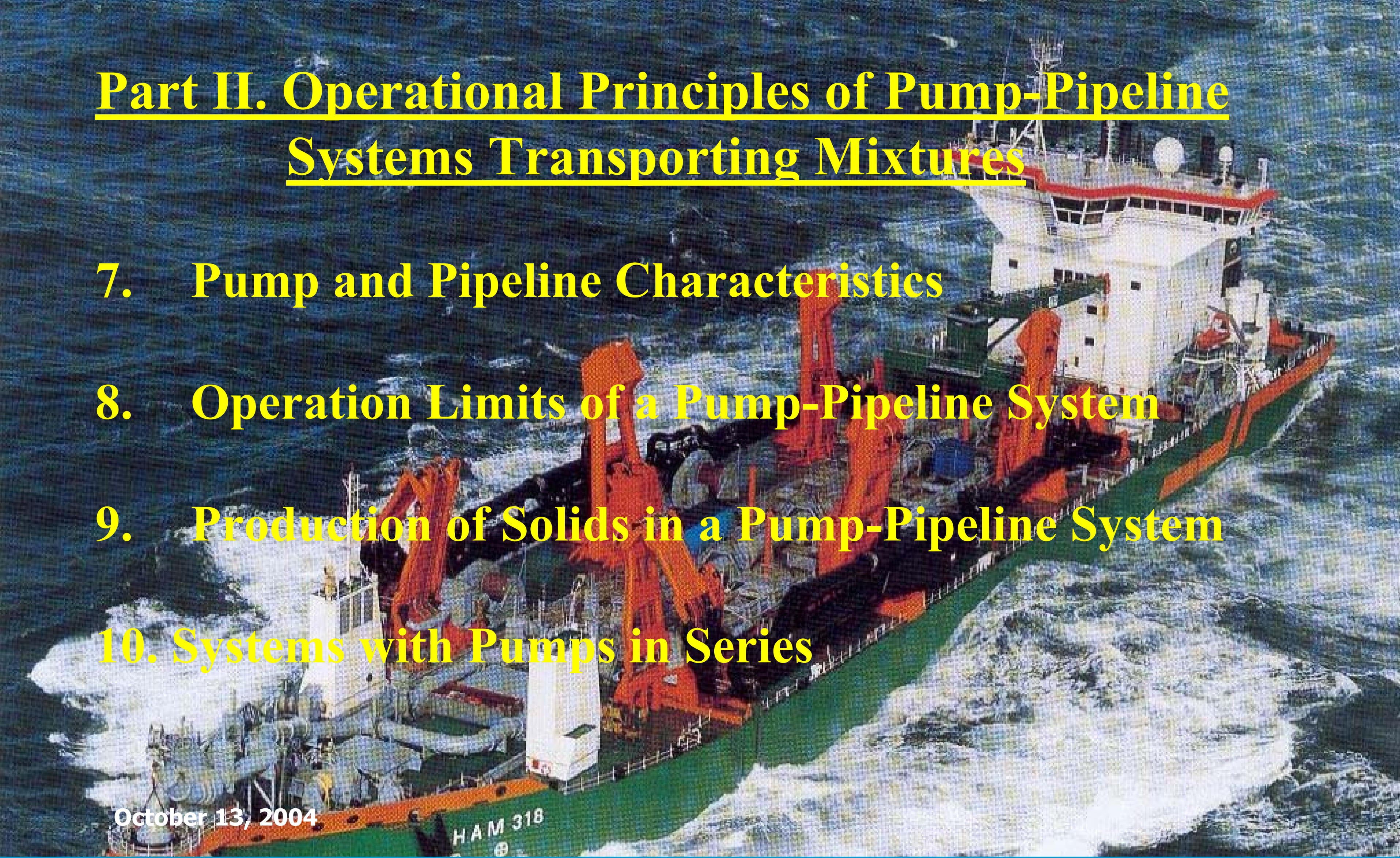
oe4625 Dredge Pumps and Slurry Transport

Vaclav Matousek

October 13, 2004



Part II. Operational Principles of Pump-Pipeline Systems Transporting Mixtures

7. Pump and Pipeline Characteristics

8. Operation Limits of a Pump-Pipeline System

9. Production of Solids in a Pump-Pipeline System

10. Systems with Pumps in Series

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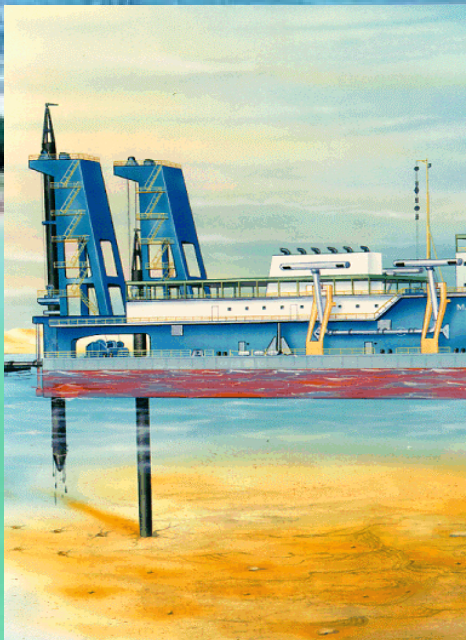
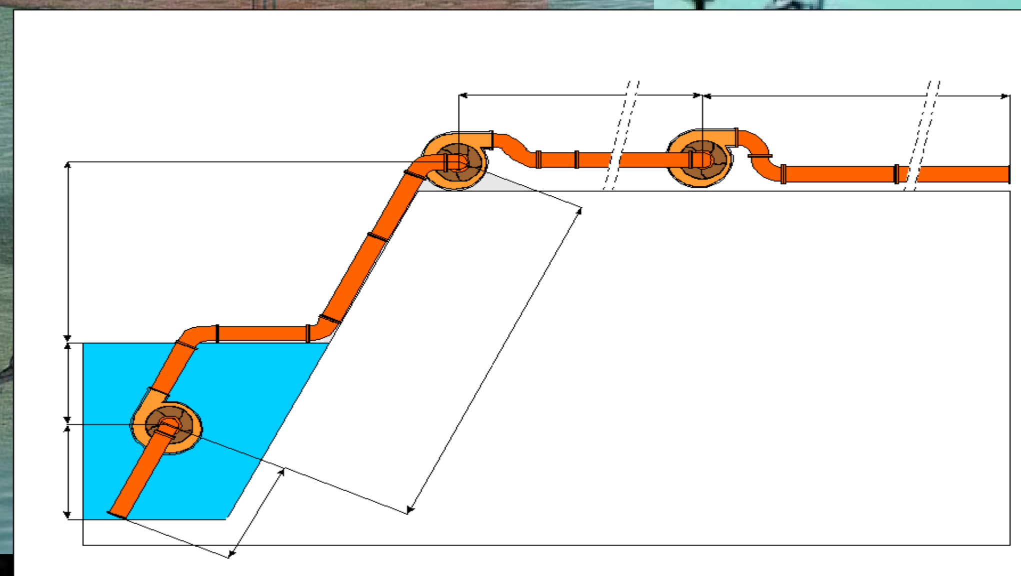
wb3414 Dredging Processes 2





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7. PUMP AND PIPELINE CHARACTERISTICS

HOW TO SELECT A SLURRY PUMP

H-Q CURVES FOR PUMPS AND PIPES

WORKING POINTS/RANGES OF PUMP-PIPE SYSTEM

HOW TO SELECT A SLURRY PUMP

A pump operates at the intersection of

- the ***pipeline H-Q curve*** (modified I_m-V_m curve) and
- the ***pump H-Q curve***.

Two separate curves must be created:

- the pipeline curve, H-Q, which represents the head (H) required by the particular pipeline for various flow rates (Q) and
- the pump curve, H-Q, which represents the head (H) produced by the pump at various flow rates (Q) at a certain impeller speed (rpm).

HOW TO SELECT A SLURRY PUMP

The ***head H required by the pipeline*** is the head lost in the entire pipeline due to:

- the friction loss: major and minor losses
- the loss/gain due to the change in elevation: potential energy loss/gain.

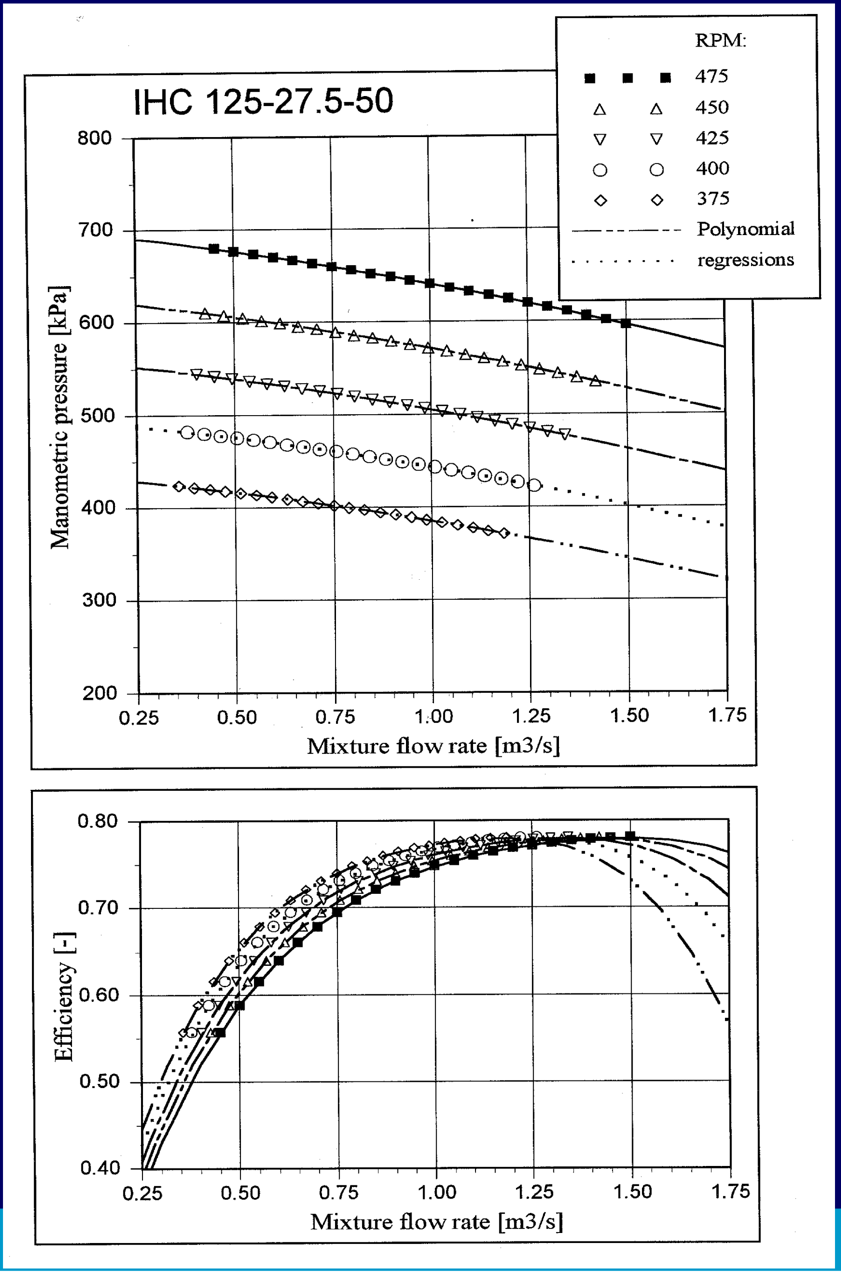
The ***head H produced by the (centrifugal) pump*** is the head (the manometric pressure) developed in the mixture flowing through the rotating impeller of the pump.

