9.
PRODUCTION OF SOLIDS IN A PUMP-PIPELINE SYSTEM

9.1 PRODUCTION RANGE FOR A PUMP-PIPELINE SYSTEM

9.1.1 Maximum production attainable in a system

The maximum production theoretically attainable in a pump-pipeline system is limited by an upper limit of a working range of a system, i.e. by cavitation of a pump. For a system of a certain lay-out of a suction pipe the maximum production is obtained from the points of intersection between vacuum curves for various mixture densities in a suction pipe and a decisive vacuum curve of a pump. A point of intersection of a vacuum curve for certain mixture density and a decisive vacuum curve gives the maximum mixture flow rate, Q_m, attainable for mixture flow of the certain density, ρ_m. Then the corresponding solids flow rate, i.e. solids production, is obtained as

$$Q_s = Q_m \frac{\rho_m - \rho_f}{\rho_s - \rho_f} 3600 \qquad [\mathrm{m^3/hour}] \qquad (9.1).$$

Thus all points of intersection for various mixture densities in a suction pipe of a certain lay-out give a set of ρ_m, Q_m, Q_s data. These provide a characteristic curve of maximum production as a function of mixture flow rate in a pump-pipeline system (Fig. 9.1). The curve has a maximum at a certain value of mixture density. This indicates that pumping of mixture at the highest densities does not provide the highest production. This is because pumping of these high-dense mixtures is possible only at very low mixture velocities, otherwise cavitation occurs. Theoretically, the curve approaches zero production at its boundaries. At the lower boundary (Q_m = 0) a pumped mixture is so dense that a cavitation criterion is reached already at the lowest mixture velocities in a suction pipe. The upper boundary gives the maximal velocity at which the decisive vacuum is reached. The maximal velocity is reached in flow of the lowest solids concentration (approaching zero). Naturally, production of such flow approaches zero too. More concentrated mixture flows provide more resistance and thus the decisive vacuum is reached already at lower velocities An analysis of the cavitation criterion shows that a dredging depth is the major factor limiting the production by a pump-pipeline system (see Fig. 9.1).

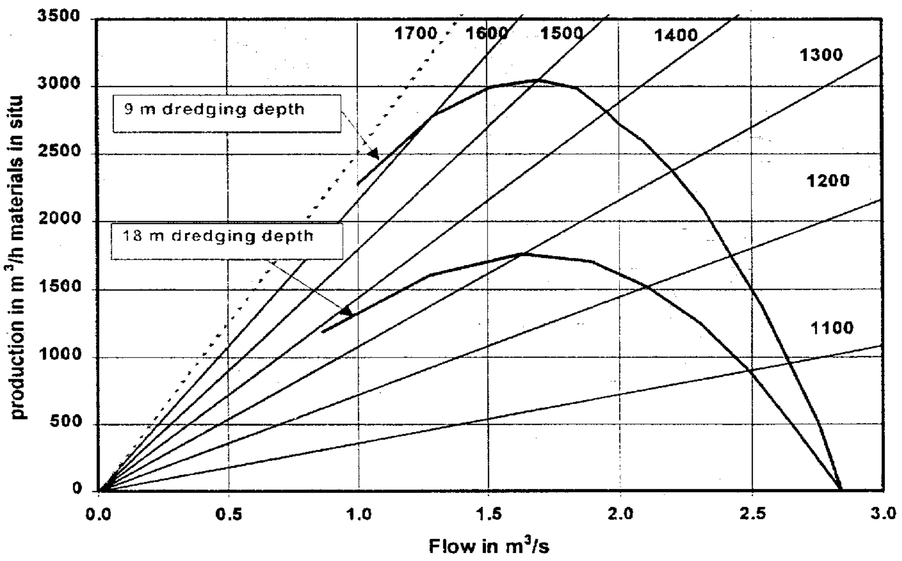


Figure 9.1. Production limited by decisive vacuum. Q_s - Q_m diagram (Q_s is the production on the vertical axis and Q_m the flow rate of mixture on the horizontal axis).

9.1.2 Minimum production acceptable in a system

An implementation of the deposition-limit (critical) velocity to a Q_s - Q_m curve (see Fig. 9.2) gives an range of production values that may be reached within a working range of a pump.

