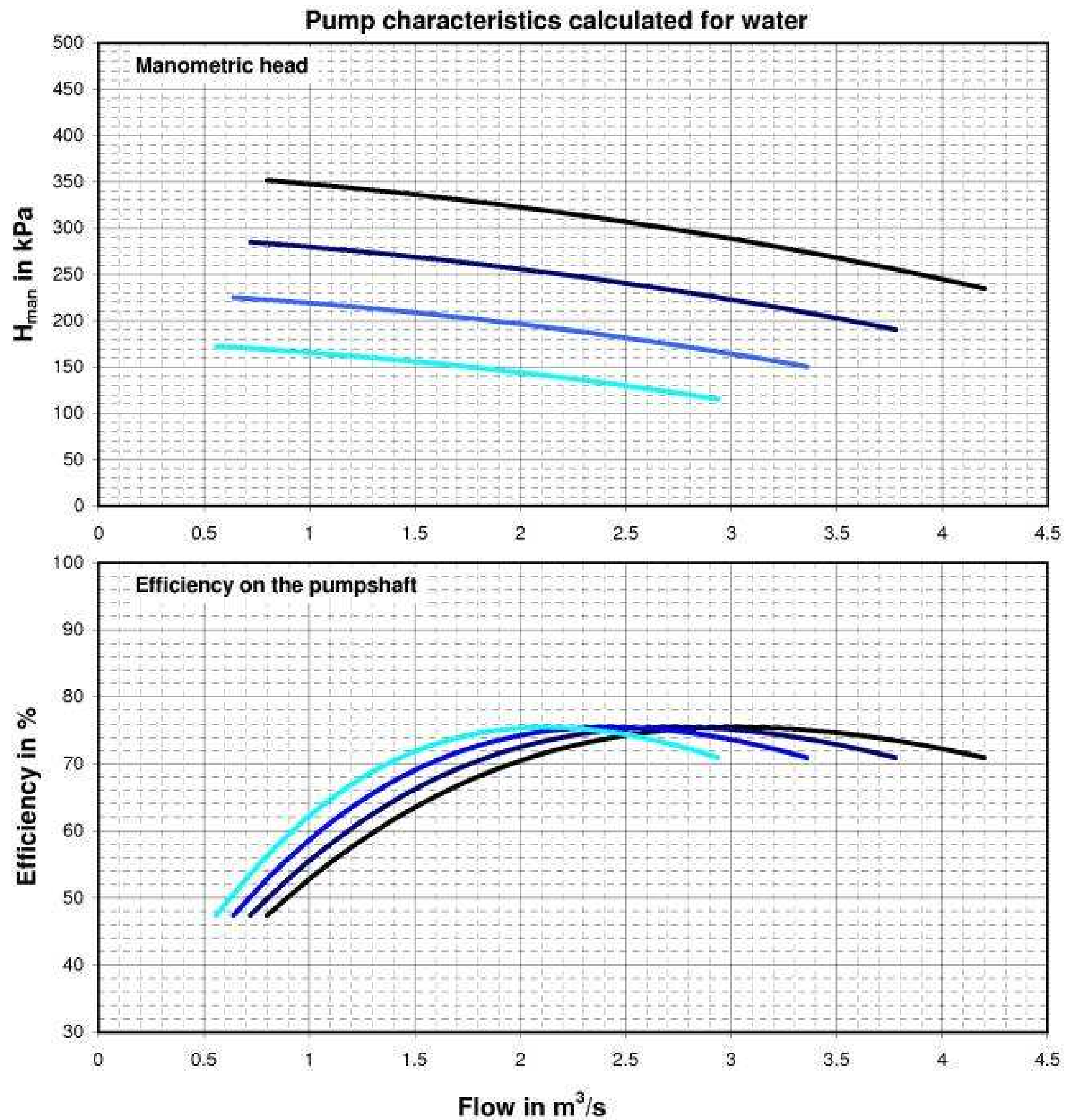
⇒Determine pump-characteristics for a variable rpm

⇒Homologue workpoints : flow-regime in pump is similar

Discharge: $Q \sim n$

Manometric pressure: $H \sim n^2$

Power: $P \sim n^3$



Centrifugal Dredge-Pump

How to select the most appropriated dredge-pump?

1. **Determine the working area of the pump**
   - **Discharge is determined by the diameter of the pipe**
   - **Pressure is determined by the installed and available power**
2. **Choose the type of pump**
   - **number of blades (determines the transit-aperture)**
   - **Low pressure, medium pressure, high pressure**
3. **Choose the maximum allowable rpm**
   - **A high rpm yields**
     - **°a small and cheap pump**
     - **°lesser suction-characteristics**
     - **°small transit-aperture**
   - **Tip-velocity of pump-blades is limited because of wear (40-45 m/s)**

Driving system of Dredge-Pumps

Most common driving systems:

- **Direct diesel driving**
- **Diesel-electric driving**

Direct Diesel driving systems

Advantages:

- **Loss of efficiency between pump and engine is limited**
- **Simple and cost-effective**

Drawback:

- **Necessity of gear-boxes: dredge-pumps are typically low rpm (150 -200 rpm: suction pump; 300 rpm: pressure pump). 2 or 3 gears (Low, Medium, High)**
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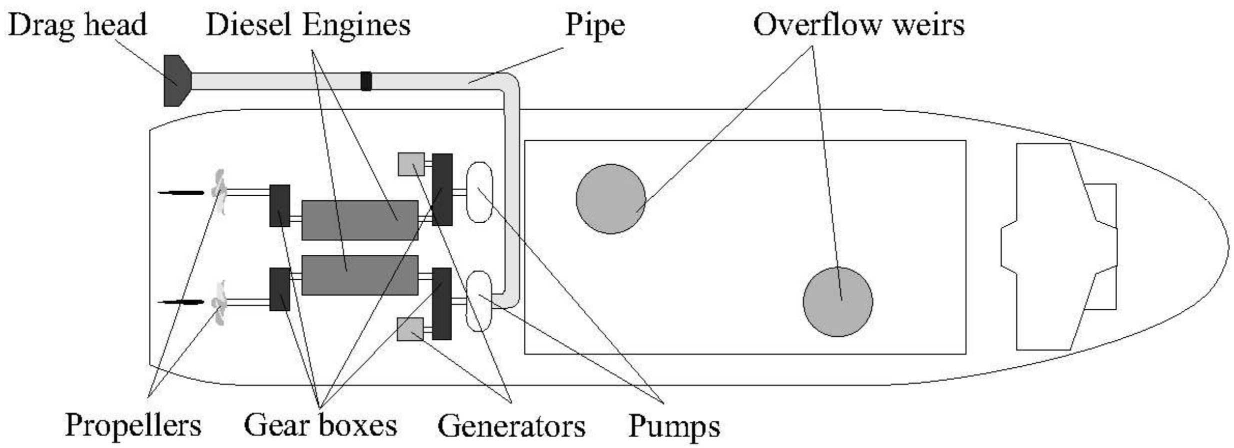
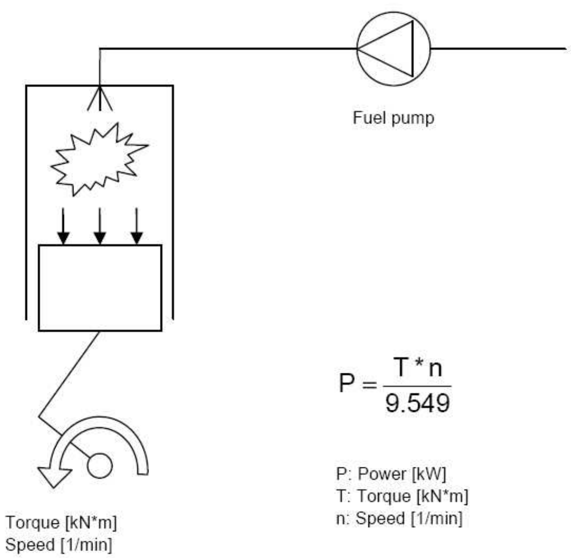
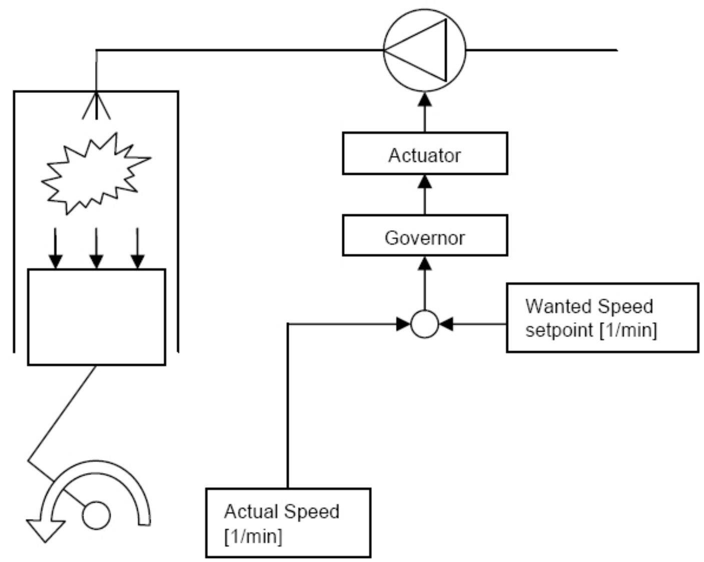


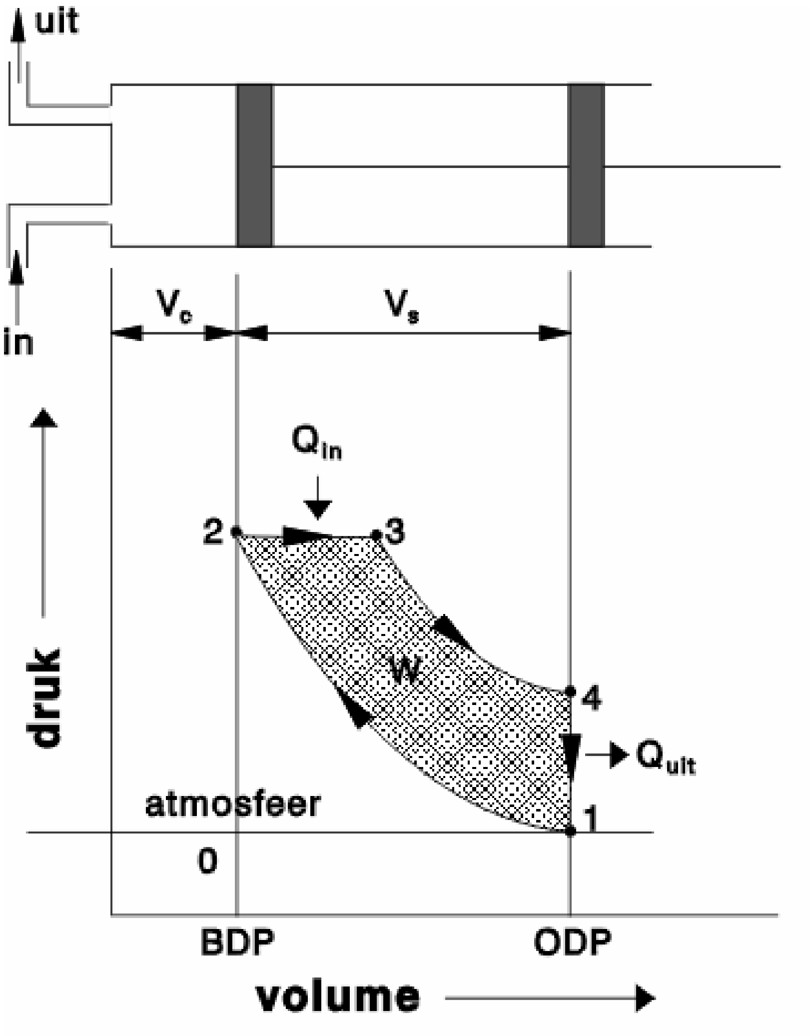
Direct Diesel driving: principles of Marine Diesel Engines

- **Principles of a Diesel-engine as used in dredgers:**
  - **fuel: cheaper (40 % approx) Heavy Fuel Oil (to be pre-heated and special precautions for 3 % S-content) or Marine Gas Oil (universal marine engine fuel)**
  - **8, 10, 12 cylinder engines in line or in V: generally 2-stroke**
  - **Medium Speed Engine: 500- 1.000 rpm**
  - **Gearbox to Pump (1 to 3 gears): reduction to 150 rpm/300 rpm**
  - **Gearbox to Generator (1 gear): upgrade to 1.200 rpm**
  - **Efficiency: 30 – 45 %**
  - **Torque (T) is proprtional with fuel-volume**





pV-diagram of an diesel-cyclus



The 'Carnot' cycle

The piston travels between the Lower Dead Point (LDP), and the Higher Dead Point ((HDP)

The PV- Diagram shows the following sequence:

0-1 : Inlet-stroke: air is admitted

1-2 : Air is compressed adiabitacally and temperature raises to 550 à 600°C

2: Fuel is injected at P = 15MPa

2-3 : Diesel-fuel self-ignites isobaric

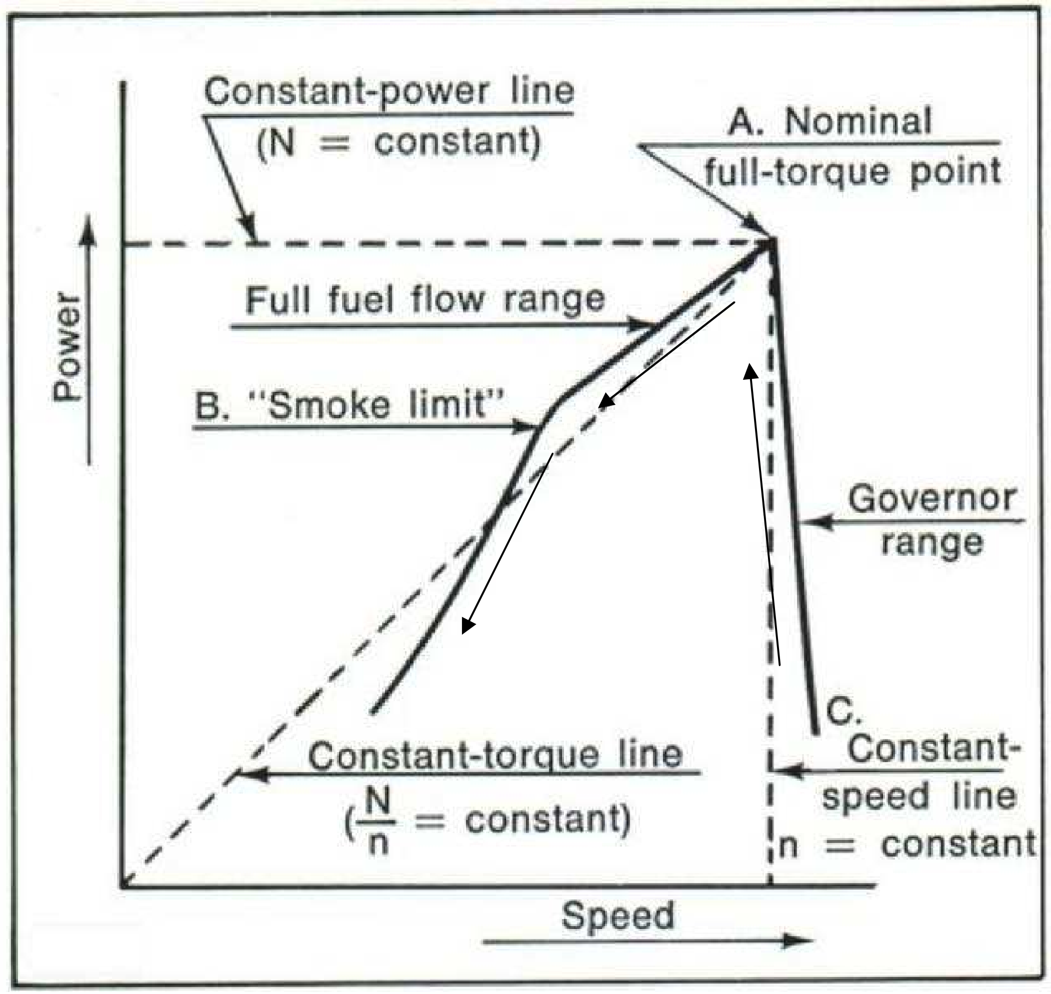
3-4 : Gas-expansion & temperature raise increases pressure adiabatically to 4,5 - 7MPa

