oe4625 Dredge Pumps and Slurry Transport

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8. OPERATION LIMITS OF PUMP-PIPELINE SYSTEM

REQUIRED MANOMETRIC PRESSURE

MAXIMUM VELOCITY – INITIAL CAVITATION

MINIMUM VELOCITY – STATIONARY BED

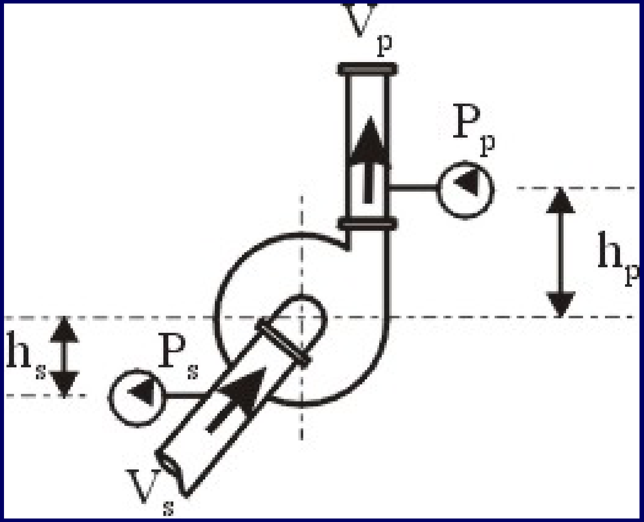
REQUIRED MANOMETRIC PRESSURE

DETERMINATION OF SUCTION PRESSURE

DETERMINATION OF DISCHARGE PRESSURE

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

