oe4625 Dredge Pumps and Slurry Transport

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3. FLOW OF SOIL-WATER MIXTURE

FLOW REGIMES

FLOW PATTERNS

FLOW QUANTITIES/PARAMETERS

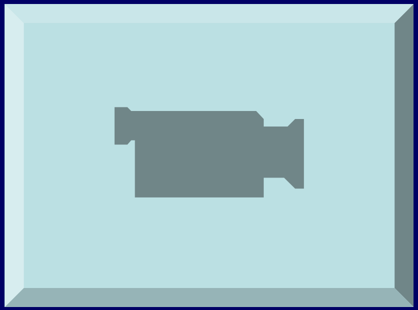
FLOW REGIMES

LAMINAR

TURBULENT

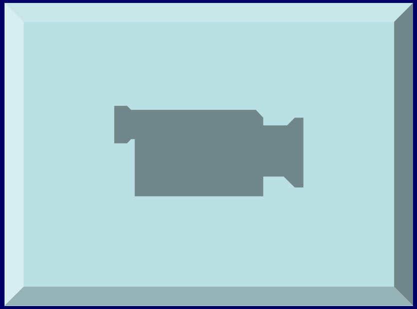
Regimes: Flow confined by boundaries

Example of general flow

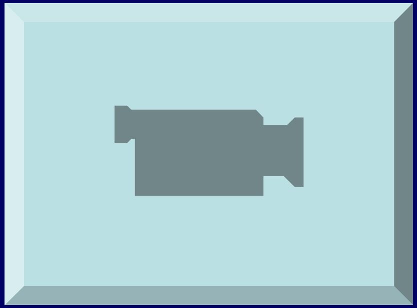


Laminar and turbulent flows

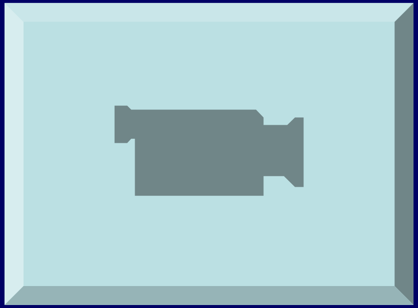
Laminar flow



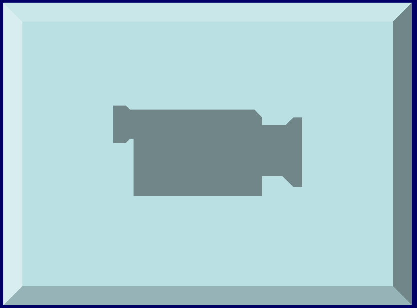
Initiation of turbulence



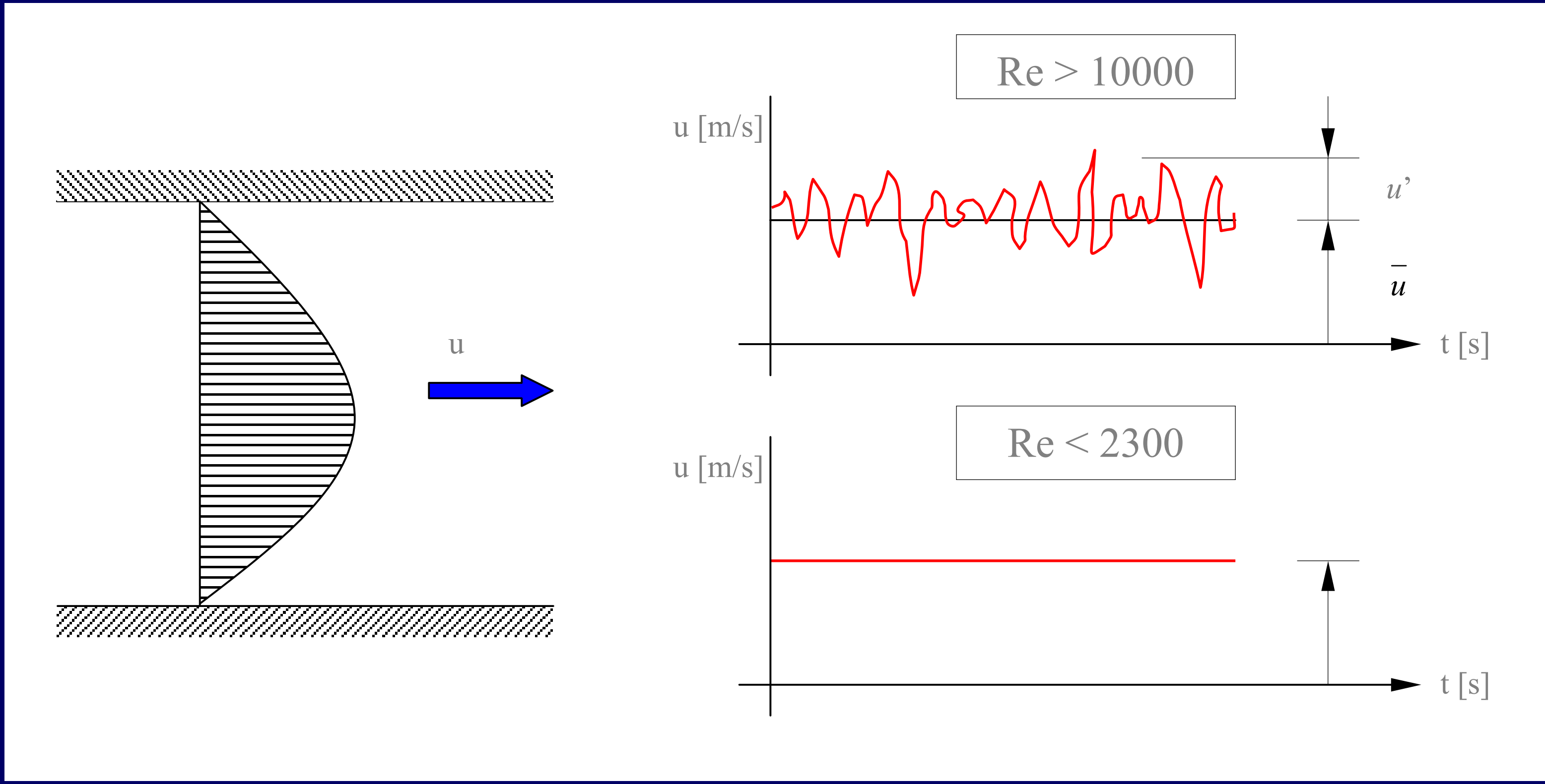
Structure of turbulence



Comparison laminar and turbulent flows



FLOW REGIMES



Laminar Flow in Pipe

