TECHNICAL INFORMATION

FLOWTITE® GRP PIPE AND FITTINGS

HYDRAULIC DESIGN

FLOW AND PRESSURE CAPACITY CALCULATIONS

To assist the designer in selecting the appropriate pipe diameter, these tools enable the designer to determine the relationship between friction losses, flow rate and velocity for all available diameters and classes in the FLOWTITE® range.

FLOWTITE® pipelines provide exceptionally good hydraulic performance when new, as they fall in the "smooth" polymer pipe category. However, these may in some instances be affected by various adverse service factors including:

- Growth of slime (varies with age of the pipeline and available nutrient in the water)
- Siltation or settlement of suspended particulate matter
- Fittings types and configurations

The flow charts are based on the following parameters:-

- Operating temperature of 20°C which corresponds to a kinematic viscosity of water $u = 1.01 \times 10^{-6}$ m²/s
- Equivalent roughness k = 0.02mm and 0.06mm ± 0.015mm

An approximate allowance for the effect of variation in water temperature on the chart values can be made by increasing the chart value of the head loss by 1% for each 3°C below 20°C and by decreasing it by 1% for each 3°C in excess of 20°C of pressure rating.

The value of roughness adopted for the charts was determined experimentally from a FLOWTITE® transmission main in Norway that had been in service for many years. While the "experimental error" for roughness 'k' at ± 87% was quite large, the effect of this on flow calculations is only of the order of ± 7%. By way of comparison the ranges of roughness for new polymer based pipes when assumed to be clean, straight and concentrically joined given in AS 2200 "Design Charts for Water Supply and Sewerage" is between 0.003 to 0.015mm.

The notation used for the equations in this section follows:

C = Hazen Williams roughness co-effcient

D = internal diameter (m)

F = Darcy friction co-efficient

g = acceleration due to gravity (m/sec²)

H_L = friction head loss (m)

H = Total (pumping) head

i = annual interest rate

j = annual interest rate including inflation

k = equivalent hydraulic roughness (m)

m = assumed inflation rate

n = Manning "n"

N = planned life of system (years)

Q = flow or discharge (L/s)

Q_p = most probable peak flow (L/s)

Q_f = flow or discharge - pipe flowing full (L/s)

R = hydraulic mean radius i.e. flow area/perimeter (m)

R_p = hydraulic mean radius for partly full pipe (m)

R_f = hydraulic mean radius for full pipe i.e. d/4 (m)

S = hydraulic gradient (m/m)

V = mean velocity (m/sec)

V = mean velocity in part full pipe (m/s)

V_p = mean velocity in part full pipe (m/s)

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V_f = mean velocity - pipe flowing full (m/s)

T = duration of pump operation (hours/year)

Y = depth of flow above pipe invert (m)

ρ = fluid density (kg/m3)

v = kinematic viscosity (m2/sec)

2θ = angle (radians) subtended at pipe centre by water surface in invert

τ = average boundary shear stress (Pa)

The flow charts are based on calculations using the Colebrook-White Transition Equation. For pipes flowing full this equation takes into account liquid viscosity and pipe roughness and is recognized as being one of the most accurate in general use but requires iterative solutions.

The Colebrook-White transition equation is as follows:-

$$V = -2\sqrt{2gdS}\,\log\left(\frac{k}{3.7d} + \frac{2.51v}{d\sqrt{2gdS}}\right) \quad \text{(m/s)}$$

The smooth bore, the size of the internal diameter and the anticipated pipeline service should be taken into account by designers when comparing FLOWTITE® with other pipe systems. Different applications may require a variation of the values of roughness coefficients chosen to conform to accepted practice. In the case of sewerage, it may be considered necessary to allow for slime development. Generally smooth pipe materials have a Colebrook-White 'k' value equal to less than one fifth of the value used for the rougher materials such as cement lined concrete and vitrified clay pipes used for the same purpose.

Empirical formulae, exponential in form, have been in engineering use for many years. Being relatively easy to use they are still favoured by some engineers.

For water supply applications, Hazen Williams' equation is frequently used i.e.

$$V = 0.354\,C\,D^{0.63}S^{0.54} \text{ (m/s)} \quad \text{and} \quad Q = 278\,C\,D^{2.63}S^{0.54} \text{ (L/s)}$$

Using the Norwegian experimental data the derived value of Hazen-Williams Coefficient "C" for FLOWTITE® is between 152 and 155.

