SLURRY FRICTION HEAD LOSSES IN PIPELINES

3.1 INTRODUCTION

Despite the long history of successful slurry pumping operations covering a wide range of slurries, limited published data is available to estimate \( H_f \) accurately for every possible duty. A high degree of accuracy is normally required only if \( H_f \) represents a high proportion of the Total Dynamic Head, \( H \), for a proposed application so that large errors in estimating \( H_f \) would be reflected in correspondingly large errors in estimating \( H \).

This normally applies to very long distance pumping duties only. For most Warman Pump applications, a high degree of accuracy in estimating \( H_f \) is not required.

3.2 HOMOGENEOUS SLURRIES: (PARTICLES ESSENTIALLY ALL FINER THAN 50 \( \mu \)m)

At sufficiently low concentrations \( H_f \) will be close to that for clear water and may be estimated by the same empirical method as applied to Category 'A' Heterogeneous Slurries.

At sufficiently high concentrations, the Yield Stress characteristic largely influences the value of \( H_f \). For further information on pumping, homogeneous slurries with high concentrations, contact your nearest Warman representative.

3.3 HETEROGENEOUS SLURRIES: (PARTICLES ESSENTIALLY ALL COARSER THAN 50 \( \mu \)m)

Category 'A': Particles essentially all coarser than 50 \( \mu \)m and finer than 300 \( \mu \)m and with \( C_w \) from ZERO to 40%.

Typical friction head loss curves for this category, are illustrated in Figure 4-3-1. Analyses of \( H_f \) data on these slurries indicates that, for any given solids concentration, the slurry \( H_f \) is numerically higher than the water \( H_f \), for velocities below approximately 1.30 \( \text{VL} \). However, the \( H_f \) value does not fall below a minimum at lower velocities, due to the effect of solids which settle in the pipe. This minimum occurs at approximately 0.70 \( \text{VL} \), where the slurry \( H_f \) is approximately numerically equal to the \( H_f \) for water at \( \text{VL} \).

The empirical data are summarised:

At 1.30 \( \text{VL} \) (approximately):
- Slurry \( H_f \) is numerically equal to water \( H_f \).

At 0.70 \( \text{VL} \) (approximately):
- Slurry \( H_f \) is at its minimum value.
- Slurry \( H_f \) is numerically equal to the \( H_f \) for water at \( \text{VL} \).

The most economical slurry velocity is a velocity a little in excess of \( \text{VL} \), thus these empirical relationships allow the construction of the useful portion of the estimated slurry \( H_f \) curve, in relation to the water \( H_f \) curve, for the same pipe.

Consequently, a reliable method of estimating \( H_f \) for water should be adopted, when estimating a Category 'A' Slurry \( H_f \).

NOTE: Both water \( H_f \) (head of water) and slurry \( H_f \) (head of mixture) should each be expressed in head of actual "mixture" pumped.

Figure 4-3-1 also illustrates the construction of the estimated slurry \( H_f \) curves, based upon the estimated water \( H_f \) curve. Each slurry \( H_f \) curve meets tangentially with its minimum \( H_f \) value and meets tangentially with the water \( H_f \) curve where the value of \( \text{VL} \) corresponds to 1.30 \( \text{VL} \).

It is emphasised that this empirical method of estimating \( H_f \) for these Category 'A' slurries is not precise but, in the absence of pipeline test rig data, or other more reliable data, it provides estimates designed to be reasonably accurate for many practical slurry pumping applications.

![Figure 4-3-1 Typical Hf Curve for Category 'A' Slurries](image_url)
3.4 HETEROGENEOUS SLURRIES

Category 'B': Particles essentially all coarser than 50 µm and finer than 300 µm but with Cw greater than 40%.

Generally, friction head losses for this category are much higher than for Category 'A' due largely to the increased friction effect of the more closely-packed solids content upon the pipewall. This effect generally increases with increasing Cw and is so greatly influenced by a number of variables, for example, Cw, S, Sl, d50, and actual sieve analysis of solids present that it is not possible to provide a simple empirical method for estimating slurry Hf.

In general, slurry Hf values may vary over a range, commencing with values approximately equal to those applicable to Category 'A' slurries at Cw = 40%, to values up to double or more those of Category 'A' slurries, for velocities in excess of VL.

Consequently, Hf values for Category 'B' slurries must often be estimated, then adjusted by an "experience factor". The Hf values are first estimated as if for category 'A', after allowing for the lower values of FL (and VL) associated with values of Cw in excess of Cw = 30%, see Figure 4-3-1.