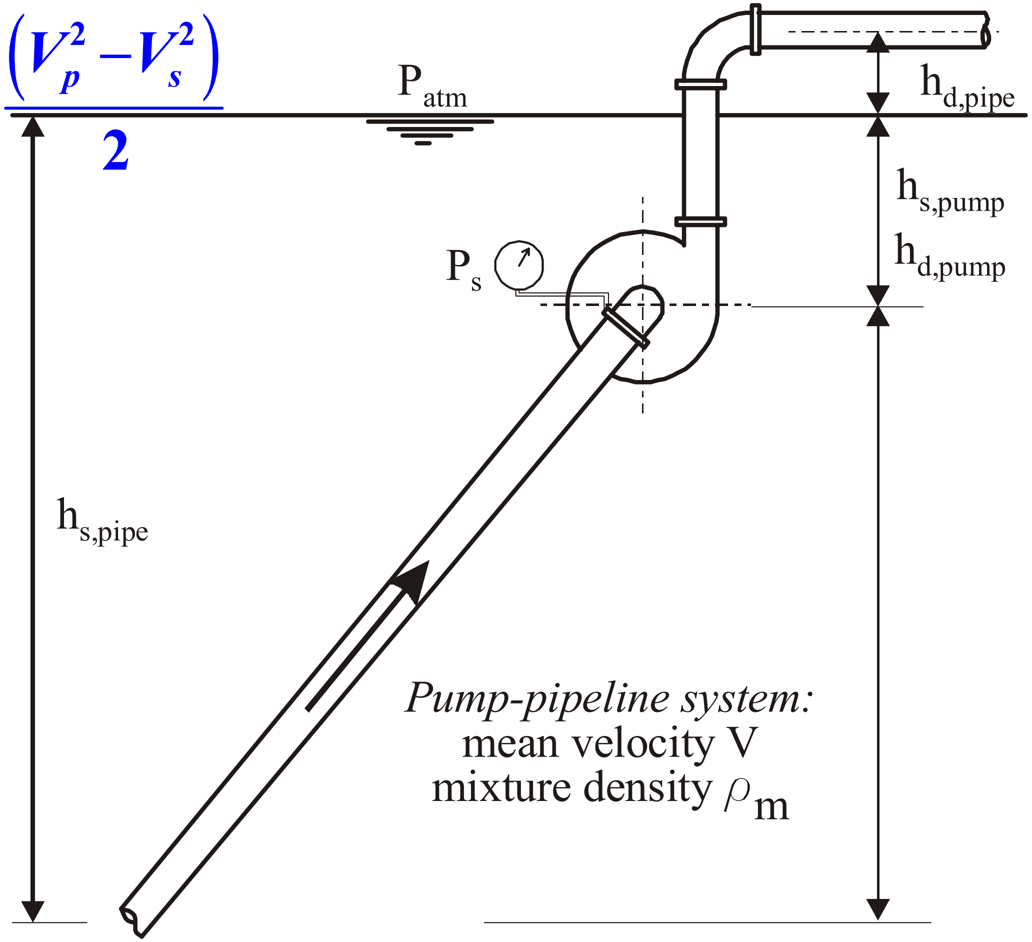
$$H_{man} = \frac{P_{man}}{\rho_f g}$$

REQUIRED MANOMETRIC PRESSURE

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

$$P_p = ?$$

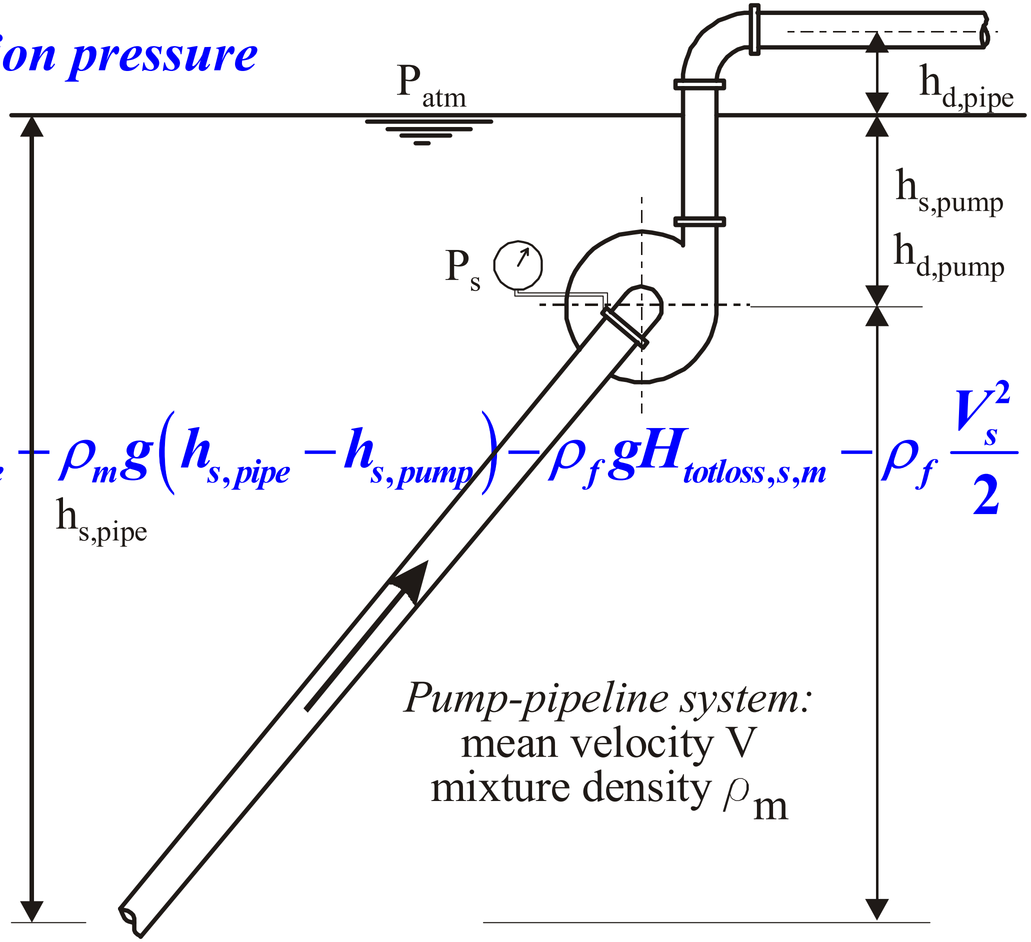
$$P_s = ?$$



REQUIRED MANOMETRIC PRESSURE

P_s = *absolute suction pressure*

$$P_s = P_{atm} + \rho_f g h_{s,pipe} - \rho_m g\left(h_{s,pipe} - h_{s,pump}\right) - \rho_f g H_{totloss,s,m} - \rho_f \frac{V_s^2}{2}$$