The slurry pump is chosen that offers the most efficient (BEP) and safe (V_{dl}, NPSH) operation of a pump-pipeline system.

HOW TO SELECT A SLURRY PUMP

The ***characteristics of the IHC slurry pump*** (water operation):

- **ΔP(H) – Q** for various impeller speeds (rpm)
- **Efficiency – Q** for various impeller speeds, the Best Efficiency Point (BEP) varies with rpm.



INTERMEZZO: Conservation of Energy


Daniel Bernoulli

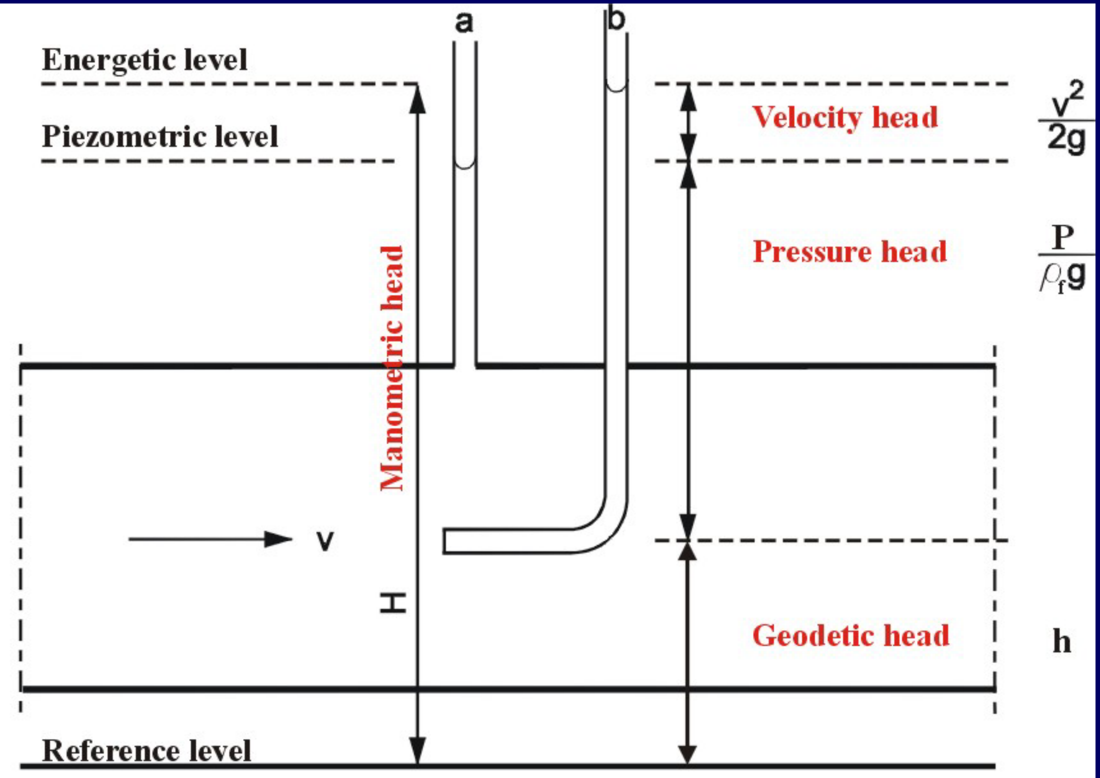
The Bernoulli equation:

quantifies the **amount of mechanical energy** available at a certain location in a flow.

Mechanical energy components:

- the ***potential energy*** of fluid control volume per unit gravity force, expressed as the <u>geodetic height</u> (head) — h [m]
- the ***flow energy*** (or flow work), expressed as the <u>pressure head</u> — $\frac{P}{\rho_f g}$ [m]
- the ***kinetic energy***, expressed as the <u>velocity head</u> — $\frac{V_m^2}{2g}$ [m]

INTERMEZZO: Conservation of Energy



$$h + \frac{P}{\rho_f g} + \frac{V_m^2}{2g} = Level.of.Mech.Energy$$

INTERMEZZO: Conservation of Energy

Incompressible, steady and frictionless flow (ideal liquid):

The level of mechanical energy (H), i.e. the sum of three energy components, is constant at all locations along a pipe.

$$h + \frac{P}{\rho_f g} + \frac{V_m^2}{2g} = const.$$

Thus for two locations (1) and (2) distant from each other along a pipe

$$h_1 + \frac{P_1}{\rho_f g} + \frac{V_{m1}^2}{2g} = h_2 + \frac{P_2}{\rho_f g} + \frac{V_{m2}^2}{2g}$$

INTERMEZZO: Conservation of Energy

Incompressible, steady and viscous flow (real liquid):

The level of mechanical energy (H), i.e. the sum of three energy components, drops along a pipe due to energy loss.

$$h + \frac{P}{\rho_f g} + \frac{V_m^2}{2g} \neq const.$$

Thus for two locations (1) and (2) distant from each other along a pipe

$$h_1 + \frac{P_1}{\rho_f g} + \frac{V_{m1}^2}{2g} = h_2 + \frac{P_2}{\rho_f g} + \frac{V_{m2}^2}{2g} + H_{loss}$$

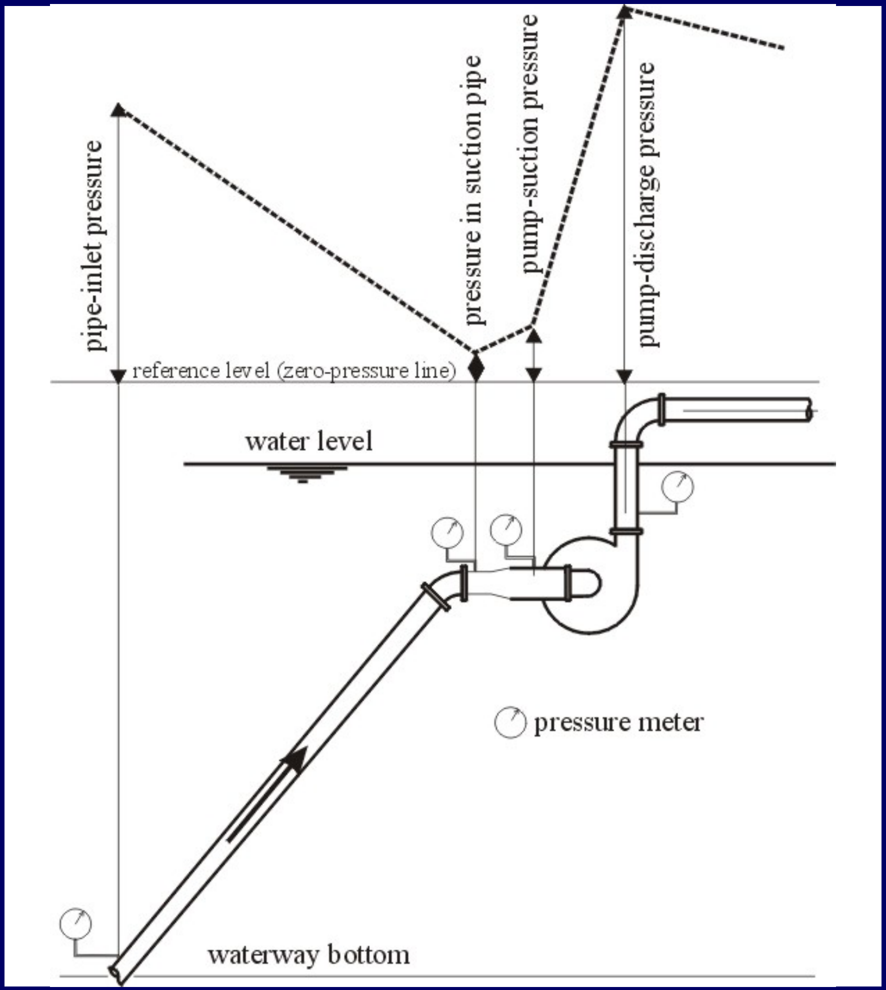
INTERMEZZO: Conservation of Energy

The static-pressure (P) variation along suction and discharge pipes connected with a pump (schematic).

The static pressure varies due to changes in

- the geodetic height (suction pipe)
- the velocity [head] (change in pipe diameter in front of the pump) and…

due to the losses (both in suction and discharge pipes).