4-1 : Combustion gases are exhausted isochorically

1-0 : Piston travels back to 0

Characteristic of Diesel Engines

- (Almost) Constant rpm-area: area where required power is lower than maximum power: regulation of Power is function of volume of fuel injected/stroke
- Nominal full-torque or full-power point
- At higher required power, rpm will decrease at constant torque , still with maximum fuel-consumption
- Till “Smoke point” below which the engine is running at low efficiency, incomplete combustion, …
- In the whole process, the rpm varies between 70%-100%

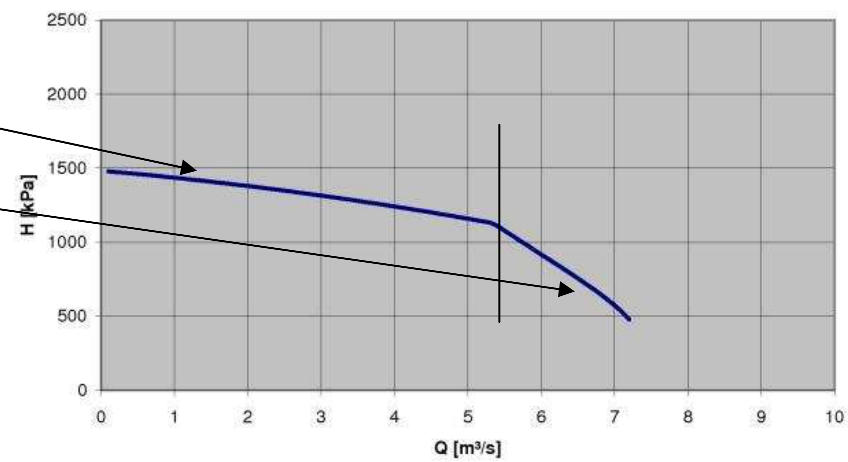


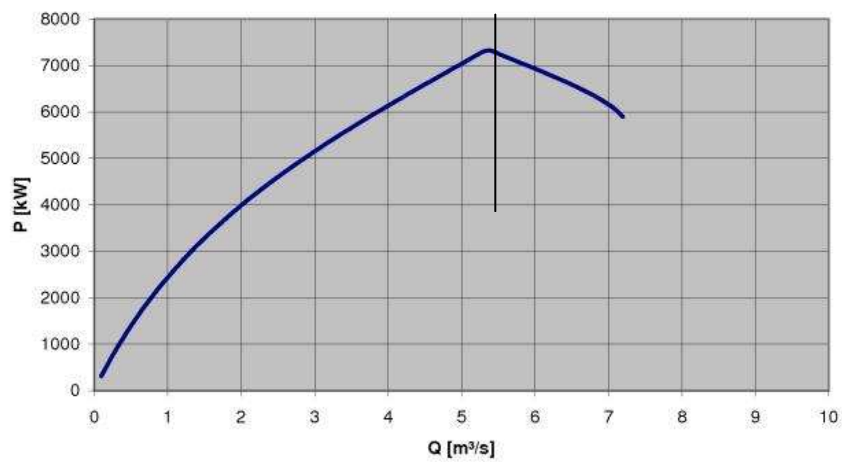
Superposition of Dredge-Pump and Diesel drive characteristics

- Constant rpm-area
- Full-torque point
- Constant torque area

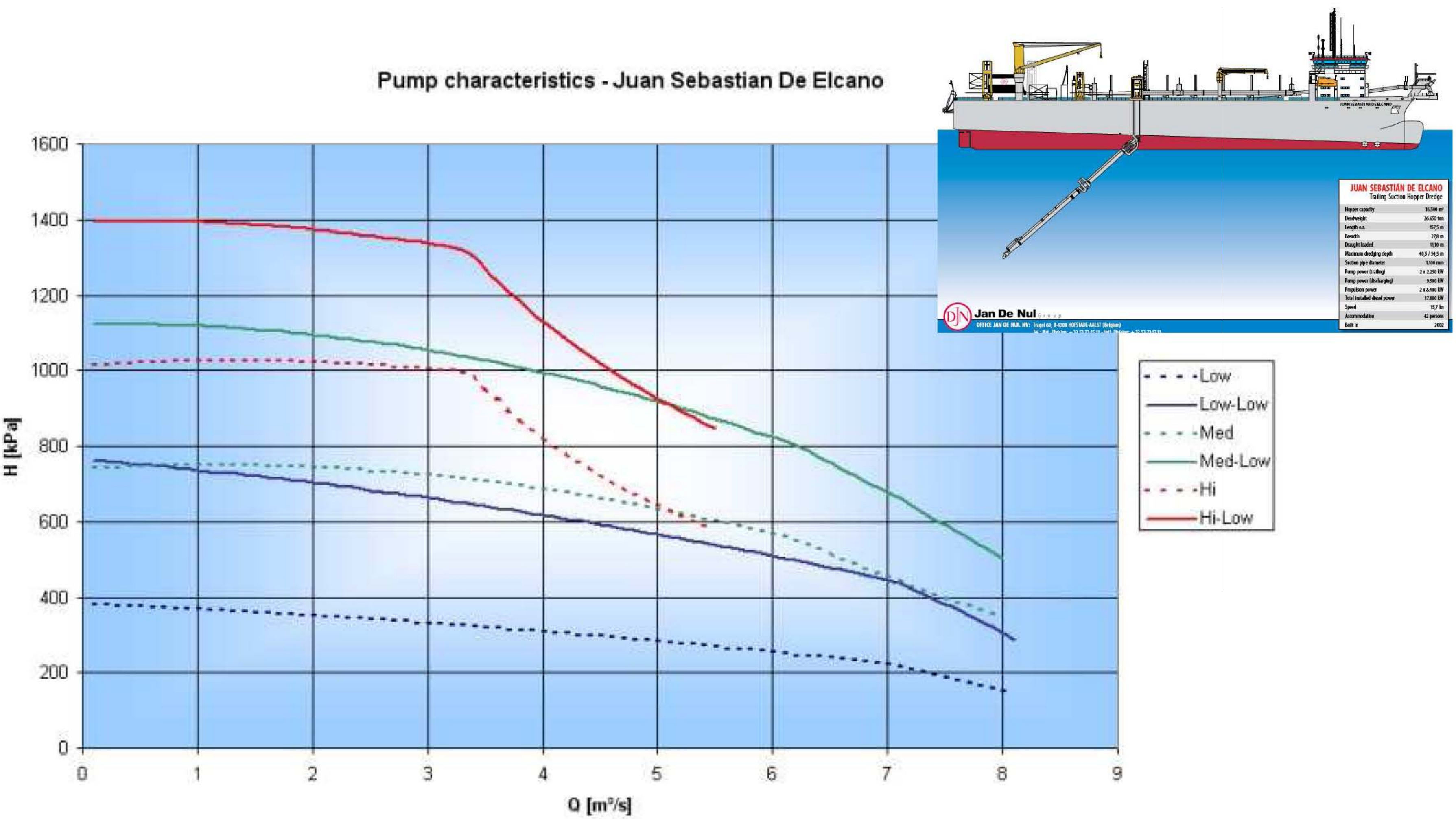
Points of attention:

- other power users may influence the rpm, hence the available power of the engine
- the rpm may only vary within 100 % and 70 %: below 70 % of n, the engine may stop
- engine must be able to cope with variations in power-demand and rpm and therefore is often impeded to deliver as much power as a diesel-generator.





Dredge Pumps: Direct Diesel Drive for single and serial pumps

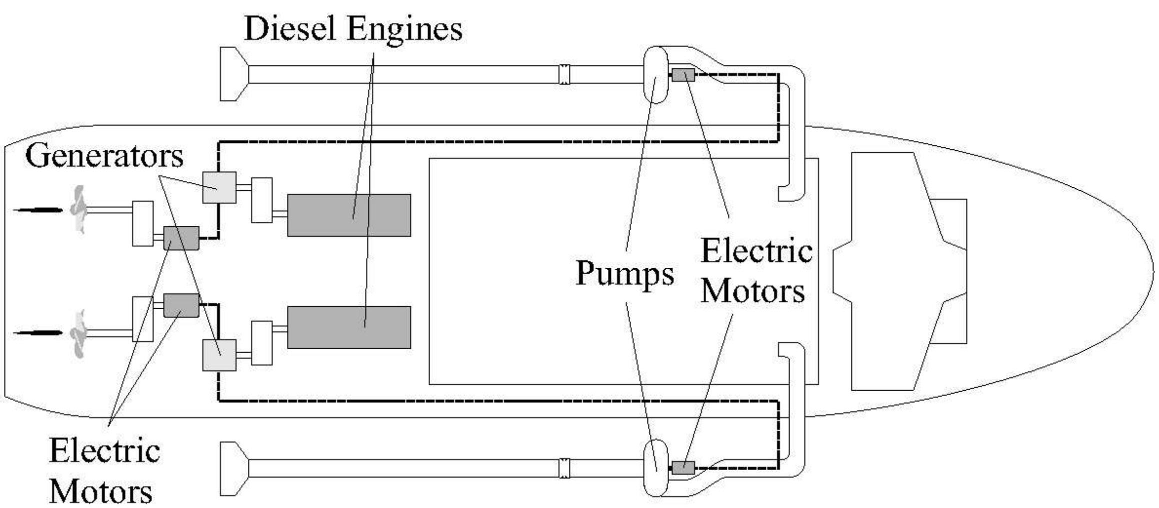


Dredge Pumps: Diese-Electric Drive

Since 2000, general application because of increased reliability and frequency-regulation systems for high power

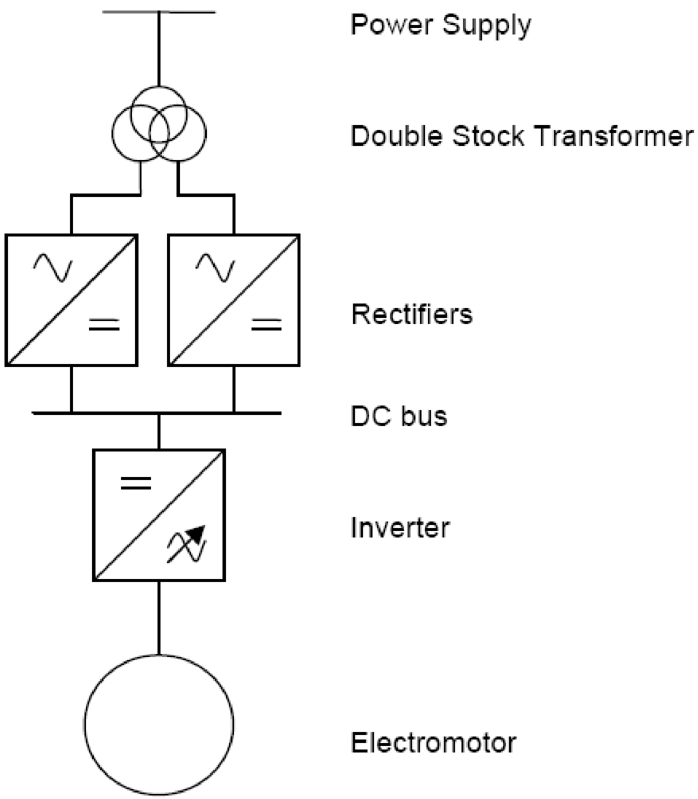
Advantages:

- **Flexible power distribution between dredge-pumps and propulsion**
- **Possibility for submerged pumps (on suction tube)**
- **Limited loss in efficiency between generator and pump: 10 – 15 %**

