Centrifugal Dredgepumps
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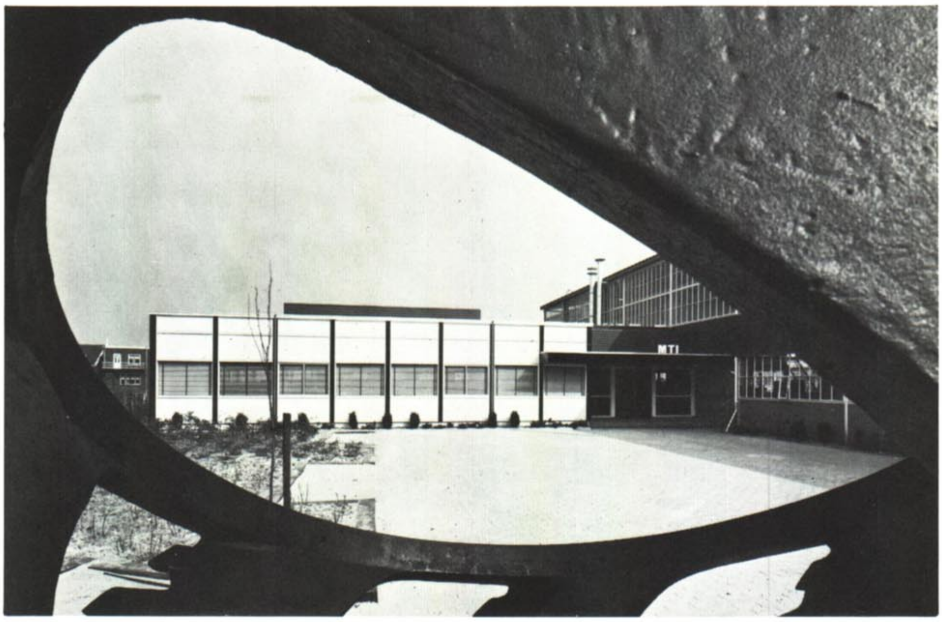
By Ir. S. E. M. de Bree



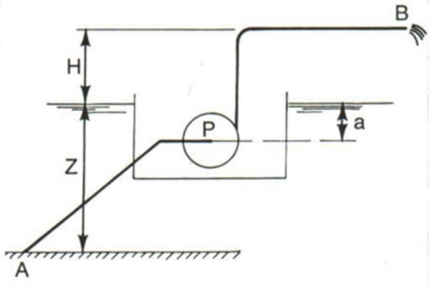
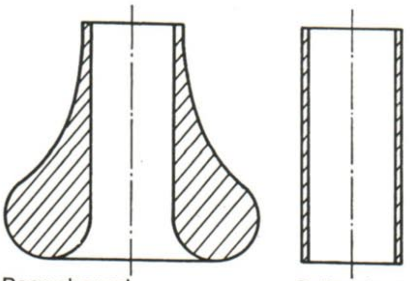


Fig. 1



Pear-shaped suction inlet

Cylindrical suction inlet

Fig. 2

This article is the fourth in a series concerning centrifugal dredgepumps, written by Mr. S. E. M. de Bree, Manager of the Mineral Technological Institute, the development laboratory of the Dredger Division of IHC Holland. The preceding articles appeared in issues 77, 78 and 80.

In this article, the author deals with the characteristics of pipelines and then proceeds to discuss the positions of the working points and the working range of a pumping installation, and the phenomenon of cavitation.

Pipeline characteristics

The pipeline characteristics are determined on the basis of the sketch of a dredgepump and pipeline system as shown in Fig. 1.

A given pressure differential is required to transport a mixture of soil and water. This is provided by the pump P. This pressure differential – the pipeline resistance – comprises the static suction head (Z-a), the static delivery head (H+a) and the various resistances present in the pipeline itself and in the bends, bifurcations, hoses, ball joints, swan neck bends and other components present throughout its length.

In calculating the resistance of the pipeline one must also ensure that the pressure on the suction side of the pump does not become too low. The limit of vacuum, the decisive vacuum, is the threshold below which the system must operate if choking of the pump is to be avoided.

The total pipeline resistance can be calculated as follows.