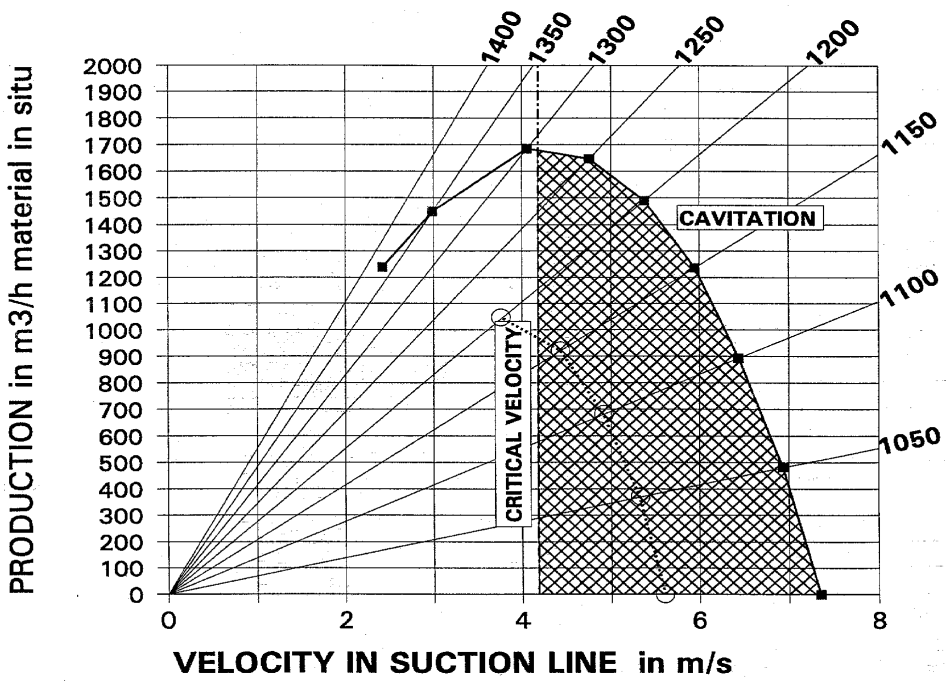


Figure 9.2. Production limited by decisive vacuum and deposition-limit velocity. Q_s - V_m diagram (this for a different installation than on Fig. 9.1).

9.2 PRODUCTION LIMITED BY A PIPELINE LENGTH

Consider a pump-pipeline installation operating at the maximum pump speed and pumping mixture of certain maximum density attainable under the given dredging conditions (soil type, soil condition in a pit etc.). The vacuum measured at the pump inlet is slightly lower than a decisive vacuum of the pump. A working point of the pump-pipeline installation determines a mixture flow rate through a pipeline and so a solids production by the installation. A position of the working point on the pump characteristic curve depends on the course of the pipeline resistance curve, i.e. on the total resistance of a pipeline. The longer the pipeline the higher the total resistance and the lower the mixture flow rate through an installation. **The pipeline length is a factor limiting the production.**

9.2.1 Cases for which a change of a pipeline length requires a change in a working range of a pump

Imagine that during the job a discharge pipeline must be considerably lengthened. The total pipeline resistance increases considerably and a system finds a new working point at the much lower mixture flow rate. The mixture velocity drops below a deposition-limit velocity. Thus the new working point falls outside the acceptable working range of the installation. To prevent the formation of a stationary deposit in a pipeline the mixture density (i.e. concentration of solids in a pipeline) must be reduced to diminish a total pipeline resistance and maintain the working point within the working range of the installation. **A considerable decrease in the mixture density and the mixture velocity leads to a considerable drop in a solids production due to the prolonging of a discharge pipeline.**

Imagine that during the job a discharge pipeline must be shorten. The total pipeline resistance diminishes and a system finds a new working point at the higher mixture flow rate. However, an increase in the mixture velocity in a pipeline increases the vacuum at the pump inlet so that it becomes higher than the decisive vacuum. The pump starts to cavitate. To prevent the cavitation the mixture velocity must be lowered by reducing a pump speed. Thus the new installed flow rate, and so production, is approximately the same as that before a discharge-pipeline shortening.
In installations where the production is limited by a cavitation criterion the production is virtually independent of a pipeline length.

9.2.2 Cases for which a change of a pipeline length does not require a change of a working range of a pump

Within the working range of a pump-pipeline installation the production drops with an increasing pipeline length but the drop is considerably smaller since only mixture velocity is reduced if mixture is pumped at maximum pump speed. The mixture density can be maintained at the constant level.