- \- composed of thin **layers (*lamina*)** that move over each other at different velocities forming a typical parabolic velocity profile in a pipeline cross section
- \- ***no exchange*** of mass and momentum between neighboring layers
- \- a stability of a laminar flow is given by ***Reynolds number*** of the flow and its value *2300* is experimentally determined as a threshold for the maintaining of a laminar flow regime in a conduit.

Laminar versus Turbulent Flow in Pipe

The dimensionless group Re, ***Reynolds number***, is a ratio of the inertial forces and the viscous forces in the pipeline flow

$$\mathrm{Re} = \frac{V_f D \rho_f}{\mu_f} = \frac{inertial.force}{viscous.force}$$

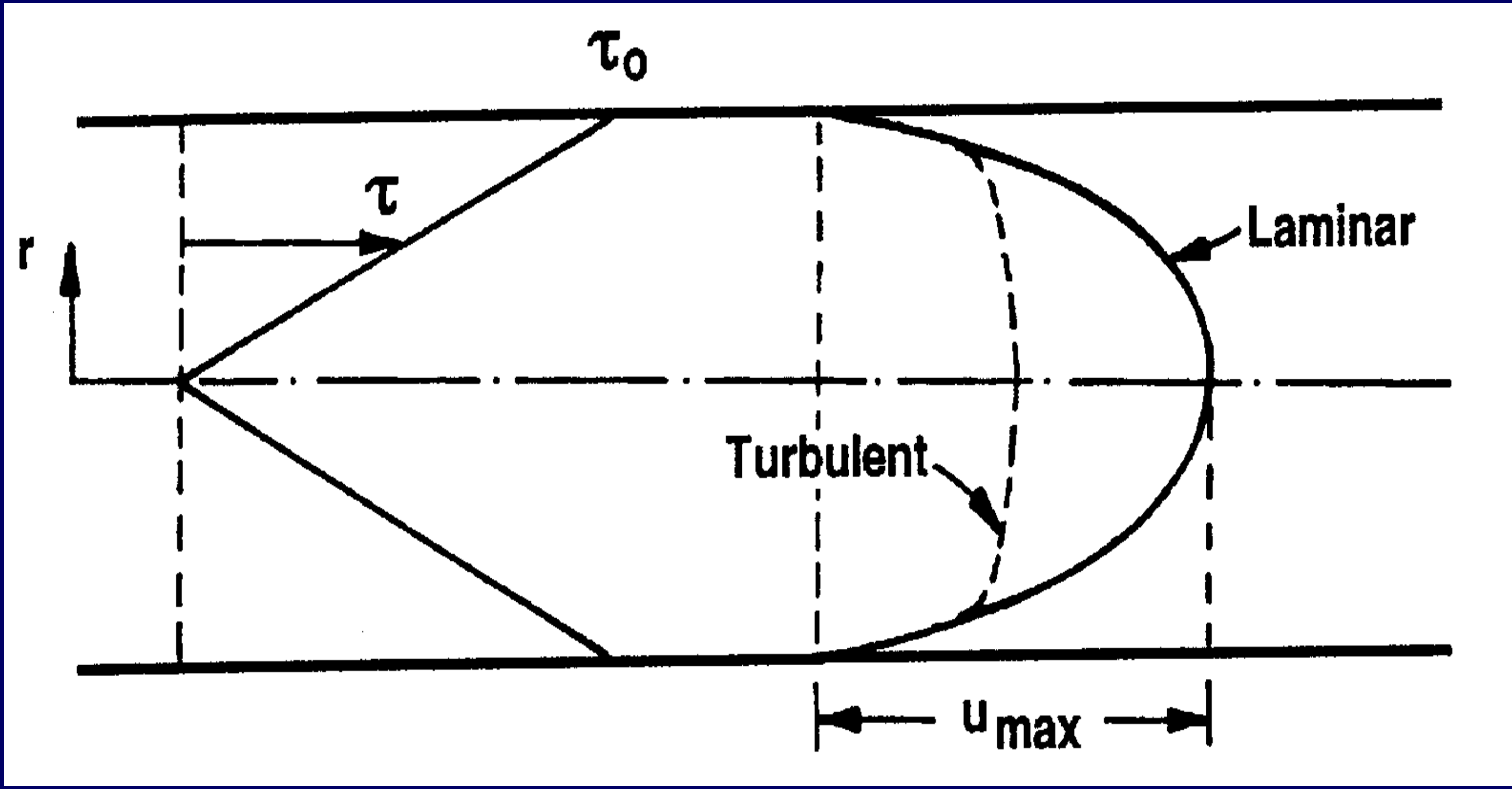
Remark: The Reynolds number determines a threshold between the laminar and the turbulent flows in a pipe.