Let Q be the flowrate of the pumped mixture and d_z the diameter of the suction line. The mixture velocity in the suction line will be:

$$V_z = \frac{Q}{\pi/4\ d^2_z}$$

The velocity in the delivery pipeline with a diameter d_p will then be:

$$V_p = \frac{Q}{\pi/4\ d^2_p}$$

Let the specific gravity of the pumped mixture be γ_m.

Losses on the suction side

These are:

1. Velocity height, i.e. the pressure required to accelerate the mixture
$$\frac{V^2_z}{2g} \cdot \gamma_m$$
2. Losses occurring at the suction inlet
$$\alpha . \frac{V^2_z}{2g} \cdot \gamma_m$$
In this equation, the factor α is governed by, among other things:
a) the shape of the suction inlet. Investigations have shown that considerably lower entry losses occur with a pear-shaped suction inlet than with one of cylindrical form (Fig. 2);
b) the nature of the soil. With a suction dredger, for example, lower entry losses are experienced with coarse sand which is amenable to this method of dredging than with compacted fine sand;
c) the degree of penetration of the suction pipe.
3. Resistance produced by straight sections of the suction line
$$\frac{L_z}{100} \times W_{100}$$
in which L_z is the length of the straight sections and W_{100} the resistance encountered by the pumped mixture per 100 metres of straight pipeline of the given suction pipe diameter, at the velocity V_z and with a mixture s.g. of γ_m.
4. Resistance produced by other components of the suction line
$$\xi_z \frac{V^2_z}{2g} \cdot \gamma_m$$
The factor ξ_z in this equation is the sum of the loss factors attributable to bends, hoses, restrictions, stone traps, etc.

5. To raise the mixture from the dredging point to the pump requires a static head of
$$(Z\text{-}a) \times (\gamma_m\text{-}1)$$
in which Z is the geodetic suction depth and a the vertical distance from the centre of the pump shaft to the water level

6. In order to calculate the vacuum required at the centre of the pump, it is necessary to deduct the distance from this point to the water level:
$$-a$$

The total vacuum required at the centre of the pump is thus:

$$H_{z_{req.}} = (1 + \alpha + \xi_z)\frac{V^2{}_z}{2g} \cdot \gamma_m + \frac{L_z}{100} W_{100} + (Z\text{-}a)\ (\gamma_m\text{-}1)\text{-}a$$

As mentioned at the beginning of this article, the necessary vacuum $H_{zben.}$ may not exceed the decisive vacuum, as otherwise cavitation will occur and the behaviour of the pump will deviate from the normal pattern.

In order to minimize losses in the suction pipe, due regard must be paid to the following:

a) adequate suction pipe bore. In most cases the suction pipe diameter chosen is 50 mm greater than the discharge pipeline diameter; in the case of pipelines 800 mm or more in diameter, a difference of 100 mm is commonly maintained;
b) absence of restrictions at the pump inlet;
c) minimum suction pipe length and minimum number of obstructions in the shape of bends, hoses, stone traps, etc.;
d) lowest possible pump level, which implies that the value of factor "a" must be as great as possible.

The water pressure above a pump situated below the water level represents additional pressure on the suction side of the system. Accordingly (all other circumstances being equal), the farther the pump is situated below the waterline, the lower will be the vacuum: furthermore, since the distance over which the mixture has to be raised at a given dredging depth will be less, the suction pipe will be shorter and the resistance loss smaller.

From the transport point of view, there is an optimum depth at which the pump must be situated in order to raise a mixture of soil of a given type and specific gravity from a given suction depth and convey it through a pipeline of a given layout. From the hydraulic point of view, there is no objection to the pump being situated at a point below this optimum. Placing it deeper reduces the vacuum and with this the risk of cavitation as a result of fluctuations in the pumping process.

It will be clear from the foregoing that the deeper the pump is situated, the heavier the mixture can be. There are, however, the provisos that the power available to drive the dredgepump installation must be adequate for transporting the mixture by this method, and that the "pit supply" must be capable of furnishing the higher specific gravity.

At greater dredging depths, a submerged pump is a prerequisite for a high rate of production. The submerged pump will be dealt with in a later article.

