Centrifugal Dredgepumps

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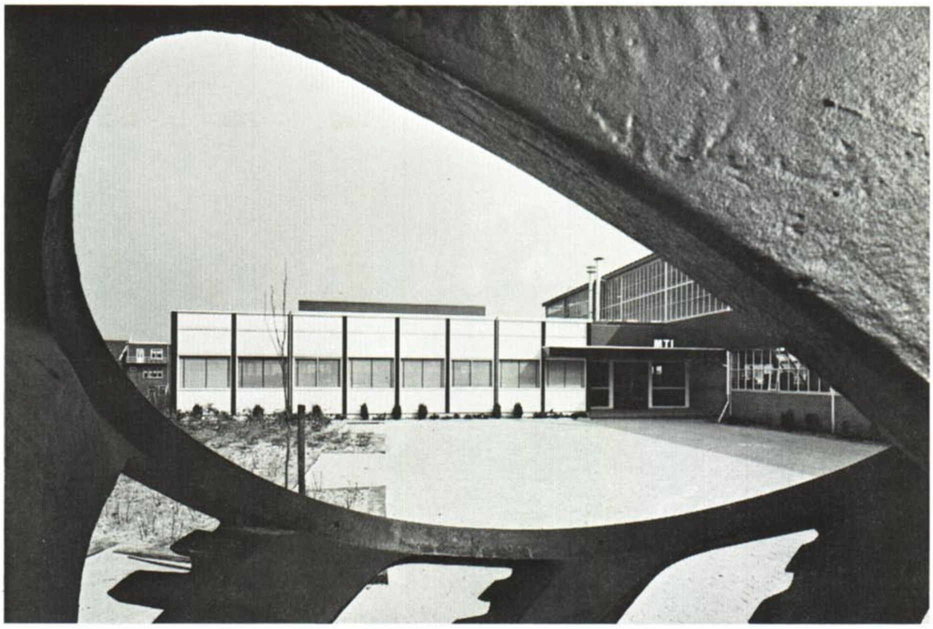
By Ir. S. E. M. de Bree



This is the fifth in the series of articles concerning 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, 80 and 82.
In this article, the author deals with the output curves of dredgepump installations.

The working range of the dredgepump installation

The working point of the pump is determined by the point of intersection of the pump characteristic and the pipeline characteristic in the Q-H diagram (Fig. 1). In contrast to other types of pump, a dredgepump is not designed for a specific working point, but must be capable of spanning a large number of potential working points which together constitute a working range.

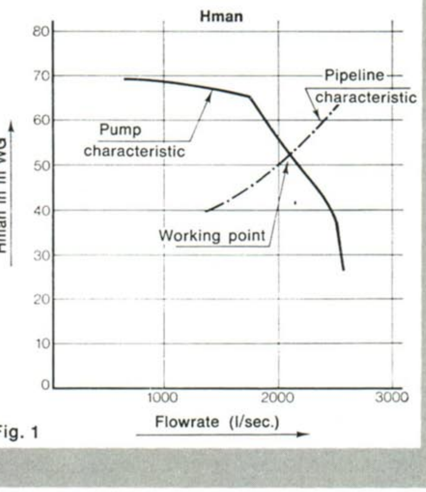


Fig. 1

The position of the momentary working point of a given dredgepump installation is determined by the pit supply, the nature of the soil to be dredged, the concentration of the mixture, the suction depth, the length of the delivery pipeline, the geodetic head and any delivery pipeline resistance factors which were not taken into account when designing the basic pump installation.

The working range is limited at one end by the flowrate corresponding to the critical velocity of the mixture to be transported through the system (the lower limit), and at the other end by the flowrate corresponding to the decisive vacuum of the pumping installation and associated suction pipe (the upper limit).