The flow is LAMINAR if Re < 2300.

Turbulent Flow in Pipe

- \- a result of ***disturbances*** occurring at the interface between neighboring layers
- \- ***turbulent eddies*** are developed as a result of the disturbances; they are responsible for an intensive ***random transfer of mass and momentum*** in all directions within a liquid stream; this is sensed as a continuous fluctuation of velocity of fluid particles in time and space within a stream
- \- the flow eddies due to turbulence produce ***energy dissipation*** additional to that due to friction in a laminar flow. Turbulent flows dissipate more mechanical energy than laminar flows.

Internal Structure of Pipe Flow

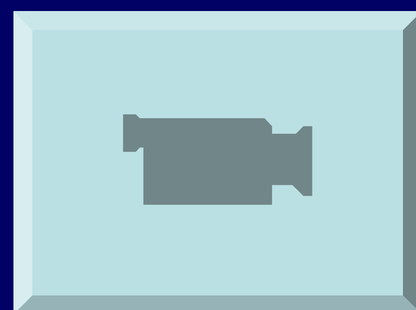


FLOW PATTERNS

FULLY SUSPENDED
PARTIALLY STRATIFIED
FULLY STRATIFIED

Fully stratified flows

Example of fully stratified flow



Flow Patterns: Indicators

- \- a tendency of a solid particle to settle in a flowing carrying liquid (given by the *particle settling velocity*)
- \- a tendency of a flowing carrier to suspend solid particles (given by intensity of turbulence, i.e. basically by *mean velocity of a stream* in a pipe).