Losses on the delivery side

These are:

1. The static head, i.e. the vertical distance between the centre of the pump and the elevation of the pipeline where this terminates at the point of reclamation
$$(H+a) \times \gamma_m$$

2. The resistance encountered in the straight sections of the delivery pipeline
$$\frac{L_p}{100} \times W_{100}$$
in which L_p is the length, in metres, of the straight sections and W_{100} the resistance encountered by the pumped mixture per 100 metres of straight pipeline of the given delivery pipe diameter, at the velocity V_p and with a mixture s.g. of γ_m.

3. Resistance produced by other

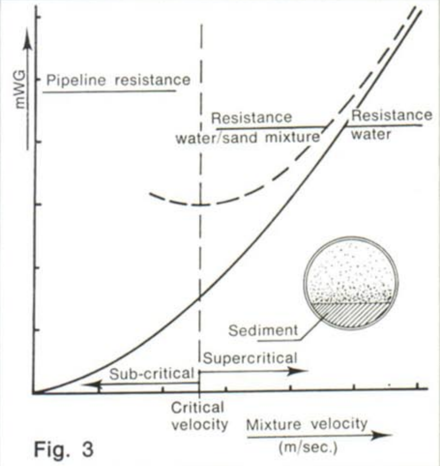


Fig. 3

components of the delivery pipeline

$$\xi_p \times \frac{V^2_p}{2g} \times \gamma_m$$

The factor ξ_p in this equation is the sum of the loss factors attributable to bends, ball joints, hoses, branches, gate valves, swan neck bends, etc.

The sum of these losses, which is the delivery pressure required of the pump, is thus:

$$H_{pers_{req.}} = (H+a) \times \gamma_m + \frac{L_p}{100} \times W_{100} + \xi_p \times \frac{V^2_p}{2g} \times \gamma_m$$

The total head required is the sum of the vacuum and delivery pressure required, i.e.

$$H_w = H_{man_{req.}} = H_{z_{req.}} + H_{pers_{req.}}$$

The variable factor W_{100}, to which reference was made in calculating the resistance offered by the straight sections of the pipeline, is determined by:

- the pipeline diameter (d)
- the type of soil to be transported
- the specific gravity of the mixture (γ_m)
- the mixture velocity (V)
- the roughness of the pipe bore
- the length of the pipeline where this is classed as short, and other factors.

The formulae for arriving at W_{100} put forward by researchers in this area differ appreciably. These researchers include Durand, Condolios, Führböter, Gibert and many others. No attempt will be made to provide a general formula here.

Critical velocity

An important factor which must be borne in mind when pumping mixtures of soil and water is the Critical Mixture Velocity (Fig. 3). This can be described as the minimum velocity at which the particles of soil in the mixture remain in suspension. If the velocity falls below this critical value, sedimentation occurs in the pipeline. The smaller the margin between the critical velocity and the actual velocity of the mixture, the lower is the resistance offered by the pipeline. This implies that the resistance is minimal at a velocity which lies just above the critical value.

A situation in which sedimentation occurs in a pipeline, indicating that the velocity has become sub-critical (see Fig. 3), may be compared to one in which the mixture is pumped through a pipeline of smaller diameter at a higher velocity. It is obvious that the pipeline resistance will be greater – indeed, that this will increase in proportion to the thickness of the sediment.

The critical velocity is determined by a number of factors, among which are the pipe diameter, the nature of the soil being transported, the specific gravity of the mixture and the length and slope of the straight section of the delivery pipeline. Operating at sub-critical velocities is inadvisable because:

a) the pipeline resistance required is higher than it would be in the vicinity of the critical velocity;
b) there is a danger of blockage of the pipeline.

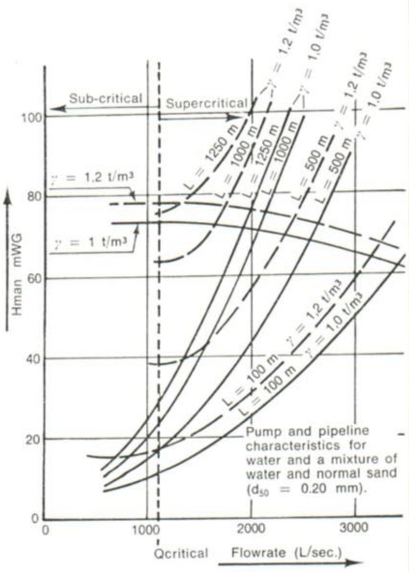
Working point

The working point of the pump is determined by the intersection, in the Q-H diagram, of the pump characteristics described above and the pipeline characteristics.