The true values of Hf may be double or more the estimated values. This is allowed for by providing reserves of speed and power for values of Hf up to double, or more, of the values estimated for Hf. While this introduces the risk of large error in the estimation of Hf, the effective overall error in estimating Total Dynamic Head (H) is relatively small, if the other components of H (for example, Z, Hpf and Hve), when combined, represent the major portion of H.

Should the value of H be estimated with a relatively small error, the effect would probably be almost insignificant. For example, it would simply result in a slightly higher or lower value of Zs in the hopper and/or a correspondingly slightly higher or lower power consumption. Should the error be more significant, with obvious overspeed or underspeed, the pump speed may be adjusted, for example, by changing the motor pulley or via a variable speed control, if provided. In either case, the drive motor should be adequately rated.

NOTE: Some test work results for slurry containing heavy solids (S = 4.6 to 5.3) of approximately 150 µm sizing has shown a trend towards decreasing head loss with increasing solids concentration, between Cv = 10% and Cv = 25% (that is, Cw between approximately 40% and 60%).

Many Warman pumps are used in heavy-duty, Category 'B' slurry applications.

Typical examples include the following:

a. Mill Discharge Plant,
b. Thicker Underflow,
c. Sand Tailings Stacking, and
d. Gravity Concentrator Feed.

3.5 HETEROGENEOUS SLURRIES

Category 'C': Particles essentially coarser than 300 µm and Cw from ZERO to 20%.

Generally, friction head losses for Category 'C' slurries are also much higher than for Category 'A'.

The more common applications for Warman pumps on Category 'C' slurries are the suction dredging of gravel and/or coarse sand. In normal dredging operations, Cw is often less than 20%, due to the impracticality of continuously entraining such coarse particles at the intake of the suction pipe at a higher value of Cw.

Hf for these slurries is estimated on the basis of the minimum average velocity FOR DESIGN being no less than VL when FL = 1.4.

For VL and for velocities greater than VL - the slurry Hf is taken to be numerically equal to 1.10 Hf for water, that is, numerically 10% higher than the estimated water Hf.

3.6 HETEROGENEOUS SLURRIES

Category 'D': Particles essentially coarser than 300 µm and Cw greater than 20%.

Generally, friction head losses for Category 'D' slurries are higher than for Category 'A': The values of Hf may be first estimated by the same method as for Category 'A'. However, the true slurry Hf may vary from values close to those for Category 'A' up to three times or more those of Category 'A' slurries, (for velocities in excess of VL).

Consequently, reserves of speed and power should be provided.

3.7 ESTIMATION OF FRICTION HEAD LOSSES FOR CLEAR WATER

The recommended method for estimating Hf for clear water is by using Darcy’s formula as follows:

$$Hf = \frac{f \times \frac{V^2}{2g}}{D}$$

Where,

- $Hf$ = Friction Loss (m)
- $L$ = Total Equivalent Length of pipe (m)
- $D$ = Inside diameter of pipe (m)
- $f$ = Darcy Friction Factor
- $V$ = Velocity (m/s)
- $g$ = Gravitational Acceleration (9.81 m/s²)

Use the Warman Pipe Friction Chart, Figure 4-3-2, to evaluate the Darcy Friction Factor, f.

*NOTE*: For convenience, this chart is entered at values of Inside Diameter of Pipe: "d", expressed in mm.

a. The application of Darcy's formula, in combination with the Warman Pipe Friction Chart, is the recommended method of estimating Hf for water. This information should
then be used for construction of the System Resistance Curves for clear water and Category 'A' slurries (by the empirical method) illustrated in Figure 4-3-1.

The advantages of this procedure are:

i. The Warman Pipe Friction chart provides the Darcy Friction Factor (and thus HF) values for clear water based on the most reliable data available to the date of this publication. This data takes into account the maintenance of certain values for Relative Pipe Wall Roughness, k/d, due to the continuous 'polishing' action of abrasive slurries flowing through the pipes.

For example, on Figure 4-3-2, the values of k/d for 'commercial steel' pipes are the same as the values for 'cement' and 'polythene' pipes. However, when these pipes are used for handling non-abrasive liquids only, such as clear water, the true values of k/d for steel pipes would be actually a little higher, yielding correspondingly higher values of HF for water.

ii. The empirical method for the construction of the estimated System Resistance Curve for water, and the subsequent construction of the System Resistance Curve for slurry, allows for the varying degrees of difference between HF for water and HF for slurries. This is particularly the case in the range of flow rate between VL to 1.30 VL, which is the usual range of most interest.

b. Example of Friction Head Loss Estimation for Water

Given L = 700 m of commercial steel pipe
d = 200 mm (i.e. D = 0.200 m), see Figure 4-3-3.
\[ \Omega = 94.25 \, \text{L/s} \]
\[ g = 9.81 \, \text{m/s}^2 \]