Figure 9.3 shows a relationship between the solids production from a pump-pipeline installation and the length of a pipeline for various operational regimes of a pump:

I. TOO SHORT PIPELINE (the pump tends to operate outside a normal working range, the pump speed must be lowered to avoid cavitation = a pump operation is limited by a pump cavitation)

II. PIPELINE DISTANCES WITHIN A NORMAL WORKING RANGE OF A PUMP (a pump operates at maximum speed and mixture of maximum attainable density is transported)

III. TOO LONG PIPELINE (the pump tends to operate outside a normal working range, the mixture density must be lowered to maintain velocity above the deposition limit in a pipeline = a pump operation is limited by the deposition-limit velocity in a pipeline)

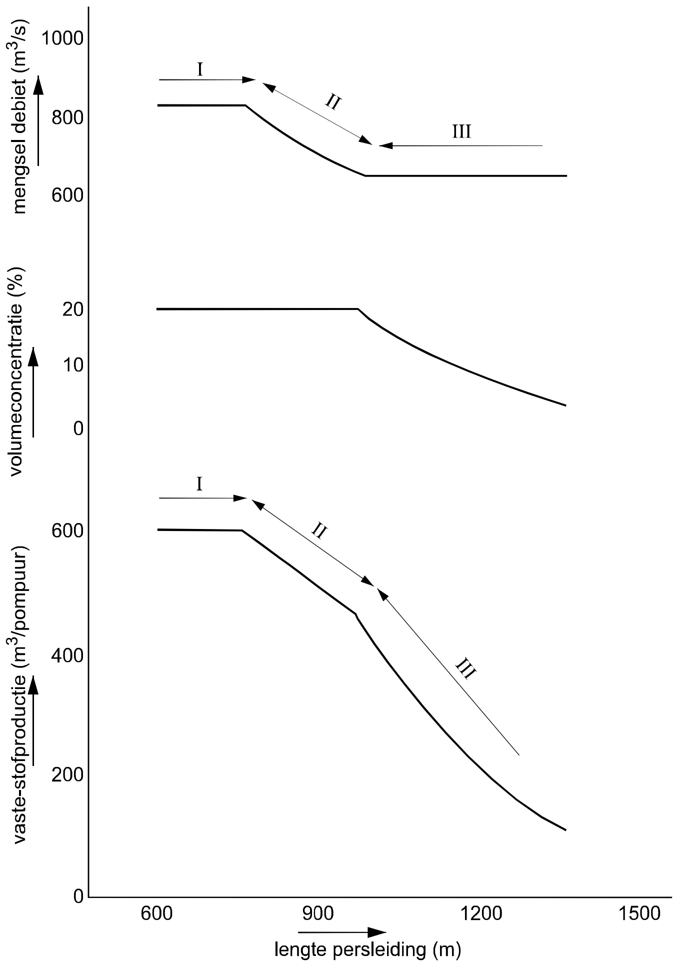


Figure 9.3. Q_s - L diagram and corresponding Q_m – L and C_{vd} - L diagram.

The measure of the production drop is different in different working ranges of a pump. If the working point is found at the constant torque line of a pump the production drop is usually smaller than for the working point at the constant speed line of a pump. This is because the reduction in a manometric head provided by a pump results in bigger flow rate drop for the constant-speed operation than for the constant-torque operation of a pump.

