

SLUDGE SYSTEMS

Mr Tony Salisbury

SEWAGE SLUDGE PUMPING

Sewage sludges are complex fluids. They are typically:

Slow settling, viscous, non-Newtonian, time dependant, shear thinning, gaseous, bio active

This makes them difficult to characterise with any accuracy.

The prediction of system performance from a known set of sludge characteristics is more complex than for Newtonian fluids, but not unduly difficult. However, the process is not well understood throughout the water processing industry.

1. SLUDGE TESTING

The science of testing the viscosity of a fluid is known as rheology. Rheology examines the total response of a fluid to shearing stress and includes the liquid, plastic and semi plastic regimes. Rheological testing should also examine the time dependant response of the liquid.

In a few cases, samples of the medium to be pumped are available. The first problem is therefore to obtain a reliable sample. This is actually the source of many problems and the result is often an unrepresentative skim of water from the top or a semi-solid lump from the very bottom of a lagoon. Neither of these is of much use in designing pipework and selecting pumps. The answer is to assign sufficient resources to this phase of the project and undertake a realistic sampling and measurement programme. This requires money and unfortunately is often overlooked during the pre-contract stage of a project.

A review of the pitfalls waiting for the sludge tester is worthwhile:

The first, but relatively simple, problem is that most sludges are non Newtonian. This presents a mathematical complication, but does not of itself give the engineer a problem. The usual models are illustrated in Fig 1 and in the authors experience, sludges generally fit the pseudoplastic or Herschel Bulkley models well enough for most purposes.

An important point to remember is that the rheological model is just that - a model. It is an approximation to an observed behaviour. Like any other model to observed data, the fit can be improved as the model becomes more complex. For example a three parameter Herschel Bulkley model can always be made to fit an individual data set better than a pseudoplastic model. However, if a correlation across a range of solids contents is required then the degree of scatter in the correlation of the more complex model will render the technique useless. Therefore, the complexity of the rheological model must be chosen to suit the task in hand.

The underlying problem with most sludges is that the rheological response depends on a whole range of factors. Typically these will be as shown in Table 1. It will be seen that there are plenty of traps waiting for the unwary in both testing and interpreting test results on sludges.

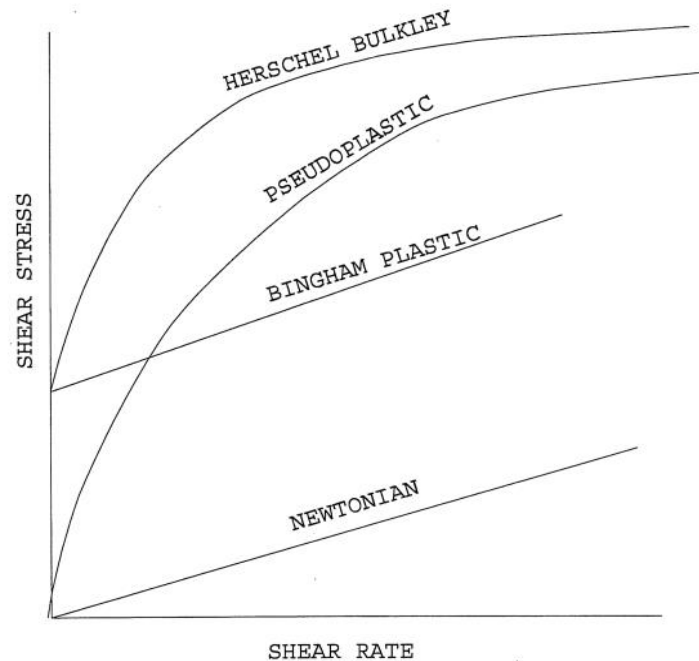


Figure 1 - Summary of principal rheological models showing shear stress – shear rate behaviour in the laminar regime.

A few general rules that can be drawn from this are:

- Sample carefully and assign sufficient resources to ensure a statistically significant sample.
- Undertake tests at as large a scale as possible to minimise scaling errors.
- Replicate the intended pumping regime as closely as possible in terms of material storage and shear prior to pumping.
- Use only personnel skilled in testing and handling complex fluids exhibiting the above problems.
- Perform correlations of data with caution and quantify the extent of scatter that can be expected.
- Rheological tests will generally use one of two types of viscometer for sludge testing, these are the rotational and the tube type.

The rotational type shears a sample of sludge between a rotating inner cylinder ("bob") and an outer cylinder ("cup"). Typical geometries are shown in the figure below. The inner cylinder is rotated at a range of speeds to vary the shear rate.

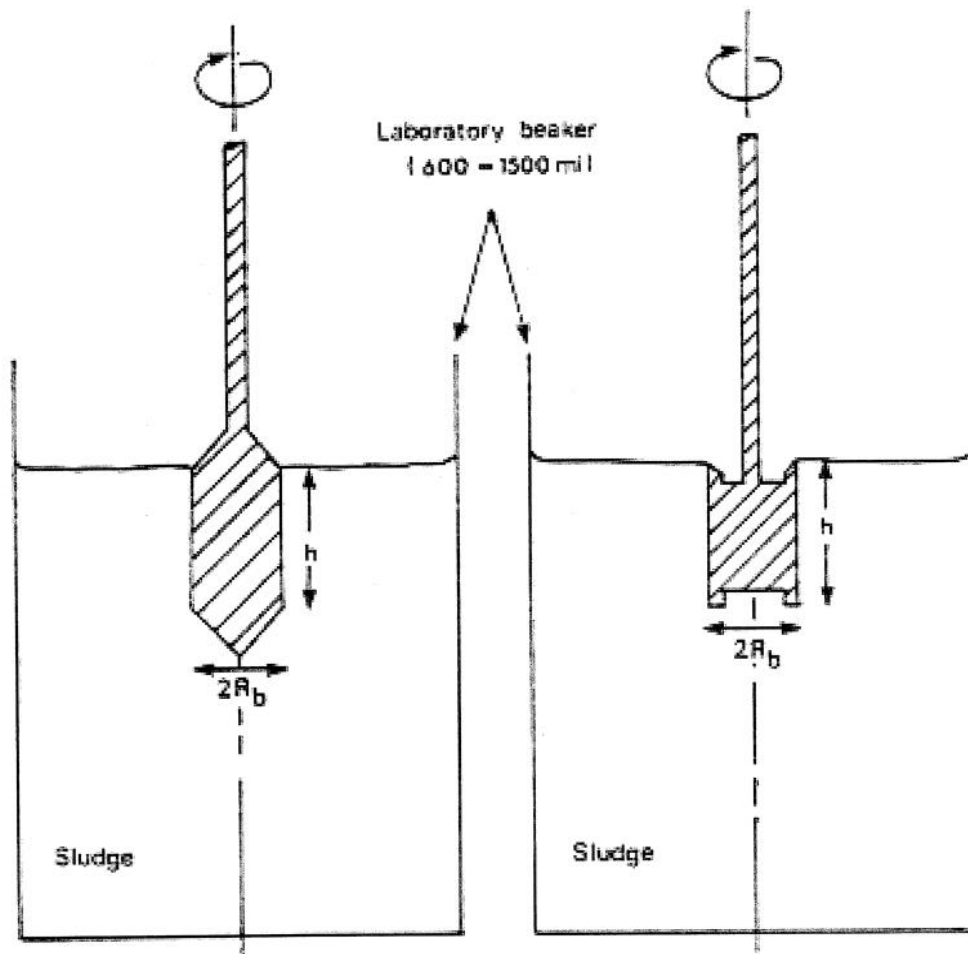


Figure 2 Illustration of typical rotational viscometer geometries.

Frost recommends using a range of bob sizes and surface finishes at increasing and decreasing speeds to isolate the effects of phase separation, wall slippage and shear thinning.

The tube viscometer is usually a specially constructed rig and models far more closely the pipe situation that is usually the case that needs to be solved. A typical set up is illustrated below:

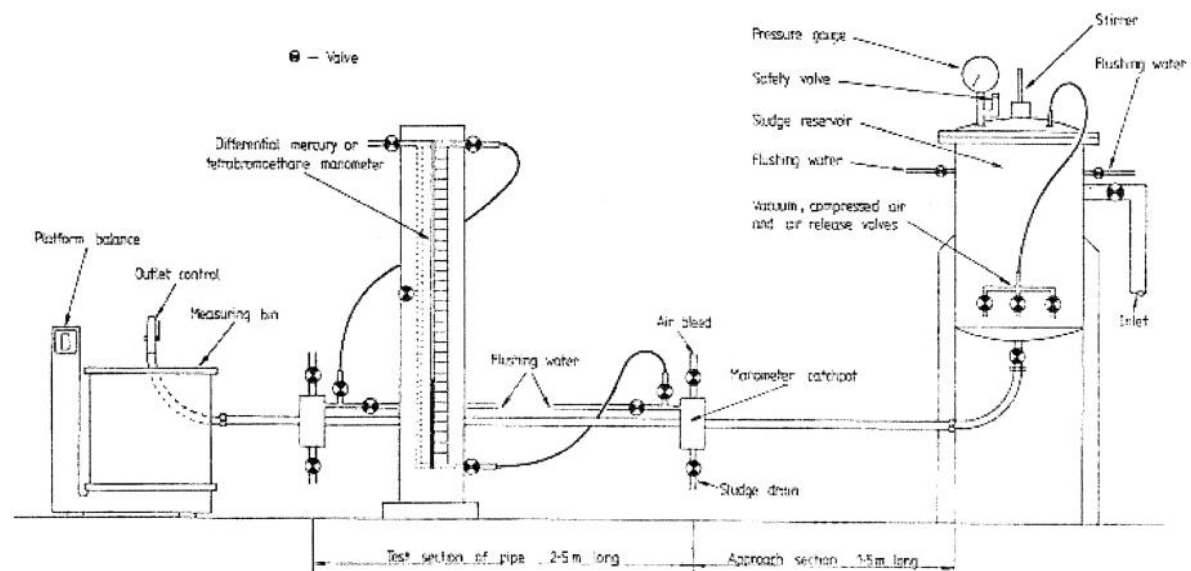


Figure 3 - Illustration of typical tube viscometer.

Neither arrangement of viscometer is able to test across a range of shear rates and shear stresses that is likely to reflect those in a full sized pipe system, hence a degree of extrapolation of the experimental data is inevitable.

Interpretation of the viscometer data is quite complex and involves the following steps:

- Apply instrument constants to the readings to calculate shear stress and shear rate for each data point.
- Filter the data to eliminate any readings corresponding to turbulent flow within the viscometer.
- Filter the data to eliminate instrument effects due to the finite length of rotational viscometer cups or approach length effects in a tube viscometer.
- Cross reference the data to isolate effects such as shear thinning & wall slippage.
- Fit the data to a rheological model. Frost recommends the use of a three parameter model to cover the whole shear rate range, and then a two parameter model to cover limited shear rates relevant to laminar flow.

The above is a complex process and will not be covered in detail here. The reader is referred to Water Research Centre report TR 185 for guidance.

It will be appreciated that rheological testing of sludge is a complex business and must be done by personnel skilled in the art.

2. ESTIMATION OF RHEOLOGICAL PROPERTIES

When a sample is not available, it will be necessary to make estimates of the liquid properties. This can only be done using a statistical analysis of data from similar materials. The prediction can never be as good as the original data and often the original data is of poor quality.

Most correlations relate viscometric properties against sludge solids content for a given type of sludge. Solids content is determined by drying a sample of sludge in an oven and measuring the weight before and after drying. Factors such as the presence of quite small quantities of road grit, for example, can significantly affect the measured solids content.

Frost, R.C. (How to design sewage sludge pumping systems, TR185, Published by Water Research Centre) also suggests correlation against the nominal compressive pressure achieved in the thickening process. This parameter is fundamental to the design of thickening equipment (hence known from process design considerations) and will therefore influence the final solids content achieved and hence the sludge properties. It is also suggested that the degree of scatter in the correlation of sludge properties against nominal compressive pressure is less than that for correlation against dry solids content.

In terms of practical design, the best correlation of reliable viscometric data against solids content has been summarised by Frost and is included in Table 2 below. Frost advocates modelling the sludge properties as:

Laminar viscosity - η_l
Turbulent viscosity - η_t
A power law index - n
A yield stress - R

Frost presents correlations for the upper & lower bounds plus the median of observed data. He gives further guidance on how the results might be further modified to account for observed loss on ignition data. This helps to eliminate the effect of sludges containing a lot of heavy grit or light fibrous material. Other effects such as amount of shear, temperature, gas content and salinity are also discussed.

3. PREDICTION OF SYSTEM BEHAVIOUR

The following will only deal with the calculation of pipework and fitting friction resistance and will follow the method proposed by Frost. Calculation of static head is as for any other system.