Pump and pipeline characteristics relating to the transport of water and of a water/sand mixture with a specific gravity of 1.2 ton/m³ over various distances are shown in Fig. 4. Fig. 5 contains similar details relating to water and to a mixture of water and clayey soil.

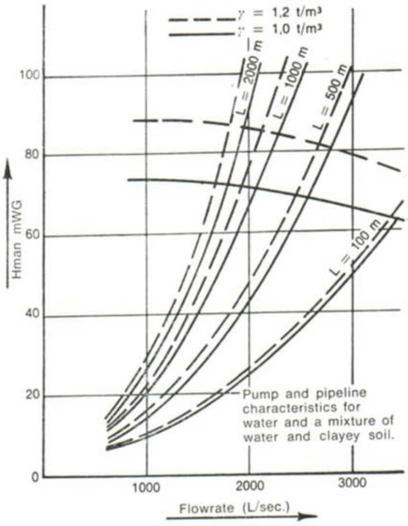
As the figures show, a dredgepump does not necessarily operate at a fixed working point, but can have a working range comprising a series of working points.

It is clear that a mixture of water and clayey soil can be pumped over a substantially greater distance than a water/sand mixture of comparable specific gravity. The explanation for this lies in the fact that the particles of



Pump and pipeline characteristics for water and a mixture of water and normal sand (d_{50} = 0.20 mm).

Fig. 4



Pump and pipeline characteristics for water and a mixture of water and clayey soil.

Fig. 5

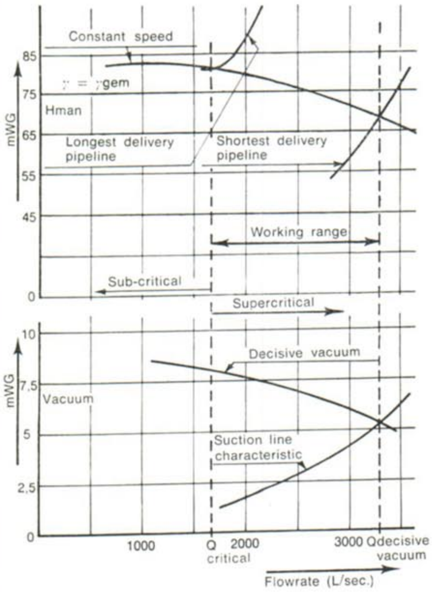


Fig. 6

clayey soil are considerably smaller than the grains of sand. The critical velocity of this mixture is therefore much lower and the resistance encountered in the pipeline smaller.

Working range

The magnitudes which serve to limit the working range in the Q-H diagram of a dredgepump (see Fig. 6) are:

a) As the lower limit at low flowrates, the flowrate corresponding to the critical velocity. Flowrates of less than this should be avoided.

b) As the upper limit at high flowrates, the flowrate corresponding to the decisive vacuum of the pumping installation and suction pipe concerned. Flowrates in excess of this must be avoided.

Lower limit of working range

The critical velocity forms the lower limit of the working range and thus limits the flowrate on the left-hand side. It limits the low flowrates to which longer delivery distances correspond (see Fig. 6).

If the delivery distance is greater than that for which the pumping installation was laid out (see Fig. 7, working point A), the flowrate will be subcritical. A need to exceed the designed pipeline length for a given type of soil can arise as a result of unexpected extension during the progress of a job, or the length can be deliberately increased for a limited period in order to reach a distant point of reclamation.