The Manning Equation is the most common for non-pressure gravity flow.

$$V = \frac{1}{n}R^{\frac{2}{3}}.S^{\frac{1}{2}} \text{ (m/s)} \quad \text{and} \quad Q = \frac{4000}{n}\pi\left(\frac{D}{4}\right)^{\frac{8}{3}}S^{\frac{1}{2}} \text{ (L/s)}$$

For FLOWTITE® Manning "n" may be taken as 0.01 for a clean pipeline. Again this is conservative compared with Australian Standard AS 2200 which provides the range of "n" for thermosetting plastics of 0.008 to 0.009.

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DESIGN FLOW VELOCITIES

The Water Services Association of Australia Code WSA 03 provides design recommendations and may be applied to FLOWTITE® pipe installations. In pumped transmission mains capital cost and discounted running costs should be determined – see Economic considerations. However as a guide the Code suggests that the most economic design is likely to have velocities in the range 0.8m/s to 1.4m/s. In some circumstances, it also suggests that 2.0m/s may be accept-able or 4.0m/s for short periods with 6.0m/s as the maximum. Generally head losses should not exceed 3m/km. Where the water is carrying abrasive material the design velocity should not exceed 3.0m/s.

ECONOMIC CONSIDERATIONS

Since energy consumption is a significant factor in pumped pipelines, an economic analysis is necessary to optimize the cost of capital involved in building a pipeline and the present worth of the anticipated energy consumption over the life of the pipeline.

The equations needed for these calculations are:

Annual pumping cost 'Y'

$$Y = \left(\frac{0.0098 \times Q \times H}{\text{pump efficiency}} \right) \times C \times T$$

Present value of annuity 'A' can be calculated from:

$$A = Y \times (1 - (1+i)^{-n}) / i$$

Where the rate of inflation is to be included, then

$$A = Y \times (1 - (1+j)^{-n}) / j$$

The adjusted interest rate 'j' is calculated from

$$j = (i-m) / (1+m)$$

Note that in the special case where i = m then the value of A = n x Y

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AIR VALVES, ANTI-VACUUM VALVES AND SCOUR VALVES

Air must be expelled from a pressure pipeline during the filling operation and also allowed to enter a pipeline if it is being emptied for any reason. Also, because most water is saturated with air, which will leave the solution when the water pressure is reduced, air will tend to collect at high points in a pipeline system under normal operating conditions. As air accumulates, it has the effect of lessening the effective pipe diameter leading to reduced discharge or increased friction head. In extreme situations the flow may actually cease (see Fig 1.0). Pressure surges of high magnitude may also result from the unstable flow conditions created.

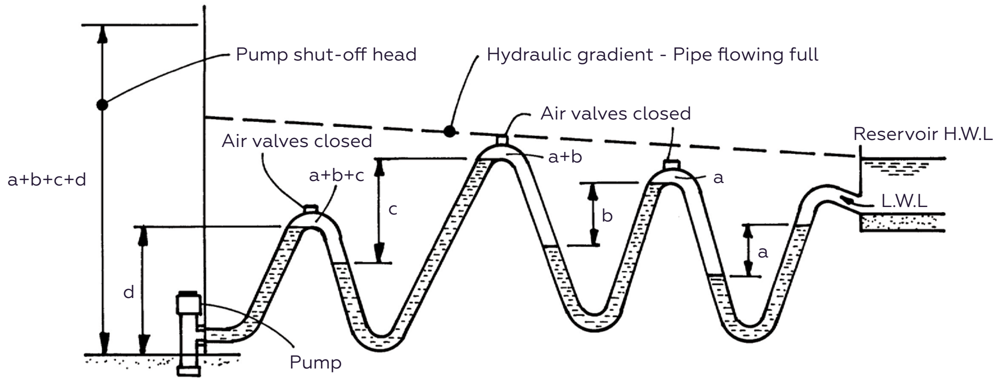

Fig 1.0

An automatic air valve is comprised of a float confined in a chamber with an orifice to atmosphere on top and connection to the pipeline at the bottom. When the chamber is full of water the float seals the orifice, but when air from the line enters the chamber or the pressure drops below atmospheric the float drops. It remains open until water refills the chamber and air is bled from the line.