Assuming that rheological properties have either been measured or calculated from anticipated solids contents as outlined above, the next problem is to use this data to predict pipework resistance. The procedure is as set out below. For sludges, it is usual to calculate the performance over a range of flows, since there are no "short cut" methods of generating a system curve as there are for inviscid fluids such as water. The type of result that will be obtained is illustrated below:

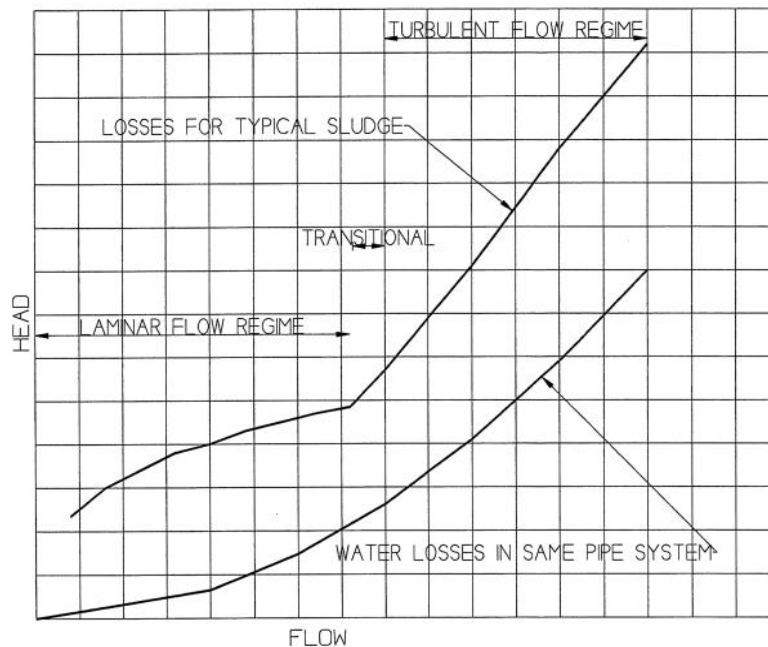


Figure 4 - Illustration of typical sludge system losses compared to water losses.

It will be seen that in many cases, the laminar, transitional and turbulent parts of the system curve will be of interest.

3.1. Losses in Straight Pipework

Step 1 - Laminar Reynolds number

$$Re_{lam} = \frac{\rho U D}{\eta_l} \left[\frac{8U}{D} \right]^{1-n}$$

where:

Re_{lam} = Reynolds number [Dimensionless]

ρ = Liquid density [kg/m^3] Usually in the range 1000 to 1005 for water based sludges.

U = Mean flow velocity [m/s]

D = Internal pipe diameter [m]

n = Sludge power law index [Dimensions vary]

η_l = Laminar viscosity as predicted by Frost [Dimensions vary]

If the value of Re is less than 2300, laminar flow is confirmed. Proceed to calculate the laminar friction factor and losses, Steps 2. If the value is greater than 4000, flow will be turbulent. Proceed to step 3.

If the value of Re is between 2300 and 4000, calculate both laminar and turbulent losses and take the higher value of the two.

Step 2 – Laminar Friction Factor

$$f = \frac{C_f}{Re}$$

where:

C_f = 64 for circular cross sections

Re = as defined above.

Step 3 – Turbulent Reynolds Number

$$Re_{turb} = \frac{\rho U D}{\eta_t}$$

where:

Re_{turb} = Reynolds number [Dimensionless]

ρ = Liquid density [kg/m^3] Usually in the range 1000 to 1005 for water based sludges.

U = Mean flow velocity [m/s]

D = Internal pipe diameter [m]

η_t = Laminar viscosity as predicted by Frost [Dimensions vary]

Step 4 – Turbulent Friction Factor

Friction factor may be read directly from the 'Moody Chart', or calculated from the following explicit equation. This is not the true Colebrook White equation, but gives results with a similar accuracy:

$$f = \frac{0.25}{\left(\log_{10} \left(\frac{k_s}{3.7 D} + \frac{5.74}{Re^{0.9}} \right) \right)^2}$$

where:

Re = Turbulent Reynolds Number as defined above.

k_s = Pipe wall roughness [m]

D = Hydraulic diameter [m]. *Ensure pipe INTERNAL diameter is used.*

f = Friction factor [Dimensionless]

The choice of pipe wall roughness is discussed in depth in the module on plant hydraulics, but values in the order of 0.6 to 3 mm are suggested for design purposes regardless of pipe material.

Step 5 – Head loss

Take the relevant value of f from the laminar or turbulent case as indicated in Step 1 above and apply the following equation:

$$h_f = f \frac{L U^2}{D 2 g}$$

where:

- h_f = head loss due to friction in length of pipe [m of liquid]
- f = friction factor as calculated above.
- L = length of pipe [m]
- D = diameter of pipe [m]
- U = mean velocity in pipe (flowrate/area) [m/s]
- g = acceleration due to gravity = 9.81 [m/s²]

3.2 Losses in Fittings

Losses for fittings are calculated generally as for turbulent Newtonian flow, but with an additional factor to account for lower Reynolds numbers as follows:

Step 1 – Laminar Reynolds Number

Calculate laminar Reynolds number for the flow as described in Step 1 above.

Step 2 – Derive Reynolds Number Fitting Correction

Look up the correction factor F on the following graph:

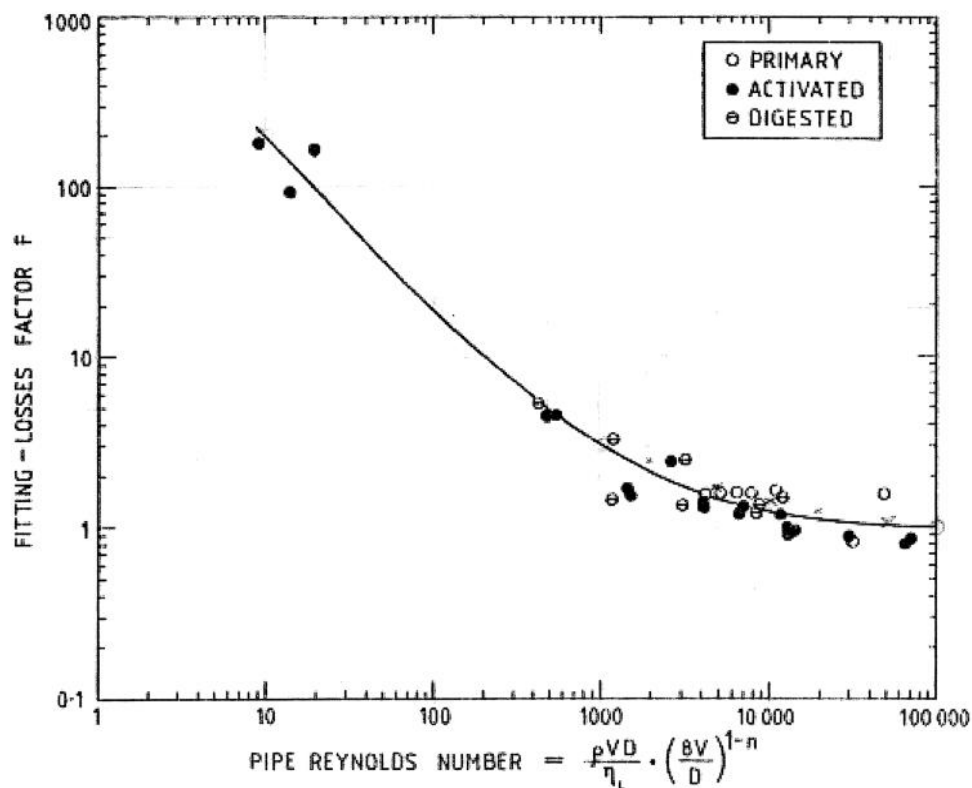


Figure 51 Fittings loss correction factor

Step 3 – Fitting K Factor

Derive the relevant fittings K factor from either Miller or the Manual of British Water Engineering Practice. This is discussed in detail in the hydraulics design module.

Step 4 – Fitting Head Loss

$$h_f = KF \frac{U^2}{2g}$$

where:

h_f = Frictional head loss in metres of liquid [m]

k = k value [dimensionless]

K = Correction factor derived from

Figure 515

U = Flow velocity (Flow/Area) [m/s]

g = Acceleration due to gravity (9.81) [m/s²]

In the authors experience, the above procedure may give unduly high losses particularly at low Reynolds numbers.

4. UNCERTAINTY & HOW TO COPE WITH IT

Figure 4 has shown the form of system curve for a typical sludge, the discussion above has demonstrated how many factors can combine to give significant errors in the prediction. Therefore, the problem is how to design a pump and system that will cope with this uncertainty. In general, a successful system might be defined as one that moves the required quantity of sludge while keeping power demand within rated limits.

Figure 6 below shows how measurement uncertainties might affect the single line prediction of Figure 4. The curve is calculated using data presented by Frost (Ref. 8.4) for sewage sludges and the upper and lower bound curves are based on limits as observed during an extensive series of tests.

Figure 6 clearly shows how uncertainty can be reduced by operating in the turbulent regime or at as higher velocity as practical.

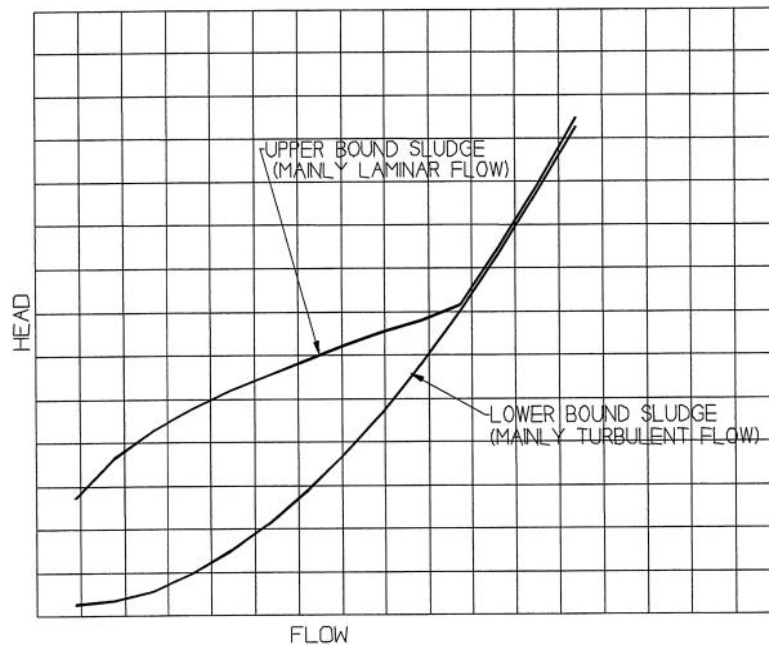


Figure 6 - Upper and lower bound range system curve of typical sewage sludge of 5% dry solids (after Frost)

Figure 7 shows how two rotodynamic pump selections would interact with the system curves shown in. In Figure 6 it will be seen that the steeper Head Flow curve significantly reduces the likely variation in flowrate. An extreme case of this is the use of a positive displacement pump which has an almost vertical head flow curve. This will reduce flow variation to virtually zero at the expense of significant variations in power demand. This may not matter provided the demand does not exceed the installed power.

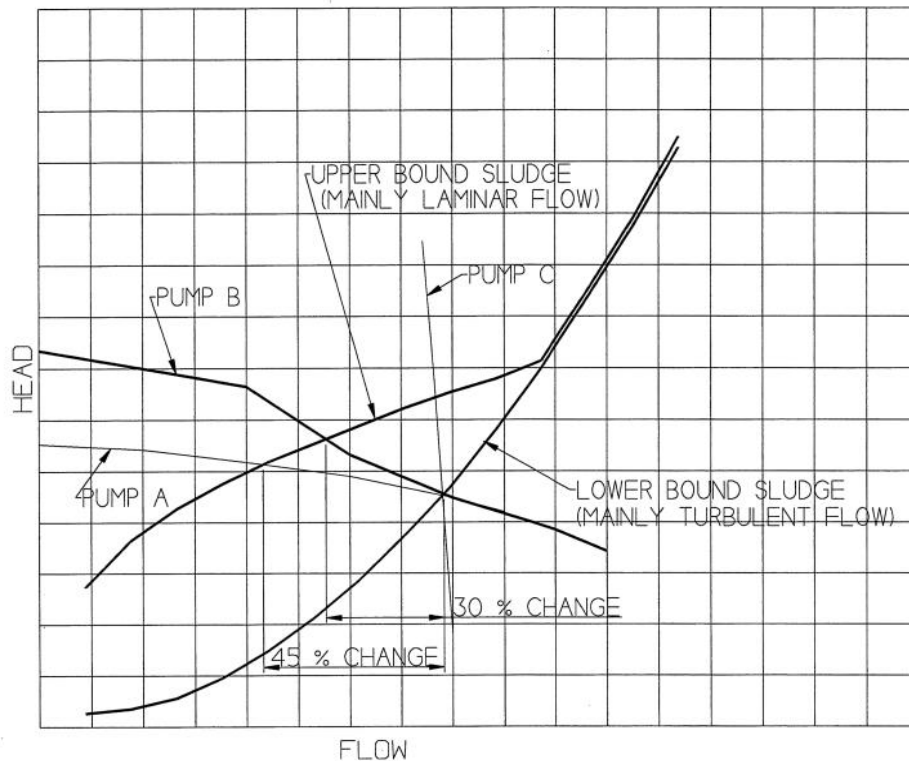


Figure 7 - Effect of sludge viscosity range and pump type on variation in pumped flow.

Clearly, the steeper the pump head flow curve the less flowrate will vary with sludge consistency. However, a rotodynamic pump with a steep head flow curve generally requires a larger impeller for a given duty. This is not generally compatible with good solids handling and a competitive price. Positive displacement pumps are usually more expensive than rotodynamic units and require more maintenance.

Figure 8 shows how the three pumps considered in Figure 7 would perform if selected to operate in the turbulent regime. It will be seen that flow and head variation is relatively small regardless of which pump type is considered. There are two possible conclusions to draw from this:

Pump in the turbulent regime to avoid uncertainty, but accept that sludges will probably have to be unduly "thin" or pumping velocities (and hence powers) will have to be unduly high.