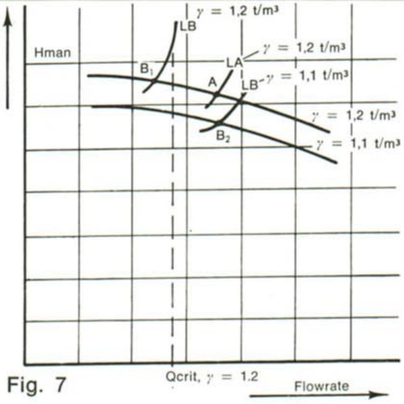


Fig. 7

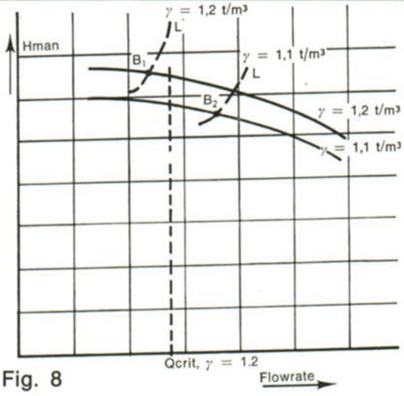


Fig. 8

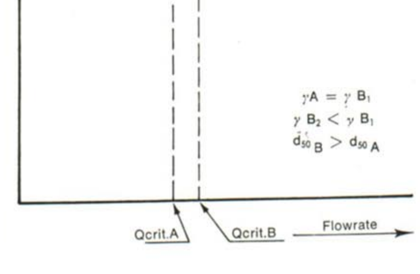


Fig. 9

The result of working at a sub-critical mixture velocity will be sedimentation in the pipeline and a major risk of blockage (see Fig. 7, working point B_1).

In such circumstances it is preferable to reduce the mean solids concentration slightly, causing the resistance to decrease and restoring the flowrate to a supercritical value (see Fig. 7, working point B_2).

Operating with the maximum length of pipeline for which the installation was laid out, and pumping mixture with a higher mean specific gravity than that contemplated in the design of the installation, produces a similar situation. The choice is the same: either to run the risk of delivering into a blocked pipeline, or to reduce the mean solids concentration somewhat and restore the flowrate to a supercritical value (see Fig. 8).

If soil of another type is pumped through the maximum-length pipeline, the foregoing ceases to apply (see Fig. 9, in which soil A is of the type for which the system was designed and soil B is considerably coarser). If the critical velocity for soil B should prove to be substantially higher by reason of its coarser nature, the situation shown in Fig. 9, working point B, will obtain.

At working point B_1, this would imply operating with a partially sedimented pipeline, the inherent risks of which increase in proportion to the coarseness of the soil. The solution lies in reducing the specific gravity of the mixture to the point at which a supercritical velocity is achieved (working point B_2). If this action results in the solids output falling to an unacceptable level, other measures must be adopted, e.g. shortening the pipeline by rerouting or altering the method of operation, or introducing a booster. The choice is governed by numerous local factors such as the nature of the soil, the duration of the sub-critical phase, the availability of other plant, cost considerations, etc.

Upper limit of working range

If the pump is to operate satisfactorily, cavitation must be prevented as far as possible. On the right-hand side, the working range of a dredgepump installation is limited by the flowrate at which the resistance in the suction pipe is equal to the decisive vacuum and cavitation commences. This upper limit corresponds to the minimum delivery distance at maximum capacity (see Fig. 6).

Cavitation

The phenomenon of cavitation can be described as follows (see Fig. 10). If the vacuum on the suction side of the pump rises to the point at which the pressure of the pumped water equals the vapour pressure at the water temperature at this point, the water will vaporize. The vapour bubbles in the flow are carried to the impeller, where the pressure is increased, causing the bubbles to implode. This process may be accompanied by hissing and rattling, severe vibration, fairly heavy shocks and other irregularities. Furthermore, cavitation causes wear and damage to the pump parts, especially the impeller.

At the onset of cavitation, the delivery pressure deviates from the Q-H curve. It is at this point that, in most instances, the suction head and the output rise marginally. The pump operates very well, but there is heavy vibration. This explains the saying among dredging men that a dredger can only be said to be working well "if your teeth fall out as you step on board." Further excursion into the area of cavitation leads to a steady fall in the delivery pressure, ending in total collapse. The pump chokes. The solids yield falls away with the delivery pressure. The flowrate rapidly drops to zero.

Decisive vacuum

If the pump is to operate satisfactorily, the vacuum on the suction side must not exceed the threshold of cavitation, which constitutes the decisive vacuum for the pump and suction line concerned.