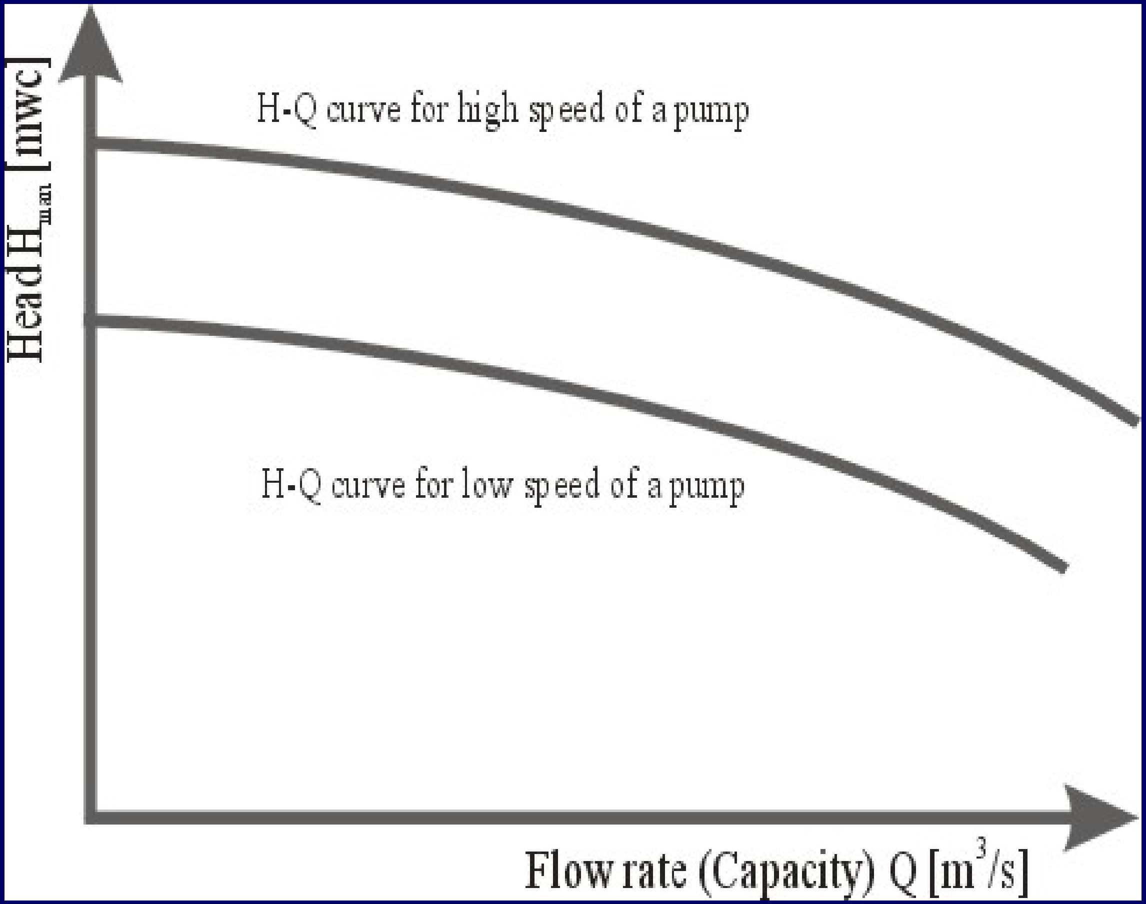
H-Q CHARACTERISTICS

H-Q PUMP

H-Q PIPELINE

H-Q PUMP-PIPELINE SYSTEM

H_{man}-Q CURVE OF A CENTRIFUGAL PUMP



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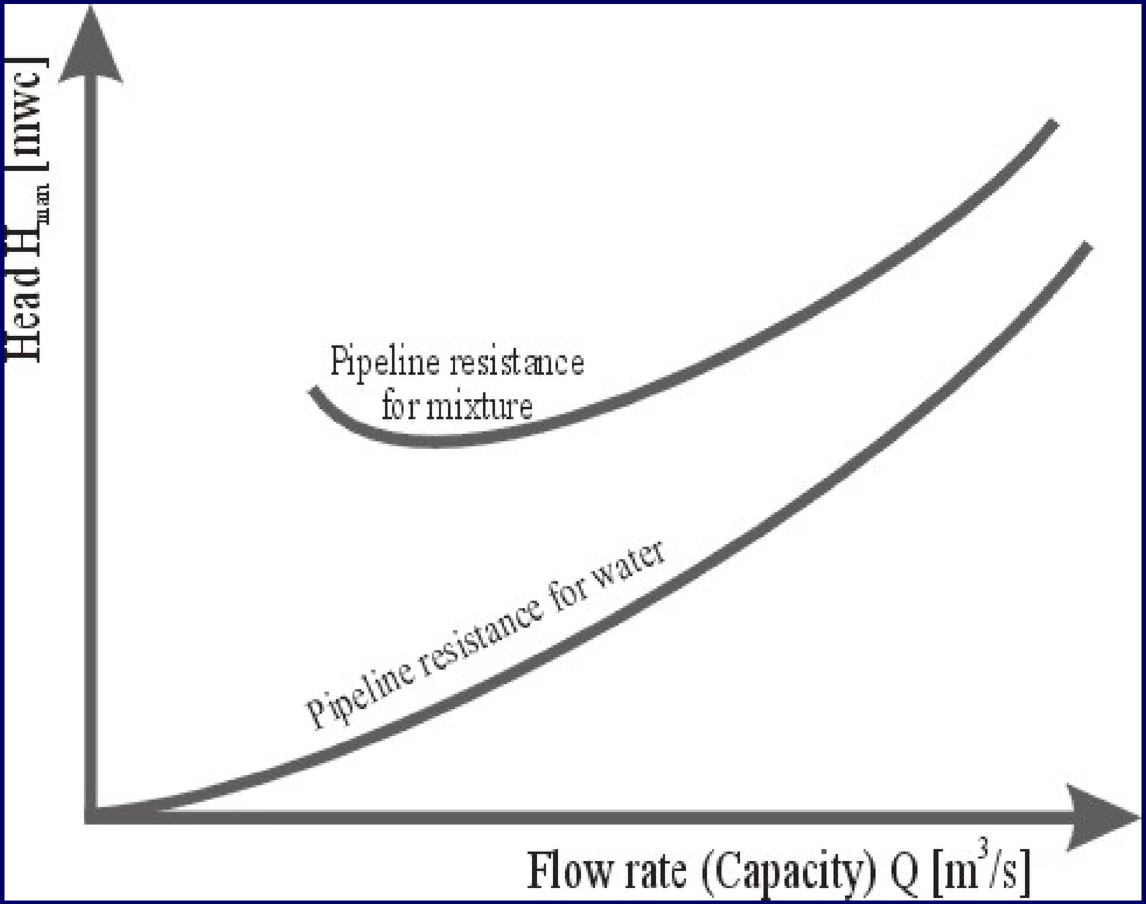
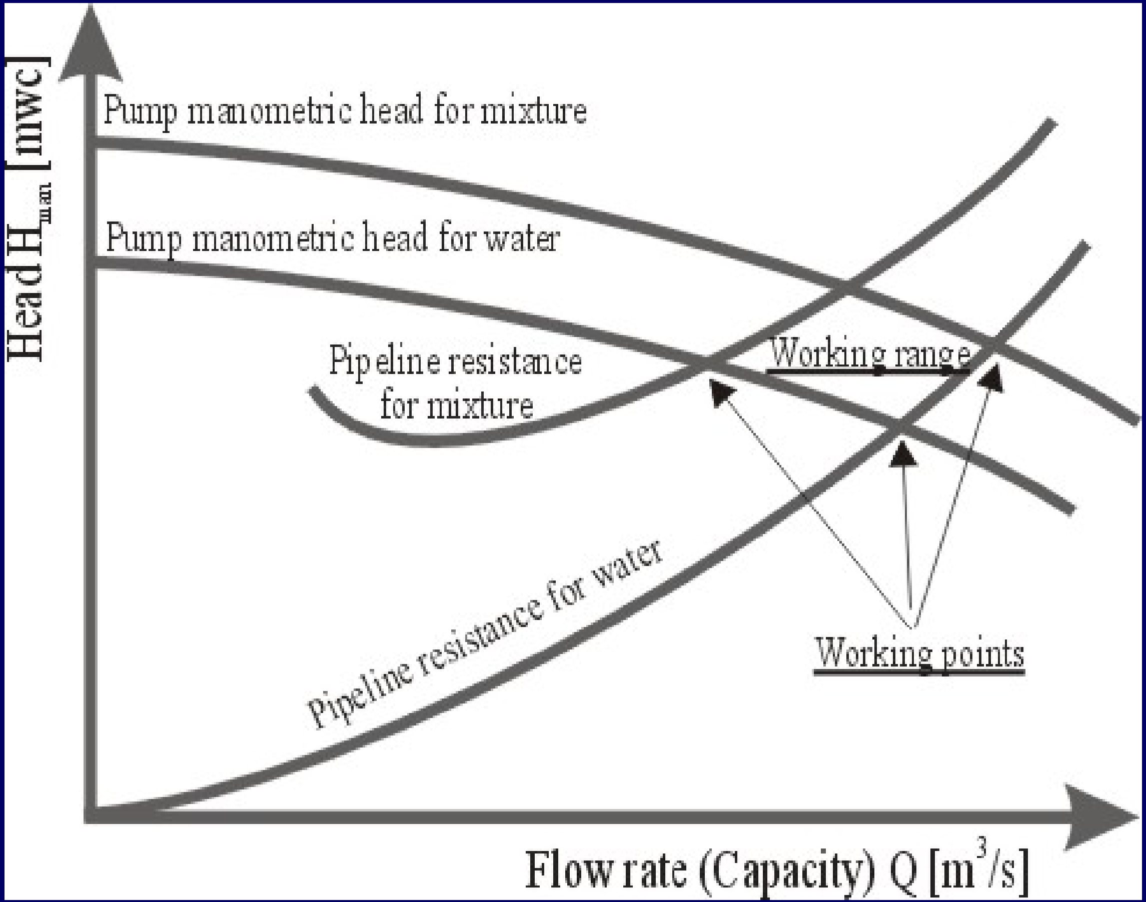
H-Q CURVE OF A PIPELINE



H-Q CURVES OF A PUMP-PIPELINE SYSTEM



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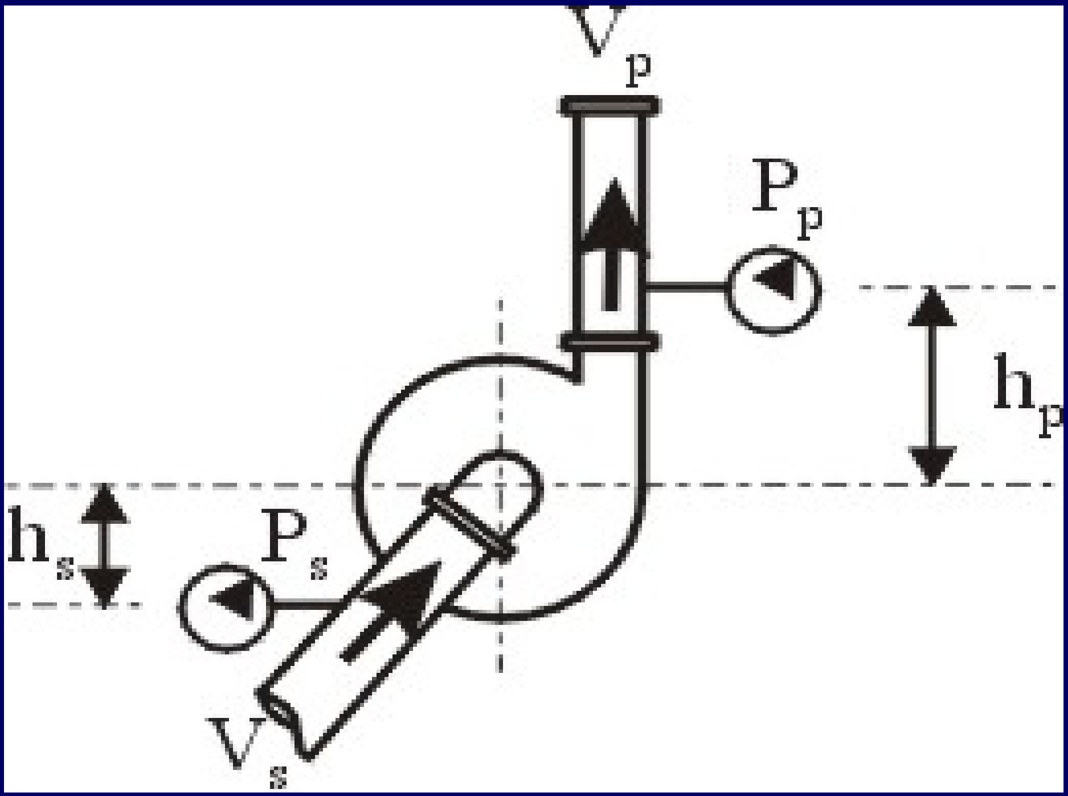
H_{man}-Q CURVE OF A CENTRIFUGAL PUMP