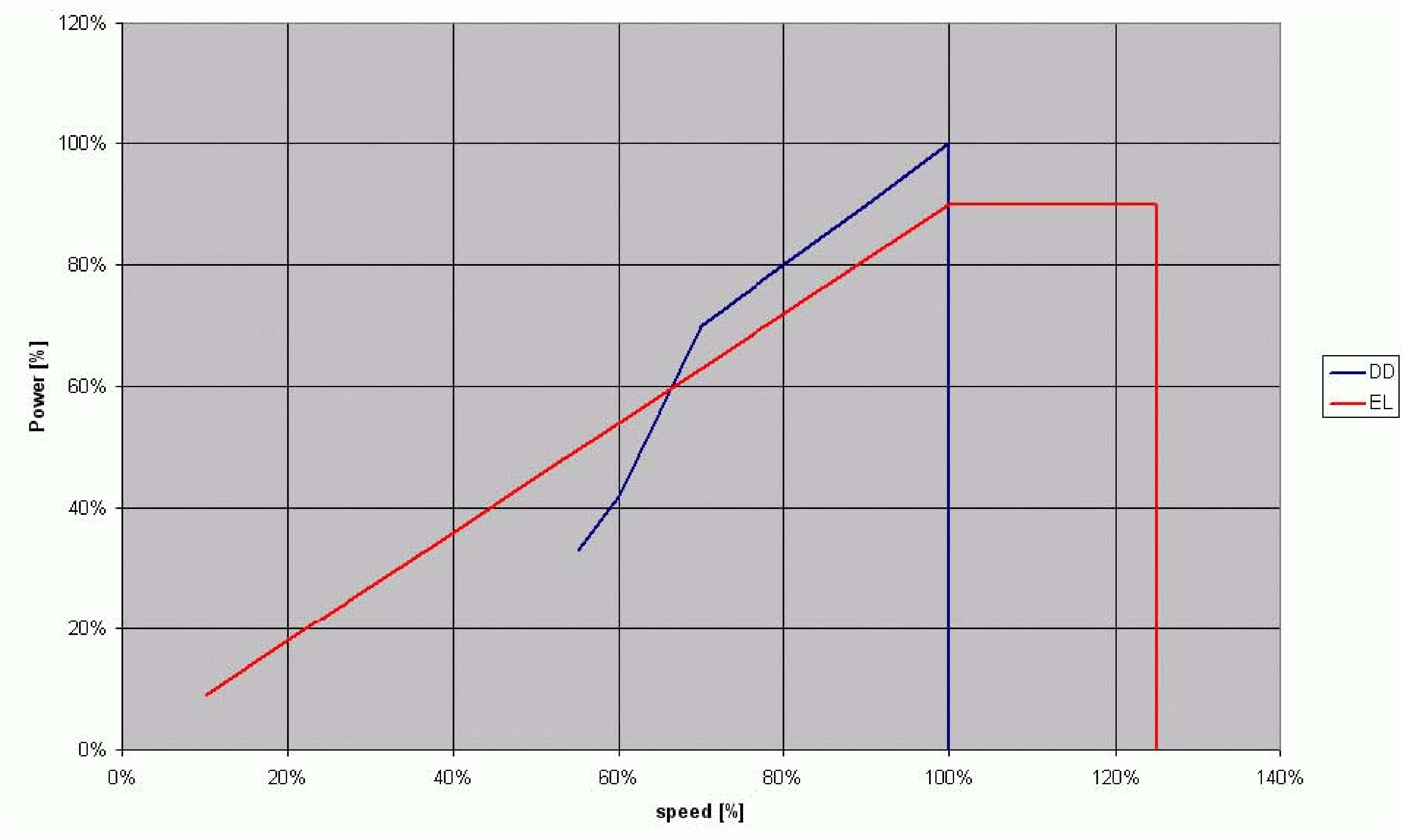


Dredge Pumps: Electric Drive

Frequency-regulation is necessary to be able to regulate the pump's rpm



Pump-DieselElec Drive: P / H characteristic

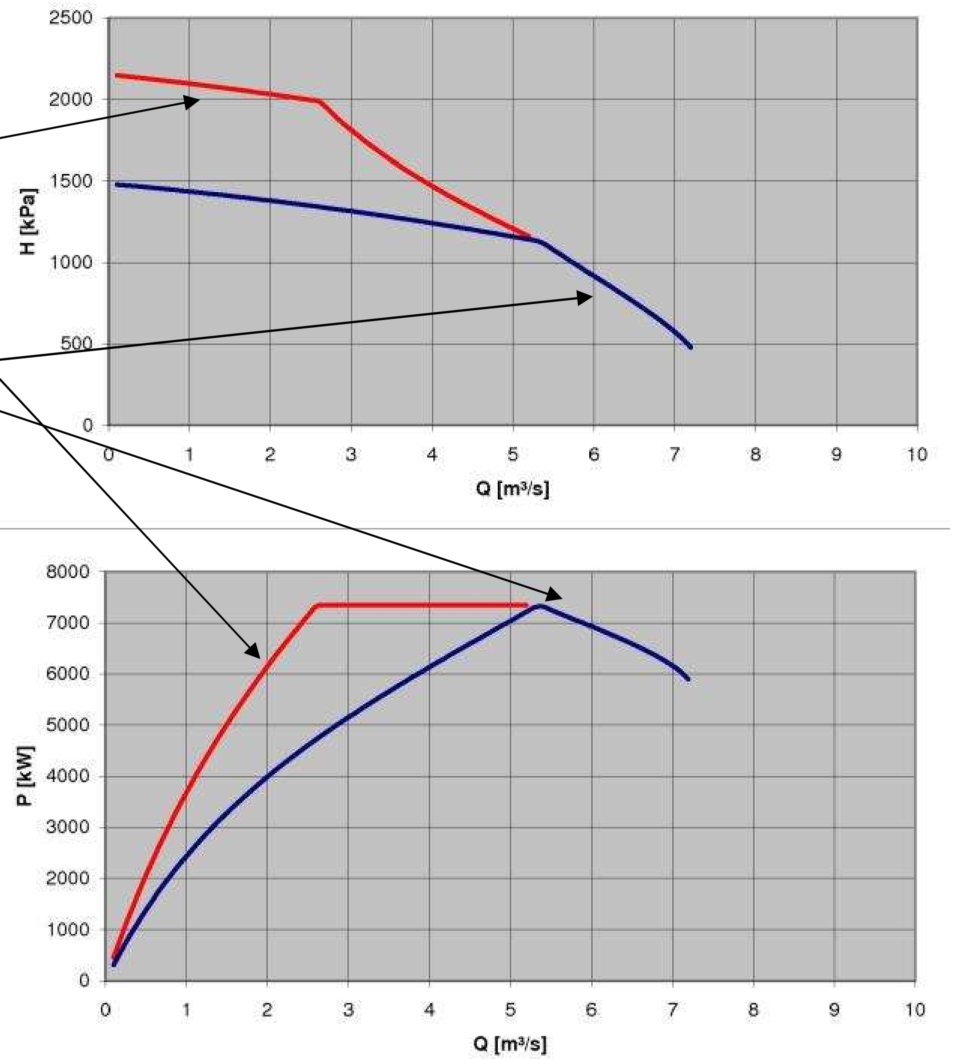


Dredge-Pump: Diesel and DieselElec drive and influence on H / Q characteristic

- **RPM ajustable between 0 % and 125 %**
- **Regulation:**

constant rpm between 100 en 125%

constant torque between 0 en 100%



Dredge Pumps: Effects of solids in the fluid on H and η

Water: $H_w = aQ^2 + bQ + c$ $\eta_w = a'Q^2 + b'Q + c'$

Homogeneous mixtures:

$$H_m = H_w \frac{\rho_m}{\rho_w}$$ $$\eta_m = \eta_w$$

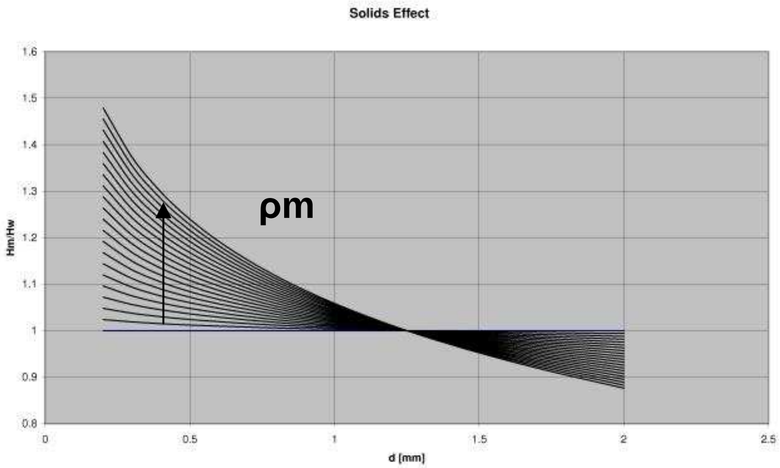
Heterogeneous mixtures:

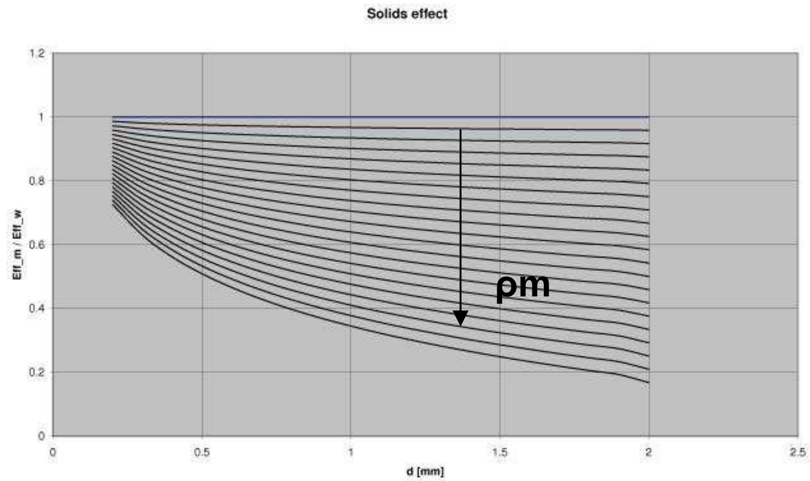
$$H_m = H_w \alpha$$ $$\eta_m = \eta_w \beta$$

met α, β = f(d50, ρ_m)

Dredge Pumps: Effects of solids in the fluid on the Q / H relationship

Factors α en β are determined empirically





The decrease in Head and Efficiency with increasing grain-size, are linked with the less efficient energy-transfer, impact-losses, friction between wall and particle,….

There are various empirical formulae available, each of them applicable for specific conditions. Experience will decide which is the best suited one for the case under concern: dredging, reclamation, coarser particles,…

References:

- Stepanoff (1965)
- Wilson (1992)

Dredge Pumps: Solids effect

Full-Torque point will shift:

- **to the left and up for d < 2 mm:if concentration increases (blue line >> green line)**
- **to the left and down for d > 2 mm: if grain-size increases (green line >> red line)**