Where the hydraulic grade is close to the high point of a pipeline a simple vent tube extended above the grade line may be used as an Air Valve.

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LOCATION OF AIR VALVES

Air (and gases) periodically released from the liquid in a pipeline due to temperature changes, water movements etc. will accumulate in the more elevated sections or "peaks". It is good practice in pressure pipelines to grade evenly between these peaks to ensure that the locations of all potential air traps are known. Air valves are required at peaks or sharp changes in grade in the pipeline to allow the air to escape progressively and avoid any reduction of flow capacity or unnecessary pressure surges. Peaks relative to the hydraulic gradient as well as the horizontal datum should be considered for air valve locations.

Generally the large orifice diameter should be at least 0.1 of the pipe diameter. The volume rate of flow air through an orifice is roughly 40 times that of water under the same pressure differential. The following is the list of typical conditions where air valves may be necessary.

01 Where a section of pipeline

a) Runs parallel to the hydraulic gradient

b) Has a long horizontal run. Double air valves are required at the end of a run and single air valves located at every 500-1000 metres of run.

02 Where pipeline peaks above the operating hydraulic gradient but below the higher (source) level, air can be expelled at this point by installing a manually operated gate valve (not an air valve) which is opened when the lower (outlet) level valve is closed. The operation should be carried out at regular intervals. Where the pipeline peak above the higher (source) level, syphoning will occur and special provision will have to be made to expel air such as a vacuum pump. It is recommended that peaking above the hydraulic gradient and the source level should be avoided.

03 Where abrupt changes to the grade occur on both upward and downward slopes, a small orifice air valve should suffice.

04 During long ascents, large orifice air valves are required at 500-1000 metre intervals.

05 During long descents, double air valves are required at 500-1000 metre intervals.

06 On the downstream side of section valves in trunk mains, or where flow on both sides is in both directions.

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In large diameter pipelines (e.g. DN600 or greater) consideration should be given to the likely operating conditions. For example where flow capacities are significantly below the design maximum, hydraulic jumps may develop due to the pipeline being partially full or in a "channel flow" mode.

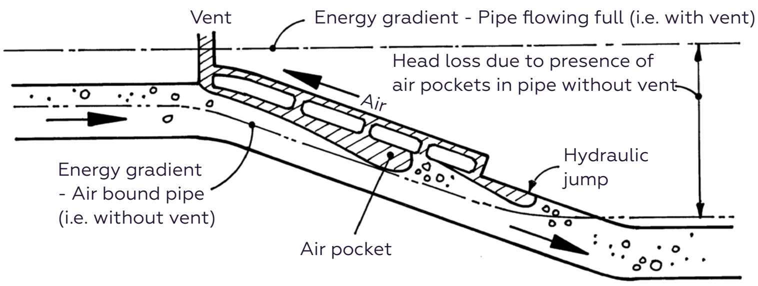

Fig 1.1 - Hydraulic jumps require additional vents

As illustrated in Figure 1.1 a series of unstable hydraulic jumps may cause air to accumulate downstream from the peak. This air may need to be extracted using a series of suitably spaced vents and may be combined with a series of interconnected tapping's to permit air to return to the air space upstream of the jump.

Where air valves are required on mains of major importance it is normal practice to install a gate valve directly onto the tee branch prior to connecting the air valve. Alternatively, an air valve incorporating a control valve can be used. This allows maintenance to be carried out on the air valve without dewatering the pipeline.

Under operating conditions care should be taken to ensure that this valve is always left in the open position.

SINGLE AIR VALVES

The single air valve, with a small orifice is used to release small quantities of air, which may accumulate in a charged water main. Although designated by their inlet connection, e.g. 25mm, this has nothing to do with the orifice size, which may be as small as 3mm.

DOUBLE AIR VALVES

The double air valve, with small and large orifice in separate chambers, performs the dual function of releasing a small quantity of air as it collects (similar to the single air valve), and admits or releases large volumes of air when a pipeline is emptied or filled. They are designated by their inlet connection, which is usually slightly smaller than the orifice diameter. Sizes range from 50mm to 100mm.