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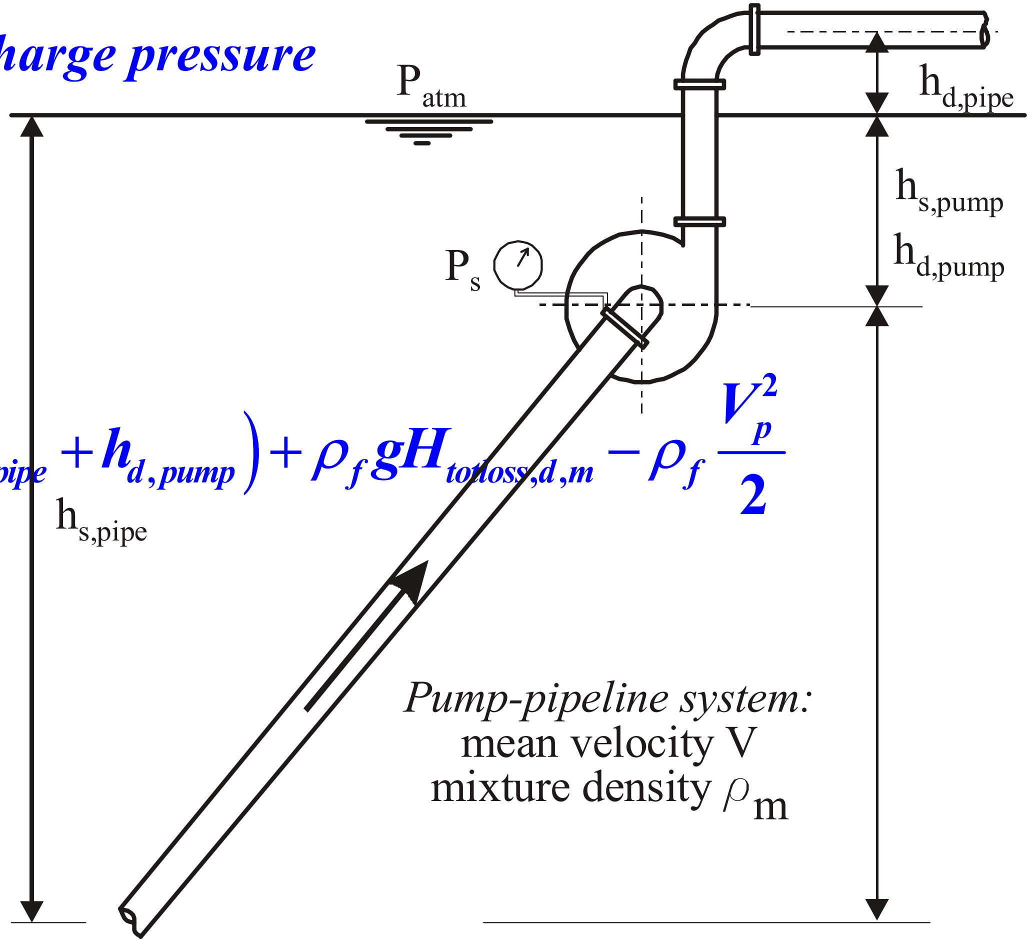
REQUIRED MANOMETRIC PRESSURE

P_p = *absolute discharge pressure*

$$P_p = P_{atm} + \rho_m g\left(h_{d,pipe} + h_{d,pump}\right) + \rho_f g H_{totloss,d,m} - \rho_f \frac{V_p^2}{2}$$



MAXIMUM VELOCITY IN THE SYSTEM

THE UPPER LIMIT FOR A SYSTEM OPERATION:

<u>VELOCITY AT THE INITIAL CAVITATION OF A PUMP</u>

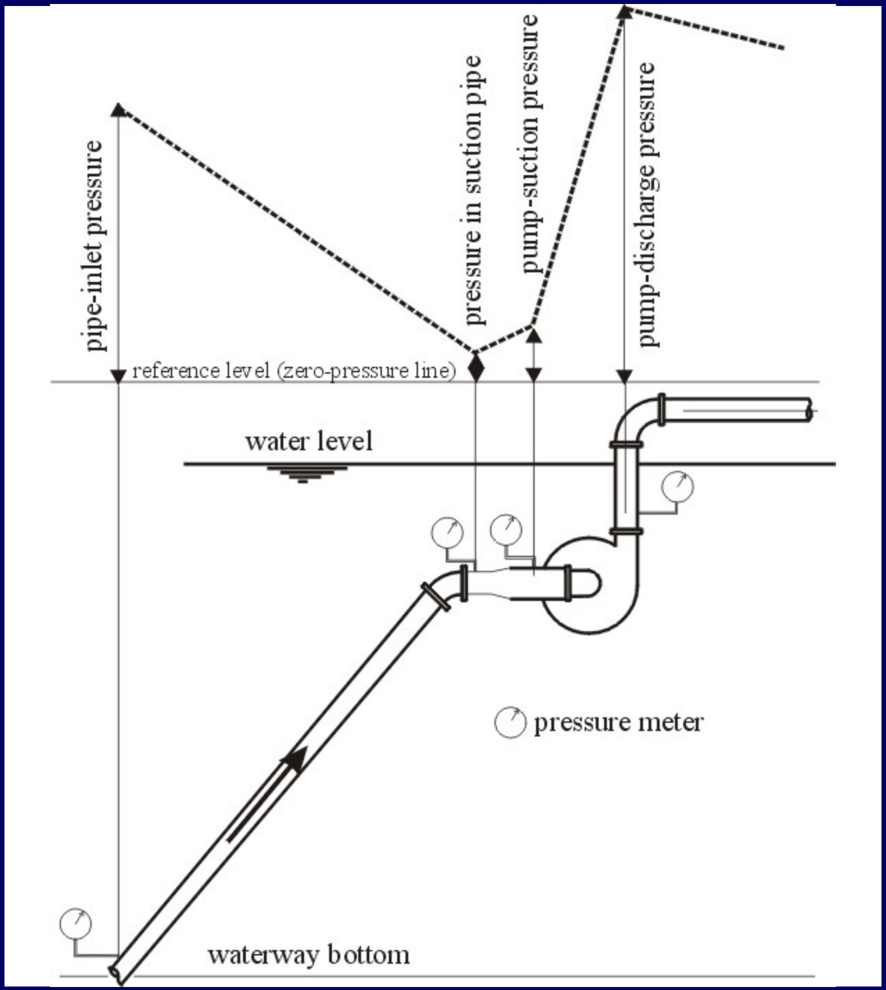
Static Pressure Variation Along System

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).



MAXIMUM VELOCITY IN THE SYSTEM

Criterion for non--cavitational operation of a system

The no cavitation condition for a certain pump-suction pipe combination is:

$$(NPSH)_{REQUIRED} < (NPSH)_{AVAILABLE}$$

The available Net Positive Suction Head is a total available energy head over the vapour pressure at the suction inlet to the pump during an operation at velocity V_m in a suction pipe of a certain geometry and configuration.

$$\left(NPSH\right)_{AVAILABLE} = \frac{P_s - P_{vapour}}{\rho_f g} + \frac{V_m^2}{2g}$$

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MAXIMUM VELOCITY IN THE SYSTEM

Criterion for non--cavitational operation of a system

The no cavitation condition for a certain pump-suction pipe combination is:

$$(NPSH)_{REQUIRED} < (NPSH)_{AVAILABLE}$$

The required Net Positive Suction Head is a minimum energy head a certain pump requires to prevent cavitation at its inlet. This is a head value at the incipient cavitation.

$$(NPSH)_{REQUIRED} = \frac{P_{s,\min} - P_{vapour}}{\rho_f g} + \frac{V_m^2}{2g}$$

MAXIMUM VELOCITY IN THE SYSTEM

Criterion for non--cavitational operation of a system

The no cavitation condition for a certain pump-suction pipe combination is:

$$(NPSH)_{REQUIRED} < (NPSH)_{AVAILABLE}$$

The $(NPSH)_{REQUIRED}$-Q curve is a characteristic specific for each pump and it must be determined by a pump cavitation test. A design (dimensions, shape) and an operation (specific speed) of a pump decide the absolute suction pressure at the initial cavitation.

$$(NPSH)_{REQUIRED} = \frac{P_{s,\min} - P_{vapour}}{\rho_f g} + \frac{V_m^2}{2g}$$

MAXIMUM VELOCITY IN THE SYSTEM

Criterion for non--cavitational operation of a system

The no cavitation condition for a certain pump-suction pipe combination is:

$$(NPSH)_{REQUIRED} < (NPSH)_{AVAILABLE}$$

At the incipient cavitation, the absolute suction pressure $P_{s,min}$ at the pump inlet is equal to the difference between the atmospheric pressure P_{atm} and the so-called "decisive vacuum" (Dutch: maatgevend vacuum) $(Vac)_d$, i.e.

$$(Vac)_d = P_{atm} - P_{s,min}.$$

MAXIMUM VELOCITY IN THE SYSTEM

Criterion for non--cavitational operation of a system

The upper limit for the working range of a pump-pipeline system is given by points of intersection of a pump decisive vacuum curve and a set of vacuum curves of a suction pipe for various mixture densities.