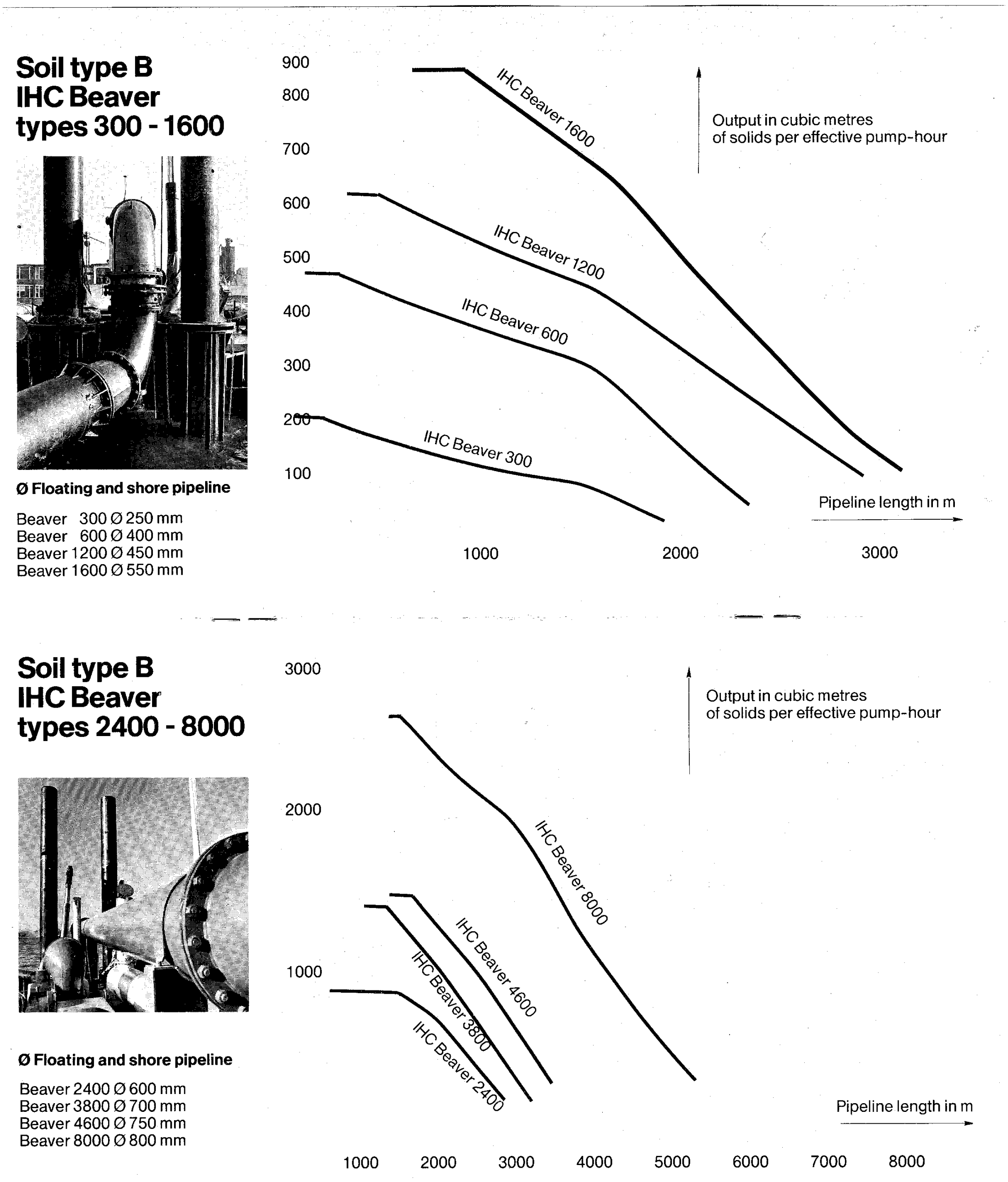


Figure 9.4. How to select the right dredge for the job. The Q_S - L diagrams for various types of the IHC cutter suction dredge Beaver if dredging medium sand (i.e. Soil type B).

9.3 EFFECT OF PUMP POSITION ON PRODUCTION

It was shown in Chapter 8 (par. 8.5) that a submerged pump allows pumping mixture of higher density than a pump placed on board of a dredge. Therefore the production in a system with a submerged pump is limited by decisive vacuum at higher values than in a system with an on-board pump (Fig. 9.5). The curve on Fig. 9.5 is given by cross points of the decisive vacuum curve and the vacuum curves for different mixture densities on Fig. 8.6 (see also Tab. 8.2).