For reasons of convenience, the mean operating conditions are assumed in calculating the output of solids obtainable with a given dredgepump installation. The characteristics of this installation and associated pipeline layout constitute fixed data in these calculations, together with the given predetermined suction depth; in addition, the highest mean specific gravity attainable with the soil and under the operating conditions concerned is determined. The pit supply is governed by the nature of the soil and its condition at the point of dredging. If mechanical means are employed to disturb the cohesion of the soil, the quantity of soil which they are able to dislodge is similarly limited by the nature of the soil and its condition at the relevant point.

The method of calculating the potential pit supply and the output of installations employed to dislodge it, however, fall outside the scope of these articles. It is nonetheless clear that the dredger employed for a given job must be matched to the pit supply.

Output as a function of delivery distance

Where the pipeline layout, the suction depth and the pit supply as determined by the soil and operating conditions are known, the only variable factor in calculating the output of solids of a dredgepump installation is the length of the delivery pipeline.

The anticipated mean output of a dredger can be calculated from the attainable mean point of intersection of the pump and pipeline characteristics. By calculating the mean outputs corresponding to a number of pipeline lengths, a graph can be produced showing the output as a function of the pipeline length. In compiling this, the existence of a set number of additional obstructions in the delivery pipeline, such as bifurcations, gate valves, etc. (the quantity and nature of which depend on the pipeline layout) must be assumed. Where a pipeline is to be extended, the extra resistance factors can, of course, be embodied in the calculation. Whether or not this is done depends upon the exact layout of the pipeline and the desired accuracy of the calculation. A typical output graph relating to a dredgepump installation is shown in Fig. 2. In the majority of cases, the curve will be found to bend sharply at two points, effectively dividing the graph into three zones corresponding to:

1. short, or too short, delivery distances (Zone I)
2. delivery distances within the normal working range of the pump (Zone II)
3. long, or too long, delivery distances (Zone III).

1. (Too) short delivery distances

These constitute the first zone of the graph. At a high flowrate, when the upper limit is reached, the vacuum becomes decisive, i.e. the flowrate at the attainable mean specific gravity of the mixture is so high that the corresponding vacuum on the suction side of the pump installation is equal to the decisive vacuum, which may not be exceeded and thus constitutes the limit of the attainable vacuum. Fig. 3 shows the decisive vacuum applying to a delivery pipeline length L_1.

The decisive vacuum is reached at working point P_1. If the decisive vacuum is exceeded – for example, as a result of shortening the delivery pipeline, with the result that a lower resistance curve, e.g. L_2 in Fig. 3, applies – cavitation ensues.

During cavitation the Q-H curve is distorted, initially turning downwards and finally falling off vertically. It is possible to conceive of a momentary point of intersection P_2 of the pipeline characteristic of a shortened pipeline and the cavitation curve of the pump, but the latter will then be cavitating. The pumping installation, indeed the whole vessel, will vibrate violently. With the delivery pressure on the point of collapse and choking of the pump imminent, an unstable situation will exist.

If the length of the pipeline is less than L_1 in Fig. 3 (at which the pipeline characteristic exactly passes through point P_1), the dredging process will be taking place in the cavitation area with forementioned consequences.

If it is desired to operate with a shorter delivery pipeline, the speed n_1 of the pump must be reduced to the point where the intersection of the corresponding pump characteristic and that of the shorter pipeline falls within the normal working range of the pump. This implies that the point of intersection (working point P_3) must coincide with a flowrate at which the vacuum is slightly below the decisive level corresponding to the lower pump speed. This is shown in Fig. 3. The two working points P_1 and P_3 have a virtually equal flowrate. If the delivery distance is less than L_1, this flowrate