Full Power Point

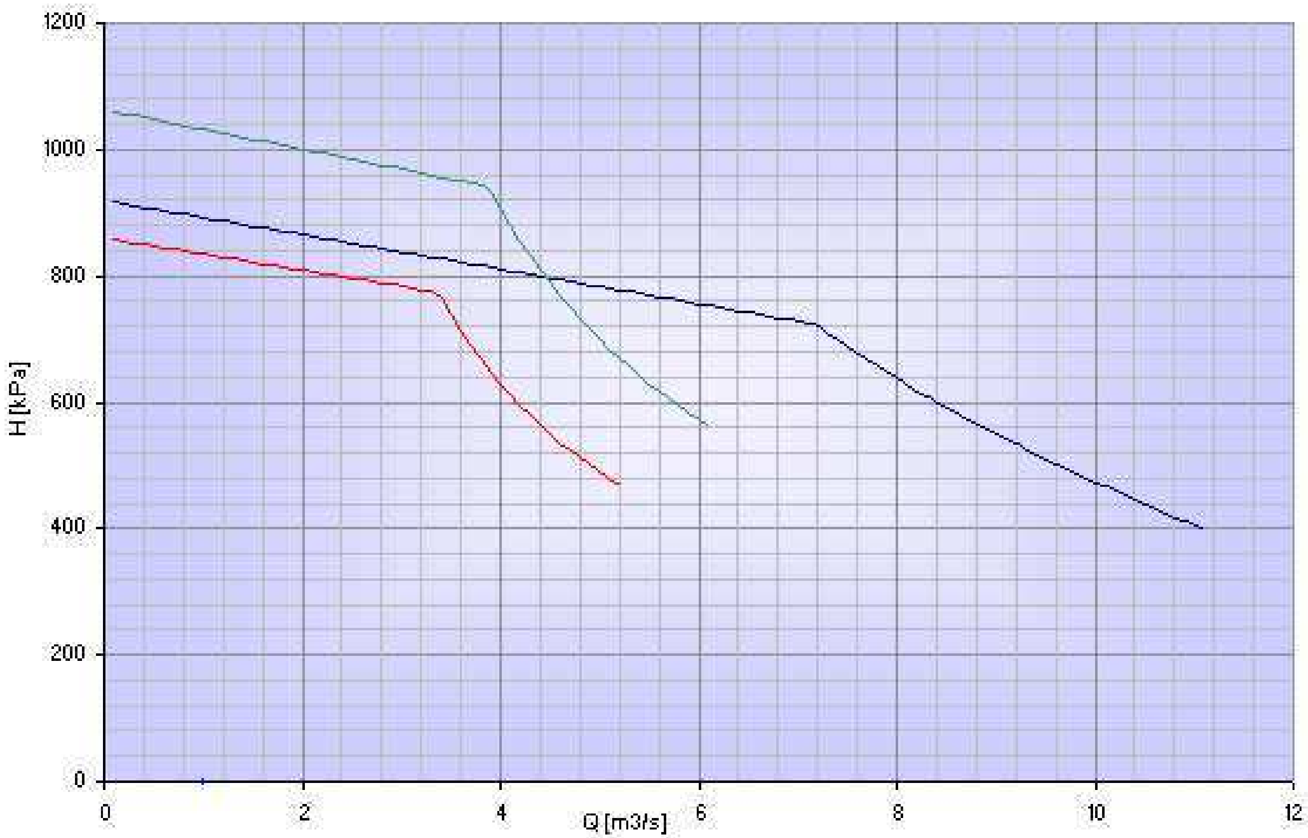
D: mm

P=QH/eff=cst

H increases

Eff const or decrea

>> Q decreases

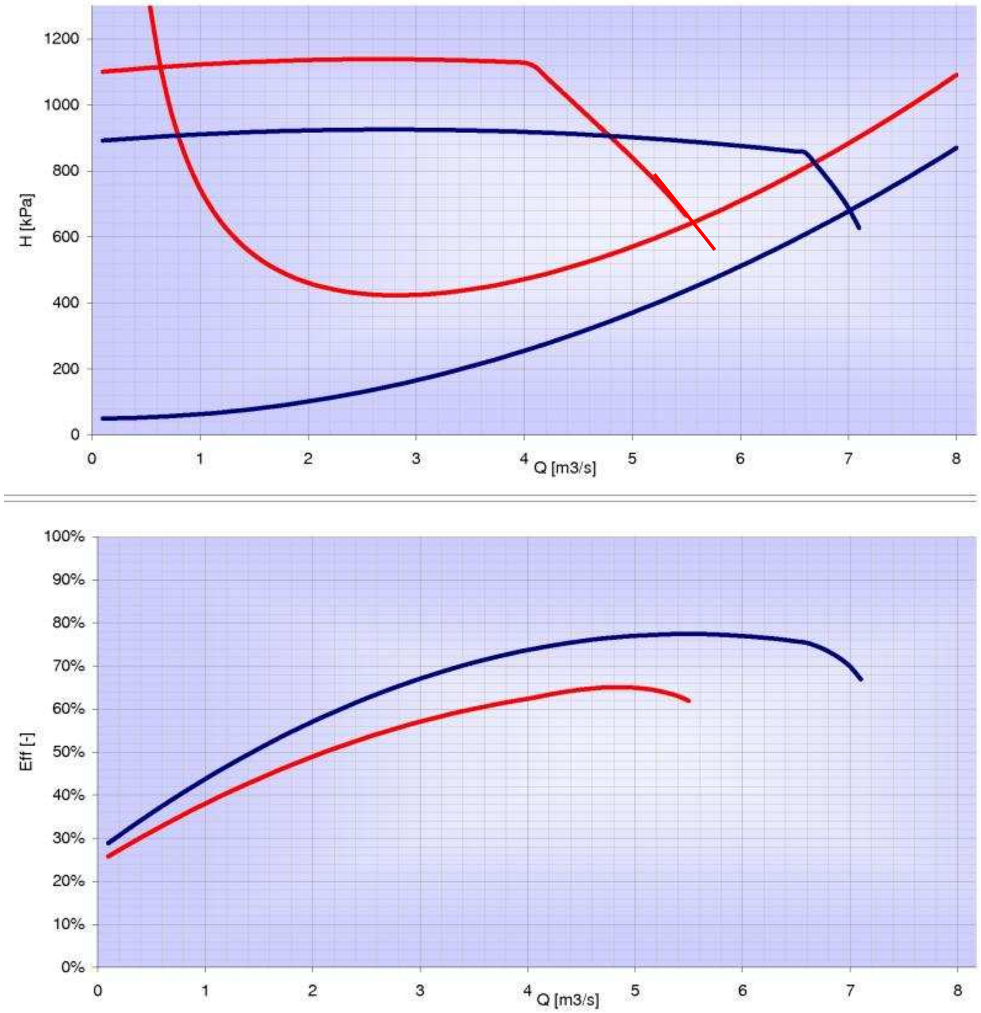


Dredge Pressure Line: Interaction between Pump, Drive and Pipeline

Length of pipeline: L= 500 m

Blue: ρ_m = 1.025 t/m³

Red: ρ_m = 1.5 t/m³
d_{50} = 400 µm

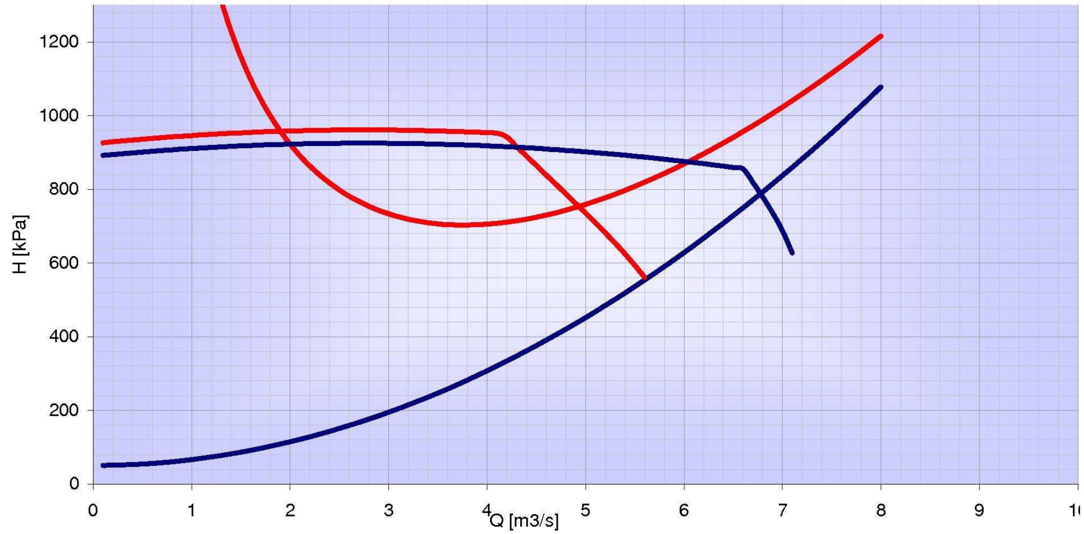


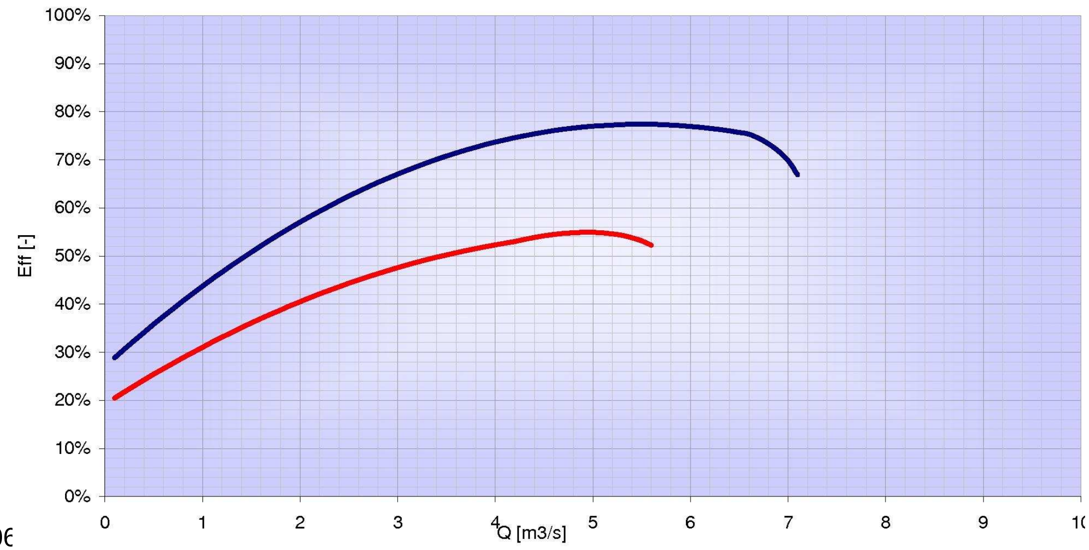
Dredge Pressure Line: Interaction between Pump, Drive and Pipeline

Length of pipeline: L= 500 m

Blue: ρ_m = 1.025 t/m³

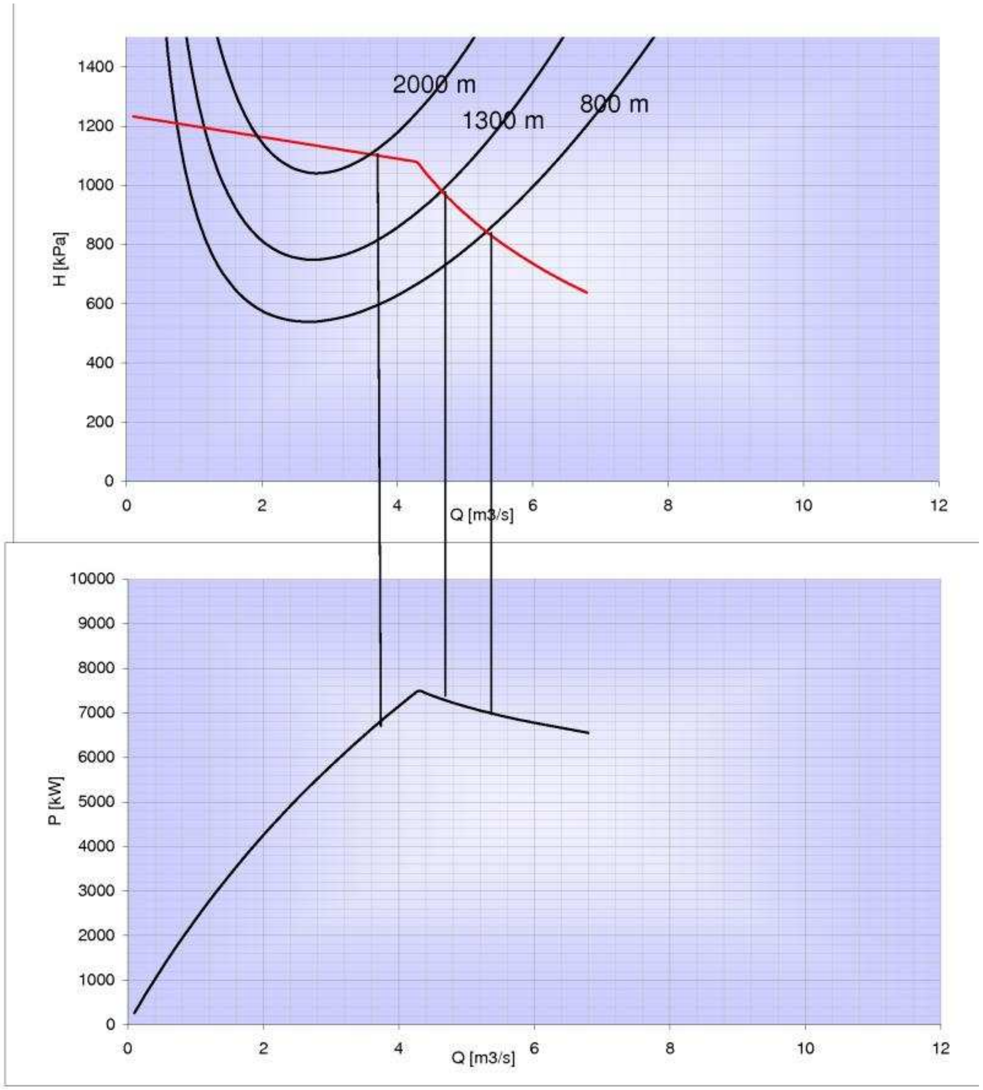
Red: ρ_m = 1.5 t/m³
d_{50} = 2000 µm





Dredge Pressure Line: Interaction between Pump, Drive and Pipeline

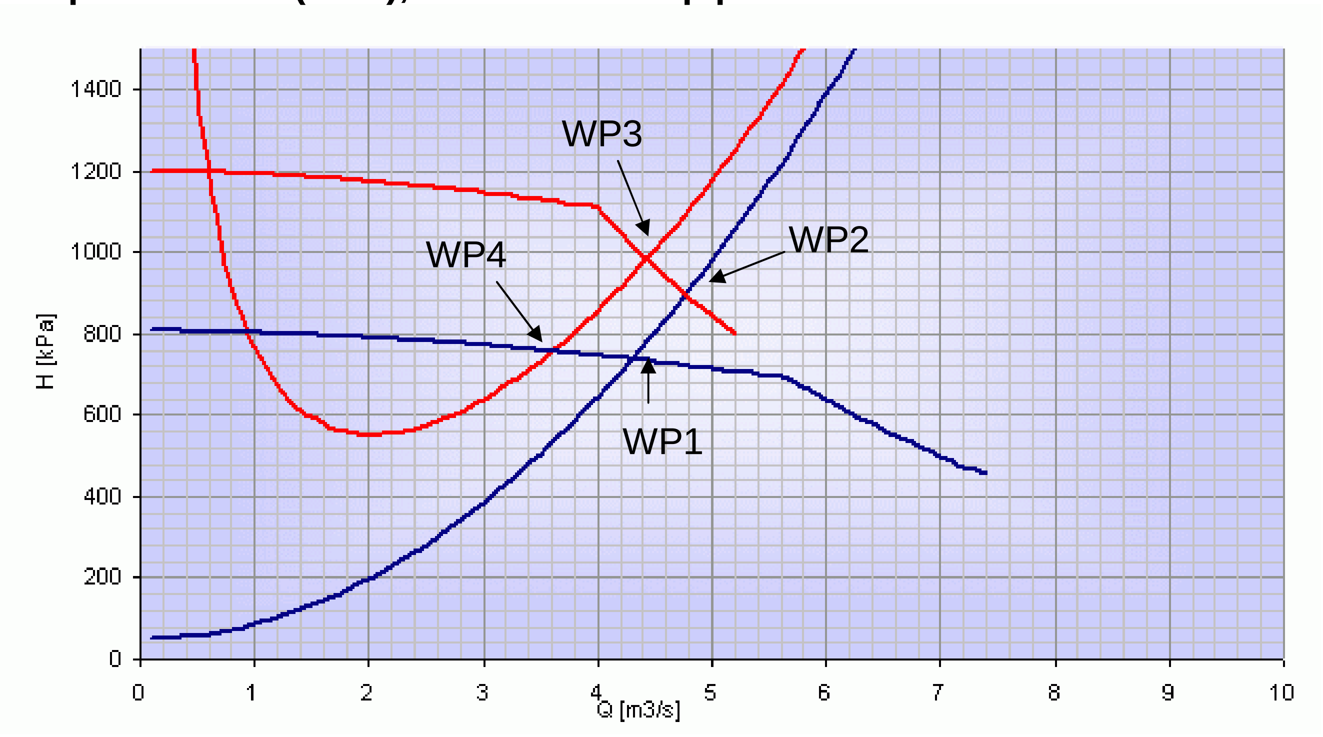
Influence of length of pipeline



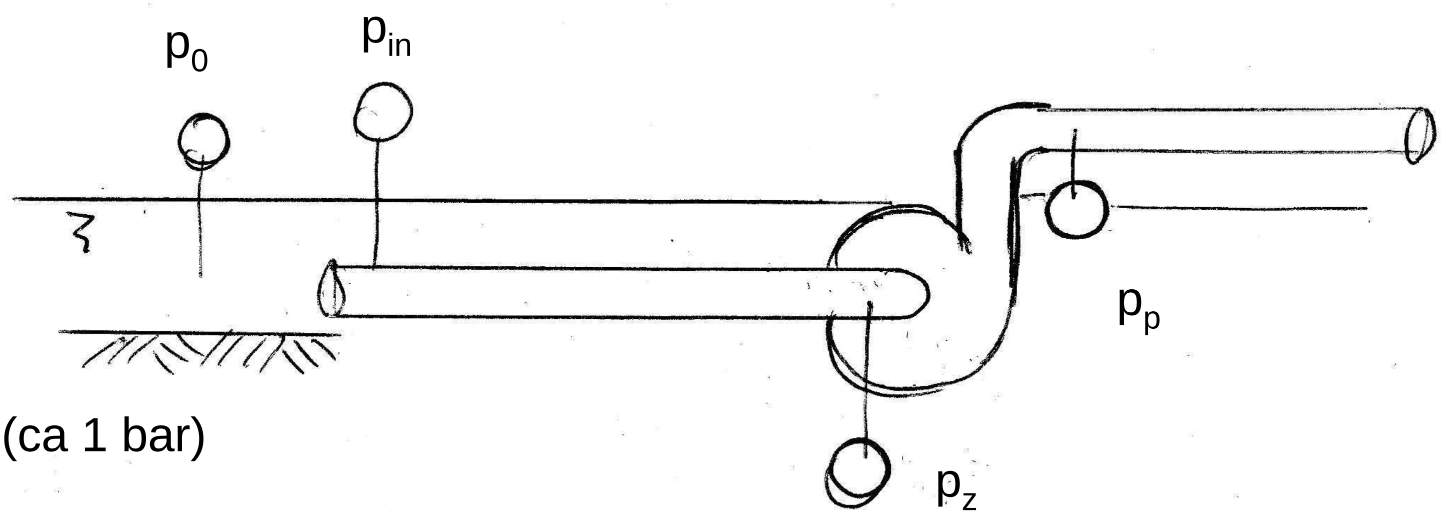
Dredge Pump: Priming and Stop Procedure

At the start, the pipe is filled with air
=> Low resistance
=> Fill pipe with water (WP1)
⇒Add mixture: mixture gets quickly to pump, pipeline fills gradually with mixture (WP2)
⇒Focus on workpoint pump, drive and pipe (WP3)

To stop process:
Bij stoppen is de leiding gevuld met mengsel, de pomp met water (WP4)
⇒Lift draghead in order to fill pump with water (WP4), mixture still in pipe
⇒Spool pipe with water (WP1)
=> Stop pump gradually



Suction Pipe Characteristic for horizontal pipe



$p_0 = p_{atm}$ (ca 1 bar)

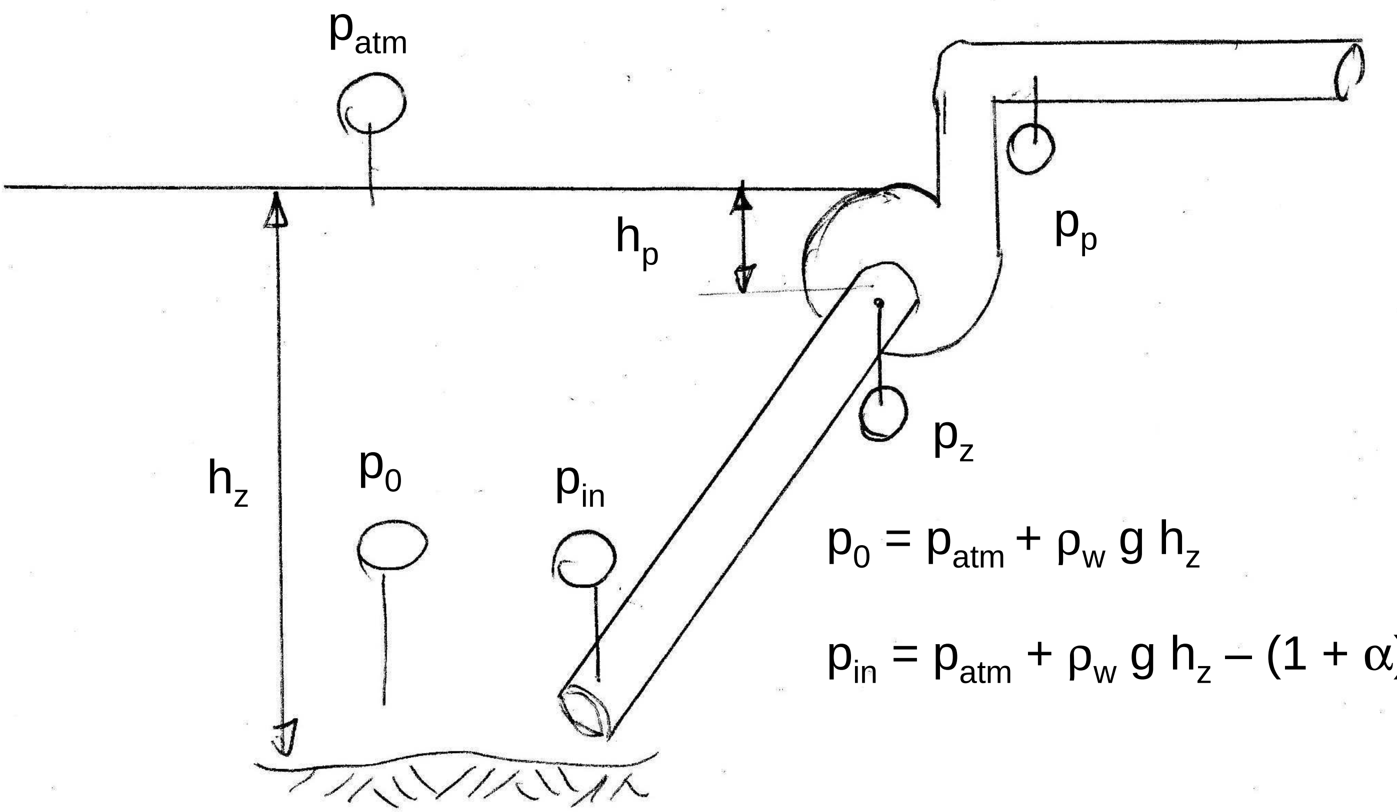
$p_{in} = p_{atm} - (1 + \alpha)0.5\ \rho_m\ v^2$ (ca 0,7 bar or 0,3 bar vacuüm)