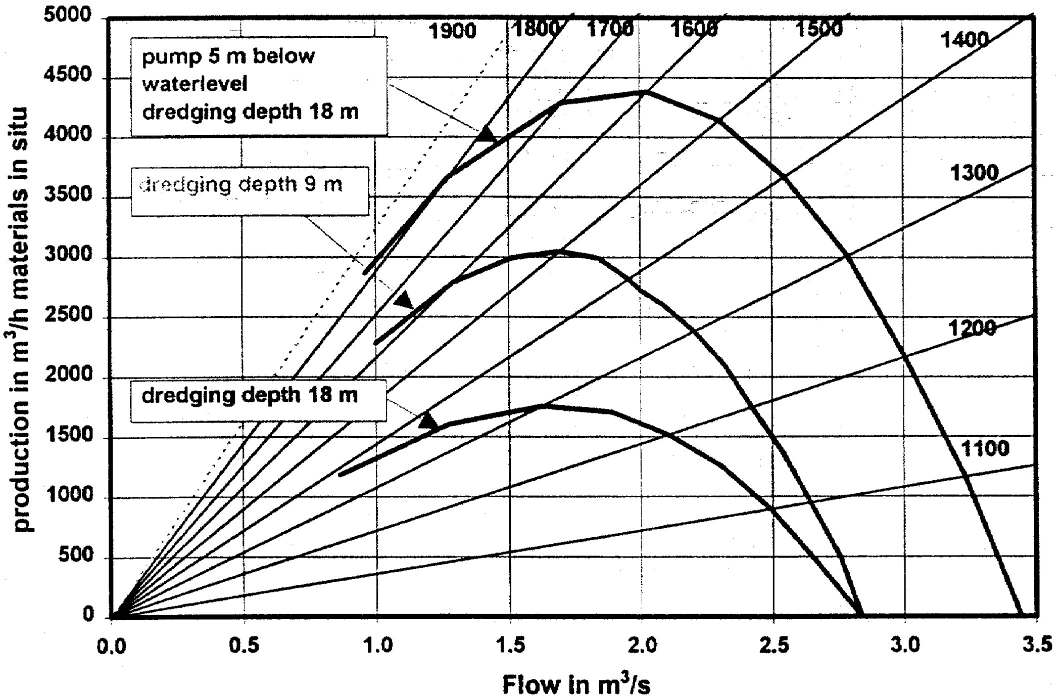


Figure 9.5. Production limited by decisive vacuum. Q_S - Q_m diagram (Q_S is the production on the vertical axis and Q_m the flow rate of mixture on the horizontal axis).

9.4 SUMMARY

Production of solids by a pump-pipeline installation drops if a pipeline is prolonged. In some cases, particularly if a discharge pipeline is short, the production is limited by a cavitation criterion rather than by a total pipeline resistance, i.e. a pipeline length.

9.5 RECOMMENDED LITERATURE

van den Berg, C.H. (1998). *Pipelines as Transportation Systems.* European Mining Course Proceedings, MTI.

de Bree, S.E.M. (1977). *Centrifugaal Baggerpompen.* IHC Holland.

CASE STUDY 9

In Case studies 7.2 & 8.2 the range was determined for lengths of a pipeline connected with a centrifugal pump that pumps the mixture of density 1412.5 kg/m^3 composed of water and a 0.3 mm sand. Furthermore, the flow rate of pumped mixture was determined for various pipeline lengths (see Tab. C7.4). From these outputs the production of solids can be determined as a function of a length of a pipeline in a transportation system.

Determine the production of solids by a pump-pipeline system (the system is defined in Case study 7.2) for different lengths of a pipeline from the range that admits pumping mixture of density 1412.5 kg/m^3.

CALCULATION:

Production of solids (Eq. 3.3):

$$Q_s = Q_m \frac{S_m - 1}{S_s - 1} 3600 = 3600 \frac{1.4125 - 1}{2.65 - 1} Q_m = 900 Q_m \ \text{[m}^3\text{/hour]} \qquad \text{(C9.1).}$$

Production of in situ solids (Eq. 3.4): (for porosity n = 0.4)

$$Q_{si} = \frac{Q_s}{1 - n} = 1500 Q_m \quad \text{[m}^3\text{/hour]} \qquad \text{(C9.2).}$$

OUTPUT:

Table C9.1:
Production of solids at different lengths of a pipeline (see also Fig. C9.1):

S_m [-]	L [m]	Speed [rpm]	Q_m [m^3/s]	Q_{si} [m^3/hour]
1.4125	610	385	1.115	1672.5
1.4125	700	396	1.062	1593.0
1.4125	800	409	1.004	1506.0
1.4125	900	423	0.944	1416.0
1.4125	975	435	0.897	1345.5