The *vacuum curve of a suction pipe* :

$$\frac{Vac}{\rho_f g} = \frac{P_{atm} - P_S}{\rho_f g}$$

MAXIMUM VELOCITY IN THE SYSTEM

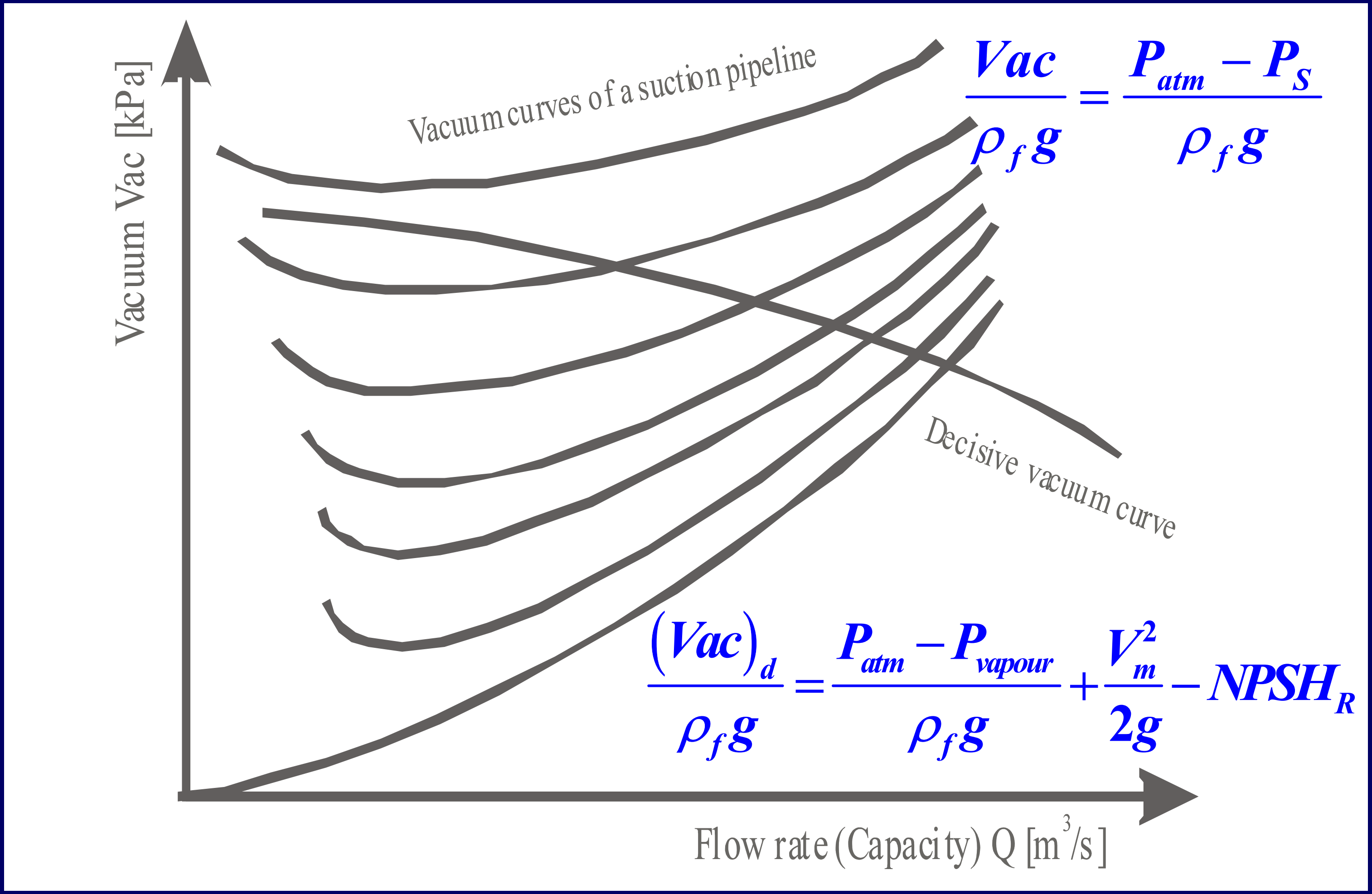
Criterion for non--cavitational operation of a system

The upper limit for the working range of a pump-pipeline system is given by points of intersection of a pump decisive vacuum curve and a set of vacuum curves of a suction pipe for various mixture densities.

The *decisive vacuum curve of a pump* :

$$\frac{(Vac)_d}{\rho_f g} = \frac{P_{atm} - P_{vapour}}{\rho_f g} + \frac{V_m^2}{2g} - NPSH_{REQUIRED}$$

MAXIMUM VELOCITY IN THE SYSTEM



$$\frac{Vac}{\rho_f g} = \frac{P_{atm} - P_S}{\rho_f g}$$

$$\frac{(Vac)_d}{\rho_f g} = \frac{P_{atm} - P_{vapour}}{\rho_f g} + \frac{V_m^2}{2g} - NPSH_R$$

MAXIMUM VELOCITY IN THE SYSTEM

HOW TO AVOID CAVITATION

In the **design of a pump-pipeline system**:

- to reduce the static head that the pump must overcome, i.e. to put the pump as low as possible
- to reduce the head lost due to flow friction, i.e. to minimize local losses and a suction pipe length
- to increase pressure by using a larger pipe at the suction inlet of a pump.