$P_z = p_{atm} - (1 + \alpha + \lambda\ L/D)0.5\ \rho_m\ v^2$ (ca 0,5 bar)

$P_p = p_{atm} - (1 + \alpha + \lambda\ L/D)0.5\ \rho_m\ v^2 + \Delta p$ (ca 2 bar)

α= Head-losses cfc at suction inlet
λ= Head-losses cfc in pipe

Suction Pipe Characteristic for inclined pipe



$$p_0 = p_{atm} + \rho_w\, g\, h_z$$

$$p_{in} = p_{atm} + \rho_w\, g\, h_z - (1 + \alpha) 0.5\, \rho_m\, v^2$$

$$P_z = p_{atm} + \rho_w\, g\, h_z - \rho_m\, g\, (h_z - h_p) - (1 + \alpha + \lambda\, L/D) 0.5\, \rho_m\, v^2$$

$$P_p = p_{atm} + \rho_w\, g\, h_z - \rho_m\, g\, (h_z - h_p) - (1 + \alpha + \lambda\, L/D) 0.5\, \rho_m\, v^2 + \Delta p$$

Dredge Pump Limitations: gas

- **Centrifugal pumps are designed for incompressible fluids. As soon as compressible fluids (dissolved air, gas-bubbles,…) are present (1 to 3 % volume concentration in-situ is sufficient to affect significantly pump-productivity) the vapour-pressure , pd, inside the fluid will augment and the efficiency of the pump will drop. Ultimatly, expansion of gas-bubbles may occur, which may lead to cavitation.Gas-concentration of more than 5 % vol may stop the process completely.**

- **Which gases ?:**

=> H_2S en CH_4, as a result of microbiological activity (reduction in anaerobic conditions), mainly in organic-rich muds

=> air-leakage via inlet or suction part of the system

=> vapour: vacuüm in suction part may become lower than vapour-pressure

- **Solutions:**

=> Degassing- installations: extra vacuüm systems capturing gas at the pump-rotor axis

=> Adapt the design of the suction-mouth

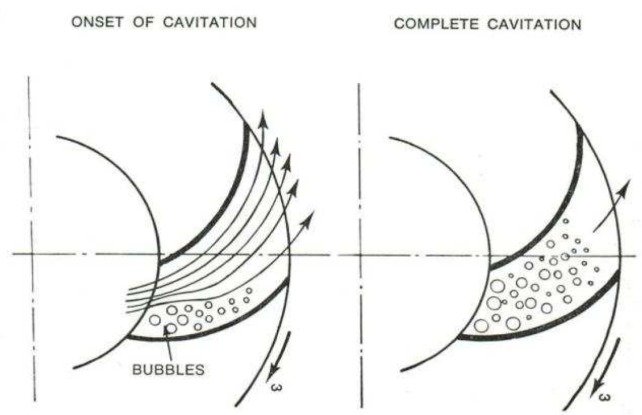
Dredge Pump : Vacuüm - Cavitation

•Cavitation: When the absolute pressure at the pump-inlet decreases, the vapour-pressure inside the fluid may be reached: the fluid starts to boil. Gas or vapour-bubbles are formed mainly at the point of high-velocity (low static pressure). Within the pump , the bubbles are dragged into areas with higher pressures: there the bubbles will implode, yielding locally extremely high shock-pressures, capable of damaging the rotor.

• For water at 20℃, is the vapour pressure ca 4 kPa, or 0.96 Bar vacuüm

• The Decisive Vacuüm, Vac_m, is the vacuüm-pressure at the pump-inlet, where the Pressure Head of the pump drops with maximum 5 %. This Vacm is the maximum value not to be exceeded in order to prevent cavitation.

• In practice, will the dredge-pump work almost continuously close to the cavitation-limit. The unknown is then the gas-content in-situ within the soil to be dredged.



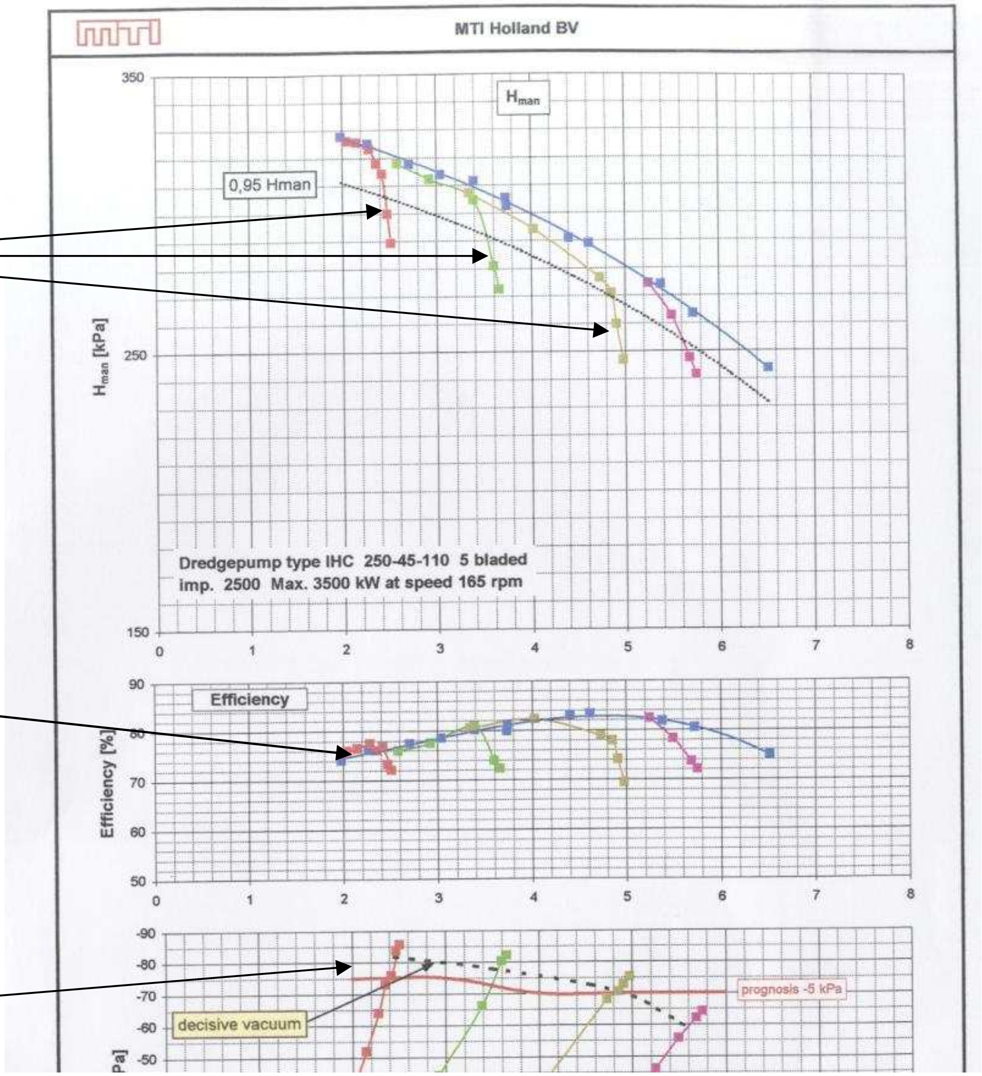
Dredge Pump: Determination of Decisive Vacuüm

The Decisive Vacuüm Vacm is determined experimentally by constriction of the pipes , e.g. shutting progressively the suction pipe with a valve:

- **Pressure Head drops rapidly**

- **Efficiency drops rapidly**

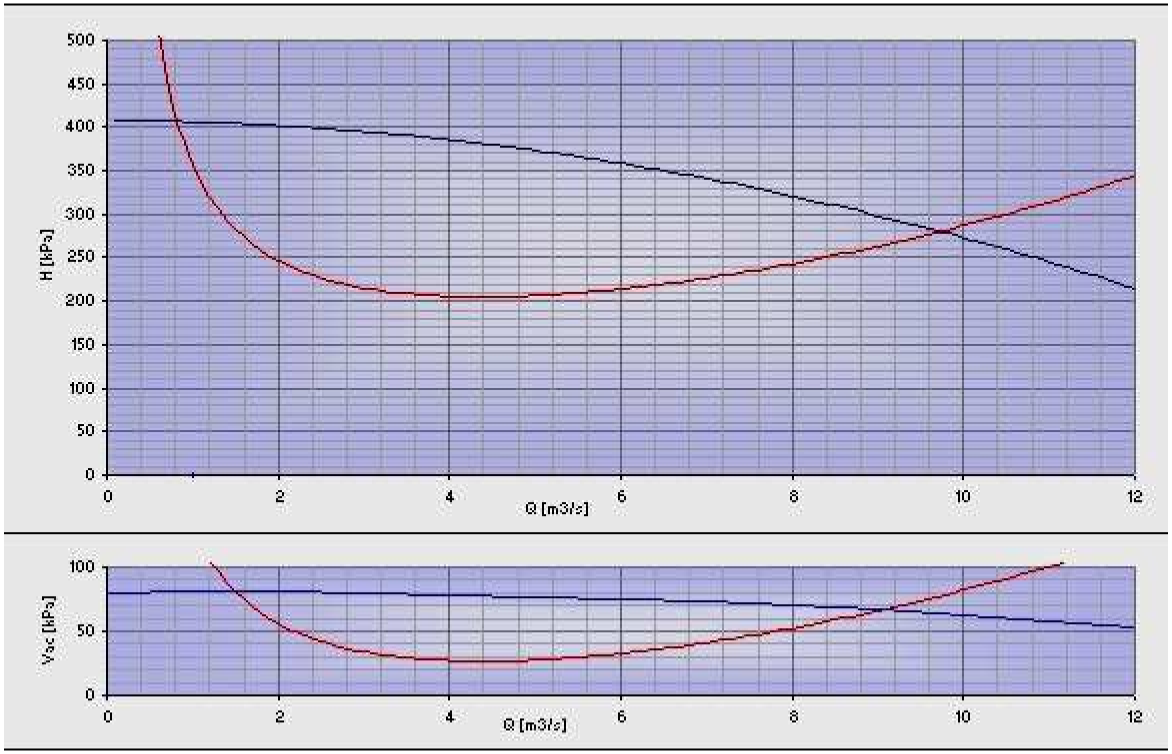
- **Intersection with 95 % of Manometric Pressure line determines Decisive Vacuüm**



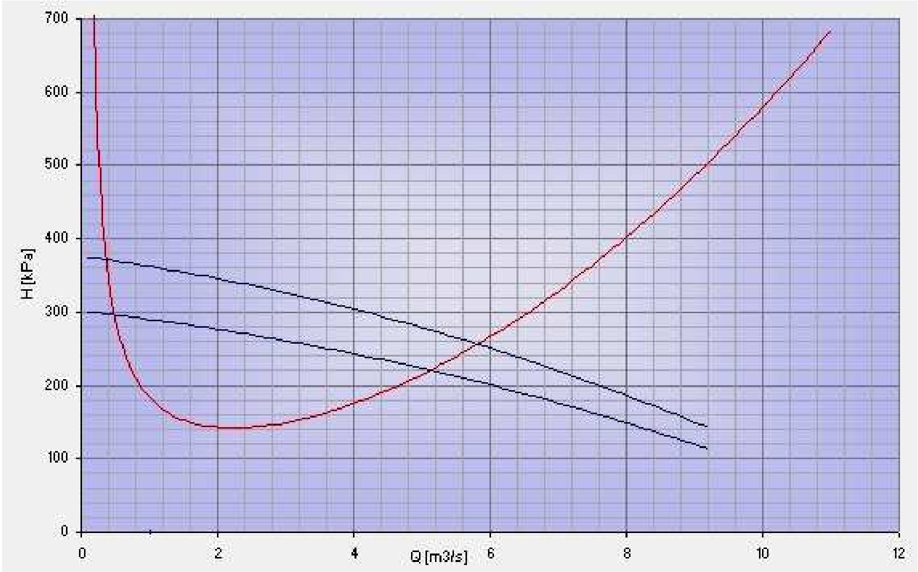
Dredge Pump: Vacuüm – Manometric pressure

- **Above: Pressure-Pipeline and pump characteristic Q / H**

- **Below: Suction –Pipeline and Pump characteristic Q / Vac**



Dredge Pump: Effects of Cavitation

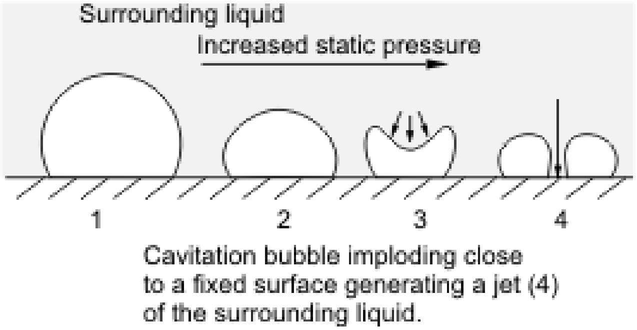


Once Cavitation occurs:

- **Efficiency drops**
- **Manometric Pressure drops**

⇒ **Discharge drops**
⇒ **Sedimentation in pipe occurs**

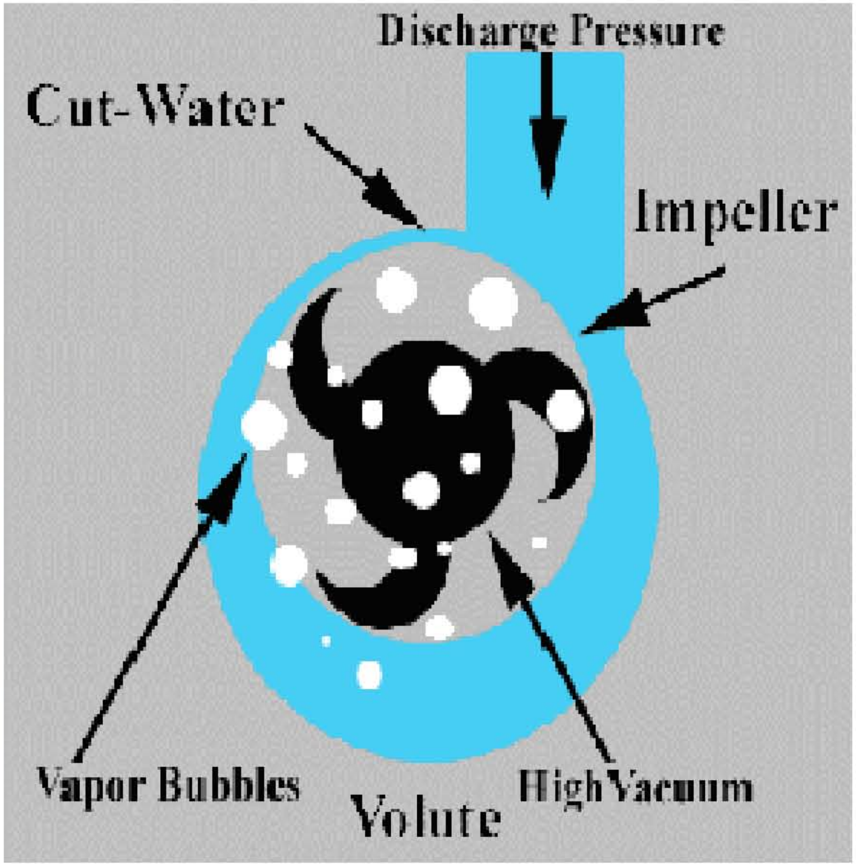
Other effects:



•Vibrations

•Damage by pitting

•Damage by water-hammer


Discharge Pressure
Cut-Water
Impeller
Vapor Bubbles
Volute
High Vacuum

Dredge Pump: Effects of Cavitation

Fracture in Pump's Volute

Dredge Pump: solutions to prevent cavitation

- **Keep the friction-resistance in the pipeline to a minimum: use large puipe diameters, avoid local head-losses, keep length to a minimum**

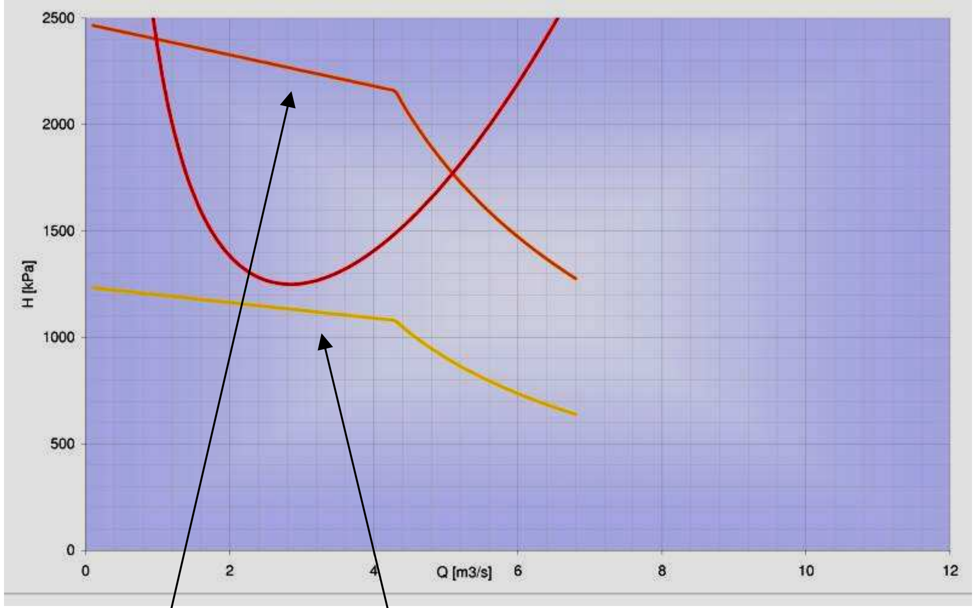
- **position pump as deep as possible under water-surface in order to benefit from the static pressure of the surrounding water**

- **Monitor the indicators of cavitation: high vacuüm, decreasing discharge and efficiency**

- **Select pump with an as high Vacm as possible**

- **Use/install a vacuüm-relieve valve before the pump (opens automatically at given underpressure)**

Increase Performance of Dredge pumps: Pumps in Series



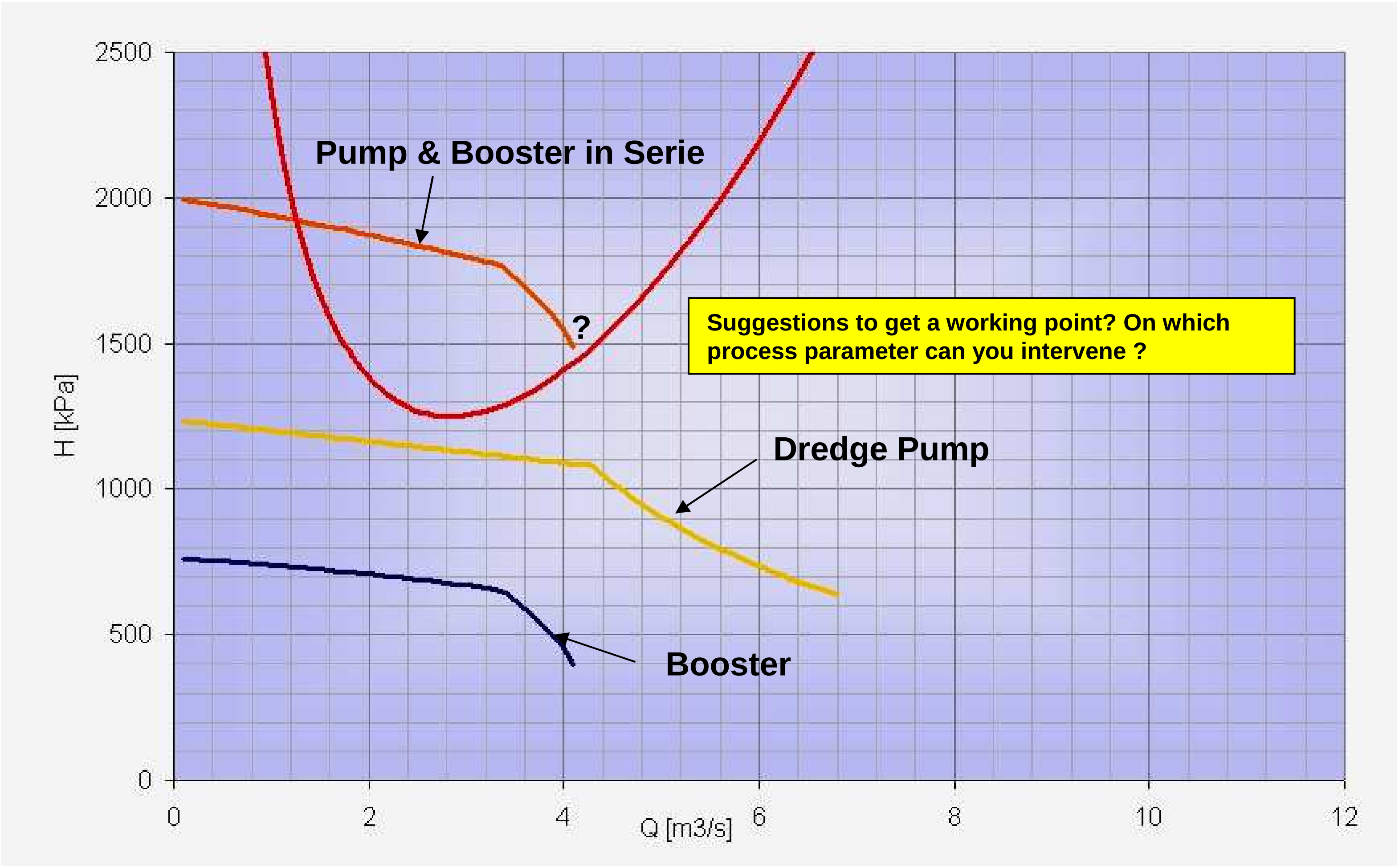
When to be considered?

- **If high friction-resistance in pipe**
- **If long reclamation pipe**
- **When compatible pumps available:**
  - **Spherical passage**
  - **Connection flanges and diameters**
  - **Best Efficient Point at same discharge**
  - **Full Power point at same discharge**

Pump/Drive-characteristic for each pump

Pump/Drive-characteristic for two pumps in serie

Dredge Pumps in series: Example of undersize of Booster



Dredge-pumps in series

Specific problems with dredge-pumps in serie are

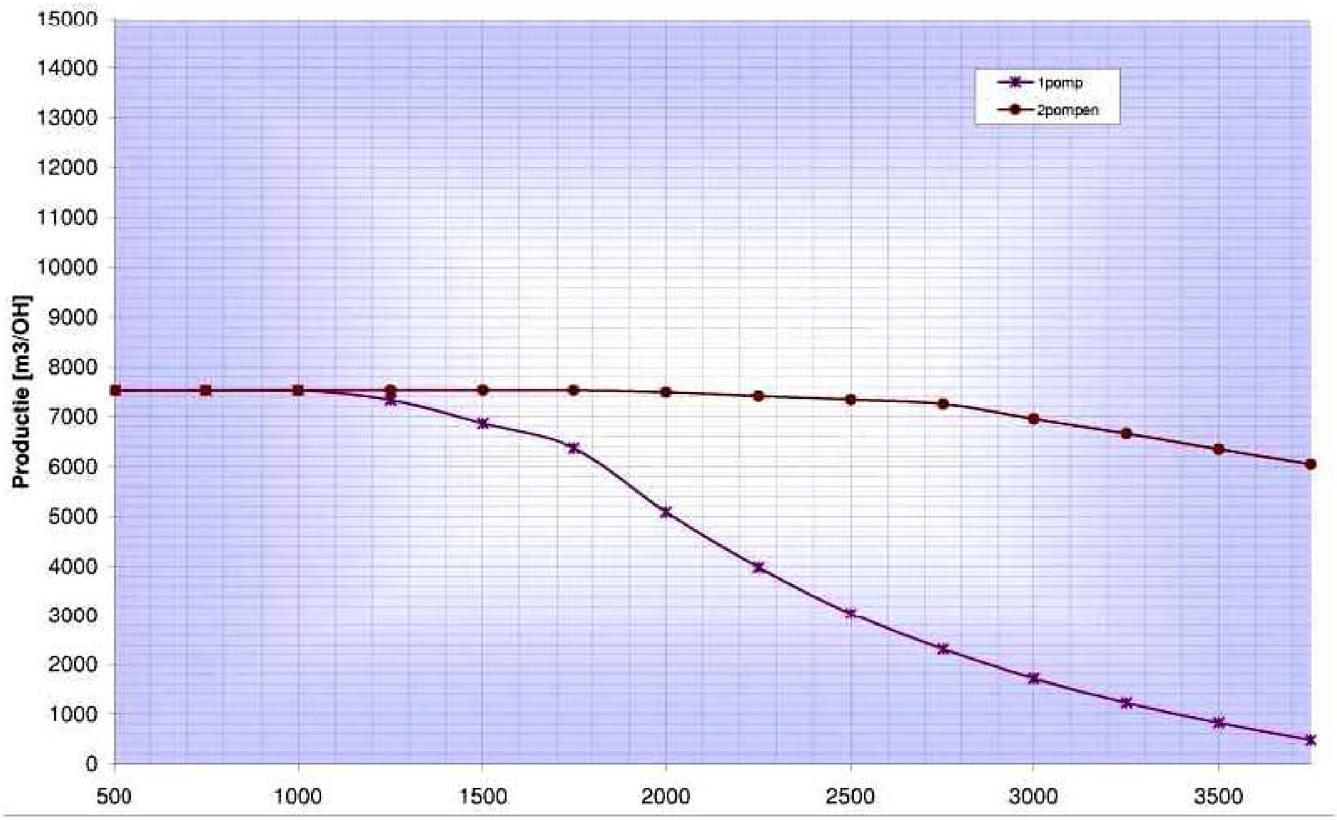
- **Negative intermediate pressures may occur and cause an instable dredging process (cavitation,…)**
- **A regulating system is required in order to stabilize the process**
- **Technical problems or clogging at the first pump, cause immediate effect on the whole process**

Application:

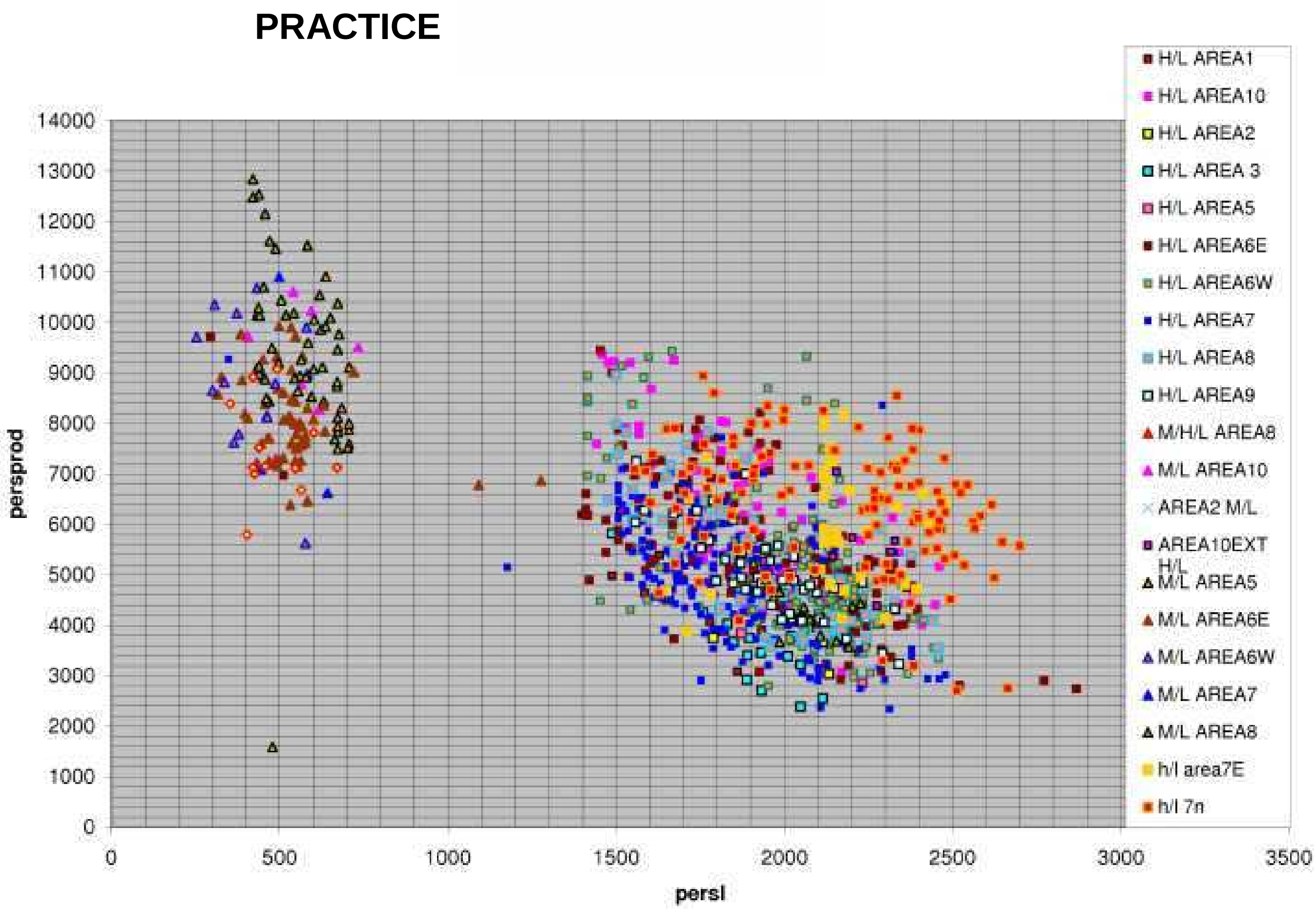
- **Reclamation with 2 or 3 pumps with CSD or TSHD**
- **Reclamation with intermediate booster-plant**
- **Dredging with submerged pump and hull-pump**