Use of a positive displacement pump is not justified where pipe flow is definitely in the turbulent regime. PD pumps can give an element of certainty for laminar flow systems **provided the pump and drive is adequately rated for maximum head or pressure.**

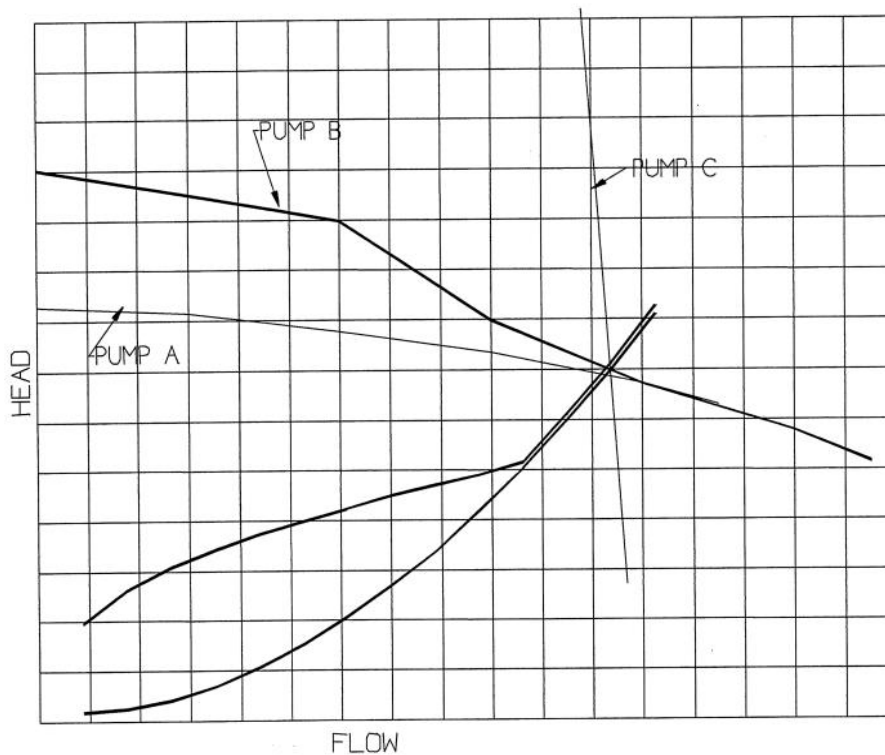


Figure 8 - Showing virtually no influence on pumped flow due to sludge variation in turbulent flow regime.

Thus far, we have considered the effect of uncertainty on the discharge system. However, the same effects apply to the suction system with a possible large effect on Net Positive Suction Head Available to the pump. Also remember that pump NPSH Required may be significantly affected by sludge viscosity.

Gas handling must also be considered and this can induce a type of instability into rotodynamic pump performance. The mechanism of failure is as follows:

A viscous sludge will move the operating point toward lower flows as illustrated in Figure 7

As the pump flow decreases, recirculation flows in the impeller inlet are set up.

Recirculation flows create a spinning vortex in the pump inlet pipe.

The vortex acts to separate dissolved and suspended gas in the sludge.

The presence of the free gas reduces the pump performance and flow reduces further, making the problem progressively worse.

The pump becomes completely vapour locked and ceases to pump.

5. SOME PRACTICAL DESIGN POINTS

The following are some useful pointers gained through experience:

Always provide a lubricating fill prior to filling a pipe with sludge. The wall slippage effect progressively de-waters the leading edge of the advancing sludge into an empty pipe. As the head of the plug thickens, viscosity increases and ultimately blockage will take place.

Design for unblocking. This should include not only rodding points and access holes, but consideration of disposal of unblocked material from pump sumps etc.

Pipes for sewage sludges should be at least 100 mm in diameter. Some authorities have found that blockage is dramatically reduced by using a minimum of 150 mm diameter.

Provide a source of water for dilution adjacent to the pump inlet and in the pump room for possible dilution, emptying of line, flushing down of work area etc.

Ensure a generous power supply with scope for extension to operate stirring devices or upgrading pump power.

Do not rely on the priming performance shown by a new PD pump. Priming performance will degrade rapidly with abrasive wear.

Provide lifting gear or vehicular access into pump intake areas, particularly on lagoon emptying applications. Consider making arrangements for moving the pump to the sludge rather than vice versa.

Ensure that sumps have steeply sloping / benched sides, are generously deep and can be hosed down / cleaned out.

6. REFERENCES

1. Dodge, D.W., Metzner, A.B. - Turbulent flow of non-Newtonian systems", A.I. Ch.E. J.52, pp189-204, (Jun 1959).
2. Kemblowski, Z., Kolodziejski, J. - Flow resistance of non-Newtonian fluids in transitional and turbulent flow. Int. Chem. Engng., 13, 2, pp 265 - (Apr. 1973)
3. Miller, D.S. - Internal flow systems 2, Publ. Elsevier (1990)
4. Frost R.C. - How to design sewage sludge pumping systems. Publ. WRC Process Engineering, TR 185. (1981)

TABLE 1 – DESCRIPTION OF RHEOLOGICAL EFFECTS

NAME OF EFFECT	DESCRIPTION	PRACTICAL IMPLICATION
Solids content	Most sludges change parameters with changing solids. Generally a higher solids means a more viscous sludge.	Seasonal or daily variation in solids give dramatic changes in rheology. Minor changes in solids content at laboratory scale (evaporation or accidental dilution) can give large errors in test results.
Shear thinning or "Thixotropy"	Often confused with pseudoplasticity, but taken here to refer to progressive decrease of apparent viscosity with prolonged shear. Time dependence.	Sludges are easier to move if they have been agitated. Viscometric results depend on the past shear history of the sample. Has the sample been repeatedly stirred and tested?
Time dependant thickening	Sludge develops a more marked "gel" structure with time. Typically exhibited as increased yield stress.	A full pipeline will thicken up, requiring a higher pressure to start flow again after prolonged shutdown.
Wall slippage	A layer of dilute sludge (water) is generated at the wall by the action of the high shear stress at that point. The plug of sludge is lubricated by the water layer at the wall.	Also affects viscometric results. The effect tends to be greater on small scale tests, hence scaling up test results can give dangerous errors. Often exhibited as a progressive fall of rotational viscometer readings with time, which can be reversed by stirring the sample. Alternatively, results may depend on surface roughness of viscometer equipment.
Surface chemistry	Floc particles are affected by changes in surface charge between particles. Hence minor changes in chemistry (e.g. pH value, surfactants, polyelectrolytes etc.) can have massive effects on rheology.	Industrial control of thickening processes is not a precise science. Daily or seasonal variations in sludge are likely.
Temperature changes	Similar change to most Newtonian liquids.	One of the easier effects to cope with.

Table 2 from Frost, R.C. giving correlations of sludge properties with dry solids content.

Variation of flow parameter values with suspended solids concentration for five broad types of sewage sludge

Sludge type	Parameter	Prediction equation					
		Upper bound		Median		Lower bound	
Primary and primary plus humus	η_L	0.039	SS ^{2.82}	0.011	SS ^{2.82}	0.0032	SS ^{2.82}
	n	0.53	SS ^{-0.172}	0.55	SS ^{-0.172}	0.57	SS ^{-0.172}
	η_T	0.00077	SS ^{1.58}	0.00056	SS ^{1.58}	0.00041	SS ^{1.58}
	R	0.067	SS ^{2.72}	0.039	SS ^{2.72}	0.023	SS ^{2.72}
Primary plus activated	η_L	0.064	SS ^{3.00}	0.019	SS ^{3.00}	0.0056	SS ^{3.00}
	n	0.51	SS ^{-0.184}	0.53	SS ^{-0.184}	0.55	SS ^{-0.184}
	η_T	0.0010	SS ^{1.68}	0.00076	SS ^{1.68}	0.00057	SS ^{1.68}
	R	0.11	SS ^{2.90}	0.066	SS ^{2.90}	0.039	SS ^{2.90}
Activated	η_L	-	-	0.22	SS ^{2.58}	-	-
	n	-	-	0.48	SS ^{-0.158}	-	-
	η_T	-	-	0.0020	SS ^{1.45}	-	-
	R	-	-	0.35	SS ^{2.49}	-	-
Anaerobically digested	η_L	0.019	SS ^{3.50}	0.0055	SS ^{3.50}	0.0017	SS ^{3.50}
	n	0.55	SS ^{-0.214}	0.57	SS ^{-0.214}	0.59	SS ^{-0.214}
	η_T	0.00051	SS ^{1.81}	0.00038	SS ^{1.81}	0.00028	SS ^{1.81}
	R	0.033	SS ^{3.37}	0.020	SS ^{3.37}	0.012	SS ^{3.37}
Humus (information based on 2 tests on one sludge only)	η_L	-	-	0.0026	SS ^{4.47}	-	-
	n	-	-	0.38	SS ^{-0.072}	-	-
	η_T	-	-	0.00027	SS ^{2.16}	-	-
	R	-	-	0.00026	SS ^{6.00}	-	-

SLUDGE PUMPING

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Presented by: Tony Salisbury

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SLUDGE

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- Sludge is a by product of clean and waste water treatment processes.
- Consistency can vary from near water to near solid.
- May contain large solids.
- May contain gas, both free and dissolved.
- May be bio-active.
- Generally non-settling.

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SLUDGE VISCOSITY

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- Non Newtonian
- Shear thinning
- Time dependent

- BUT MOST OF ALL:
- **VISCOUS (THICK & GOOEY)**
- **VARIABLE (NEVER THE SAME TWICE)**

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TO DESIGN A SLUDGE SYSTEM

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- FIRST
 - Know your sludge.

- HOW DO YOU GET TO KNOW A SLUDGE
 - Test it.

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SLUDGE TESTING

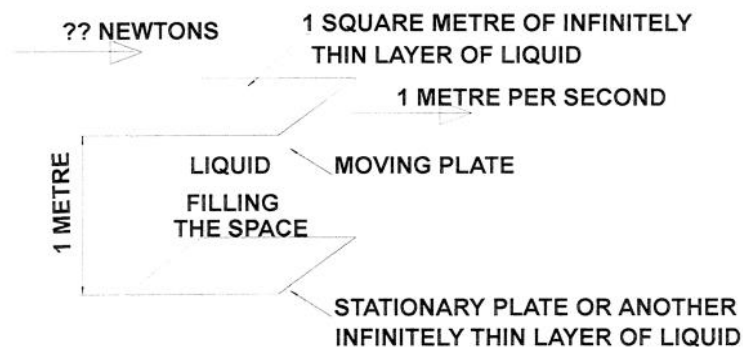
- To test a sludge, you need a **representative** sample.
- Not coloured water from the top.
- Not the solid yuk from the bottom.
- Not a sample that has been stored for weeks, months, years.
- A range of fresh samples covering depth, time, plant operating condition, season, etc.
- All this needs **TIME MONEY & RESOURCES.**

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VISCOSITY

- **Absolute viscosity.** Typical units: Newton seconds per square meter, Pascal seconds, Poise, Centipoise.



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NEWTONIAN VISCOSITY

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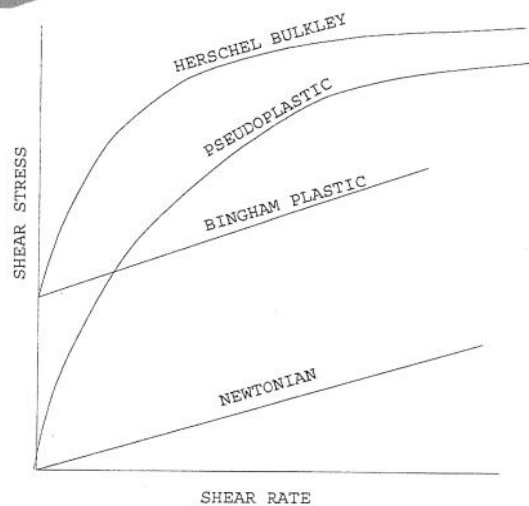
- Resistance to Flow (Shear Stress) is **PROPORTIONAL** to Rate of Flow.
- The constant of proportionality is viscosity.
- Since only one constant describes the full behaviour, only one value (The Newtonian viscosity) is needed.

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NON-NEWTONIAN VISCOSITY

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SLUDGE TESTING

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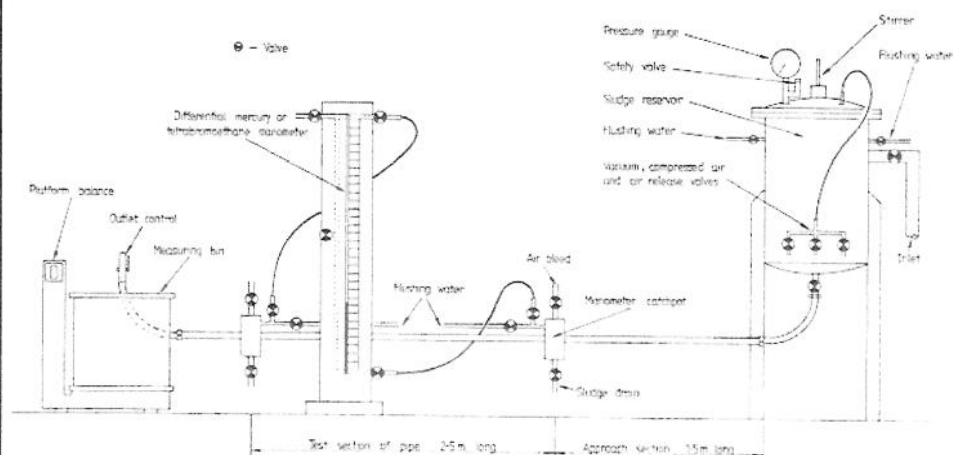
- Viscosity test
 - Must investigate viscosity over a range of shear rates.
 - Should use similar shear rates to the intended system.
 - Should investigate time dependent and shear thinning regimes.