MAXIMUM VELOCITY IN THE SYSTEM

HOW TO AVOID CAVITATION

During the **operation of a system** (the position of a pump and a geometry of a suction pipeline can not be changed):

- to reduce the head lost due to flow friction either by
  - diminishing the mean mixture velocity or by
  - reducing the mixture density in a suction pipeline.

MINIMUM VELOCITY IN THE SYSTEM

THE LOWER LIMIT FOR A SYSTEM OPERATION:

VELOCITY AT THE INITIAL STATIONARY BED IN A PIPE

MINIMUM VELOCITY IN THE SYSTEM

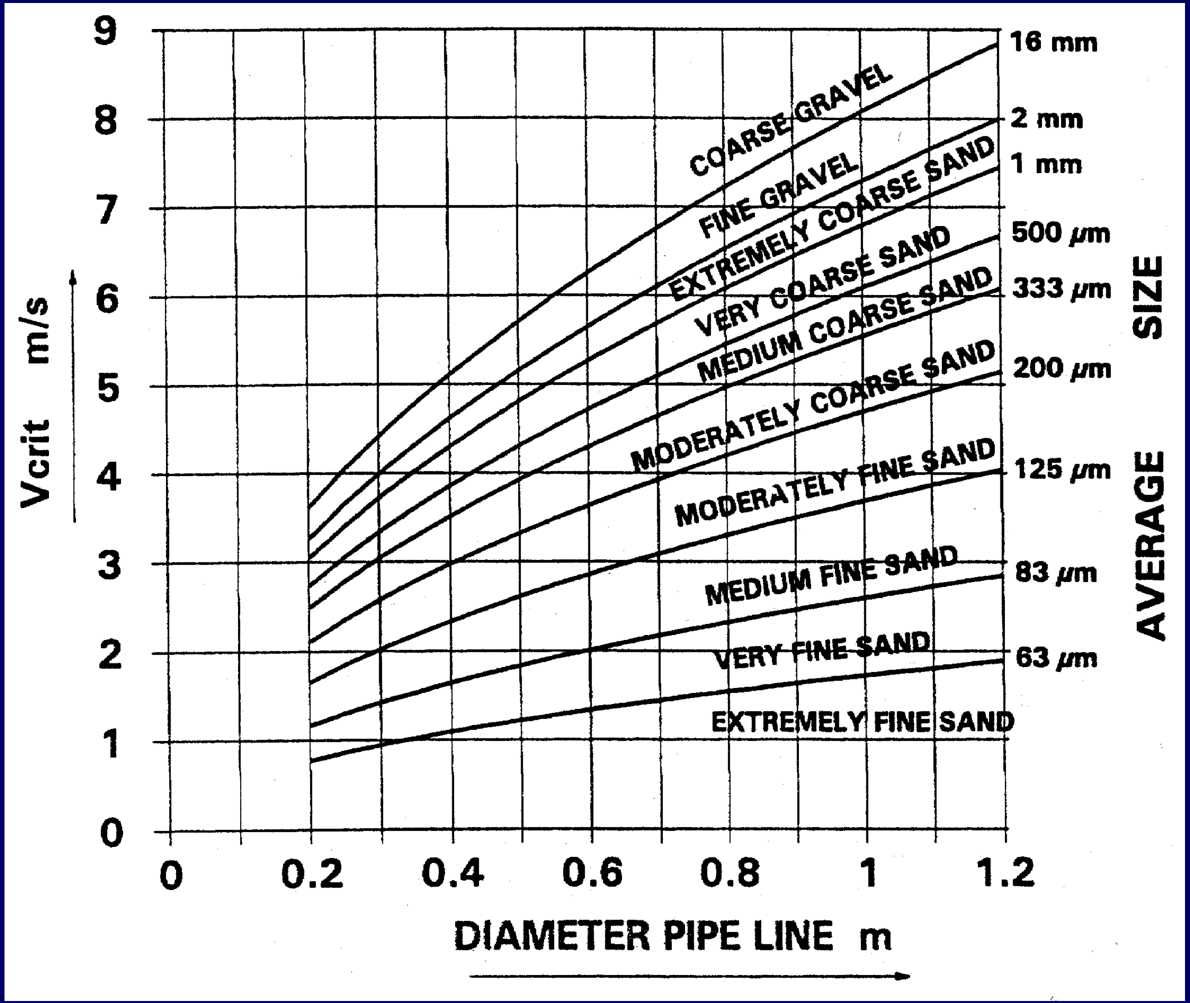
Criterion for the deposit-free operation of a system