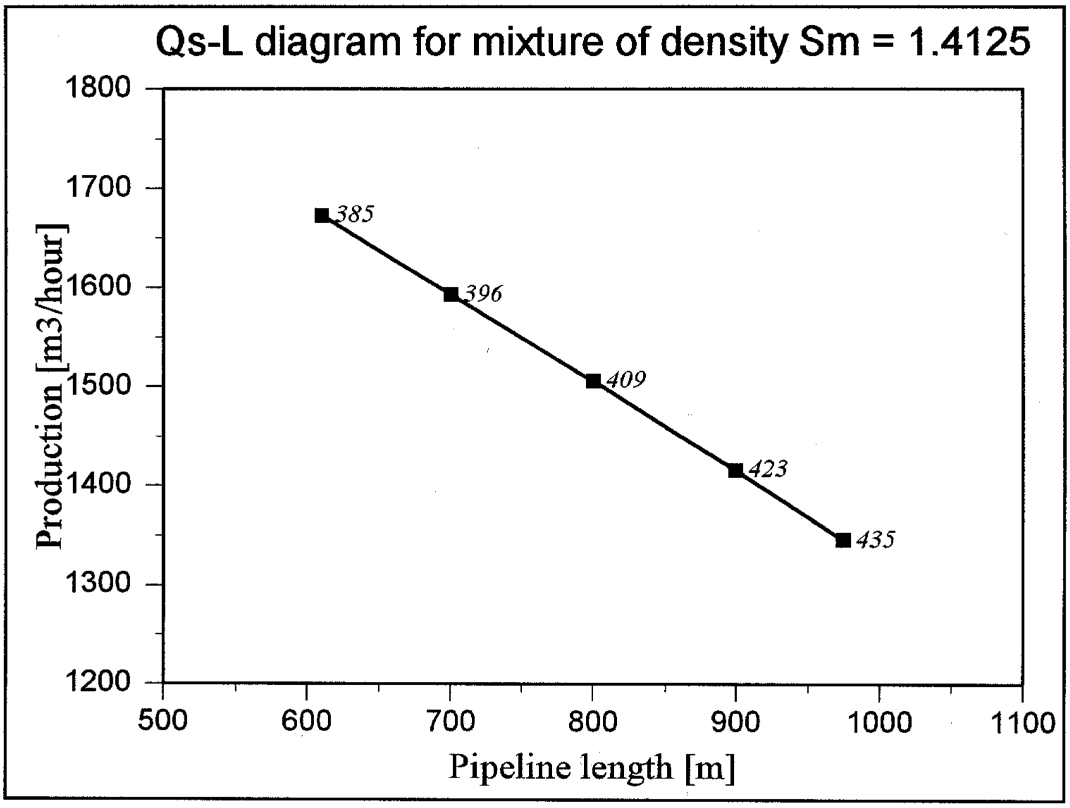
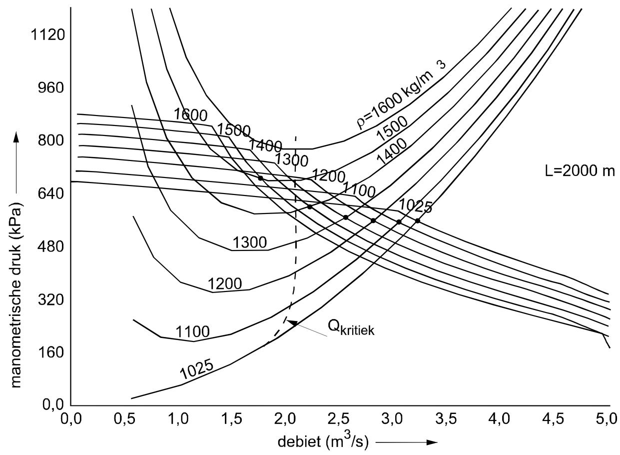


Figure C9.1. Q_s – L diagram for a system pumping mixture of constant density S_m = 1.4125. (rpm as a label in the diagram).

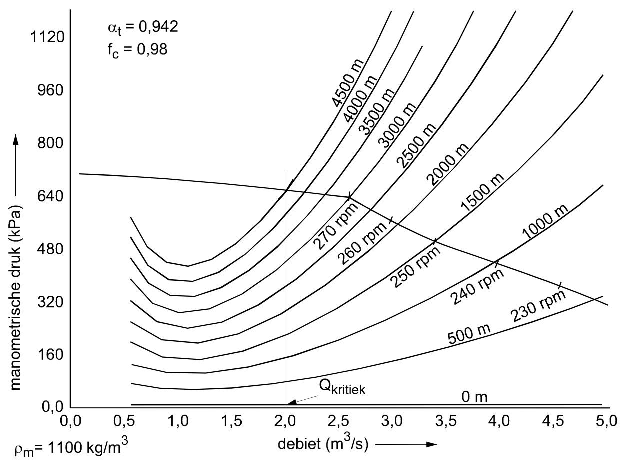
CASE STUDY from the VBKO course:

Production of solids by a pump-pipeline system pumping mixture of certain solids.