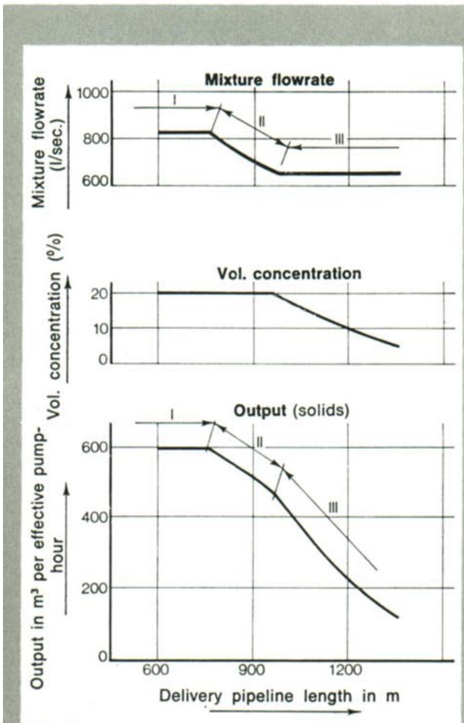


Fig. 2

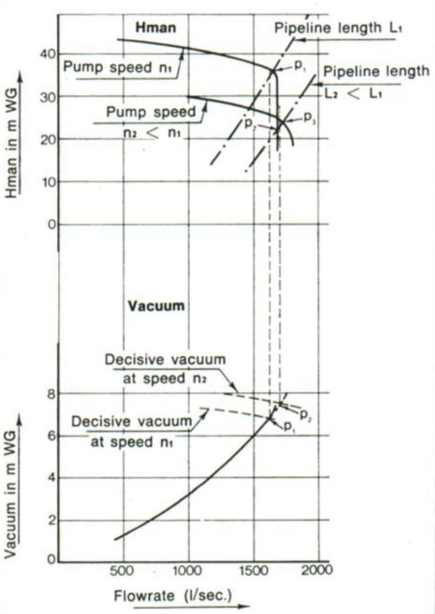


Fig. 3

must not be exceeded, or cavitation will occur. As the attainable mean specific gravity of the mixture remains virtually unchanged, the output at these (too) short delivery distances will also remain virtually constant.

The foregoing is represented in the output graph (Fig. 2) by the horizontal section I.

2. Delivery distances within the normal working range of the pump

The second section of the graph (Fig. 2, section II) represents output realized within the true working range of the dredgepump installation.

Because the pump driving power is limited, any increase in the length of the delivery pipeline and the associated pipeline resistance results in diminution of the flowrate. As this section of the output graph corresponds to the true working range of the pump, the drive characteristic of the pump installation constitutes the limiting factor.

Fig. 4 shows the working range, in the Q-H diagram, of a diesel-driven dredgepump. This diagram again is plotted for the maximum attainable mean mixture s.g. This highest mean s.g. is governed principally by the pit supply, but also by the nature of the soil, the operating method and the layout of the suction pipe.

The upper limit of the actual working range, i.e. the flowrate corresponding to the decisive vacuum of the dredgepump installation, is at point P_1 (Fig. 4). The pipeline of which the characteristic intersects the pump curve at this point P_1 is the one with the minimum required length (L_1) for operation of the dredgepump installation in its normal working range.

As the pipeline length increases, the point of intersection of the pump and pipeline characteristics will shift to a lower corresponding flowrate, eventually reaching point P_3, the lower limit of the working range. This is the flowrate which, under the given circumstances, corresponds to the critical mixture velocity.

Depending upon the characteristic of the dredgepump, an increase in the discharge distance will result in a smaller or greater rise in the delivery pressure and a fall in the mixture flowrate.

Therefore, since the attainable mean s.g. remains virtually constant within this range, an increase in the delivery distance will result in a fall in output of solids.

The foregoing is represented in the output graph (Fig. 2) by section II. Fig. 5 shows the working range, in the Q-H diagram, of a dredgepump with a so-called constant-power drive. The characteristic of a diesel-driven pump (Fig. 4) has also been incorporated. The point of the comparison lies in the fact that the nominal power and the nominal speed at the design point P_3 are the same for both drive systems.