Extreme Flow Patterns

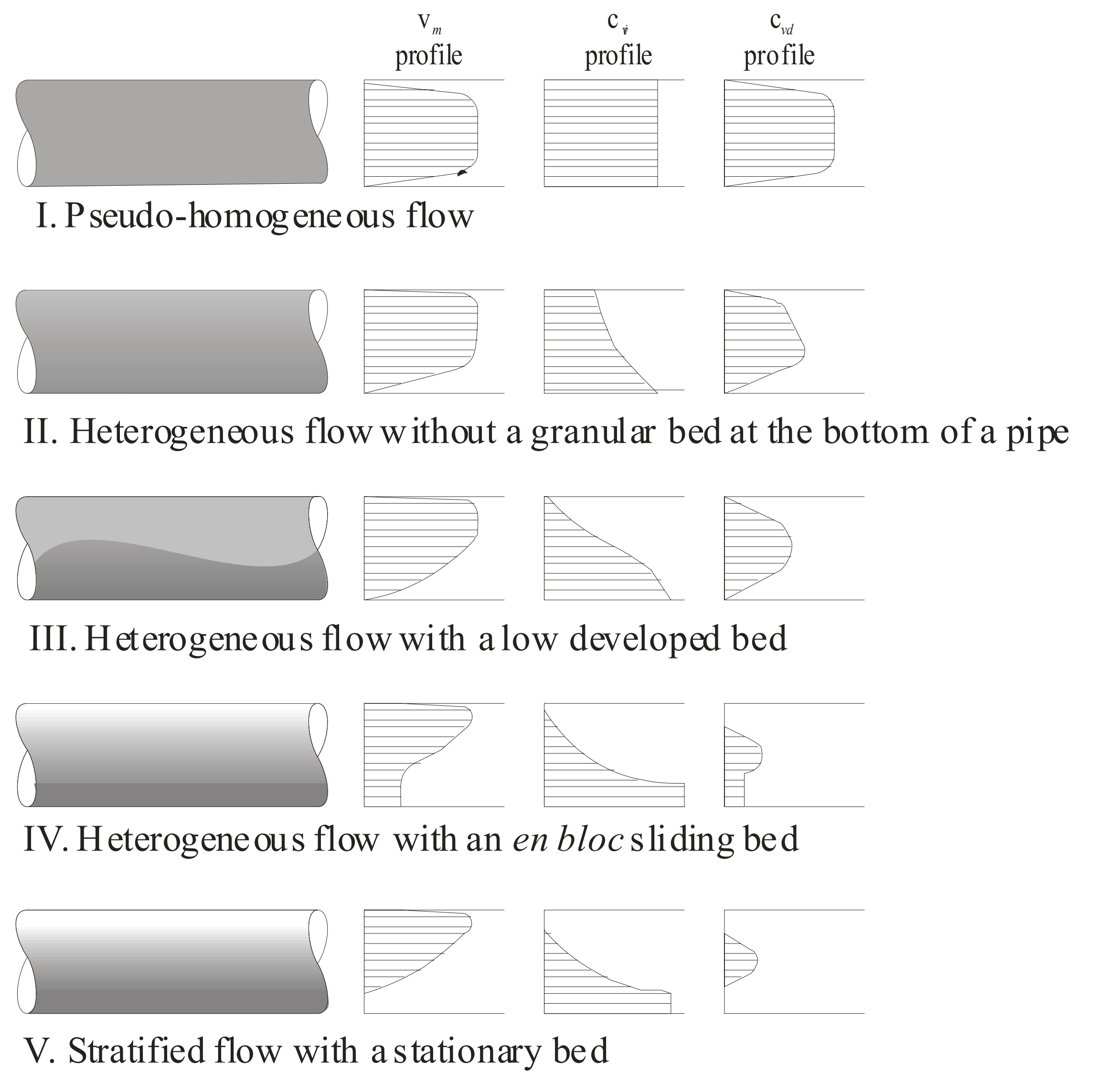
Fully-stratified flow: intensity of turbulence of a carrier flow is not sufficient to suspend any solid particle in a pipeline; all solid particles occupy a granular bed that is either stationary or slides over the bottom of a pipeline

Fully-suspended flow: all solid particles are suspended within a stream of a carrying liquid; no granular bed occurs in a pipeline; if particles distributed uniformly across the pipeline cross section than *pseudo-homogeneous flow*.

Transitional Flow Pattern

Partially-stratified flow: mixture flow exhibits a considerable concentration gradient across a pipeline cross section indicating an accumulation of a portion of solids near the bottom of a pipeline and a non-uniform distribution of the rest of solids across the rest of a pipeline cross-sectional area; this pattern is also known as a *heterogeneous flow*.

F L O W P A T T E R N S



Drop of velocity from 2.6 m/s to 1.0 m/s in the horizontal 150-mm pipe:

ZH120909a
V0 = 2.55
V av = 1.28 to 1.0

ZV120909a
V0=2.25
V av = 1.28 to 1.0

Medium sand 0.2-0.5 mm

Extremely low velocity (0.2-0.3 m/s) in the horizontal 150-mm pipe:

Medium sand 0.2-0.5 mm

FLOW PARAMETERS

FLOW VELOCITY

PRODUCTION OF SOLIDS

PRESSURE DROP

SPECIFIC ENERGY CONSUMPTION

Flow Parameters

Pipeline-flow parameters should be controlled during a dredging operation in order to *optimize the safety and the economy* of the transportation system. The parameters are:

the **mean velocity of mixture** and its threshold value(s)
the **production of solids**

the **frictional pressure loss**
the **specific energy consumption**.

Flow Parameters: Mean Velocity

Mean velocity in a pipeline of a circular pipe of an inner diameter D is written as

$$V = \frac{flow\ rate}{cross\ \ sectional\ \ area} = \frac{4Q}{\pi D^2}$$

The determination of an appropriate value of the mean mixture velocity is *crucial to safe and low-cost pipeline operation*.

The mean slurry velocity at the limit of stationary deposition is called the **deposition-limit velocity** or the *critical velocity*. This is the threshold velocity at which solid particles occupying a bed at the bottom of a pipeline stop their sliding and start to form a stationary bed at the bottom of a pipeline.

Flow Parameters: Production of Solids

The **production of solids** (production of solid particles) is an important parameter from the economic point of view. It gives the amount of dry solids delivered at the pipeline outlet over a certain time period.