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KINETIC AIR VALVES

A difficulty sometimes experienced with large orifice air valves is that the ball blows the valve shut when a water main is being filled at a high rate. A pressure differential of 100kPa could lead to air velocities approaching 300m/sec i.e. the speed of sound. The kinetic air valve has a float chamber constructed in such a way that air expelled from a rapidly filled main cannot blow the valve shut, regardless of the high emergent air velocity.

ANTI-VACUUM VALVES

Anti-vacuum valves have the primary function of preventing the formation of a vacuum in large diameter water mains or hydro-electric penstocks. They are much larger in size than conventional air valves with orifice sizes ranging from DN200 to DN500. The corresponding airflows at 50% vacuum will range from 5m³ per second to 50m³ per second respectively.

SCOUR VALVES

Scouring points located in depressions along a pressure main are essential so that the line can be drained for maintenance purposes and sediment removal. Special flanged scour tees with branches offset to invert level are available.

The discharge from a scouring point is usually piped to a nearby stormwater drain unless the effluent will cause pollution. In these cases a detention tank has to be provided so that a tanker can remove foul water.

SURGE CAPACITY

FLOWTITE® pipes are designed to resist surge pressures in excess of the nominal pressure pipe class. FLOWTITE® pipes designed in accordance with AWWA M-45 'Fibreglass Pipe Design Manual' allow 1.4 times the nominal pressure. AS/NZS 2566.1 'Buried flexible pipelines Part 1: Structural design' recommends a lower value of 1.25 times the nominal pressure.

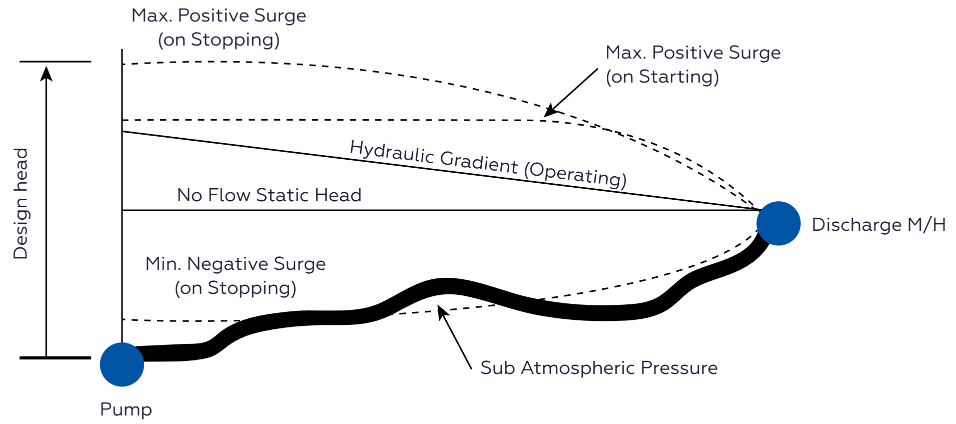

Fig 1.2 - Typical hydraulic grades and surge envelopes required for design

Figure 1.2 illustrates a typical water hammer pressure envelope. These can be determined using computer software such as WATHAM, HYTRAN or equivalent. In this diagram the maximum surge effect has been generated at the pump shutdown, a situation that is quite common.

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FLOWTITE® GRP PIPE AND FITTINGS

HYDRAULIC DESIGN

WATER HAMMER SURGE CELERITY

Water hammer effects are considerably reduced in polymeric pipeline materials including GRP when compared with iron, steel and concrete due to GRP's much lower modulus of elasticity. Typical values for celerities in FLOWTITE® GRP pipes of different diameters, stiffness's and classes are given in Table 1.1

TABLE 1.1 WATER HAMMER CELERITY FOR FLOWTITE® PIPE (M/S)

DESCRIPTION	DN 300 - 375	DN 450 - 750	DN 900 - 3000
PN6 SN5000	405	380	370
PN10 SN5000	435	420	410
PN16 SN5000	505	495	480
PN25 SN5000	575	570	560
PN6 SN10000	-	415	410
PN10 SN10000	-	425	415
PN16 SN10000	-	495	485
PN25 SN10000	-	570	560
PN32 SN10000	-	615	615

FATIGUE UNDER CYCLICAL PRESSURE REGIMES

FLOWTITE® pipes when manufactured to Australian and ISO standards and used in water, drainage and sewerage applications do not require re-rating for cyclic pressure fatigue.