$$h + \frac{P}{\rho_f g} + \frac{V^2}{2g} = Level.of.Mech.Energy$$

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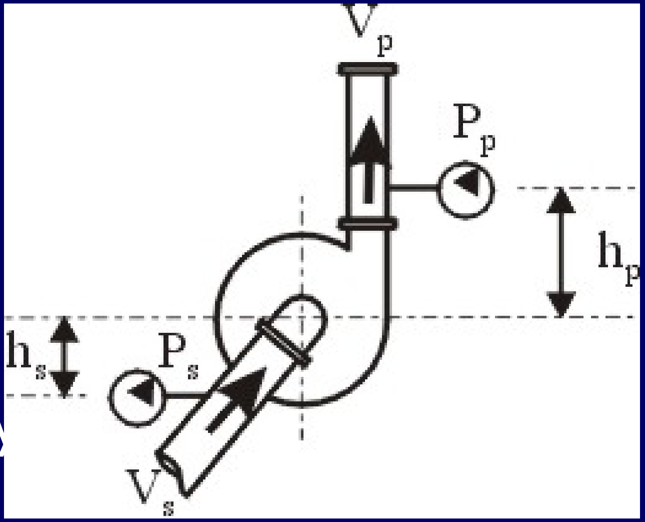
H_{man}-Q CURVE OF A CENTRIFUGAL PUMP

- A rotating impeller of a centrifugal pump adds mechanical energy to the medium flowing through a pump.
- As a result of an energy addition a pressure differential occurs in the pumped medium between the inlet and the outlet of a pump.
- The **manometric head, H_{man},** that is delivered by a pump to the medium, is given as

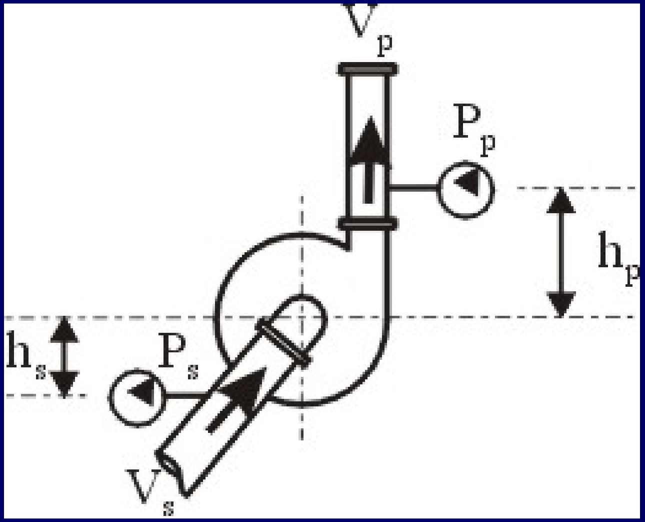


$$H_{man} = \left(Level.of.Mech.Energy\right)_p - \left(Level.of.Mech.Energy\right)_s$$

The **manometric head, H_{man},** that is delivered by a pump to the medium, is

$$H_{man} = \frac{P_{man}}{\rho_f g}$$

H_{man}-Q CURVE OF A CENTRIFUGAL PUMP



- A rotating impeller of a centrifugal pump adds mechanical energy to the medium flowing through a pump.
- As a result of an energy addition a pressure differential occurs in the pumped medium between the inlet and the outlet of a pump.
- The **manometric pressure, P_{man},** that is delivered by a pump to the medium, is given as

$$P_{man} = P_p - P_s + \rho_m \left(h_p + h_s\right) + \frac{\rho_m \left(V_p^2 - V_s^2\right)}{2}$$

The **manometric head, H_{man},** that is delivered by a pump to the medium, is

$$H_{man} = \frac{P_{man}}{\rho_f g}$$

H_{man}-Q CURVE OF A CENTRIFUGAL PUMP

Effect of <u>pump speed</u> on H_{man}-Q & Efficiency-Q
(Affinity laws)

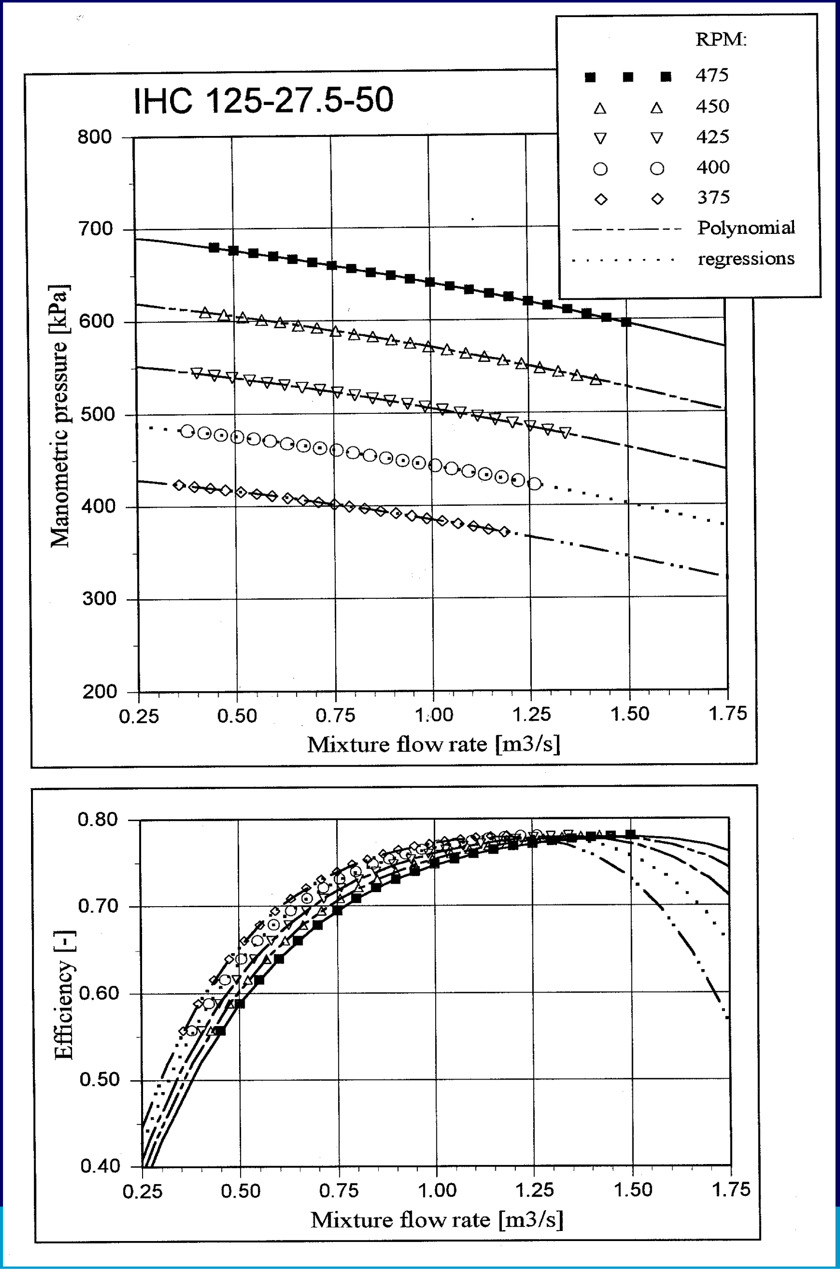
Effect of <u>solids presence</u> on H_{man}-Q & Efficiency-Q
(Slurry-pumping model)

H_{man}-Q PUMP: Affinity Laws (RPM Effect)

Pump characteristic curves are:

- H_{man}-Q (P_{man}-Q),
- (Power-Q; pump output power)
- η-Q (η is the pump efficiency).

<u>The curves hold for a constant pump speed, n [rpm].</u>



H_{man}-Q PUMP: Affinity Laws (RPM Effect)

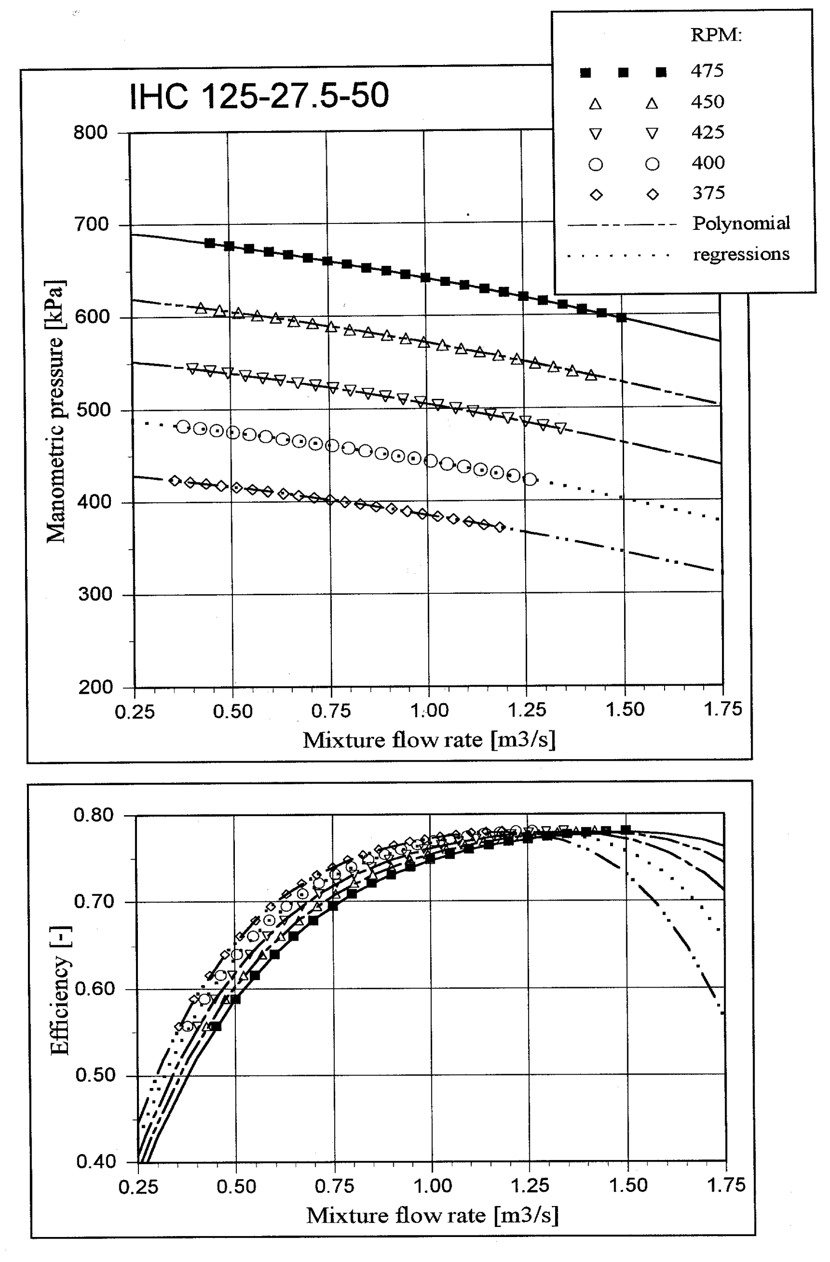
The affinity laws are:

$$\frac{Q_{m,n1}}{Q_{m,n2}} = \frac{n_1}{n_2}$$

$$\frac{H_{man,n1}}{H_{man,n2}} = \left(\frac{n_1}{n_2}\right)^2$$

$$\frac{Power_{n1}}{Power_{n2}} = \left(\frac{n_1}{n_2}\right)^3$$

$$\frac{\eta_{f,n1}}{\eta_{f,n2}} = 1$$



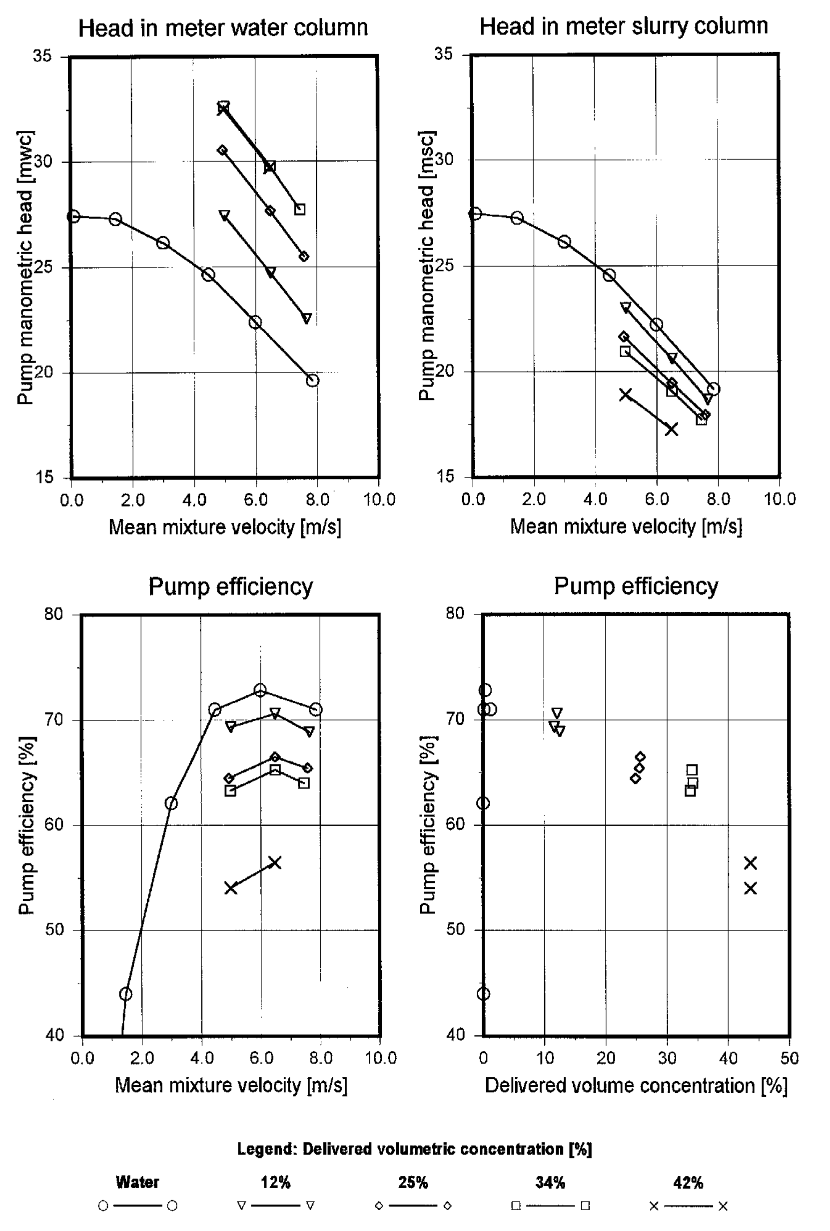
H_{man}-Q PUMP: Effect of Solids

Solid particles of a pumped slurry diminish the efficiency of a dredge pump. The ratio of pump efficiencies for mixture and water

$$f_c = \frac{\eta_m}{\eta_f} < 1$$

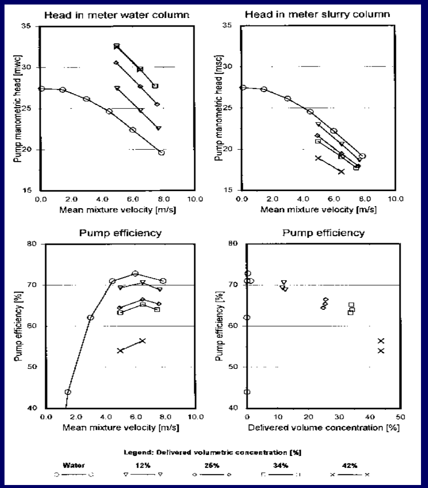
is also a measure of manometric pressure reduction

$$P_{man,m} = P_{man,f} \frac{\rho_m}{\rho_f} f_c$$



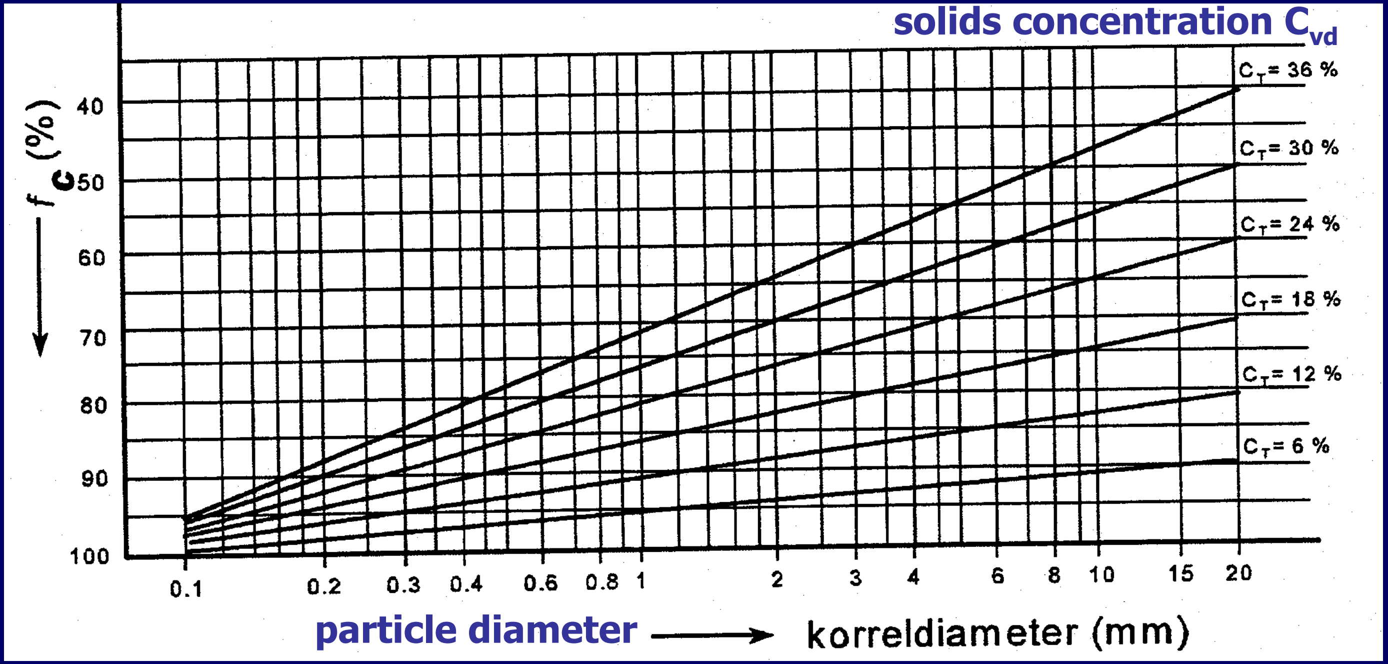
Tests of a 0.5-m-impeller pump connected with a 162 kW MAN diesel engine. Speed: 1000 rpm. Pumped material: 0.2 – 0.5 mm sand.

H_{man}-Q PUMP: Effect of Solids

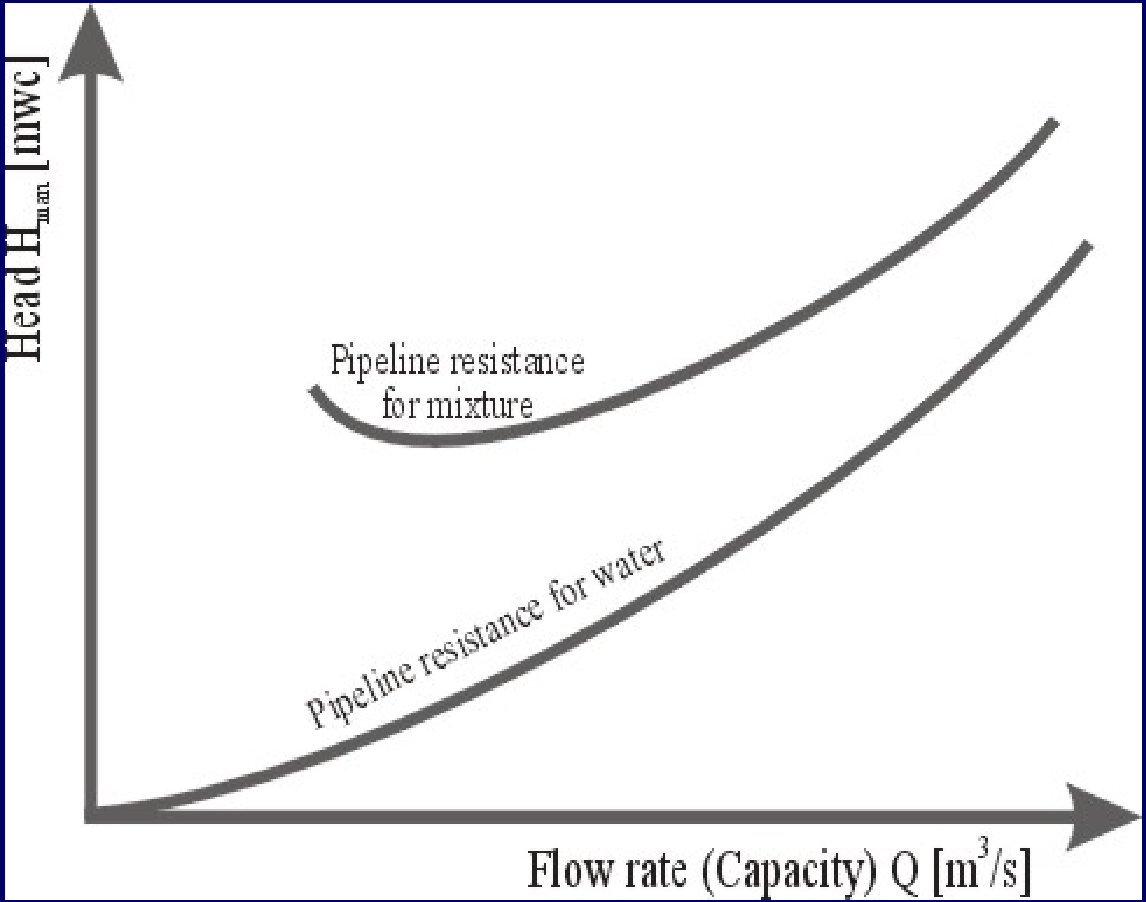


The ratio of pump efficiencies, f_c, for sand and gravel slurries (Stepanoff, 1965)