This is defined as *the (volumetric) flow rate of solids* (flow rate of solid particles) at the outlet of a slurry pipeline

$$Q_s = \frac{\pi}{4} D^2 V_m C_{vd} 3600 \quad \left[\frac{m^3}{hour} \right]$$

During a dredging operation the parameters V_m and C_{vd} are usually measured in a pipeline of known D so that the production of solids given by a solids flow rate can be determined.

Flow Parameters: Production of Solids

For the *payment of a dredging work*, the **production based on in-situ volume of transported soil** (production of solid particles + porous liquid) is decisive.

The delivered concentration of the in-situ soil $C_{vdsi} = \frac{C_{vd}}{1-n}$

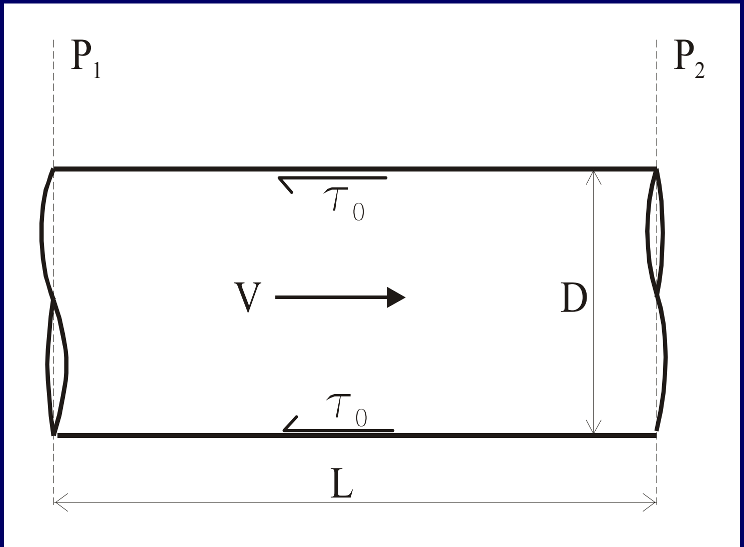
so that the production of in-situ soil can be calculated as

$$Q_{si} = \frac{\pi}{4} D^2 V_m C_{vdsi} 3600 = \frac{Q_s}{1-n} \quad \left[\frac{m^3}{hour}\right]$$

Since the porosity is lower than one (typically n = 0.4 for a loose-poured sand), the production of in-situ soil (Q_{si}) is higher than the production of the solid particles (Q_s).

Flow Parameters: Pressure Drop

Flow resistance is given by the *amount of mechanical energy dissipated in a slurry flow* when flowing through a pipeline. The energy dissipation in a steady slurry flow is characterized by the pressure difference along a horizontal pipeline section of constant diameter. The resistance is evaluated as



the **pressure drop** $\Delta P = P_1 - P_2$ (differential pressure over a pipeline section) **[Pa]**,

the **pressure gradient** (pressure drop over a pipeline section divided by the length L of a pipeline section) **[Pa/m]**

$$\frac{P_1 - P_2}{L}$$

the **hydraulic gradient** due to friction, also termed the <u>frictional head loss</u> (I_m) **[-]**

$$\frac{P_1 - P_2}{\rho_f g L}$$

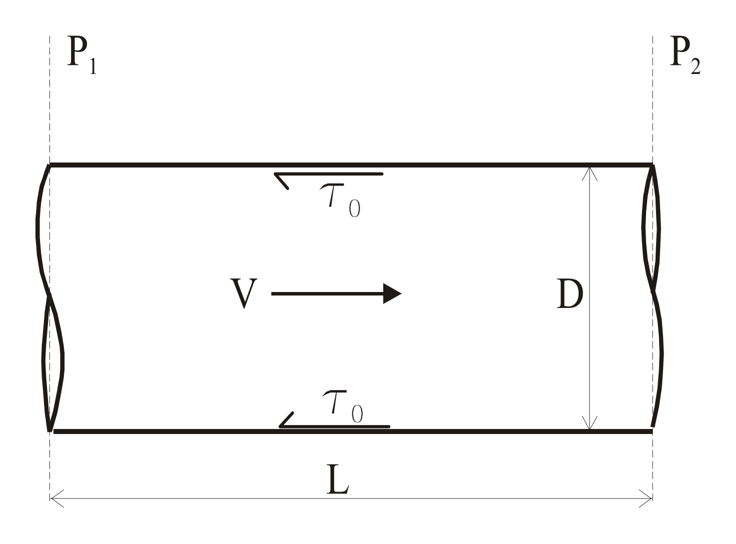
Flow Parameters: Hydraulic Gradient

The **hydraulic gradient** due to friction, also termed the **frictional head loss** (I_m) **[-]**, is the head (that is lost owing to friction) divided by the length of a pipeline section, L.

$$\frac{P_1 - P_2}{\rho_f g L}$$

The **head [m]** is a measure of the mechanical energy of a flowing liquid per unit mass. It is expressed as the height of the fluid column exerting the pressure that is equivalent to the pressure differential $P_1 - P_2$.