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TUBE VISCOMETER

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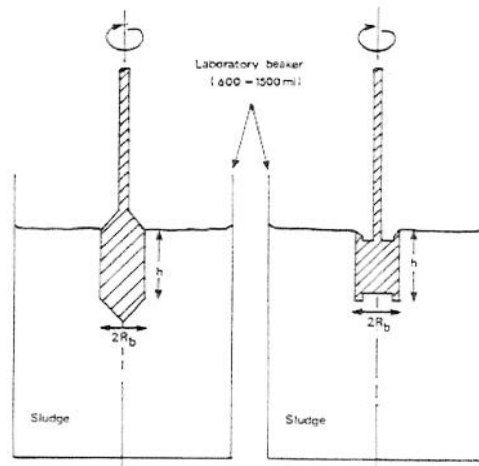


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ROTATIONAL VISCOMETER

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SLUDGE FLOW EFFECTS

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- Solids content
- Shear thinning or "Thixotropy"
- Time dependant thickening
- Wall slippage
- Surface chemistry
- Temperature changes

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SLUDGE TESTING TRAPS

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- Unrepresentative samples
- Unskilled test personnel
- Testing over a shear rate range not relevant to the final design.
- Extrapolating data widely
- Ignoring time dependency, shear thinning & wall slippage.

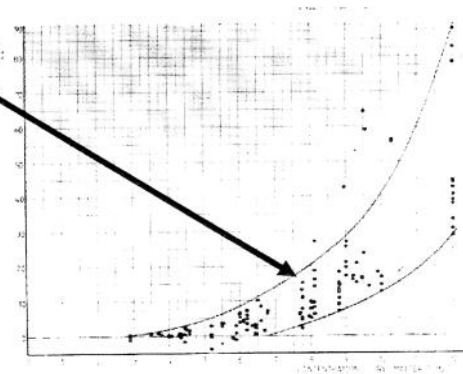
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ESTIMATION OF SLUDGE PROPERTIES

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- Based on correlation of tests on other sludges.
- Wide scatter in the data.
- Usual approach is to correlate against solids content.
- An alternative would be to correlate against "Nominal Compressive Pressure".



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CALCULATION TO TR 185

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- An industry standard document. Based on a 3 year series of tests and involving Water Research Centre, BHRA, Warren Springs Laboratory, Pump Manufacturers.

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SLUDGE PROPERTIES

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Variation of flow parameter values with suspended solids concentration for five broad types of sewage sludge

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	R	0.067	$SS^{2.72}$	0.039	$SS^{2.72}$	0.023	$SS^{2.72}$
	η_L	0.064	$SS^{3.00}$	0.019	$SS^{3.00}$	0.0056	$SS^{3.00}$
Primary plus activated	n	0.51	$SS^{-0.184}$	0.53	$SS^{-0.184}$	0.55	$SS^{-0.184}$
	η_T	0.0010	$SS^{1.68}$	0.00076	$SS^{1.68}$	0.00057	$SS^{1.68}$
	R	0.067	$SS^{2.90}$	0.039	$SS^{2.90}$	0.023	$SS^{2.90}$

$$PROPERTY = A \times SS^B$$

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LAMINAR REYNOLDS NUMBER

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$$\text{Re}_{lam} = \frac{\rho U D}{\eta_l} \left[\frac{8U}{D} \right]^{1-n}$$

If $\text{Re}_{lam} < 2300$ flow is definitely laminar
If $\text{Re}_{lam} > 4000$ flow is definitely turbulent
If between these limits calculate both laminar and turbulent losses and take worst case.

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TURBULENT REYNOLDS NUMBER

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$$\text{Re}_{turb} = \frac{\rho U D}{\eta_t}$$

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LAMINAR FRICTION FACTOR

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$$f = \frac{64}{Re_{lam}}$$

For circular pipes
Only applicable to low Reynolds numbers.

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TURBULENT FRICTION FACTOR

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$$f = \frac{0.25}{\left(\log_{10} \left(\frac{k_s}{3.7 D} + \frac{5.74}{Re_{turb}^{0.9}} \right) \right)^2}$$

Can also use Moody chart.
Only use Re_{turb} in this equation.

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HEAD LOSS - FRICTION

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$$h_f = f \frac{L}{D} \frac{U^2}{2g}$$

Take worst case f from laminar and turbulent cases if Re is in transitional regime.

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FITTINGS LOSS

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- Look up K factor for relevant fitting using Miller or BWETPA values.
- Apply factor, F , to account for laminar flow.

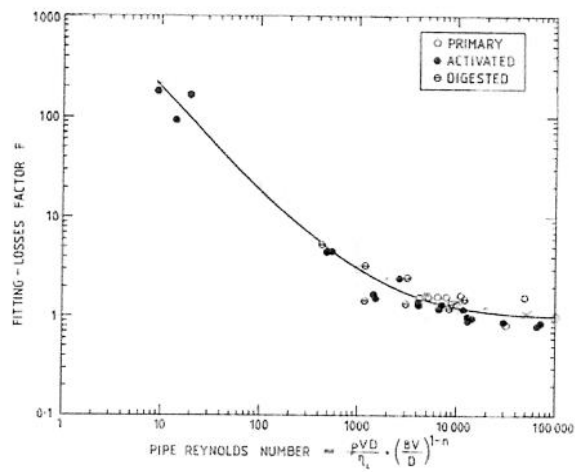
$$h_f = kF \frac{U^2}{2g}$$

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FITTINGS LOSS CORRECTION FACTOR

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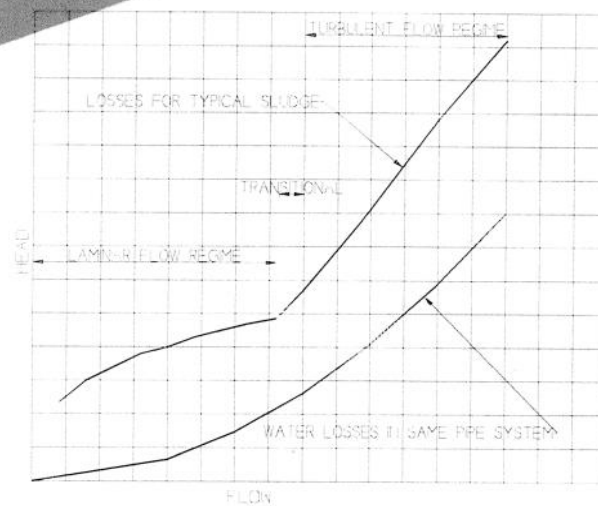


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SLUDGE SYSTEM CURVE

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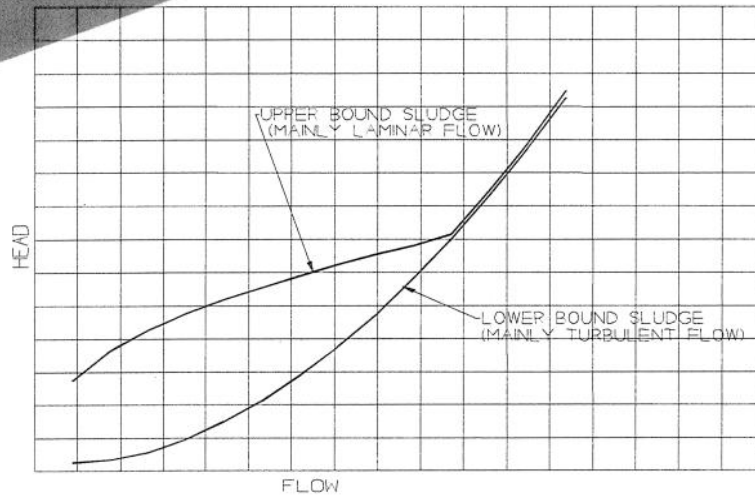
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FIGURE 2 - ILLUSTRATION OF TYPICAL SLUDGE SYSTEM LOSSES COMPARED TO WATER LOSSES

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THICK & THIN SLUDGE

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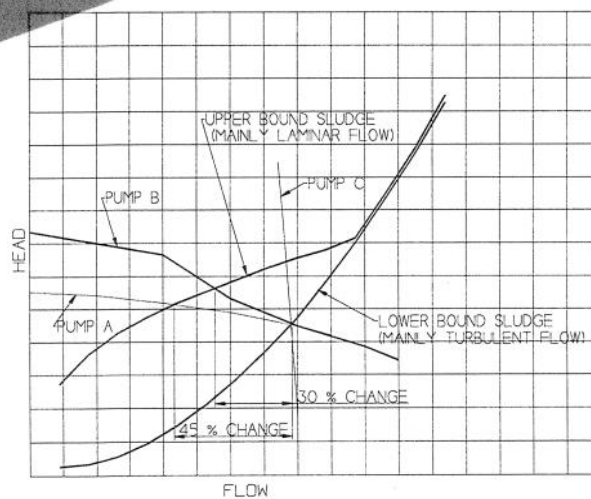


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FLOW VARIATION - 1

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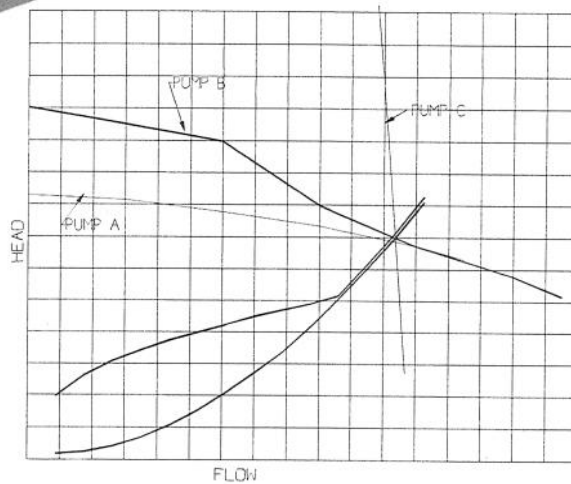


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FLOW VARIATION - 2

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UNCERTAINTY

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- Sludge properties vary widely - even on a single sludge.
- Pumping in turbulent flow regime tends to reduce flow variation.
- Use of PD pump reduces flow variation.
- Cost reduction suggests rotodynamic pumps in laminar flow system.
- What is effect on whole process of possible variations?
- Can your design cope?

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GAS HANDLING

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- Viscous sludge - - - - lower flowrate
- Decrease flow - - - - impeller inlet re-circulation
- Vortex at pump inlet - - - - spins gas out of dispersion.
- Gas reduces pump performance.
- Reduced pump performance - - - -lower flowrate.
- More gas
- Complete pump blockage with gas.

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PRACTICAL POINTS

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- Provide lubricating fill of pipe prior to sludge.
- Design for unblocking.
- >DN 100 or >DN 150.
- Provide a source of dilution liquid.
- Generous power supply.
- Do not rely on priming performances.
- Provide access into intake or sump.
- Take pump to sludge (not vice versa).
- Provide very steep benching in sumps.

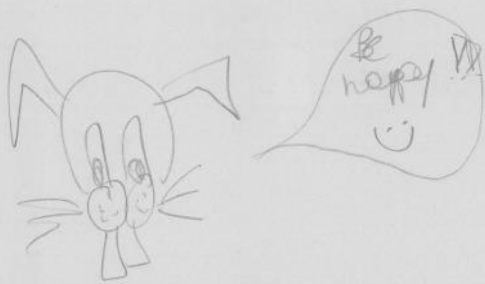
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PUMPING STATION DESIGN

Mr Peter Clark

j'en ai merre



j'en ai r

PUMP STATION DESIGN

1. DESIGN STEPS

Designing a complete pump station can be a complex task with many conflicting factors to optimise. However, the following is suggested as an outline to the design process:

Assess the proposed site and consider in what form the liquid enters the site; e.g. borehole, sewer, pipe from a process unit etc.

Assess where the liquid is to be delivered to.

Calculate flows to be handled. Select appropriate velocities for delivery pipework and make an initial estimate of pumping head required.

Consider the control requirements, and in particular the minimum flow to be pumped.

Make an initial estimate of number of pumps to achieve this required turndown from maximum flow.

From a knowledge of flow and head estimate pump type number from type number formula. Make alternative assumptions for numbers of parallel pumps, running speed, series pumping to achieve a pump type number that can be purchased and gives reasonable efficiency.

Check typical NPSH requirements using concept of suction specific speed formula (See above). Check if this NPSH would be suitable for proposed position of liquid relative to pump. If it is not, revise the pump position, running speed or number of pumps.

Calculate typical pump powers using formula:

$$Power = \frac{\rho g H Q}{\eta}$$

where:

- ρ = Liquid density [kg/m³]
- g = Acceleration due to gravity [m/s²]
- H = Pump Head
- Q = Pump Flow
- η = Pump Efficiency [Ratio]

Pump efficiency will vary depending on the type of pump, but for typical water industry usage, values of between 0.5 for a small pump but for larger units peak efficiencies indicated in the figure below **Error! Reference source not found.** would be appropriate. Further additions to installed power must be made to account for a power margin (at least 10%), power to cover the complete pump curve (another 10 %) and inefficiency of the drive (a

further 10 %). This gives a rough, but usable estimate of installed power which can be refined when pump quotations are available.

Calculate pipework and component sizes to give typical velocities. Allow 1.5 m/s on inlet side of pumps, 2 – 3 m/s for pump discharge valves, 1 – 1.5 m/s for rising main.

Consider what form of discharge arrangements will be used. Principal options are:
Combined discharge into a manifold, with each pump having an inlet isolating valve, outlet check valve and outlet isolating valve.

- Outlet by siphon into open tank
- Outlet by upturned pipe into open tank
- Outlet by flap valve

Select a standardised sump arrangement to estimate the required sump sizes, submergence values etc. For large plant this should always be the subject of a model study.

Check whether the sump has sufficient volume to allow an acceptable control regime for the pumps.