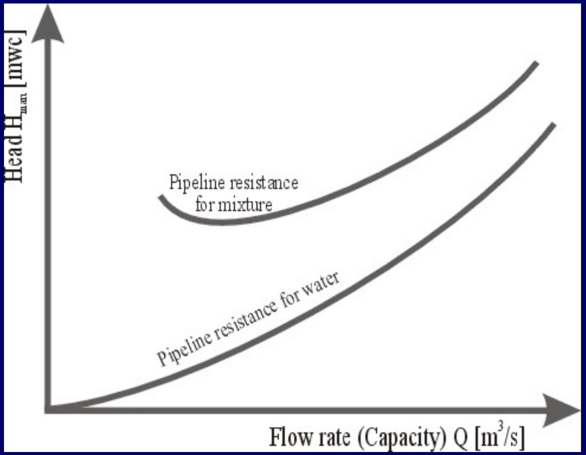
$$f_c = 1 - C_{vd}\left(0.8 + 0.6 \log d_{50}\right)$$



H-Q CURVE OF A PIPELINE



H-Q PIPELINE: Losses

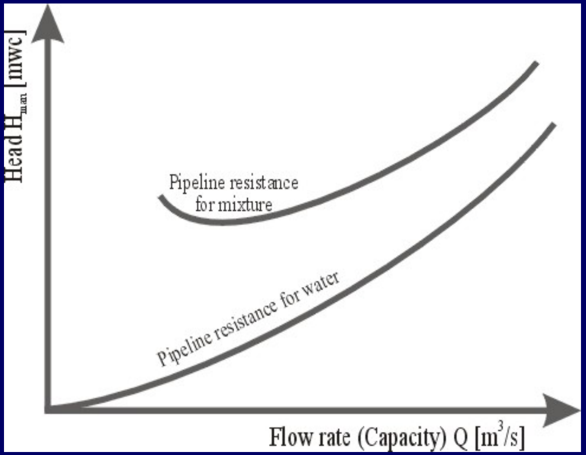


In a pump-pipeline system the manometric head of a pump is required to overcome the total head loss in slurry transported in a pipeline connected to a pump.

The **total head loss** is composed of

- the **major and minor losses** due to flow friction in a suction pipeline and in a discharge pipeline,
- the **loss due to the change in elevation** of a suction pipeline and of a discharge pipeline,
- the **losses due to mixture acceleration** in a pipeline.

H-Q PIPELINE: Losses



1. Major loss

(head loss in straight pipeline sections)

$$H_{major,f} = I_f L = \frac{\lambda_f L}{D} \frac{V_f^2}{2g} = \frac{\lambda_f L}{D} \frac{Q_f^2}{2gA^2}$$

$$H_{major,m} = I_m L$$

2. Minor loss

(head loss in fittings)

$$H_{minor,f} = \xi \frac{V_f^2}{2g}$$

$$H_{minor,m} = \xi \frac{V_f^2}{2g} \frac{\rho_m}{\rho_f}$$

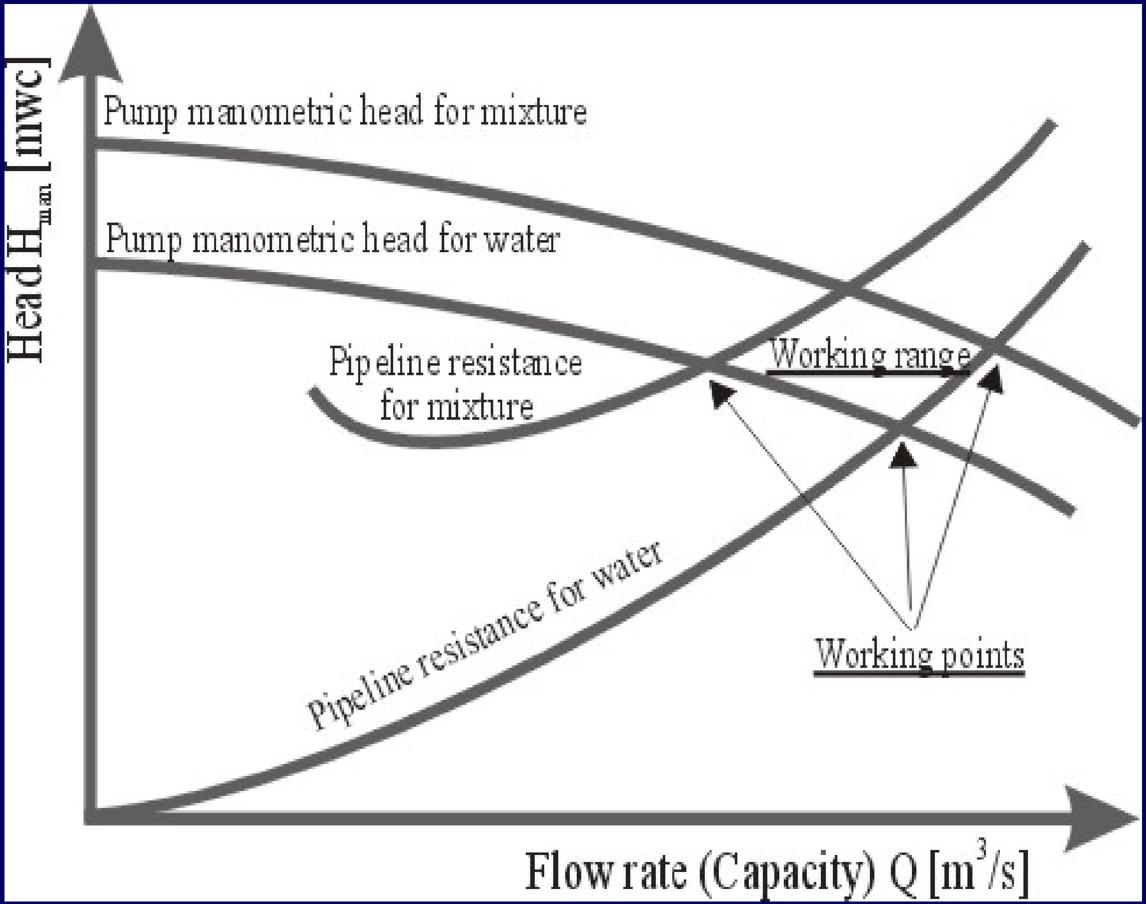
3. Static (geodetic) loss/gain

(head loss due to elevation change)