The decisive vacuum is deemed to be the vacuum at which the suction head differs by 5% from the normal suction

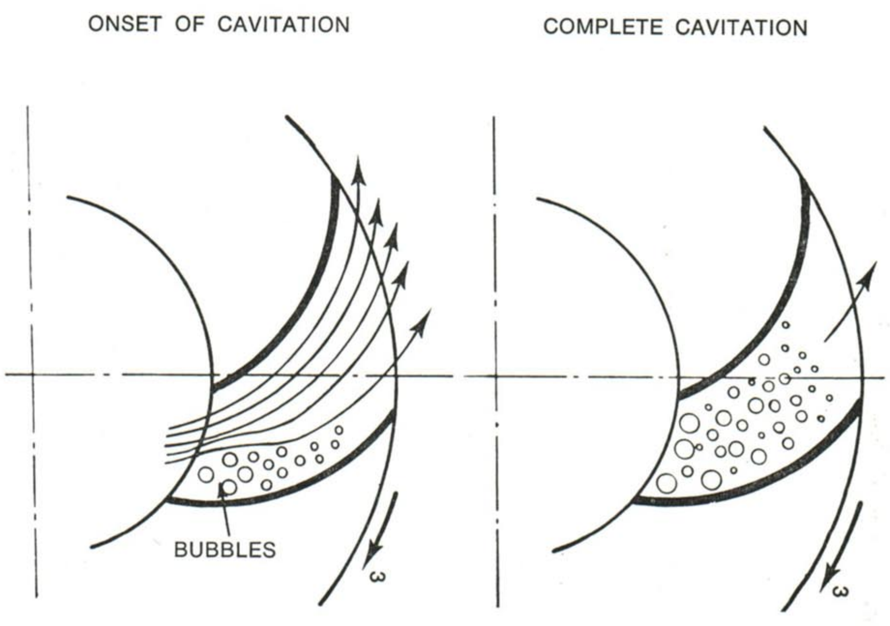


Fig. 10

head at the same pump speed (see Fig. 11). Some authorities view a deviation of 3% as the criterion in this respect.

On the one hand, the tendency of a pump to cavitate is governed by its speed, dimensions and shape. Specific speed, Thoma cavitation number and NPSH are among the terms commonly used in this context.

On the other hand, the layout of the suction line and the circumstances obtaining on the suction side of the pump are decisive. Prerotation, the ingress of air or gas to the suction line, the shape of the suction pipe and pump inlet, and any roughness on the surfaces of these also play a major role.

The higher the flowrate in the pump installation, the greater will be the loss caused by resistance in the suction pipe.

Therefore at a given flowrate, which is very high, the suction pipe resistance exceeds the threshold of cavitation, the decisive vacuum H_A. This constitutes the upper limit of the flowrate within the working range (see Fig. 11).

If the same dredgepump installation is fitted with a suction line of smaller diameter, all other circumstances remaining unaltered, the resistance in the suction pipe will be greater and the suction pipe loss will exceed the decisive vacuum (H_B) at a lower flowrate (Q_B). The upper limit of the working range with the smaller suction line coincides with a lower flowrate. If a suction line of larger diameter is installed, the resistance will be less and the upper limit of the working range will coincide with a higher flowrate (Q_C).

Each suction pipe has a corresponding, specific cavitation curve. At the relevant flowrate, this indicates a particular value for the decisive vacuum. By linking the decisive vacuum values for the various suction lines, and thus for the various flowrates, one obtains a curve showing the decisive vacuum for the installation concerned (see Fig. 11).