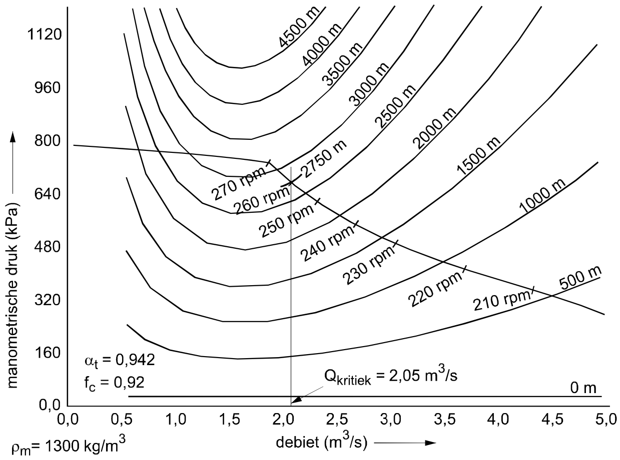
1. Working points of a system for various densities of pumped mixture. The length of a pipeline is 2000 meter.



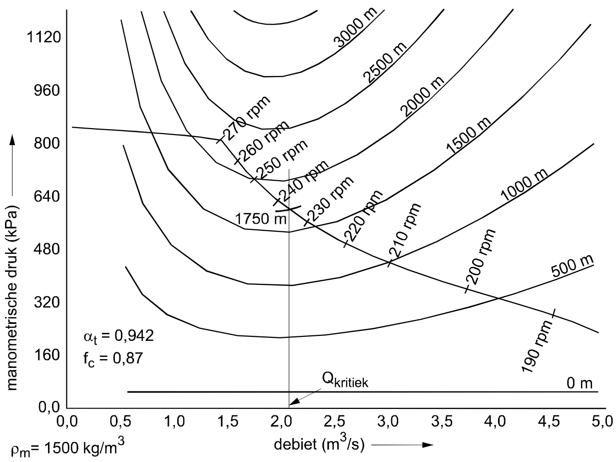
2.
a. Working points of a system for various length of a pipeline. The density of pumped mixture is 1100 kg/m^3.



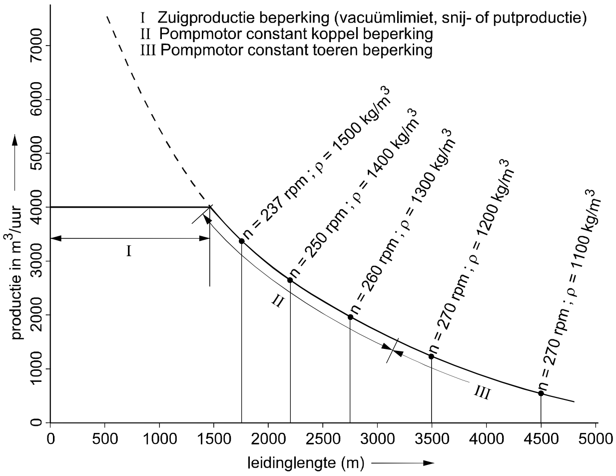
b. Working points of a system for various length of a pipeline. The density of pumped mixture is 1300 kg/m^3.



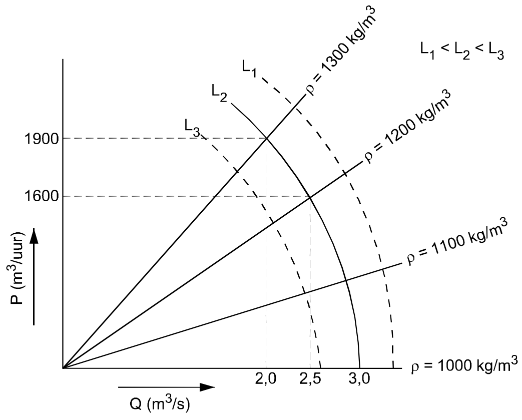
c. Working points of a system for various length of a pipeline. The density of pumped mixture is 1500 kg/m^3.



3. Q_S - L diagram composed of working points of a system for various length of a pipeline and various densities of pumped mixture.



4. Graphical determination of production Q_S (marked as P in Fig.) for various mixture flow rates and densities and for various pipeline lengths.



5. Operational range for mixture flow rate and production confined by the stationary-deposition limit and the pipeline-resistance limit for a system with a pipeline of a length L_2.