Pressure Line characteristic: Production versus Pipeline-Length

THEORY

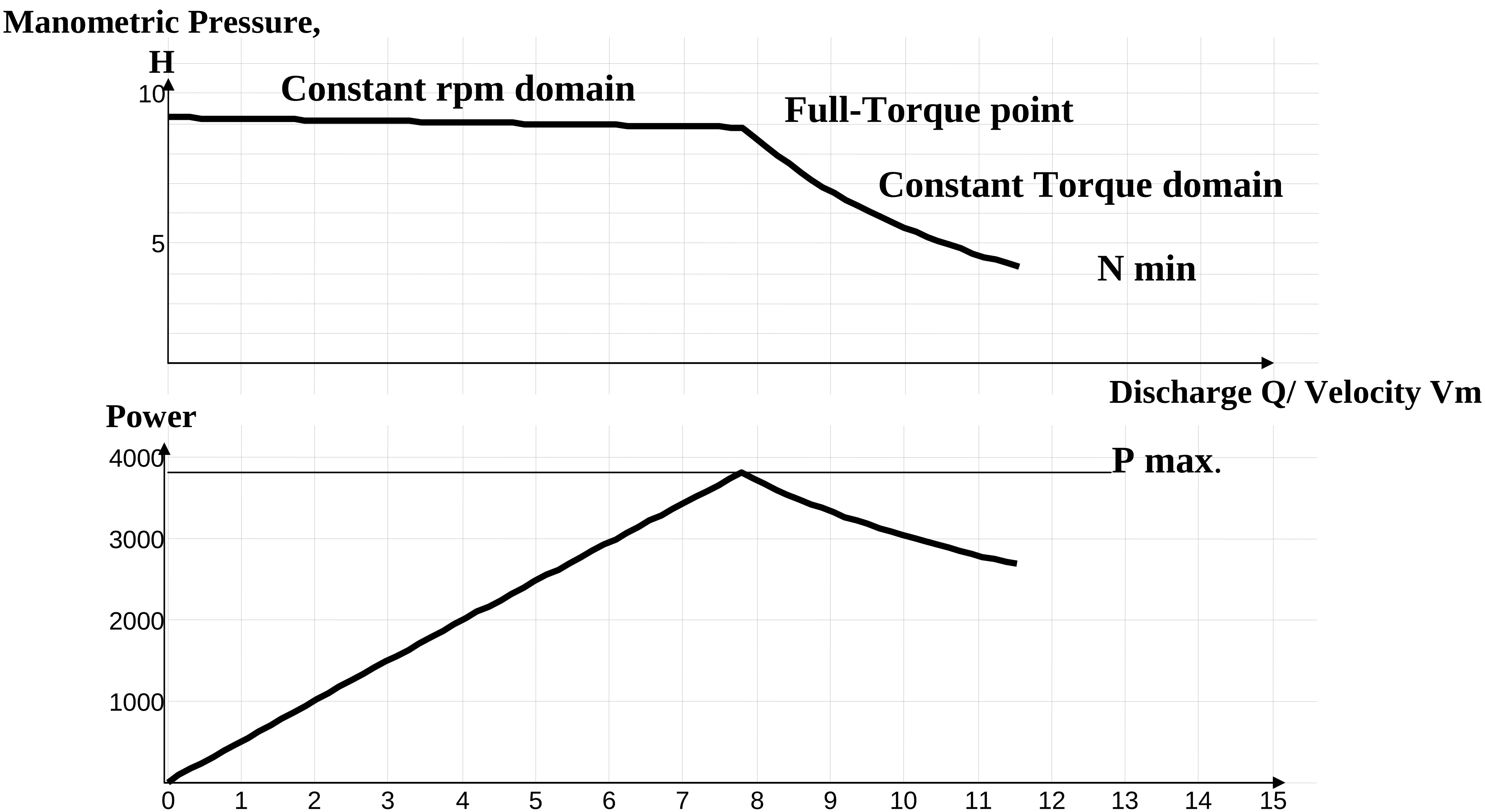


Pressure Line characteristic: Production versus Pipeline-Length PL-diagram

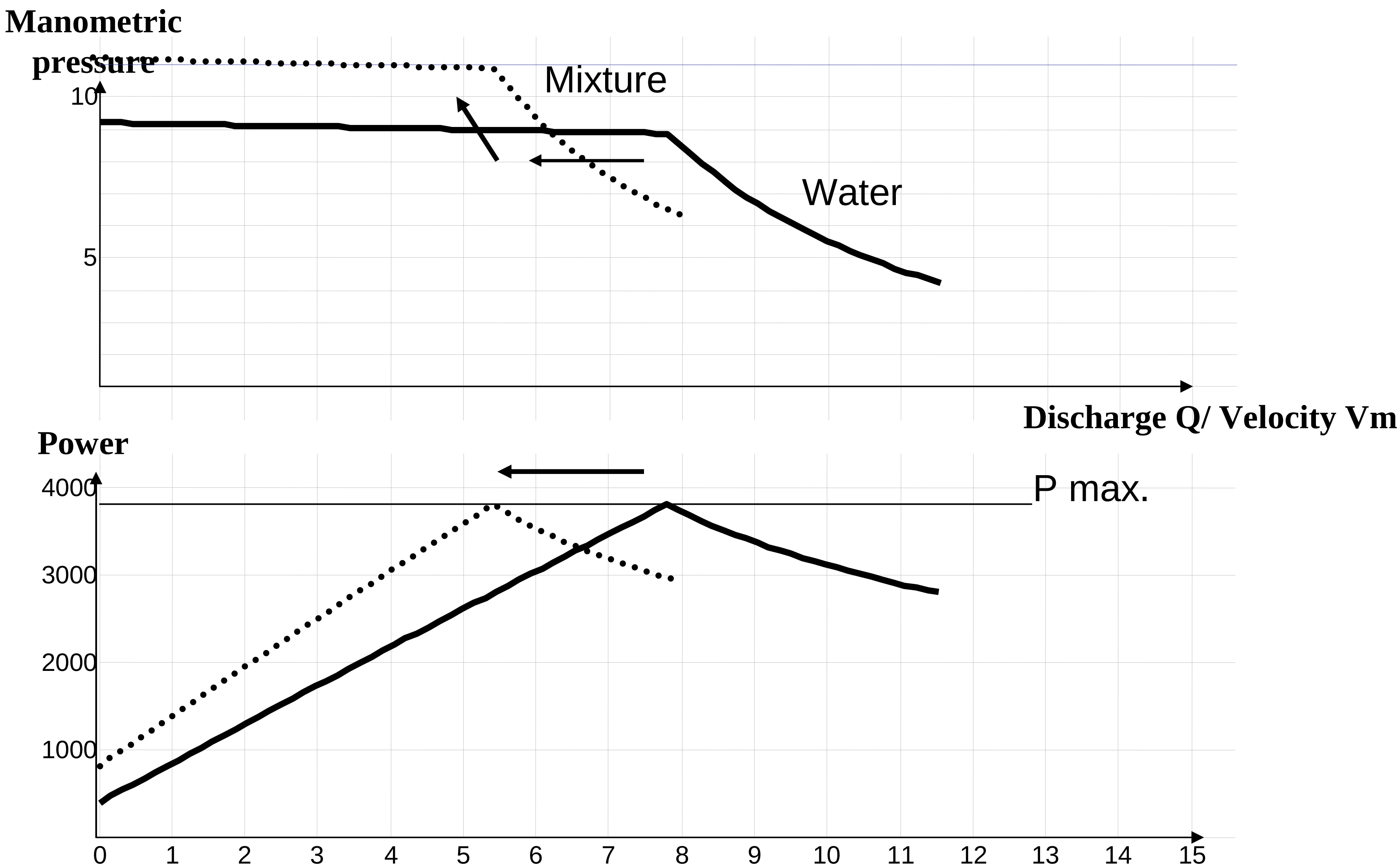


Recapitulation of most important issues

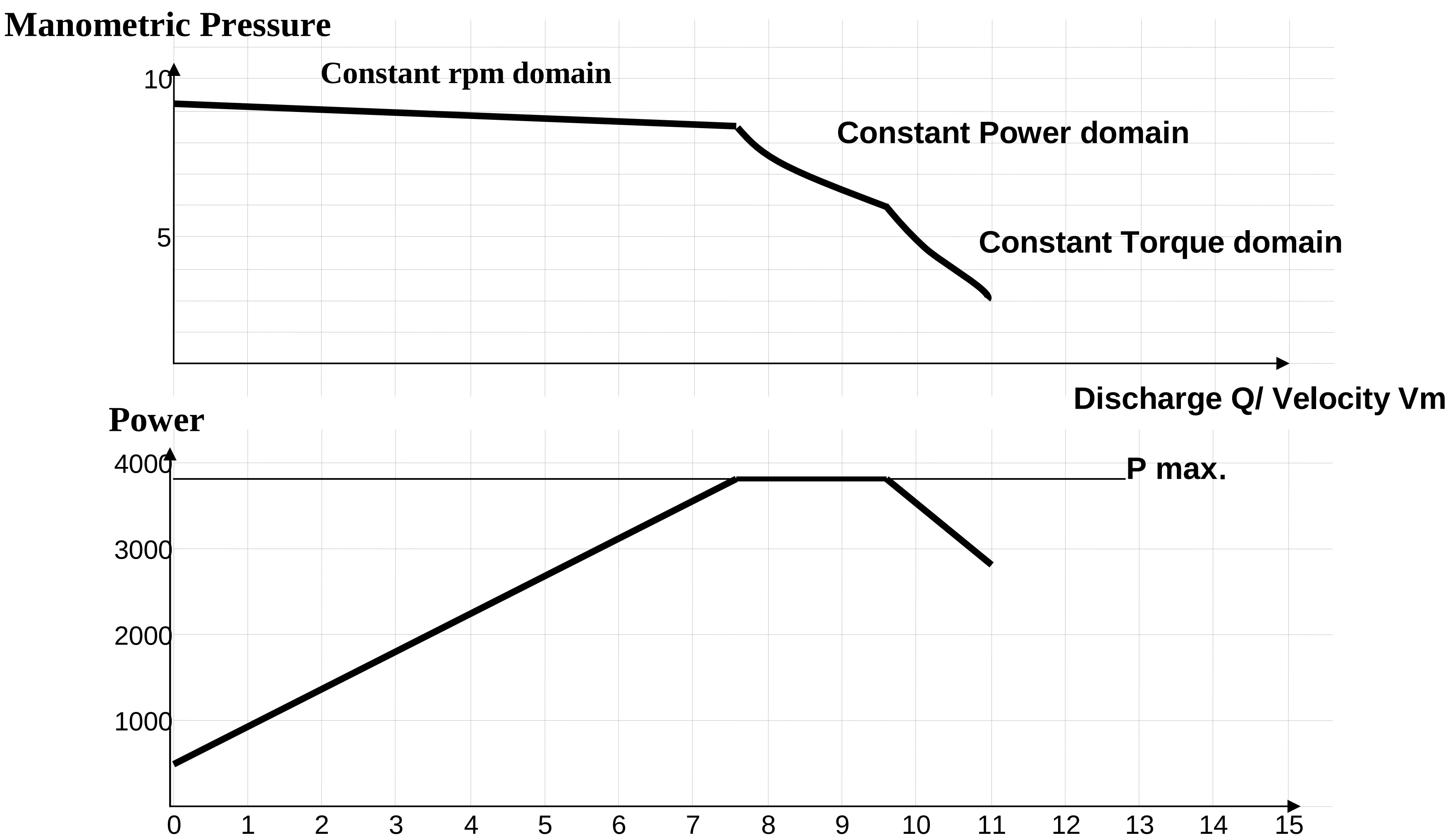
Diesel Drive



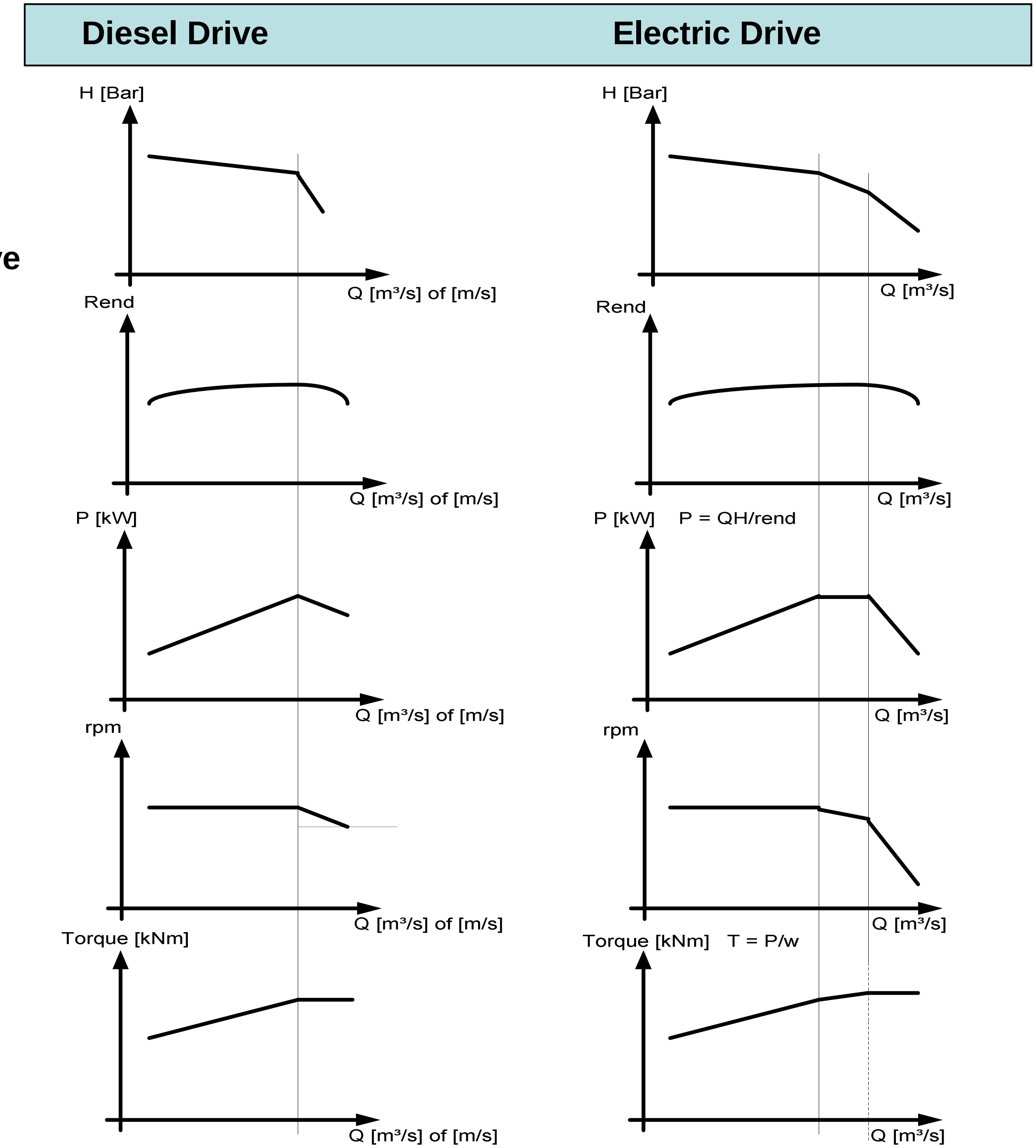
Diesel Drive



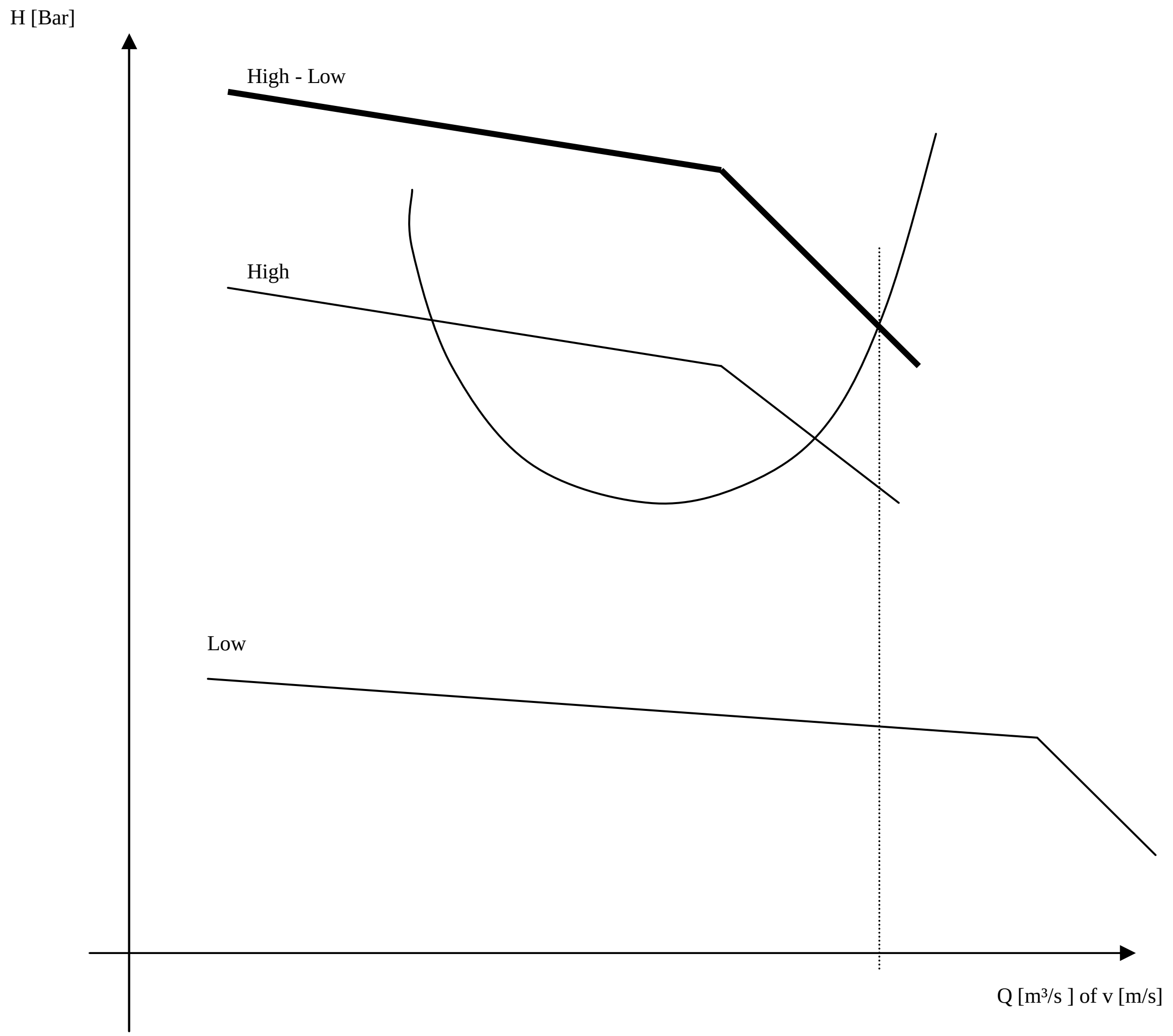
Electric Drive



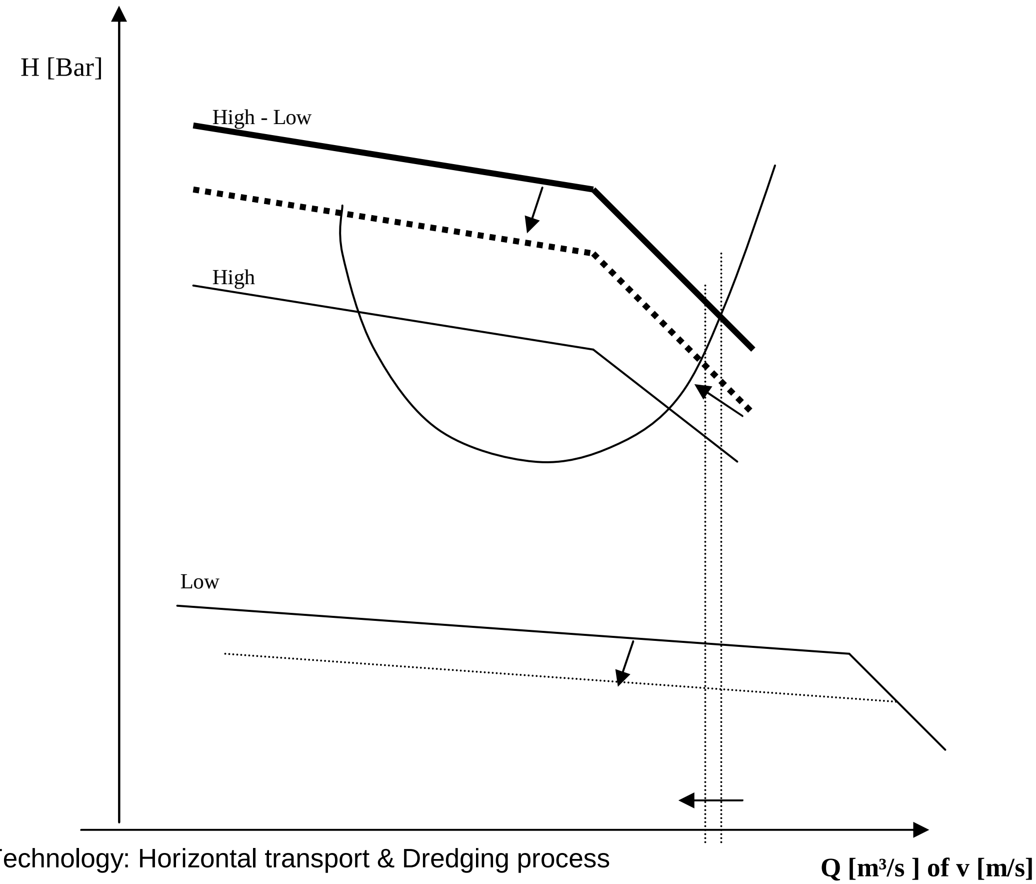
Recapitulation of pump & drive characteristics for dredge-pumps driven by direct-diesel drives and electric drives