Set out in terms of flowrate, the curve representing the decisive vacuum is seen to fall away more and more sharply as the flowrate increases, ultimately becoming almost vertical. There is a limit to the extent to which the suction pipe diameter can be increased in order to shift the upper limit of the working range to the right and thus extend it. The limitation stems on the one hand from the pattern of the decisive vacuum characteristic at higher flowrates, which has already been sketched; this is such that, at these high flowrates, increasing the diameter of the suction pipe ultimately ceases to have any effect. On the other hand, it is limited by the critical velocity of the mixture in the suction line. If sedimentation occurs in the suction pipe as a result of a sub-critical velocity or because the

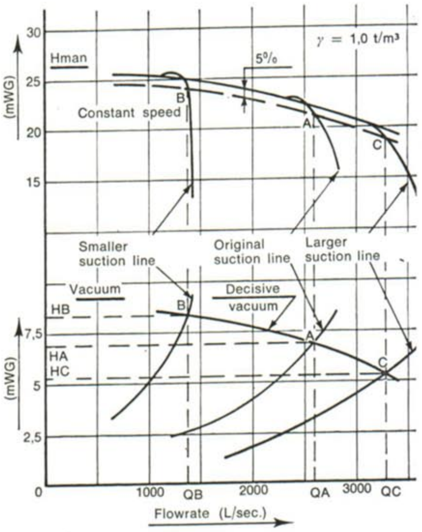


Fig. 11

pipe is of too large a diameter, the effect is the same as operating with a smaller suction pipe. In this situation, there is a high risk of blockage of the suction line and the pump installation with all its consequences (additional work, lost time, damage, etc.).

Determining the thresholds of cavitation

The thresholds of cavitation can be determined by introducing various resistances (restrictions) in the suction pipe while pumping water through the system (see Fig. 12).

In a suction line free of restrictions, cavitation occurs at the maximum flowrate. With the pump running at a constant speed, this is introduced by following the Q-H curve until a situation is reached in which reducing the resistance on the delivery side causes the suction head to drop (and thus the flowrate to rise) to the point where the decisive vacuum is exceeded. This decisive vacuum coincides with the upper flowrate limit in the working range of the dredgepump installation. Introducing a restriction in the suction pipe raises the resistance in the suction line and causes the cavitation curve to shift to the left. The decisive vacuum on the Q-H curve now coincides with a lower flowrate, a higher delivery pressure and a greater suction head.

The more the suction line is restricted, the smaller will be the flowrate with which the corresponding cavitation curve coincides. The lower the flowrate at which cavitation occurs, the more pronounced and unexpected will the collapse of the delivery pressure be. The corresponding vacuum curve becomes steadily steeper.

Minor fluctuations in flowrate at the point of curvature – at which the phenomenon of cavitation becomes apparent – produce increasingly large shifts in the vacuum.

Cavitation pattern during pumping mixtures

Generally speaking, the pumping of mixtures has an adverse effect on the cavitation pattern.

This is attributable to the presence in the mixtures of soil grains, stones, rubbish (anchor chains, etc.) and other types of foreign matter, all of which disturb the homogeneity of the fluid vehicle and encourage cavitation. Accordingly, the value of the decisive vacuum will be lower when transporting a mixture than when pumping water.

If the mixture has a high specific gravity, or if the suction pipe is blocked or the ingress of the mixture is prevented by, for example, the pipe being pressed hard against the bed or a bank, or the collapse of a vertical wall, a choking effect occurs. This is similar to the effect produced deliberately by narrowing the suction pipe in order to measure cavitation. The result is a sudden, sharp rise in the resistance in the suction line, leading to cavitation with choking of the pump and all the other consequences. It is because less than full control of the flow of soil to the suction pipe inlet has been achieved that the dredging process is so astatic and that phenomena such as choking of pumps and partial sedimentation of pumps and/or pipelines are so frequently observed. It is, however, feasible to monitor the dredging process, to regulate the "pit supply" and to prevent or correct the irregularities referred to. The available methods will be explained in later articles in this series.

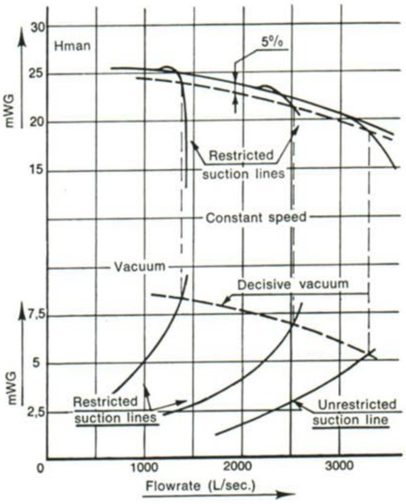


Fig. 12