The graph reproduced in Fig. 6 affords a comparison between the out-

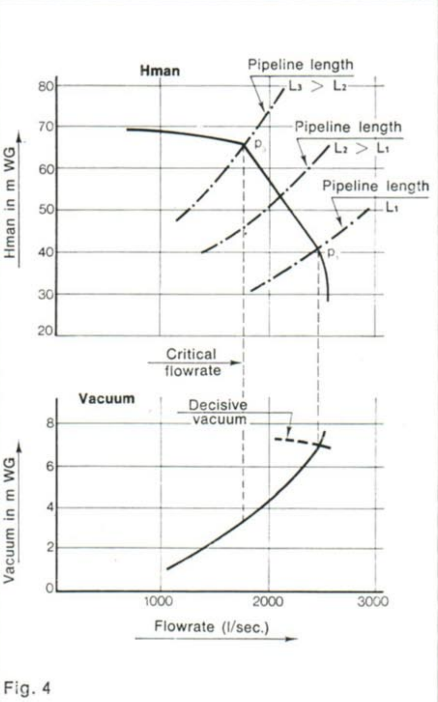


Fig. 4

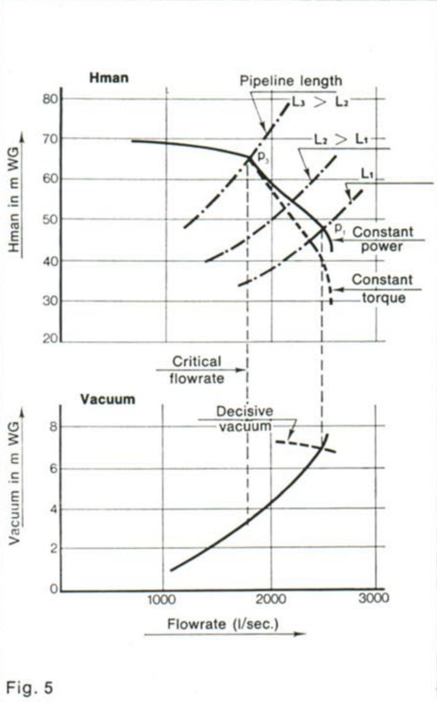


Fig. 5

put curve relating to a "constant-power" drive system and that relating to the "constant-torque" drive obtained with a diesel engine. The advantage of the "constant-power" drive is clearly revealed in these curves.

With a diesel-driven dredgepump as envisaged in Fig. 5, and operating within the range P_1 - P_3, it is quite feasible to achieve a result superior to that represented by the relevant curve in Fig. 6, by modifying the diameter of the pump impeller. In essence, the so-called constant-power drive referred to in Fig. 5 is identical to a diesel-direct system in which the impeller is continuously adapted to enable the engine to deliver full power and thus to operate constantly at its nominal full-torque point. In practice, modification of the impeller of a dredgepump with diesel-direct drive is done in stages, and then only if reduced-distance delivery is to continue for an appreciable period.

The diameter of the impeller can be reduced by machining or burning metal from the blades. From the flow technology point of view, it is preferable to replace the impeller with one having blades of suitable size and shape. This, however, is only worthwhile if the outlet diameter has to be reduced by more than 10% or thereabouts.

The feasibility of reducing the diameter by machining or flame-cutting is governed by the ratio between the outlet and inlet diameters of the blades (the d_u/d_i ratio) and other factors relating to the shape and construction of the impeller. Impellers whose d_u/d_i ratio is greater than 2, which are thus found in comparatively large pumps, can be satisfactorily reduced to 70% - 80% of their original diameter by the methods described. Where conditions require that an impeller with a d_u/d_i ratio of less than 2 (which implies a relatively small pump) be significantly reduced in diameter, it is usually preferable to replace it with one having blades of suitable shape.