$$\frac{P_1 - P_2}{\rho_f g}$$



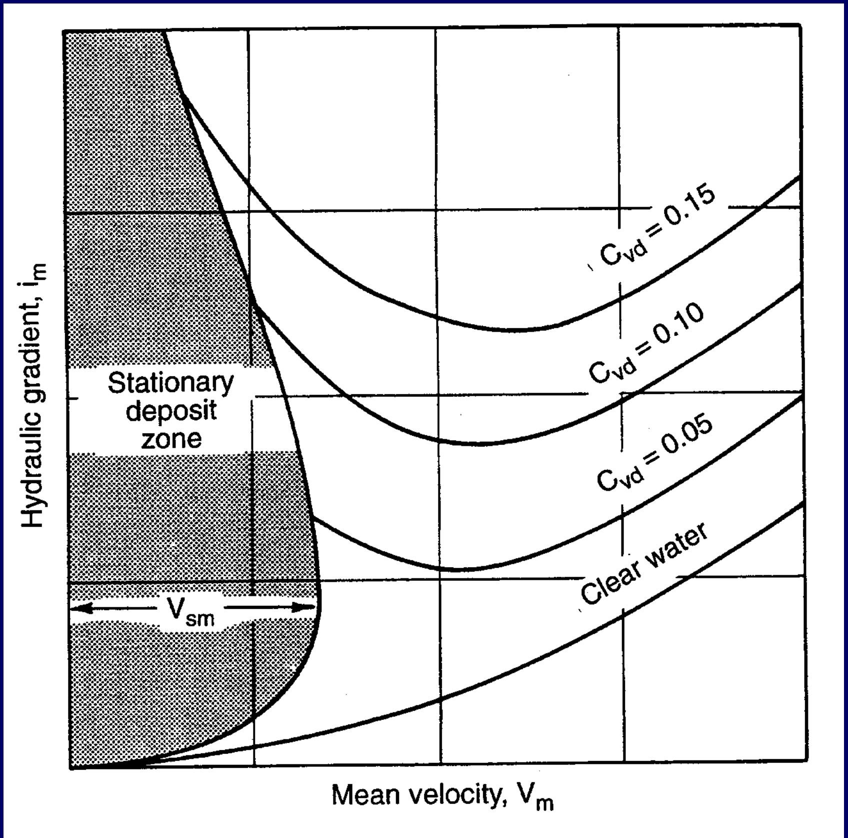
Flow Parameters: Hydraulic Gradient

The relation between the mechanical dissipation due to mixture flow and the mean mixture velocity in the pipeline section is expressed by a

pipeline-resistance curve

(I – V curve)

giving a relation between the head losses and the mean mixture velocity in a pipe.



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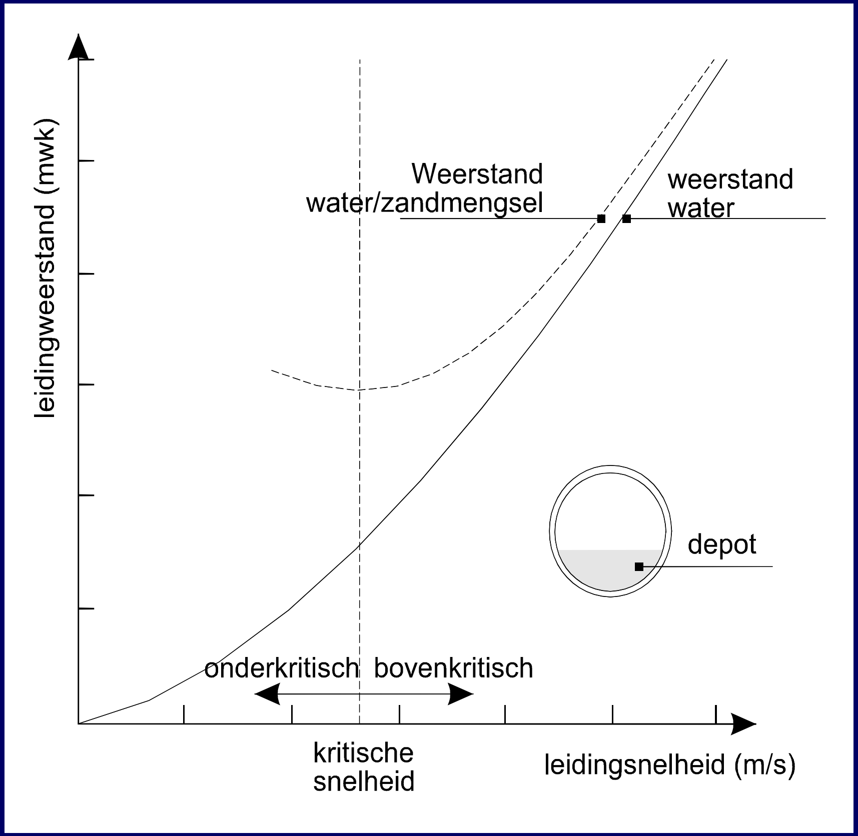