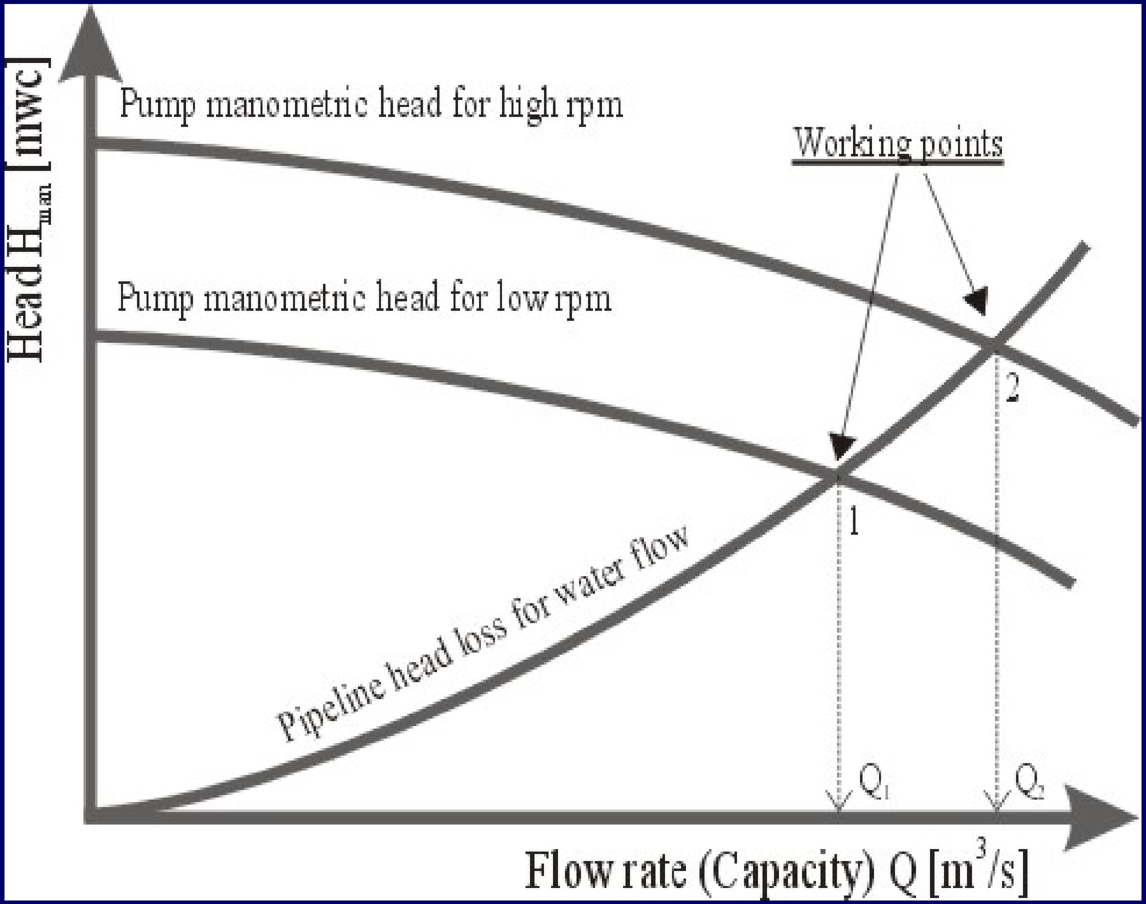
$$H_{static,f} = \Delta h$$

$$H_{static,m} = \Delta h \frac{\rho_m}{\rho_f}$$

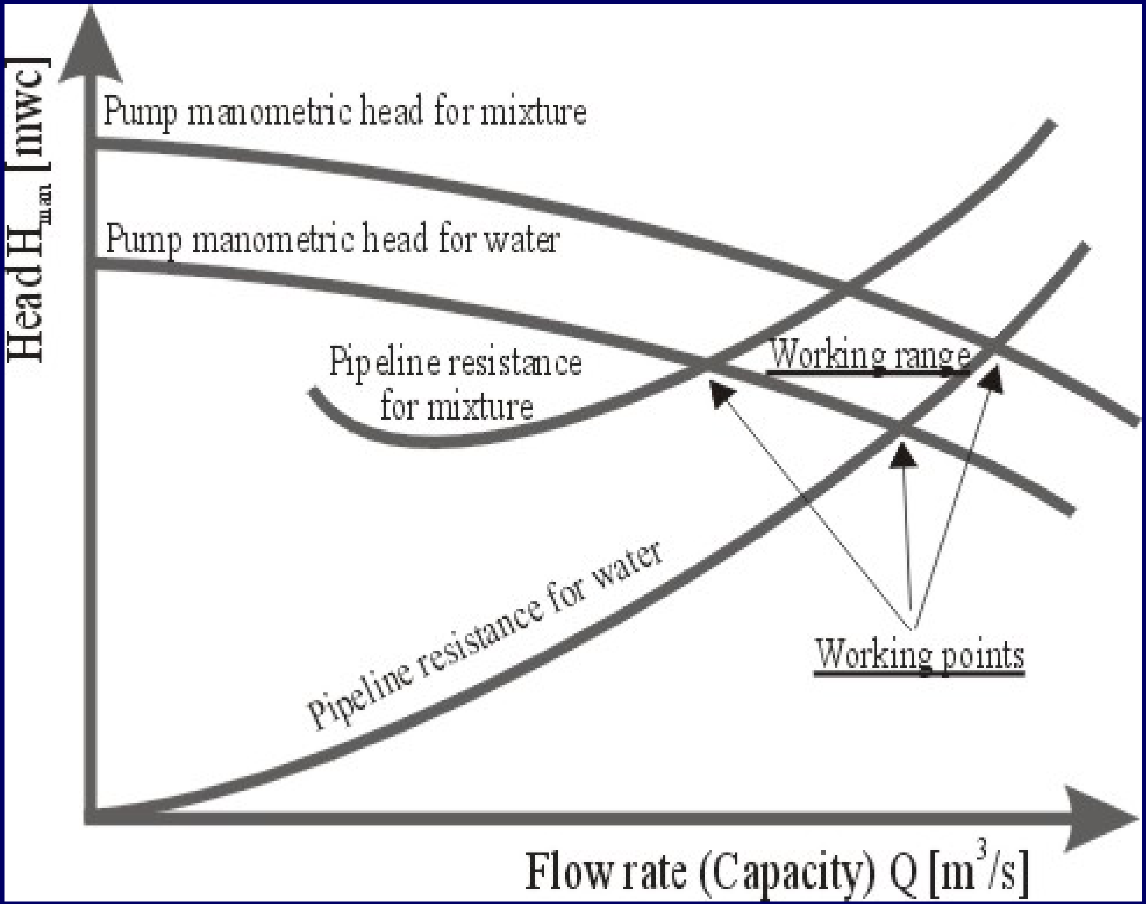
H-Q CURVES OF A PUMP-PIPELINE SYSTEM



H-Q SYSTEM: Working Point



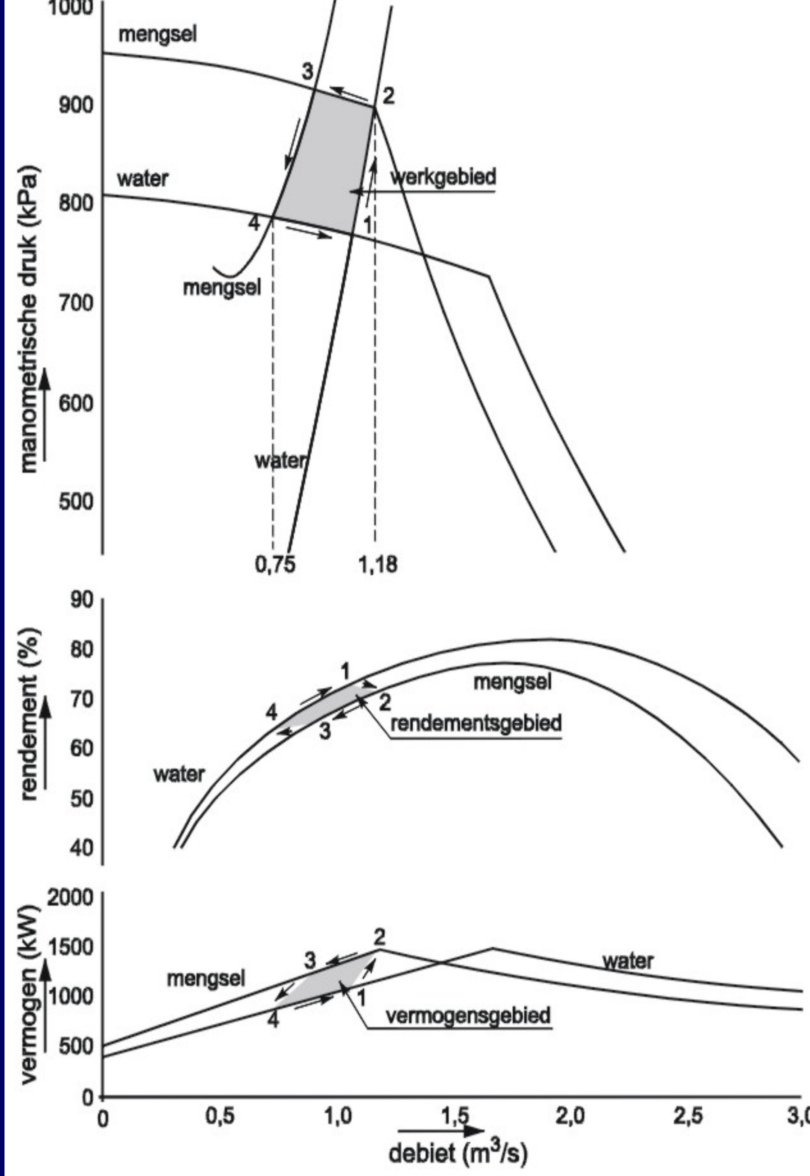
H-Q SYSTEM: Working Range



H_{man}-Q SYSTEM: Working Range

Change of Working point:

1. *the beginning of a cycle*: only water flows through the suction pipe and the discharge pipe
2. *the beginning of a soil excavation process*: the suction pipe is filled with mixture, the discharge pipe is still filled with water only
3. *the mixture transportation*: both the suction and the discharge pipes are filled with mixture
4. *the end of a cycle*: the suction pipe and the pump are filled with water, the discharge pipe is filled with mixture.

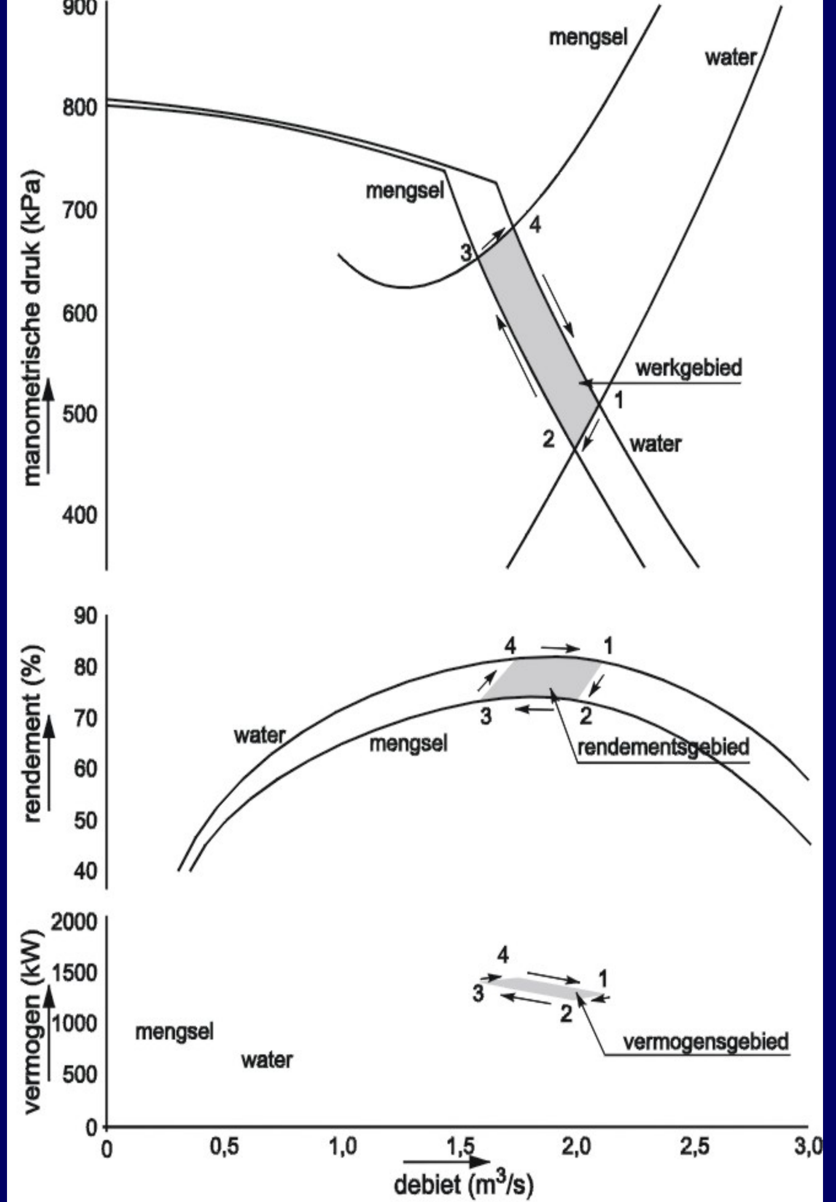


Operation at Constant Speed

H_{man}-Q SYSTEM: Working Range

Change of Working point:

1. *the beginning of a cycle*: only water flows through the suction pipe and the discharge pipe
2. *the beginning of a soil excavation process*: the suction pipe is filled with mixture, the discharge pipe is still filled with water only
3. *the mixture transportation*: both the suction and the discharge pipes are filled with mixture
4. *the end of a cycle*: the suction pipe and the pump are filled with water, the discharge pipe is filled with mixture.