It is obvious that the latter course is by far the best, for it results in an impeller with maximum efficiency. Reduction of the impeller diameter by machining or flame-cutting always reduces the efficiency of the pump. Against this, however, a pump so modified absorbs more power when delivering into a shorter delivery pipeline and thus affords a higher output; moreover, the modification is simple and commonality of impeller types is maintained. It therefore follows that large, relatively slow-running pumps lend themselves to modification.

Small, relatively fast-running pumps operating at an unchanged head don't lend themselves so good to modification; indeed, in many cases the fitting of a special impeller is the only solution if an inadmissible loss of efficiency is to be avoided.

3. (Too) long delivery distances

If the delivery pipeline is lengthened, the specific gravity of the mixture to be pumped must be reduced as soon as the critical velocity (the second bend in the output curve) is reached. This is necessary to avoid a subcritical situation, leading to sedimentation. This subject was dealt with in the preceding article. At what is in effect an excessive delivery distance, pumping a mixture of such specific gravity as to cause sedimentation in the pipeline is to risk total blockage. In practice, this danger is averted by admitting more water. The specific gravity must be reduced just sufficiently to restore a supercritical situation.

In approximate terms, it can be stated that the critical flowrate of a soil/water mixture at the reduced s.g. differs little from the critical flowrate at the highest attainable mean mixture s.g. This implies that, when delivering into (too) long pipelines, the specific gravity must be reduced when a certain flowrate, which is virtually constant, is reached. This is the flowrate corresponding to the critical velocity. Increasing the delivery distance will therefore result in a lower output of soil.

This is represented in the output graph (Fig. 2) by section III. In actual fact, the critical velocity – and thus also the corresponding flowrate – does depend upon the specific gravity of the mixture. At the specific gravities normally encountered, however, the dependence is not great and thus the foregoing remarks may be considered valid.

Examination of the three-part output curve referred to reveals that it ought in fact to consist of only one section, namely section II – the true working range of the pump. Unless the pump installation has been modified, it should not be operated in the adjacent areas I and III, which relate to (too) short and (too) long delivery pipelines respectively.

Divergent output graphs

Using a delivery pipeline with too large a diameter in conjunction with an existing dredgepump installation and suction line can produce a situation in which the flowrate at the critical mixture velocity is so high that the vacuum on the suction side of the pump reaches the decisive level while the specific gravity of the mixture is substantially below the highest mean figure attainable. The output as a function of the pipeline length then appears as shown in Fig. 7 (delivery pipeline with diameter d_1).

The output curve now obtained consists of two sections and has one bend. Section I relates to (too) short delivery distances, and section III to (too) long delivery distances. The middle section (II), the actual working range of the pump, has disappeared.