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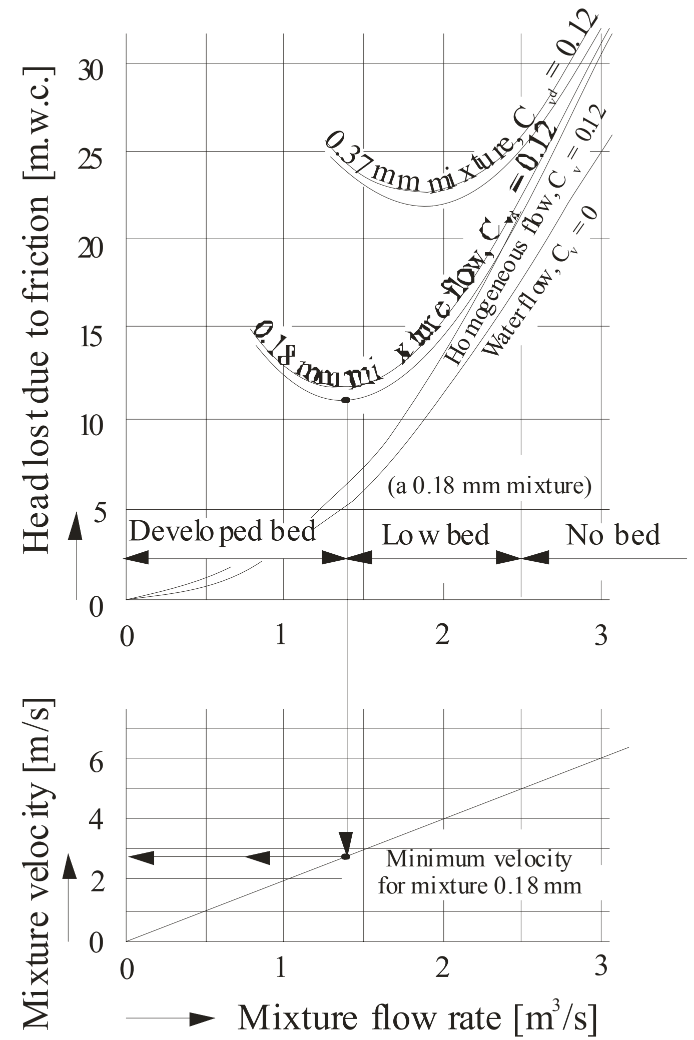

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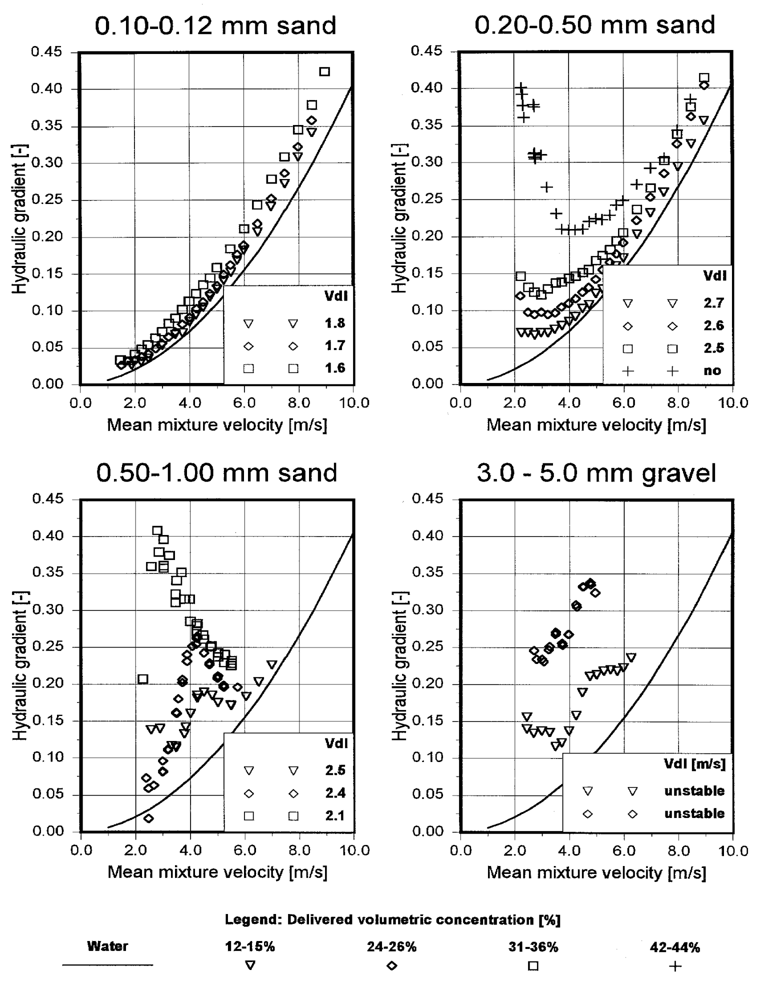

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Flow Parameters: SEC

The *efficiency of a slurry pipeline* is evaluated by means of a parameter called **specific energy consumption (SEC)**.