The standards specify that complying pipes shall be type tested in accordance with the methods of ISO 15306. In the cyclical pressure test the pipe specimen is subjected to pressure cycles ± 0.25 times the nominal pressure for at least one million cycles. For example a PN16 pipe would be subjected to a cyclical pressure range from 1200kPa to 2000kPa at a nominated frequency.

Test reports are available for FLOWTITE® specimens, which show that, after being subjected to a minimum of one million cycles, they had ultimate, burst strengths and pressure proof test performances equivalent to those of untested new pipes.

These tests illustrate that there is a considerable difference in the fatigue characteristics between GRP pipes made from reinforced thermoset plastics when compared to unreinforced thermoplastics pipes.

FLOWTITE® GRP PIPE AND FITTINGS

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THERMAL EFFECTS ON PRESSURE RATINGS

Standard FLOWTITE® pipes are designed to fulfil the requirements of the Australian Standards AS 3571.1 and AS 3571.2 and ISO Standards ISO 10467 and ISO 10639. These standards cover temperatures up to 50°C with rerating for temperatures above 35°C.

The FLOWTITE® manufacturing process is suited for a variety of applications and if necessary, allows the use of higher performance materials for even more severe operating conditions. The following are general guidelines for temperature rerating of pressure pipes. These have been created to cover all approved materials for the FLOWTITE® process.

For FLOWTITE® pipes operating at temperatures up to 35°C, no pressure rerating is required. **Note: Resin selection should also be in accordance with 'Chemical resistance guidelines' where further limitations on temperature may apply depending on the environment.**

For FLOWTITE® pipes operating at temperatures from 36°C to 50°C, it is recommended that the next higher standard pressure class (PN) be used, after applying the rerating factor to the system's design or operating pressure. For example, a pipeline intended to operate at 18bar pressure with a continuous operating temperature of 42°C, would result in a rerating of 24bar [18/0.75]. The next higher standard pressure class to select would therefore be PN25.

TABLE 1.2 THERMAL PRESSURE RERATING FOR FLOWTITE® WITH STANDARD POLYESTER RESIN

LONG TERM OPERATING TEMPERATURE °C	RERATING FACTOR *'R'*
up to 35	1.0
36 to 40	0.85
41 to 45	0.75
46 to 50	0.6

The maximum allowable operating pressure (MAOP) = PN x R.

For example a PN16 FLOWTITE® pipe operating with a continuous operating temperature of 40°C is now rerated as PN(16) x 0.85 = 13.6bar or 1360kPa maximum internal pressure.

For FLOWTITE® pipes operating at **temperatures from 51°C to 70°C** the design pressure of the pipe must be manufactured with a full body and liner vinyl-ester resin. Further reference should also be made to the 'Chemical resistance guidelines' where temperature limitations may apply depending on the environment.

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TABLE 1.3 THERMAL PRESSURE RERATING FOR FLOWTITE® WITH VINYL ESTER RESIN

LONG TERM OPERATING TEMPERATURE °C	RERATING FACTOR 'R'
51 to 60	0.6
61 to 70	0.5

Based on the information above, the maximum operating pressure for FLOWTITE® pipe is dependent on the continuous operating temperature of the system as shown in Table 1.4.

TABLE 1.4 MAXIMUM OPERATING PRESSURE FOR FLOWTITE® PIPES

LONG TERM OPERATING TEMPERATURE °C	MAXIMUM OPERATING PRESSURE (BAR)
36 to 40	25
41 to 45	20
46 to 50	16
51 to 70	16

FLOWTITE® GRP PIPE AND FITTINGS

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NON PRESSURE PIPELINE DESIGN

Gravity sewer and stormwater drainage design

The design of drainage pipe networks is discussed in "Australian Rainfall and Runoff" published by the Institution of Engineers. There are differences from other applications owing to the frequency of inlet and junction pits, which significantly affect the hydraulic capacity of the system. Similar effects are sometimes seen in gravity flow irrigation systems. In both cases high head losses occur through pits. Pits may be rectangular, circular, benched and un-benched, with and without sidelines, with and without entries for surface stormwater from gutters on roadways, and often involve changes in flow direction. The value for K_L in Figure 1.3 can range from 0.2 to 2.5 or more depending on the pit configuration. Appropriate values can be obtained from ARRB Report No.34 "Stormwater drainage design in small urban catchments" by John Argue.