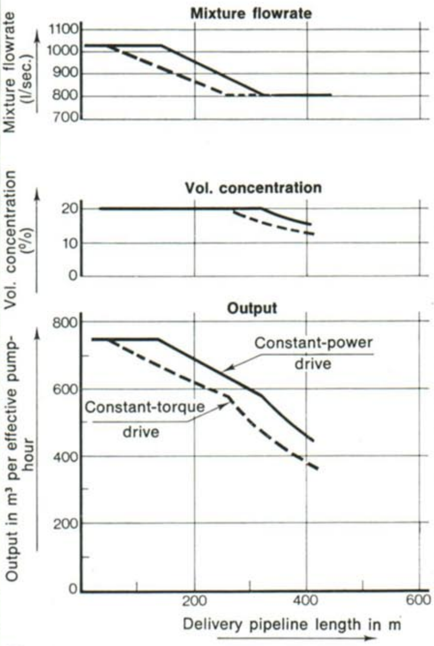


Fig. 6

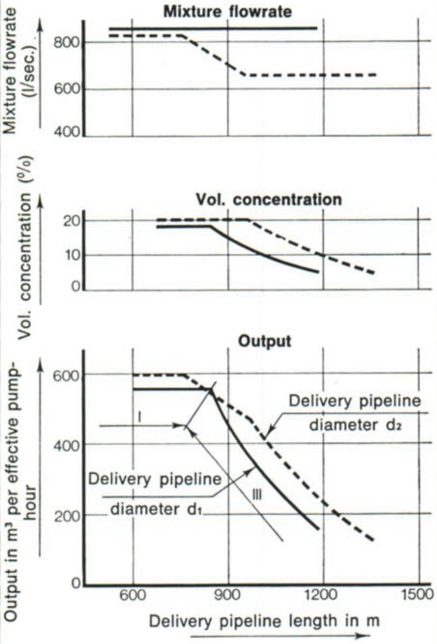


Fig. 7

An increase of output can be achieved by reducing the diameter of the delivery pipeline, e.g. from d_1 to d_2. This results in the restoration of a normal, three-part, output curve.

When pumping mixtures of water and fine sand (less than 83μ), or clayey soil and silt, or combinations of these materials, the critical velocity in the delivery pipe will be very low. Moreover the resistance offered by the pipeline is less than would be the case during the transport of mixtures of water and coarser sand under comparable circumstances. As a result, the bend in the output curve, between line section II (the actual working range of the pump) and section III (the area relating to (too) long delivery distances), will coincide with an extremely high delivery distance value, or will be missing altogether. The output curve will then be as shown in Fig. 8 and consists of only two sections.

As has already been stated, the nature of the dredged soil exerts a major influence on the yield of solids. Output diagrams for a given dredgepump installation working in various types of soil and based on the mean attainable specific gravity are reproduced in Fig. 9. The diagrams also embody curves representing the maximum attainable specific gravity and flowrate for each soil type.

The differences in output between gravel, coarse sand and fine sand when transported over the same distance are clear — as is the fact that the yield is highest with fine material. It is also evident that maximum output (over the short distances) and maximum delivery distance increase proportionally with the fineness of the soil transported in the mixture.

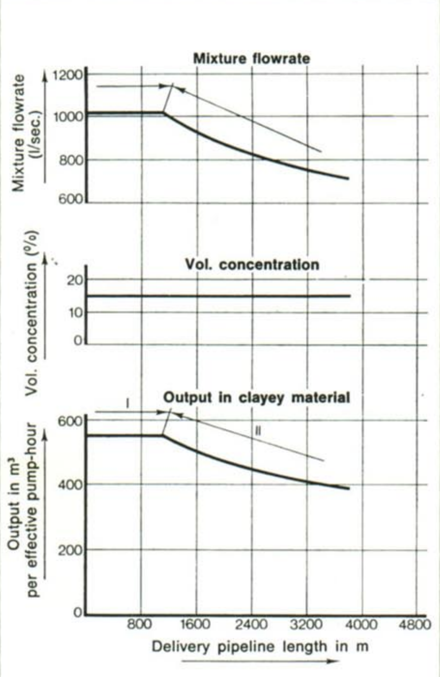


Fig. 8

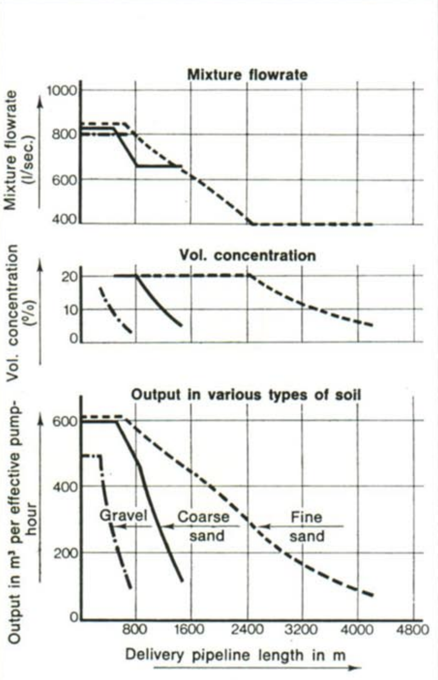


Fig. 9