The SEC is an *appropriate optimization parameter* because it contains both a measure of energy dissipation and a measure of solids load in a pipeline flow.

The SEC determines the energy required to move a given quantity of solids over a given distance in a pipeline.

Flow Parameters: SEC

The **specific energy consumption SEC** is defined as a ratio between

- the power consumption per metre of pipe, $I_m \rho_f g Q_m$, and
- the (dry) solids throughput in a pipe, $\rho_f C_{vd} Q_m$.

$$SEC = \frac{I_m \rho_f g Q_m}{\rho_s C_{vd} Q_m} = \frac{I_m g}{S_s C_{vd}} \qquad \left[\frac{J}{kg.m}\right]$$

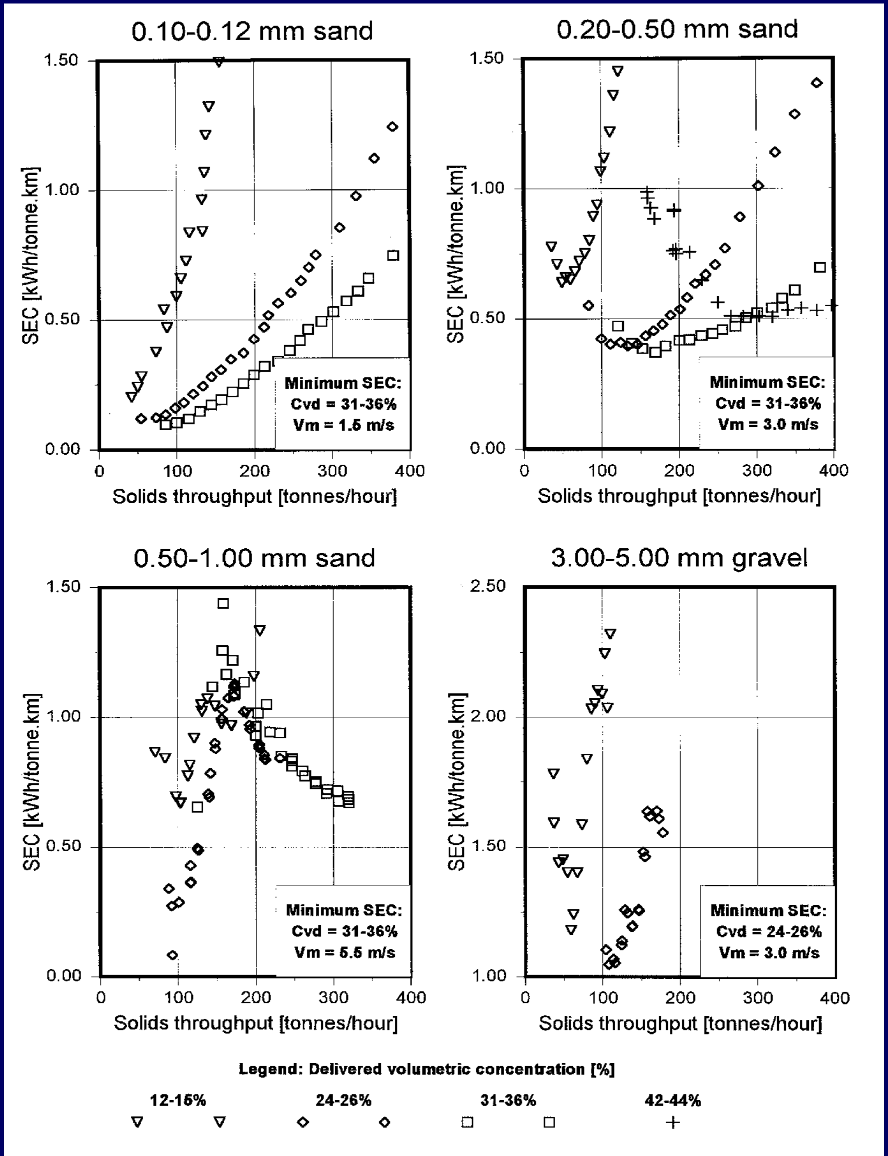
$$SEC = 2.7 \frac{I_m}{S_s C_{vd}} \qquad \left[\frac{kWh}{tonne.km}\right]$$

Flow Parameters: SEC

The optimization of transport can be done using the

SEC – Production diagram

(SEC – Q_s curve).



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