Mean mixture velocity must be higher than deposition-limit velocity:

$$V_m > V_{dl}.$$

Empirical Model for Critical Velocity (MTI)

C. Diagram for V_{cr}:



Empirical Model for Critical Velocity (MTI)

B. Correlation for V_{cr}:

$$V_{crit} = 1.7\left(5 - \frac{1}{\sqrt{d_{mf}}}\right)\sqrt{D}\left(\frac{C_{vd}}{C_{vd}+0.1}\right)^{\frac{1}{6}}\sqrt{\frac{S_s - 1}{1.65}}$$

In the equation **d_{mf} [mm]**, **D [m]** and **V_{cr} [m/s]**.

MINIMUM VELOCITY IN THE SYSTEM

HOW TO AVOID STATIONARY BED

1. If the pipeline is composed of sections of different pipe sizes: the mixture flow rate must be maintained at the level assuring a super-critical regime ($V_m > V_{dl}$) in the pipe section of the largest pipe diameter.
2. If the solids concentration fluctuates along a pipeline:

   the mixture flow rate must be maintained at the level assuring a super-critical regime in the section of an extreme concentration. For a prediction, use the highest value of the deposition-limit velocity from the entire range of expected solids concentrations.

MINIMUM VELOCITY IN THE SYSTEM

HOW TO AVOID STATIONARY BED

3. If during a job a pipeline is prolonged or coarser solids are pumped:

   the flow rate supplied by a dredge pump might become insufficient to assure a super-critical regime in a pipeline. Then two solutions must be considered:

- to pump mixture at much lower concentration; this will lead to lower frictional losses and thus higher flow rate that might be high enough to avoid a thick stationary bed in a pipeline
- to install a booster station; this increases the manometric head provided by pumps and increase a flow rate.