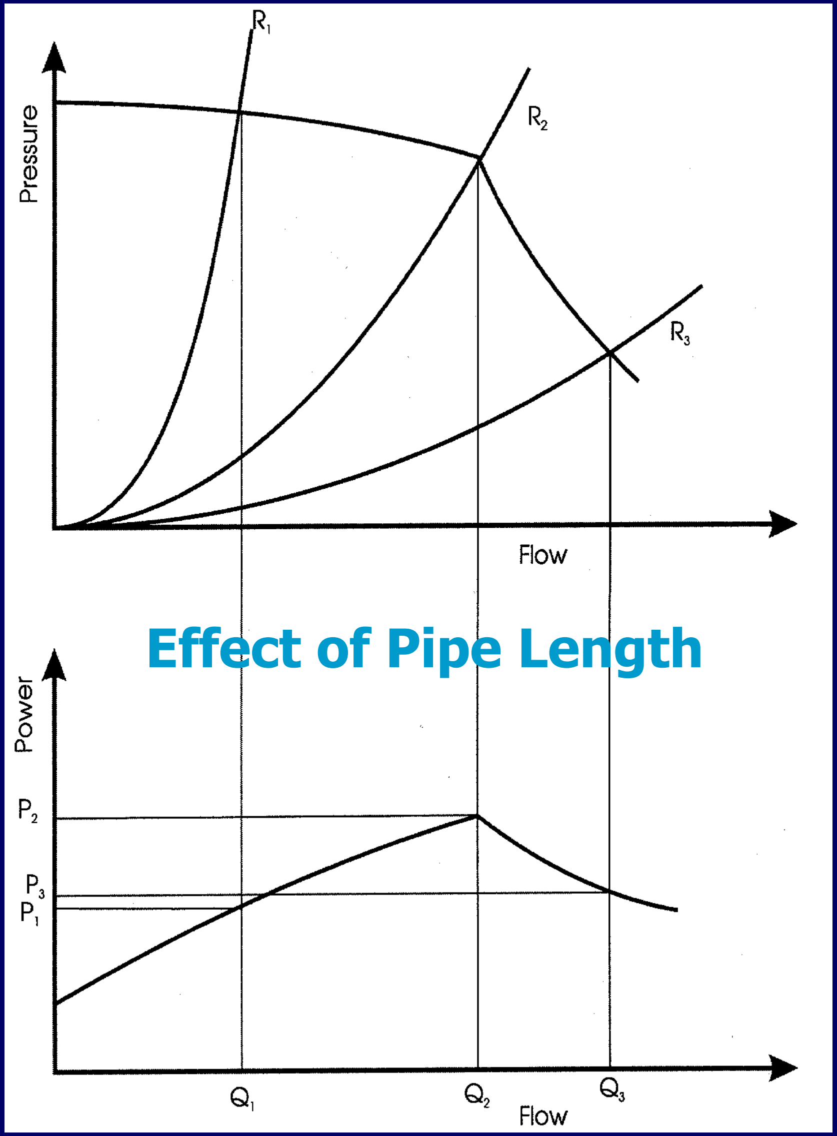


Operation at Constant Torque

H_{man}-Q SYSTEM: Working Point

Change of Working point:

1. *R1: the longer pipe*: drop in discharge and output power
2. *R2: the pipe of the original length*: maximum output power
3. *R3: the shorter pipe*: drop in output power, increase in discharge



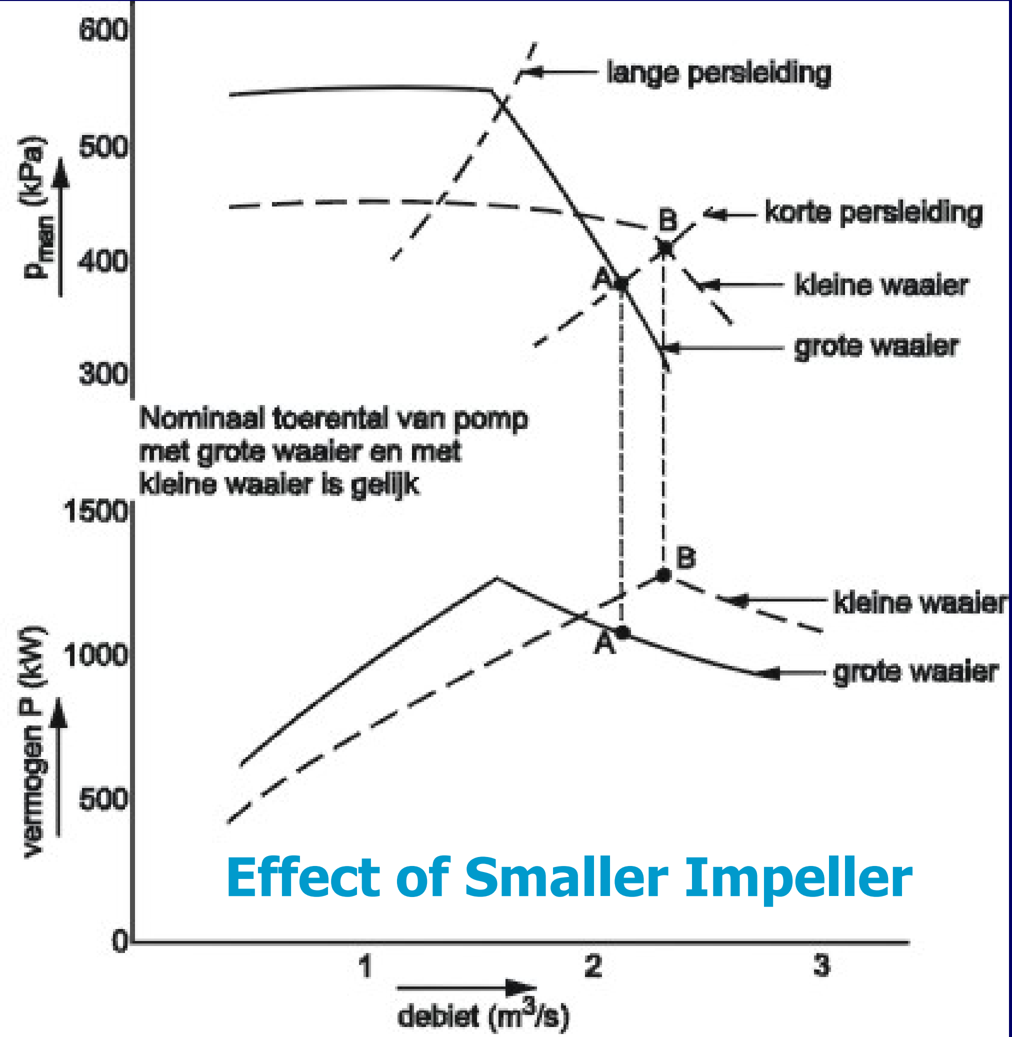
Effect of Pipe Length

H_{man}-Q SYSTEM: Working Point

Adaptation of a dredge pump for a shortened pipeline:

The pipeline becomes shorter, the power drops (point A).

Remedy: The output power does not drop if a smaller impeller is installed in the dredge pump (point B).



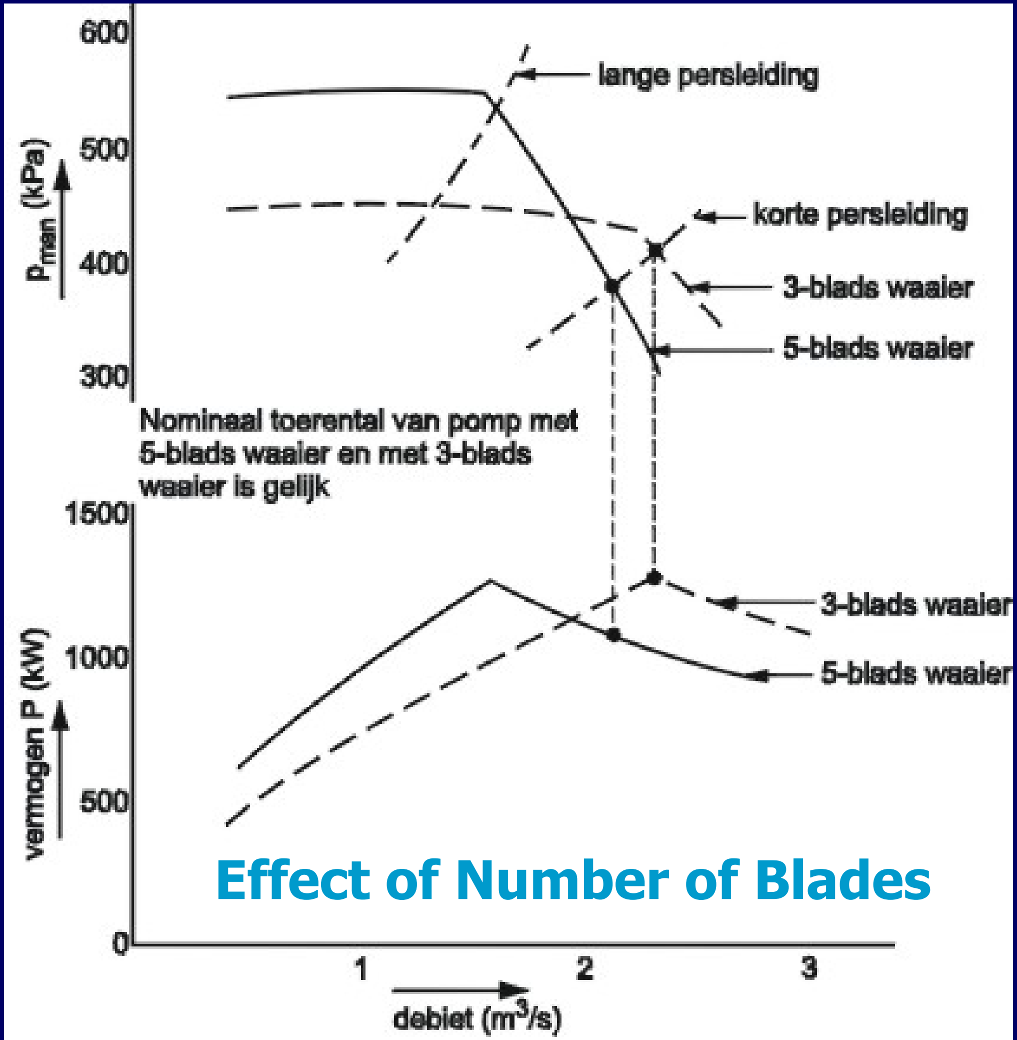
Effect of Smaller Impeller

H_{man}-Q SYSTEM: Working Point

<u>Adaptation of a dredge pump for a shortened pipeline</u>:

The pipeline becomes shorter, the power drops (point A).

Remedy: The output power does not drop if an impeller with less blades (3 instead of 5) is installed in the dredge pump (point B).



Effect of Number of Blades