Consider the layout of structures above the ground to house:

- Pump drives & control panels.
- Transformers, electricity sub-stations
- Valves, Manifolds, Pipework etc.
- Surge suppression equipment (vessels, compressors, flywheels etc.)
- Standby generation, if required.
- Cranes for installation and maintenance.
- Workshops, Accommodation & mess facilities.
- Car parking space
- Vehicular access
- Screens, trashracks, chemical dosing, ventilation, odour control, etc. etc.

Check that pump inlet pipework arrangement gives good approach flow to pump and has no high spots.

Iterate the above process and optimise the design as required.

2. BASIC OUTLINE OF SUBMERSIBLE AND DRY WELL PUMP STATIONS

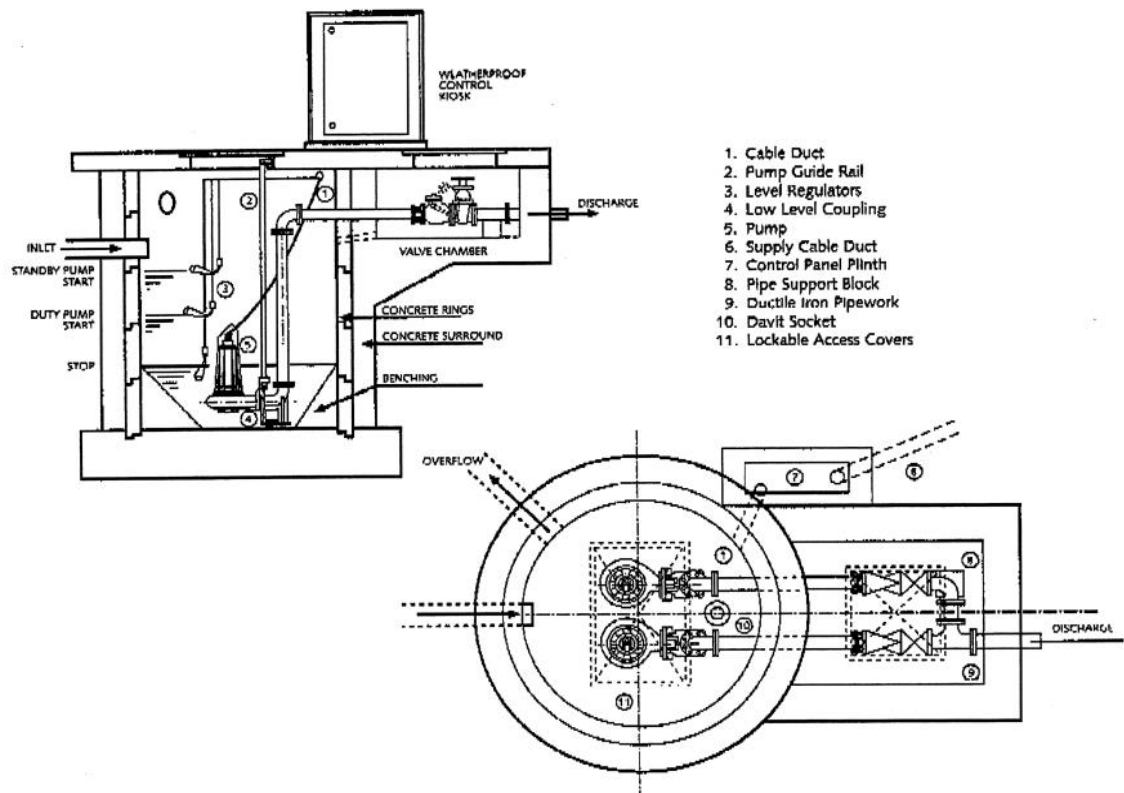


Figure 2 - Small submersible pump station

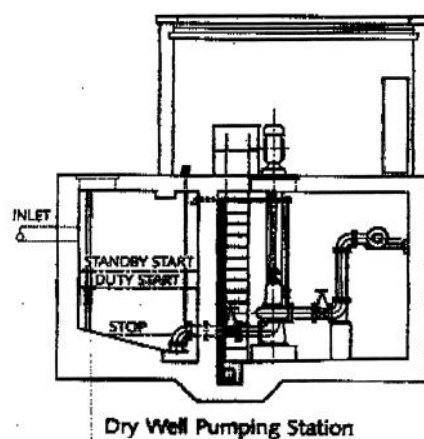


Figure 3- Small dry well station

3. PUMP STATION DESIGN – DETAIL POINTS

3.1 Lifting Equipment

In large indoor stations specify a traversing crane with motorised lift function. Handwheel & chain operation of the XY functions is adequate for the limited use it will see.

For outdoor submersible stations specify a davit & socket as an absolute minimum. Vehicle mounted lifts seem an attractive option, but are seldom available when needed. For large outdoor submersibles an overhead lifting beam is better than handling large davits. There is some variation on the health and safety implications for testing submersible pump lifting equipment, particularly submersible chains and lifting brackets. Be clear what the corporate policy and local inspectorate views are before specifying.

3.2 Valves & Pipework

Suction pipework must be continually rising – use flat top tapers and manifolds.

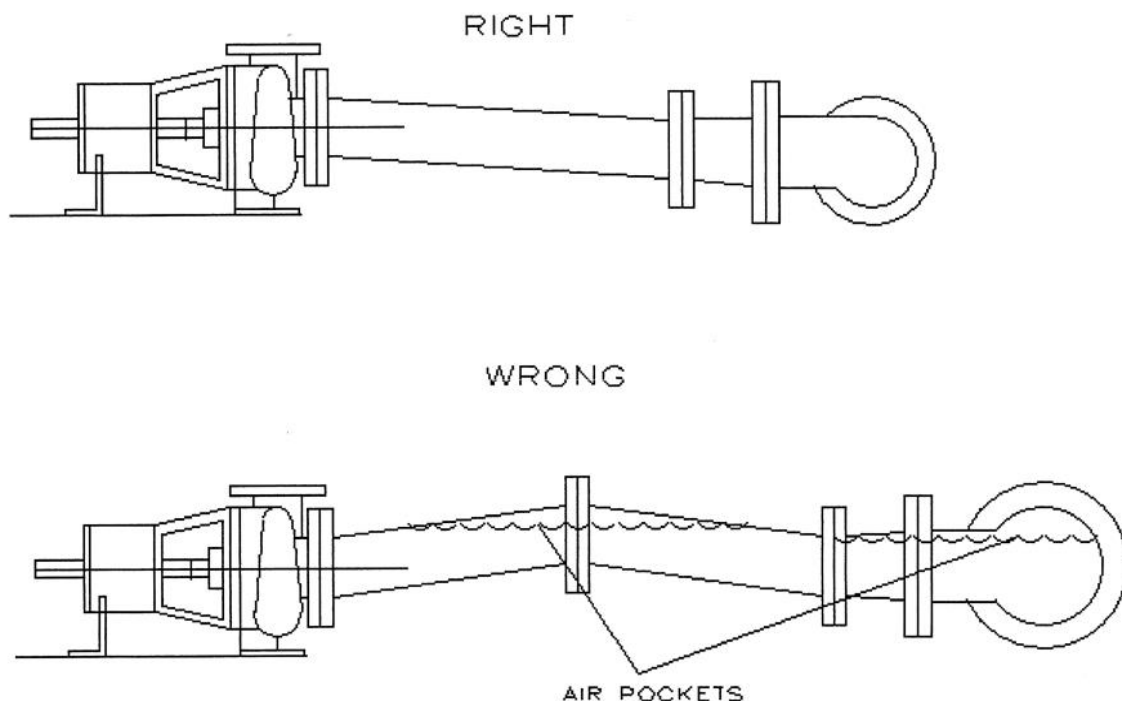


Figure 4- Points to watch on suction pipework

Suction manifolds can induce inlet swirl just as a sump can. A model test is the only sure way to avoid problems.

Pump Isolation valves – actuators and headstocks for these look very impressive but do not give good value for money, since they should be used infrequently. Use handwheels wherever possible. Actuators are quite a good solution for valves that cannot be reached easily.

Keep discharge manifolds at low level if possible. This is easier to erect, easy to get access to valves and easier to provide adequate pipe restraint for surge.

Duckfoot bends after pump discharge are very prone to vibration, loss of grout and pipework loosening. Always drill and anchor the duckfoot to the concrete plinth. Keep the plinth at least 50 mm larger than duckfoot on all sides. This component has to resist surge waves which cannot be contained by flanged or tied pipework. These bend in particular need to be tied down to concrete.

Check valves – Use fast acting (“recoil”) check valves if:

Multiple pumps are in use.

Surge vessels are used.

Wafer check valves are compact but tend to be slow closing which can give rise to valve slam. Avoid them if possible & do not use for multiple pump installations. Head losses through these devices can also be high.

Ensure that the discharge isolation valve and discharge check valve are bolted solidly onto the discharge manifold without any VJ couplings etc. in the run. These items must still retain pressure if a pump is removed for maintenance.

Put at least 0.5 m of pipe with VJ couplings at both ends in each pipe run for a single pump. This will take up pipe and pump misalignment in X, Y and Z planes. At least one VJ coupling in the pump inlet pipe will allow the pump to be levelled, taking up misalignment in puddle pipe installation.

Ensure that pipes are adequately supported. The supports must be at such a spacing to avoid resonance of the pipework. Supports at changes of direction will also have to resist surge waves. Assume an unconstrained pressure equal to the maximum surge pressure.

Suction bends with handholes for unblocking vertical shaft dry well sewage pumps are useless. If horizontal pumps are used, a short length of pipe with a VJ coupling immediately upstream of the pump can be easily removed to gain access for unblocking.

Do not forget a drain line for the rising main / manifold back to the wet well.

Allow at least 500 mm (700 mm preferred) between pipes and pumps to allow access for maintenance and installation.

3.3 Gauges & Instrumentation

Gauges never last well in position, and an inaccurate gauge is useless. Specify & fit gauge points with valves on each pump before the pump check valve. Have one set of gauges per station & keep them in a safe place. The gauges will then be available for commissioning and troubleshooting and will have a reasonable chance of remaining accurate. A blanked boss on the rising main before it leaves the station is useful in case it is needed for gauges during troubleshooting operations.

Permanently installed gas monitoring is not very reliable. Portable personal meters are a better choice unless there are special problems with gas.

3.4 Air Release Arrangements on Pumps

These are not to be confused with rising main air release arrangements. Pump air release valves will usually be approximately DN 40 diameter or less.

Specify pump air release valves on:

Dry well sewage installations – both conventional and submersible style pumps.

Clean water installations – particularly top areas of vertical spindle pumps to ensure seal is free of air.

Top of casing in split case pumps.

Air release is not usually required on submersible pump discharges. However, a blanked off boss on discharge pipework enables fitting of air release during commissioning if found necessary. Pump air release pipework should return to the wet well above top water level for below ground installations. Each pump should have a dedicated air release pipe. Air release for sewage must be at least DN 25 mm, direction changes should be made using cross pieces blanked on two sides for rodding out.

3.5 Electrical Arrangements

Specify a junction box near to the wet or dry well for submersible pumps to allow termination of the rubber cab tyre cable and change to permanently installed SWA cable. This junction box can also be used to site the emergency stop. Site this junction box above flood level if possible.

3.6 Sump Pumps

Small sump pumps for draining dry wells have a very short life due to blockage. All manner of rubbish will get into the sump – litter, nuts & bolts, gloves, hard hats etc. Fit a screen to keep debris away from the sump pump. Include a dry well level alarm linked to the telemetry system to warn of sump pump failure.

3.7 Ventilation

Specify the minimum requirement for sewage stations. The exhaust will probably have to be odour treated, and this plant can be large and expensive for large air flows.

Allow venting for wet wells – base the size on the maximum inflow and select the vent pipe on 20 m/s air velocity. This discharge will also need odour treatment in sensitive areas.

3.8 Intermediate Bearing Support Structures

The design of structures such as bearing supports for intermediate drive shaft bearings must be such that the natural frequency of vibration of the structure and its component parts do not coincide with the running speed of the pumps. This may require specialist design advice. Remember that concrete floors can also vibrate.

PUMPING STATION DESIGN

1. General

Too often pumping stations are designed by structural engineers or general civil engineers but the first priority of the design of a pumping station must be to get the hydraulics right. If the station does not deliver the required flow at the required head then the design has failed however well constructed the building and efficient the layout might be. This session will concentrate mainly on the hydraulic issues but there are many other matters that must not be forgotten. At the end of these notes there is a check list covering some of the issues that must be addressed.

Issues that tend to get overlooked initially but are essential to the efficient operation of a station include:-

- Piping and valving requirements
- Do pumps need building at all or can they be external and weather-proofed
- Access to the station and around pumps and to pipework and valves for maintenance
- Surge protection
- Provision of power and requirements for cabling
- Control needs and space for control panels
- Lifting requirements for maintenance of pumps
- Vehicle access for bringing in and removal of heavy equipment.
- Potential vibration
- Noise issues

Perhaps the biggest and certainly the most common mistake made at the initial design stage is to make the station too small. **DO MAKE SURE YOU ALLOW PLENTY OF SPACE!**

There are three main station arrangements:-

- Open-sump stations with the pumps in an adjacent dry well
- Open-sump stations with the pumps located in the wet well
- Stations with long lengths of suction pipework such that the effect of the open surface of the tank or reservoir from which the flow is drawn is negligible. These may be drawing from a storage tank some distance away or be an on-line booster station where the suction pressure is maintained by an upstream pumping station.