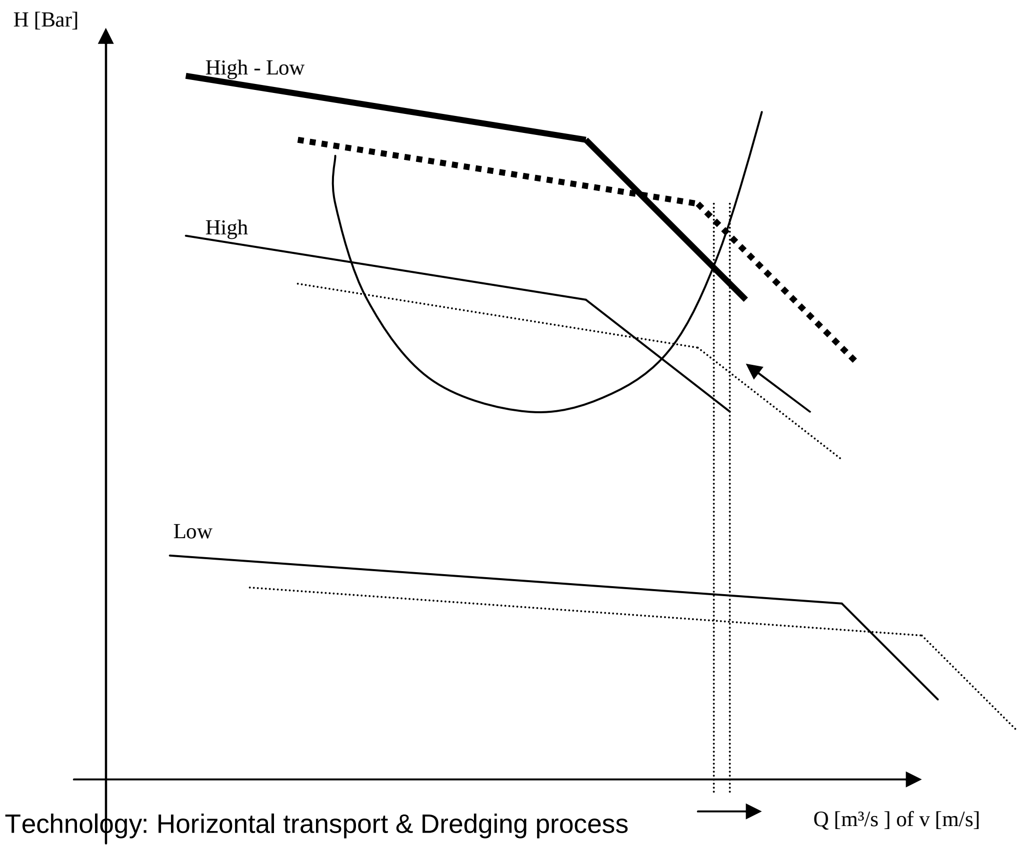
Practical Example: A reclamation job is under execution with 2 pumps in series: pump 1 in High and pump 2 in Low. During reclamation, the the rpm of pump 2 drops and nears Nmin. What do you do ?



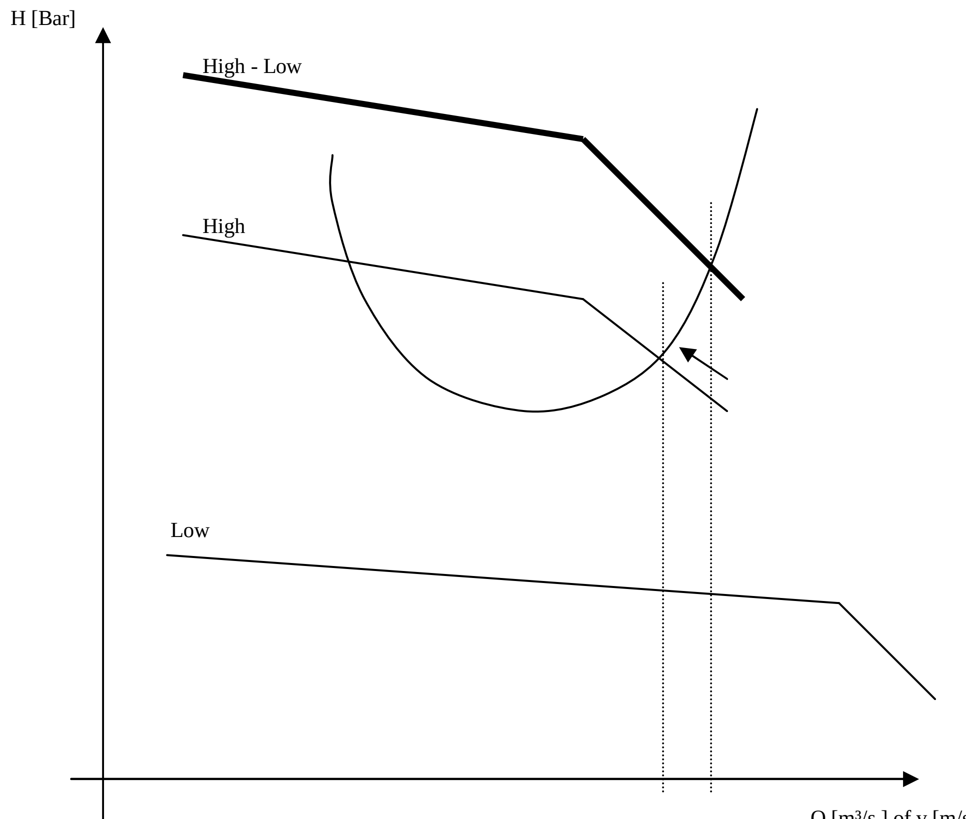
Reduce the rpm of pump 2 (Low) if possible.



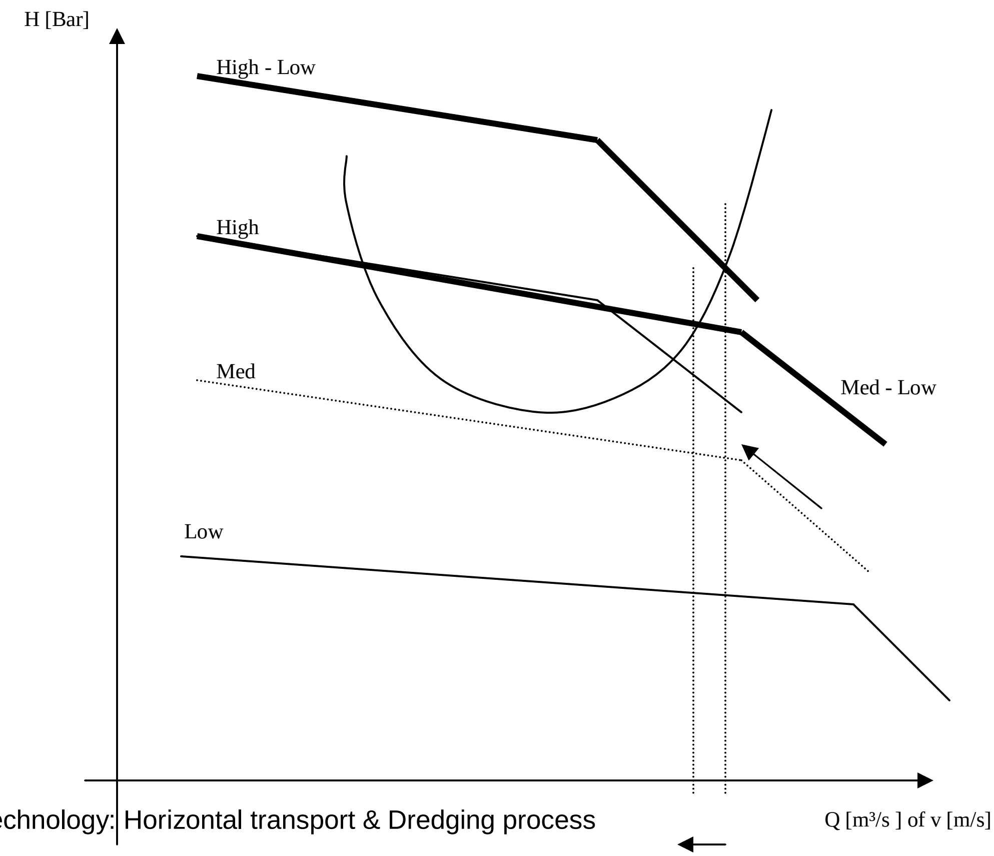
Reduce the concentration in the system: water admixture



Stop pump 2 (Low) if no danger for sedimentation in the pipeline



Gear pump 1 in Med, to get a Med-Low series if no danger for sedimentation in the pipeline



Shut partially a valve on the discharge pipe.