EFFECT OF PUMP POSITION ON

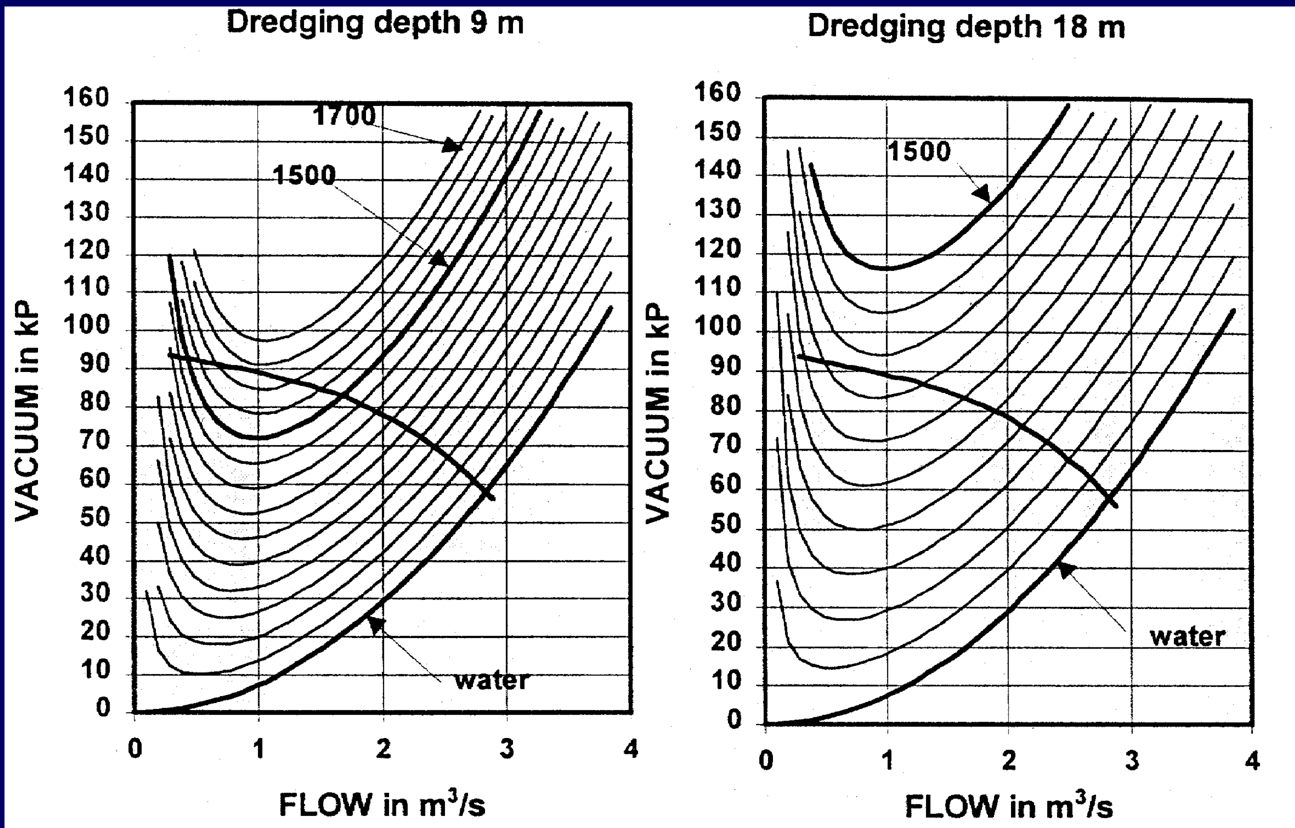
OPERATIONAL LIMITS

If a pump (e.g. a submerged pump) is placed to a lower position within a pump-pipeline system:

- the suction pipe becomes shorter
- the geodetic height over which a mixture has to be lifted becomes smaller.

EFFECT OF PUMP POSITION ON

OPERATIONAL LIMITS



	18 m		9 m	
Density in kg/m³	Q_m m³/s	Q_s m³/h	Q_m m³/s	Q_s m³/h
1000	2,840	0	2,840	0
1050	2,659	479	2,756	496
1100	2,491	897	2,644	952
1150	2,309	1247	2,538	1370
1200	2,105	1515	2,422	1744
1250	1,891	1702	2,320	2088
1300	1,627	1757	2,204	2380
1350	1,273	1604	2,089	2632
1380	0,864	1182	2.000	2725
1400			1,956	2816
1450			1,844	2987
1500			1,693	3047
1550			1,511	2992
1600			1,288	2782
1633			1,000	2279

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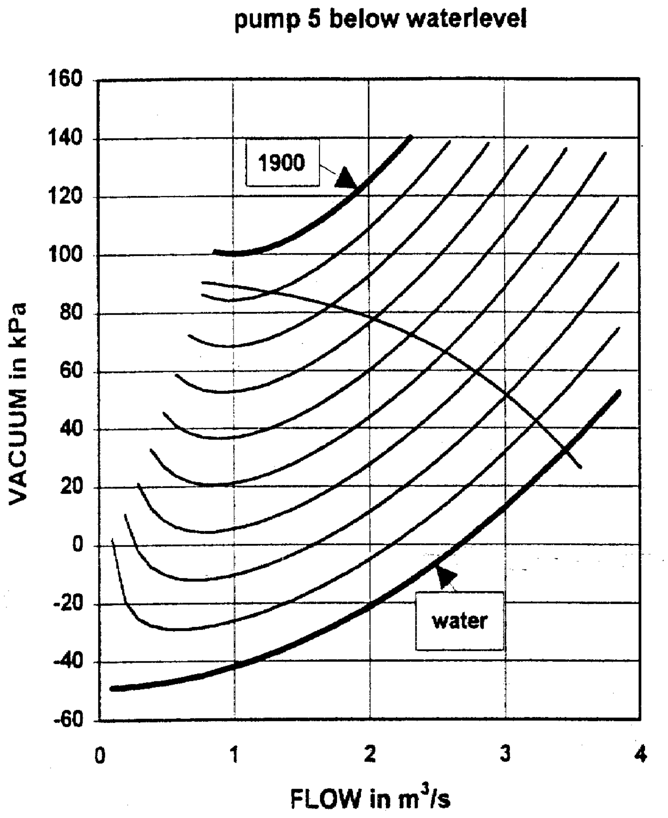
EFFECT OF PUMP POSITION ON

OPERATIONAL LIMITS



Density in kg/m³	Q_m m³/s	Q_s m³/h
1000	3.442	0
1100	3.233	1164
1200	3.007	2165
1300	2.788	3012
1400	2.548	3669
1500	2.301	4141
1600	2.027	4378
1700	1.699	4282
1800	1.272	3664
1830	0.959	2864

OPERATION LIMITS AND PIPE LENGTH

The maximum length of a discharge pipeline is limited by the deposition-limit velocity.

The minimum length of a discharge pipeline is limited by the decisive vacuum of a pump.