2 Pumping Stations with an Open Sump – A Wet Well Arrangement

The Hydraulic Requirements with an open sump include:-

- Sufficient volume is provided to allow control system to work satisfactorily;
- Swirl (pre-swirl) entering pumps is not excessive – min submergence requirements are generally defined to try and control pre-swirl;
- Vortices around the pump intake are not present;
- Air bubbles are not carried through to the pumps;

And for wastewater and drainage pumping stations

- Sediment does not build up in the sump of wastewater stations but is carried through to the pumps;
- Floating material does not build up into heavy mat;
- Rags do not build up in sump or jam in the pumps;

Thus for the efficient working of the station

- Correct choice of pump – vitally important and the theme of much of this week's course
 - Good suction conditions
 - Pump NPSH Requirements met
 - Minimal swirl in pump intakes
 - Smooth, uniform flow approaching pumps
 - Gently accelerating, uniform flow into the pump intakes
 - No air drawn in to pumps
 - In sewage pumping stations rags and sediment carried through to the pumps – not deposited in sump.

There is surprisingly little guidance on the design of pump sumps. The main references are:-

- *The Hydraulic Design of Pump Sumps and Intakes*, MJ Prosser, BHRA/CIRIA, 5th impression 1985; (useful but somewhat out of date)
- *American National Standard for Pump Intake Design*, Hydraulic Institute, AMSI/HI 9.8-1998; (the most widely quoted reference)
- *Design Recommendations for Pump Stations with Large Centrifugal Wastewater Pumps*, ITT Flygt Ltd.
- KSB also have useful design guidance

Control of fixed speed pumps

Fixed-speed pumps are usually controlled on a level basis with the pumps switching on at high level as the water level in the sump rises and turning off at low level as the sump empties as illustrated in Figure 1.

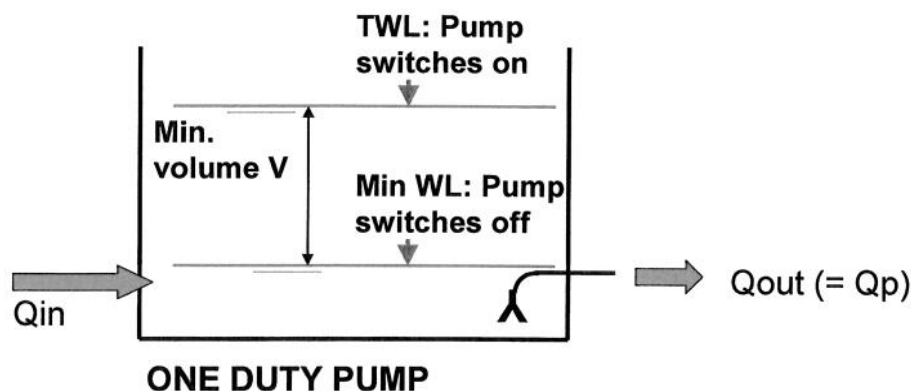


Figure 1 Control of single fixed-speed pump

There are various ways of setting these control levels for multiple pumps, usually in a cascade sequence as illustrated in Figure 2 or some variation of this simple arrangement – e.g with pump 2 switching off at higher level than pump 1.

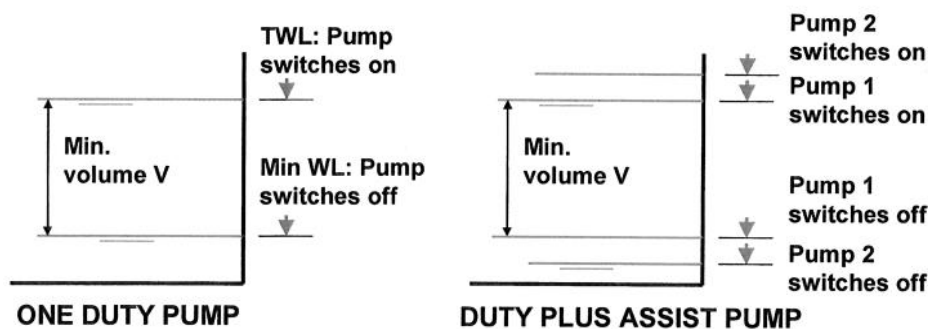


Figure 2 Control of multiple fixed-speed pumps

The minimum sump size necessary to control pumps in this way is a function of the individual pump capacity, Q_p , and the maximum frequency with which pumps can be turned on and off. With small pumps that might be as much as 15 or 20 times an hour. With large pumps and motors it might be as little as twice an hour.

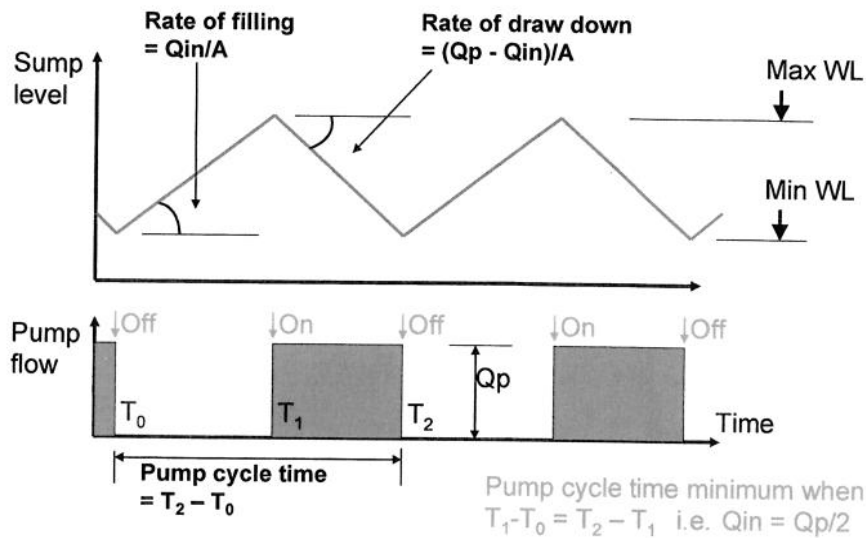


Figure 3 Minimum sump calculation

Figure 3 shows the calculation of minimum sump size which leads with a simple calculation to the result:-

Minimum sump volume: $V_{min} = Q_p \cdot T/4$ where T is the minimum cycle time of the pump and this remains the requirement for a multi-pump arrangement as illustrated in Figure 4 but there is the added need for the volume to provide adequate depth between control levels.

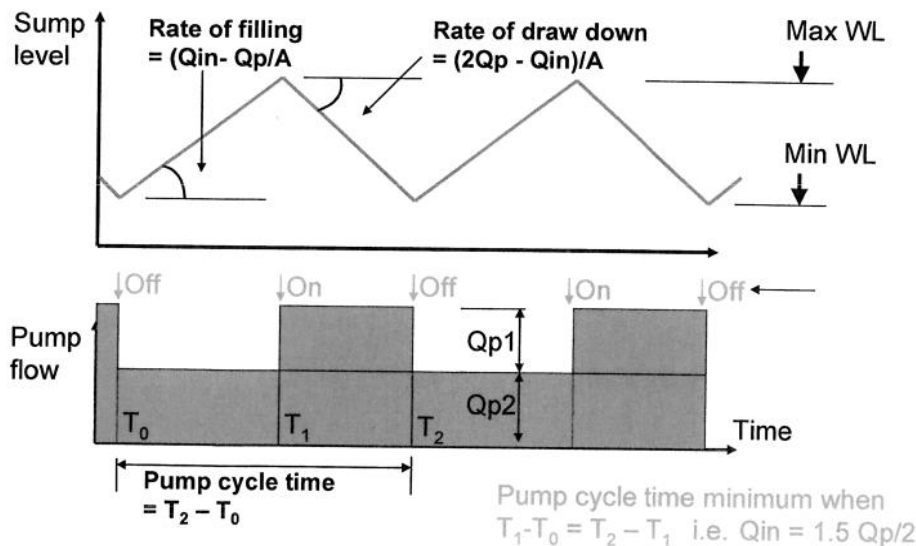


Figure 4 Minimum sump volume for two-pump arrangement

Figures 5 and 6 illustrate two level systems for controlling fixed-speed pumps.

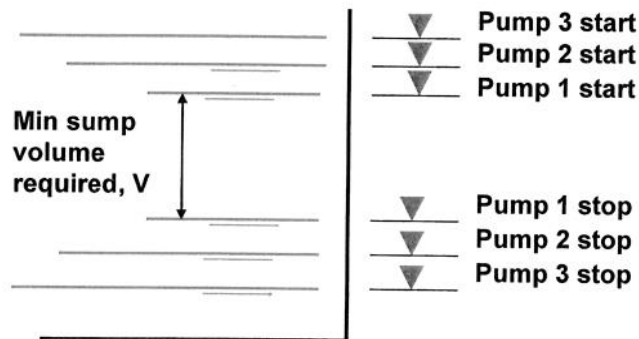


Figure 5 Typical level cascade control

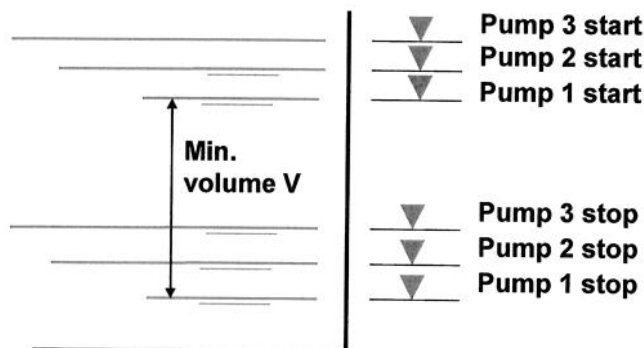


Figure 6 Alternative level cascade system

In the system illustrated in Figure 5, as the sump fills so Pump 1 will turn on first and if the pump capacity is greater than the inflow then the level will fall and pump 1 will turn off again. So at the simplest level Pump 1 will cycle on and off with the other pumps remaining as 'assist' and only operating if the inflow exceeds the capacity of the single pump. The minimum volume is required between the start and stop levels for Pump 1 but the cycle times can be increased by switching the pump duties so that after 1 cycle on and off for Pump 1, the pumps designations are switched so that Pump 2 become Pump 1 and switches on the next time the level rises to Pump 1 start.

The same basic concepts apply to the arrangement shown in Figure 6 but the minimum volume requirement is now between the lowest start level and the lowest stop level.

There are a few other considerations that must be taken into account:-

- How are you going to measure level?

Level switches possibly – but in sewage PSs such switches can get ragged up and covered in grease and slimes. Ultrasonic measurement (?) – but again in sewage pumping stations the surface blanket of floatable material may affect reading. Pressure transducers are another possibility – but some doubts as to reliability. Although less so these days.

- Need reasonable bands between level control switches. Surface turbulence may give rise to instability in pump control and again in sewage PSs surface mat may give errors in readings.

- Area of sump not particularly critical in clean water stations but in sewage pumping stations too large a sump will give rise to problems of sedimentation and possible septicity if areas of slow moving water.

There is a rule of thumb criterion that has been found to apply fairly well to the area of sewage pump sumps:-

Area 'loading' between 35 and 45 l/s/m² (But this is not always easy to achieve)

Control of variable-speed pumps

Variable –speed pumps in theory allow a much smaller sump and are often operated on the basis of matching pump output to the inflow – in effect trying to maintain a target level in the sump. In theory this is possible but in practice it is not always so easy and at the very least an operating band must be allowed.

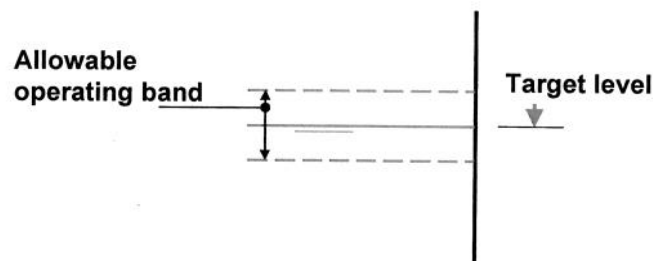


Figure 7 Target level control

There are many ways of controlling variable-speed pumps even in trying to achieve a target level control. The usual way though is what is referred to as PID control: Proportional, Integral, Derivative control. The problem with trying to maintain a fixed level is that, for example, if the inflow increases the water level will rise and the pump must speed up to give a higher output. However, it is not straightforward as to how much the speed should be increased. If a simple linear relationship is applied between speed and the 'error' in the water level (compared to the target value) then it is quite likely the system will go unstable, the pumps will speed up too much, the water level will drop and the pumps will overcompensate in reducing speed again. To try and overcome this type of instability the PID control provides a more sophisticated error correction in which the change in speed is a function of the linear error (Proportional), the rate of change of the water level (the Derivative term) and the excess volume of water that must be removed to achieve the target level (the Integral term).

This form of control is widely used but the complications come when switching pumps on and off. Figure 8 illustrates one approach when switching from one pump to two.

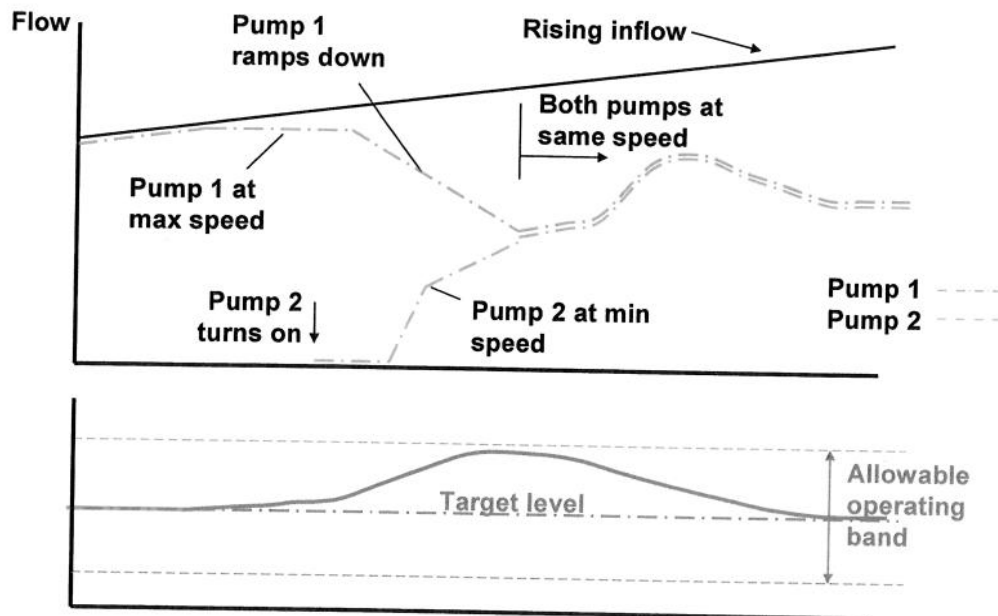


Figure 8 Variable-speed pump control – switching on a second pump

Consider Pump 1 slowly speeding up as the inflow increases. At some point, if the flow continues to increase, it will reach its maximum speed. The second pump should not immediately turn on as it needs to be confirmed that the flow is continuing to increase and is not a short term 'blip'. The water level will start to rise as the inflow increases above the capacity of Pump 1. After some delay – say 30 seconds – pump 2 switches on and runs up to a speed at which it starts to deliver flow – the minimum flow condition. The speed of Pump 2 continues to increase while the speed of Pump 1 is dropping to match that of Pump 2. During this period the total pump output may be significantly less than the inflow so the water level is rising well above the target level. Eventually the two pumps match speed and can now work together to correct the drift that has occurred in the water level away from the target level. Depending on how the controls have been set up and what rates of change of speed and the relative times at which changes are initiated, it can be difficult to keep the level within the allowable target band.

Sump Hydraulic Design

Swirl

Swirl – also known as pre-swirl – is one of the important parameters in sump design that must be minimised. It is the mass rotation of the fluid entering the pump suction. Generally, though there are exceptions, pumps are designed to most efficient with the flow passing through to the impeller axially. If that flow is rotating then the angle at which the impeller blades cut the flow is altered. If the rotation of the fluid is such as to increase the angle then the pump efficiency will fall and the power requirement will increase. If the rotation decreases the angle then not only will the efficiency fall but the likelihood of cavitation increases with all the attendant problems.

A few comments about swirl:-

- It is caused by the flow patterns in the sump – not by the pumps themselves.
- It is defined as the angle with the axis of the pump made by the flow as it spirals into the pump intake. i.e. $\tan^{-1}$ of the ratio of the circumferential velocity to the axial velocity.
- Most pump suppliers accept a swirl angle of no more than 50, but for some types of pump a lower value is necessary.
- It is generally caused by asymmetric flow approaching the pumps. Hence anything in a sump that encourages such flow patterns is to be avoided.

Figure 9 shows design of pumps umps that will inevitably give rise to swirl at the pump inlets.

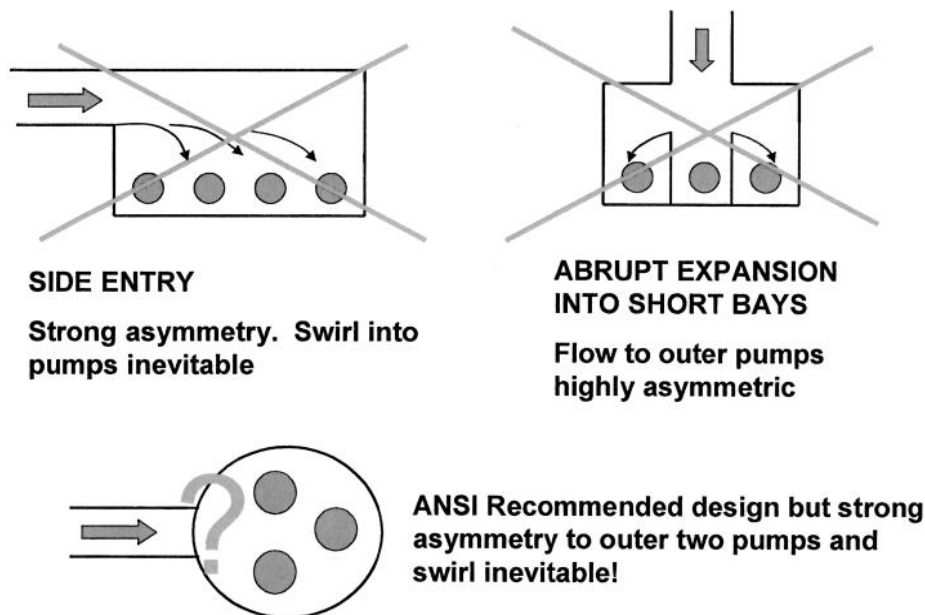


Figure 9 Poor arrangements of pumps sumps likely to give rise to swirl

Figure 10 shows some arrangements that can be use to overcome some of these problems:-

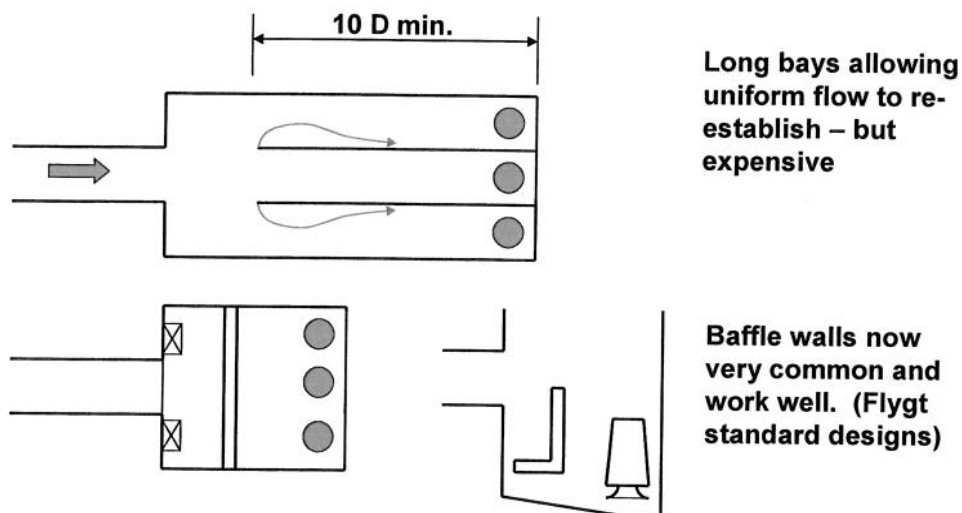


Figure 10 Arrangements that improve swirl problems in a sump

Swirl is not just a phenomenon that occurs in open sumps. It can also occur with some pipework arrangements – in particular if there are close bends turning the flow in three directions such as illustrated in Figure 11.

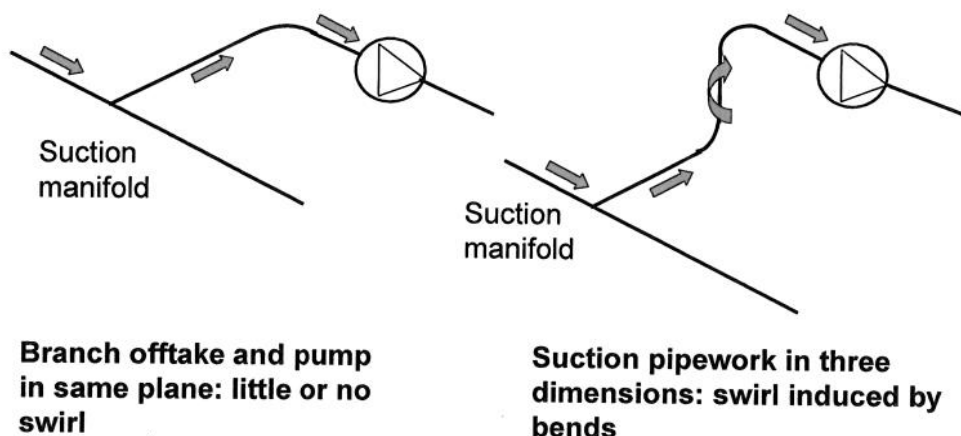


Figure 11 Swirl in pipe systems

Figure 12 shows the results of some experimental work that we had a student carry out some year ago in which she measured the swirl angle as a function of the angle of the second bend – the vertical leg in the second diagram above is shown at 90 degrees. With that leg at 90 degrees the swirl angle is between 6 and 7 degrees – in excess of that accepted by most pump manufacturers.

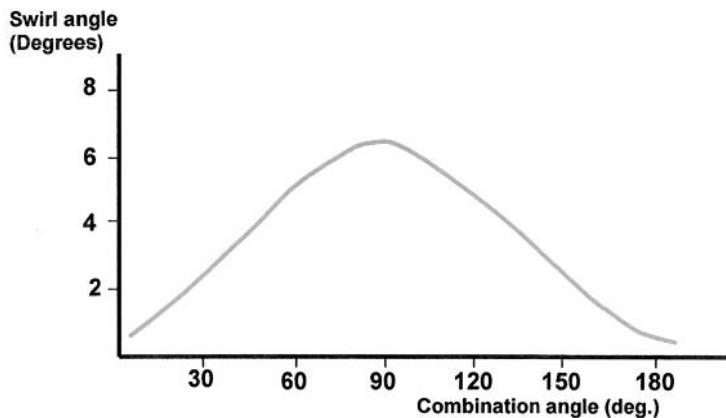


Figure 12 Swirl angle as a function of angle of second bend in Figure 11

Vortices

Vortices that may occur around the pump inlet are more intense local rotation of the flow. In extreme cases they can be observed as a drawdown in the water surface possibly even having a air core leading into the pump intake. However they can also exist as submerged vortices attached to the walls or floor of the sump. They can be very damaging possibly putting uneven loads on the pump impeller and even creating local cavitation. At the very least they can cause uneven and unstable flow conditions entering the pump. One of the main reasons for using physical models is to identify the presence of any vortices and to try and develop arrangements that will eliminate them.

Figure 13 shows the type of benching and inter-pump splitters that can work to eliminate vortices.

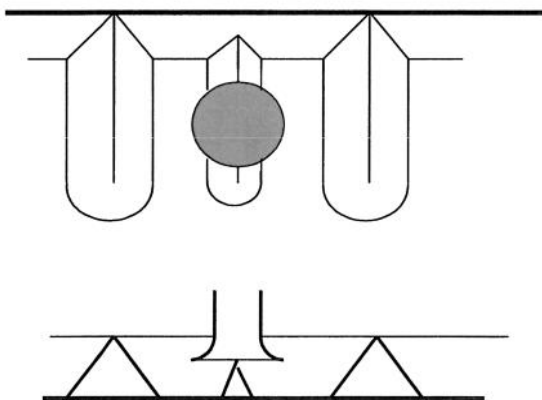


Figure 13 Typical benching around pump intake to reduce the risk of vortices

Generally vortices can be eliminated by careful design of benching and flow straighteners around the intake but it is likely there will be a need for physical model tests to identify and for benching design. CFD does not yet model vortices accurately.

Most pump manufacturers have developed their own details which will work in well designed sumps.

One way to reduce the risks of both swirl and vortex action is to increase the depth of submergence of the intake. The recommendation given in the ANSI standard is that the minimum depth of submergence should be no less than given by

$$S/D_b = 1 + 2.3 F_b$$

where $F_b = V_b/(g.D_b)^{0.5}$ and D_b is the intake diameter – the diameter of the bellmouth if there is one – and V_b is the average velocity through the plane of the bellmouth

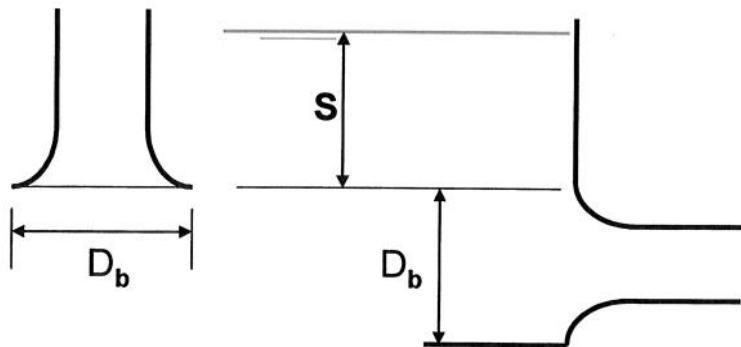
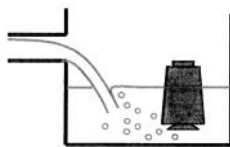


Figure 14 Submergence criteria

Air Movement

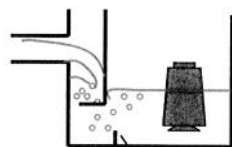
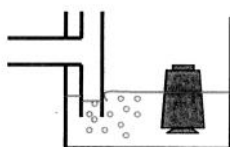
Most pumps do not like air being carried through them and this is another issue that needs careful consideration in sump design. In particular plunging flow onto or near to the pumps should be avoided. Figure 15 shows some possible solutions that reduce the risk of air being carried into the pumps. Again this can only be properly modelled with a physical model but there are scaling issues with modelling air and it must be remembered that compared to a physical model more air will be entrained and it will be harder to release it in the full scale installation.

- **Avoid plunging flow onto or near to pumps:-**



Remember: Compared to model tests, more air is entrained in full size installation and is less easily released.

- **If flow dropping into sump then possibly use drop pipe or baffle wall and encourage air movement to surface before reaching pump:-**



Possible deflector to encourage upward movement of bubbles

Figure 15 Air movement in open sumps

Sediment movement (raw water and wastewater pumping stations)

- In an ideal sump all sediment is carried through the pumps and passed on down the system. Build up in the sump can affect the hydraulics and act as a matrix for the build of slime and bacterial growth, leading to septicity and water quality and odour problems.
- Sediment transport rates cannot be properly simulated in a physical model, but potential deposition areas can be identified using light weight (usually plastic) particles. Particles are sized to have the correct scaled fall velocity in model.
- Turbulence is not necessarily a bad thing in wastewater sumps as it helps to keep sediment moving and also breaks up the steady flow conditions that can lead to vorticity around the pump intakes.

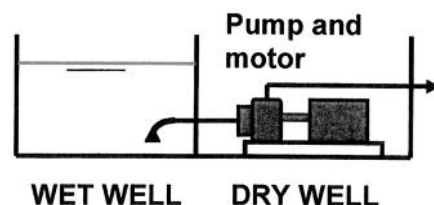
Floating material (raw water and wastewater pumping stations)

- Floating material in wastewater sumps can build up into a thick mat of material which will affect water level sensors and control float switches. Again the way it is normally dealt with is to pass it through the pumps onto the treatment works where it can be screened out and removed.
- It is normally dealt with by instigating a regular drawdown sequence in which one or more pumps have their low level 'off' control over-ridden and the sump is drawn down to the point at which significant volumes of air are drawn into the pumps – the 'snorting' or 'snoring' level. The water level will be low enough for floating material to be drawn in.
- The pump(s) must not be operated at this low level for long as the air and swirl will put unequal loadings on the impellor and damage the bearings but the procedure should be implemented fairly frequently to avoid large amounts of material being pulled through with a sudden impact on pumps and downstream screens.

3 Pumping Station Design: Pump Layouts

As noted before, there are three main station arrangements:-

1. Pumps in a dry well drawing from an open sump:-



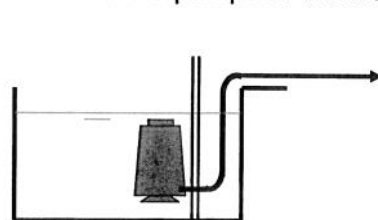
The advantages of this arrangement include:-

- Easy access to pumps, motors and valving for maintenance

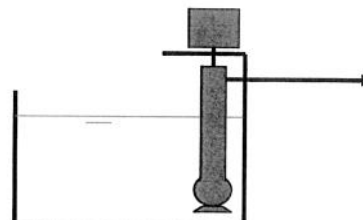
Disadvantages:-

- Larger structure – hence higher civil costs
- Possibility of flooding motors if pipework failure – motor may be located on floor above flood level with vertical-spindle pump.

2. Submersible pumps in the wet well:-



Fully submersible
pump and motor



Pump suspended in sump:
motor on floor above

Advantages:

- Smaller structure – hence lower civil costs

Disadvantages:

- More difficult to access pump and motor for maintenance. If motor on floor above then motor has to be removed to access pump.
3. Pumps supplied through a pipeline from distant reservoir or booster station:-



- Use dictated largely by location and levels of tank and pumping station.
- Also the typical arrangement for booster pumping stations
- Must check NPSH requirements as there may be significant losses in the suction pipeline

When drawing from a sump the pumps tend to be arranged in a line but for large stations with a suction main there are more options. The two most common are shown in Figure 16

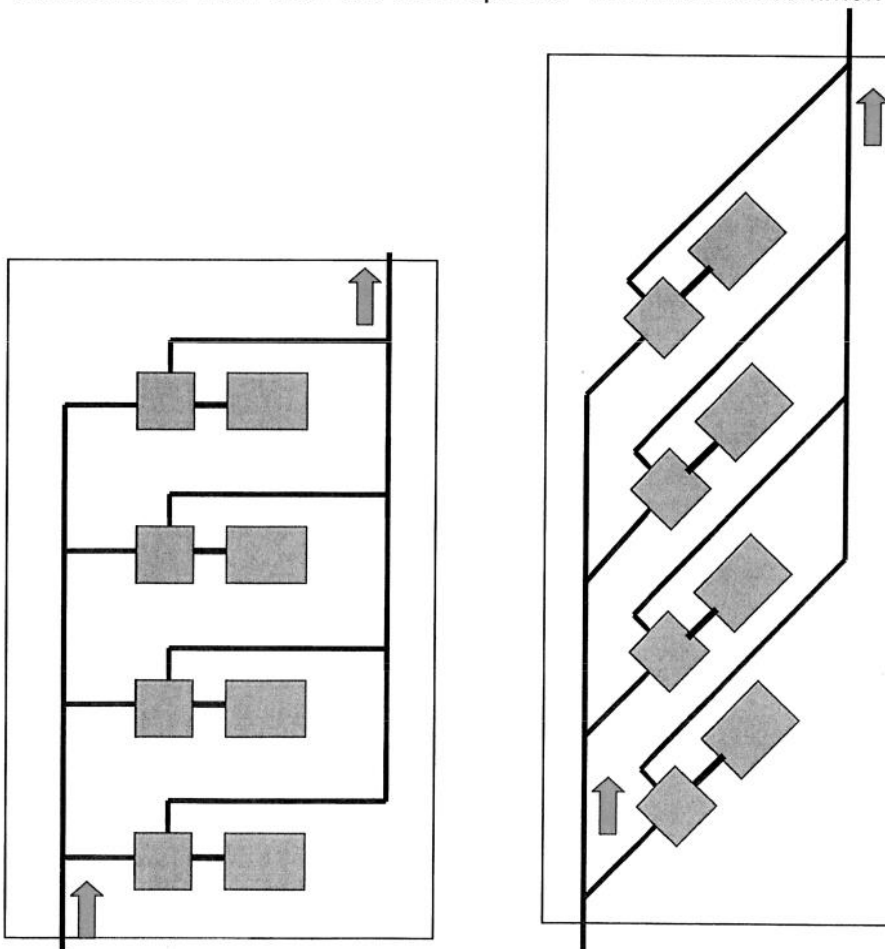


Figure 16 Station layouts

There are advantages and disadvantages to both arrangements. The arrangement with the pumps at right angles to suction and delivery manifolds is the more compact and requires a shorter but slightly wider building. The right hand layout with the pumps set diagonally across the floor is better hydraulically – the station losses are less – but the building is longer. And the space around the pumps may be less.

4 Station Pipework and Valving

Figure 17 shows typical station pipework details. Each pump should have isolating valves upstream and downstream to enable the pump to be taken out of service for maintenance. In addition, unless the pumps have separate delivery mains, there must be non-return valve on each branch to prevent back flow. The type of non-return valve needed will depend on the transient (surge) conditions that can occur but, particularly for a multi-pump installation with a surge vessel on the line, the valves will almost certainly need to be fast-acting. (The reasons are discussed in the notes on Valves and on Surge and Waterhammer)

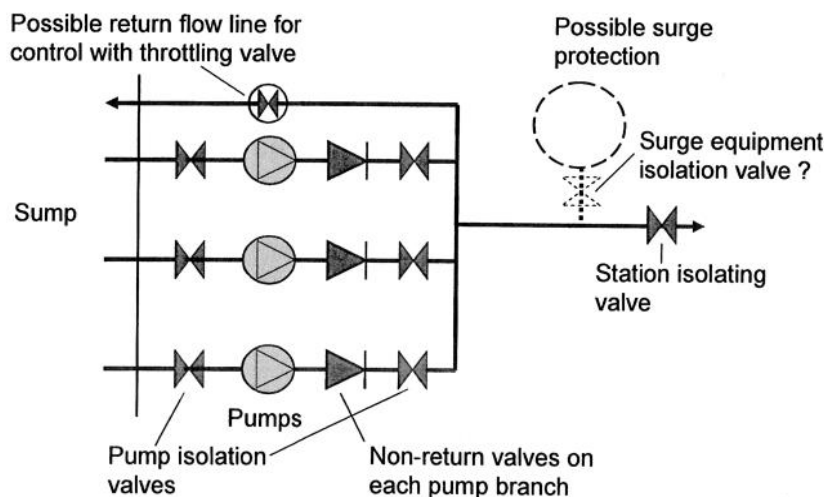


Figure 17 Typical station pipework

There may be a surge vessel on the delivery main and possibly on the suction main too if that is of significant length. The surge equipment is often provided with an isolating valve but if there is just a single vessel then it should not be possible to operate the system without the protection and that isolation valve should not be provided. When there is a need to inspect the vessel, the station isolating valve should be used and the station taken off-line. If that is not practicable then it may be necessary to provide the surge protection with several smaller vessels perhaps with a degree of redundancy so that individual vessels can be isolated without taking the station out of service.

There may also be a return pipe with throttling valve for controlling the flow. However, with variable-speed pumps becoming much more common that type of flow control is used less and less.

- Suction pipework should be designed for velocities of 1 to 1.5 m/s. Delivery pipework for a velocity in the range 2 to 3m/s. Pumping mains 1.2 to 1.5 m/s but that is an economic optimum – not dictated by engineering criteria.
- On clean water systems isolating valves can be butterfly valves. On wastewater and unscreened raw water systems they need to be gate valves with uninterrupted passage and may need to be 'knife' valves if ragging and floating material is considered to be a significant problem.
- Non-return valves should be considered with respect to surge. On multi-pump stations, particularly if a surge vessel is provided, they may need to be fast-acting valves. Again, some types of non-return valves are not suitable for use in wastewater systems.
- If throttling valves needed, either on return system or (occasionally) on pump branches then plug or ball valves should be considered. Butterfly and sluice valves are not suitable for this purpose.

Station Losses

In a single pump system, the head losses in the pumping station pipework can be included in the system losses without complications. They just become part of the suction and delivery main losses.

However in a multi-pump system it is not so straight forward. The flow is divided between the operating pumps and the head losses that occur in each pump branch cannot simply be added together and included in the system curves. Instead it is best to consider those individual losses as a reduction in the pump output and to deduct them from the individual pump characteristic curves. In effect, each pump and its branch is considered as the pump unit and the output is net of all those branch losses. Figure 18 illustrates how this is applied.

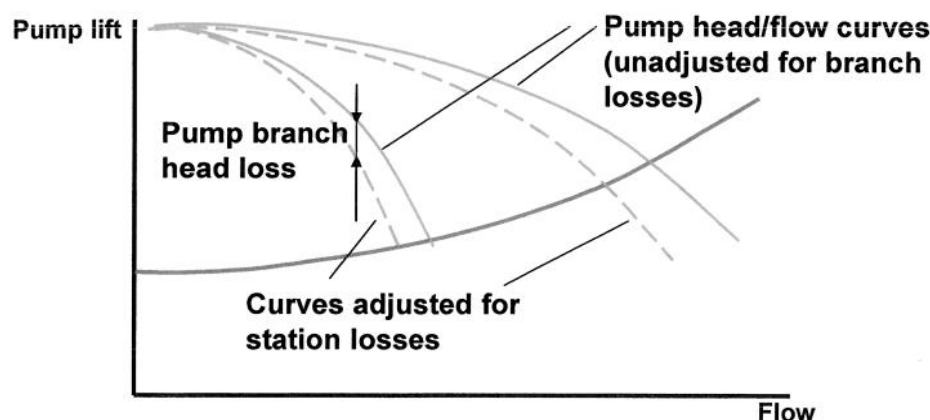


Figure 18 Pump curves adjusted for station losses

5 Pumping Station Design Process

As with all engineering designs the design process is not a simple linear programme which can be worked through to produce the perfect answer. There are many different aspects – hydraulic, mechanical, electrical, control and instrumentation, structural, planning (consents etc) and more. It must be very much a team approach with compromises between the conflicting requirements inevitably having to be accepted. However, the main requirement over which there can be no compromise is that the station must work as required. The hydraulics of the station must be acceptable and the choice of pump correct and it must not be forgotten that the pumping station is just one element of a larger system.

The following is the sort of procedure that needs to be gone through in the design process just for the pumping installation:-

- Assess proposed site and point of liquid entry.
- Assess proposed delivery point.
- Calculate quantity to be pumped.
- Make initial estimate at pumping head and system design.
- Consider turndown & control requirements.
- Fixed- or variable-speed pumps?
- Estimate number of pumps –
 - Multiple pumps have advantages for range of flows and turn down
 - Generally more pumps at smaller flow have lower NPSH requirements
 - Smaller unit weight of pumps
 - Smaller electrical equipment with more smaller pumps.
 - But multiple pumps probably more expensive
 - More pipework and valving
 - Consider need for stand-by capacity
- Outline pump selection or type number calculation.
- Check NPSH requirements.
- Calculate installed power.
- Check that the pipeline system does not have unexpected implications on the pumping duties – e.g. pumping over a hill
- Finalise drive power requirements
- Select pipework and valves
- Consider discharge arrangements:-

- Check valves & manifold
 - Individual discharge & check or flap
 - Siphon pipes
 - Weir discharge
- Select a standard sump arrangement (if possible). Take guidance from past designs if not.
 - Check sump volume is sufficient for proposed control regime.
 - Verify pump type, number, control regime.
 - Get pump tenders & revise earlier assumptions as required.

Meanwhile!

- Finalise size and layout of sump. If possible use design that has been tried and tested before.
- Consider need for model testing. Generally recommended if station large and important and especially if non-standard design. If small station possibly, consider CFD modelling with standard benching arrangements around pump intakes.
- Pump drives & control panels.
- Transformers, electricity sub-stations
- Valves, Manifolds, Pipework etc.
- Surge suppression equipment if required. Ensure system has been assessed for surge problems by an expert in that field.
- Standby generation, if required.
- Cranes for installation and maintenance.
- Workshops, Accommodation & mess facilities.
- Vehicular access and parking space,
- Screens, trashracks, chemical dosing, ventilation, odour control,
- **Etc. etc., etc.**