Another consideration affecting flow capacity is the debris and sediment load which stormwater flow often carries.

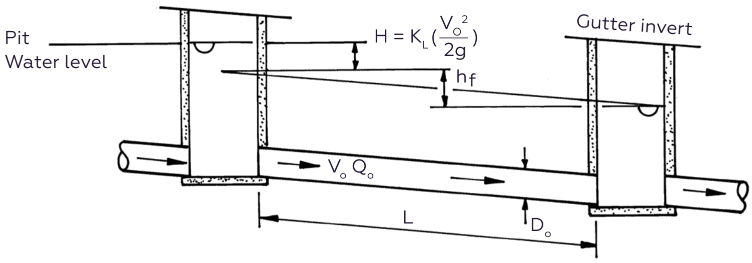

Figure 1.3 – Accounting for head losses through low head chambers

SEWERAGE DESIGN

The design of gravity sewers can be complex owing to the assumptions that must be made to cover wide variations in flows between storm flows and low dry weather sewage flows. Although the pipes must be sized to carry the high wet weather flows, the size and grade must also meet self-cleansing criteria under dry weather conditions.

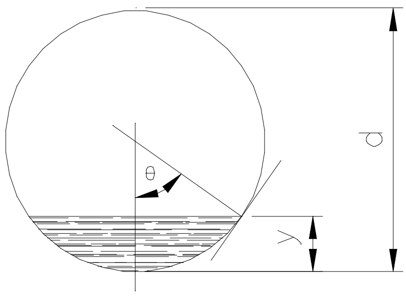

Figure 1.4 – Self-cleansing flow - angle of repose of sediment

FLOWTITE® GRP PIPE AND FITTINGS

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Acceptable design methods will vary between authorities and whether the system is to be designed for sewage flows only or combined sewage and stormwater flows. In Australia the separated sewage flow is the usual requirement. Even so these systems often carry considerable stormwater flow in wet weather due to incidental inflow and infiltration of storm water. For design purposes the normal average sewage flow of say 0.003L/s per head of population or "equivalent population" (EP) is increased by a series of empirical factors to allow for peak dry and peak wet weather flows. The resulting maximum design flow is therefore much higher than the average flow. Sewer pipes are sized to carry the maximum design flow (Q_f) flowing full. In addition a check is made to ensure that in dry weather there will be sufficient flow to ensure a self-cleansing flow at least once daily.

Historically, the normal design criterion was that a partial flow with a self-cleansing velocity of 0.6m/s had to be achieved once a day. Today most design methods are based on fluid boundary layer shear theory. Research on movement of sand particles on submerged pipe perimeters at low flows shows that deposition will occur on the flatter parts of the pipe invert where the slope of the pipe wall is less than θ = 35° - refer to Figure 1.4. Boundary layer design theory builds on this fact.

From open channel theory the following expression can be written in terms of average boundary shear stress "τ".

$$\tau = \rho . g. R. S \qquad (Pa)$$

Equation 1.0

For a circular sewer flowing part full, since Rf =d/4 Equation 1.0 can be rewritten as,

$$\tau = \rho . g. {}^{d}\!/_{4} . {}^{R_p}\!/_{R_f} . S \qquad (Pa)$$

Equation 1.1

It can be assumed for τ ≥ 1.5Pa that the pipe invert will be self-cleansing. Therefore taking this as the value for "τ", the minimum self cleansing slope can be determined by re arranging Equation 1.1:

$$S_{min} = \frac{4.\tau}{\rho . g . d . ({}^{R_p}\!/_{R_f})} \qquad (m/m)$$

Equation 1.2

Using geometrical relationships and Manning's equation, the hydraulic elements chart Figure 1.5 has been developed to relate the flow, depth and hydraulic mean radius ratios to each other. With the Q_p/Q_f ratio known, the depth ratio y/d can be found and then from this value the R_p/R_f ratio can be determined for substitution in Equation 1.2

FLOWTITE® GRP PIPE AND FITTINGS

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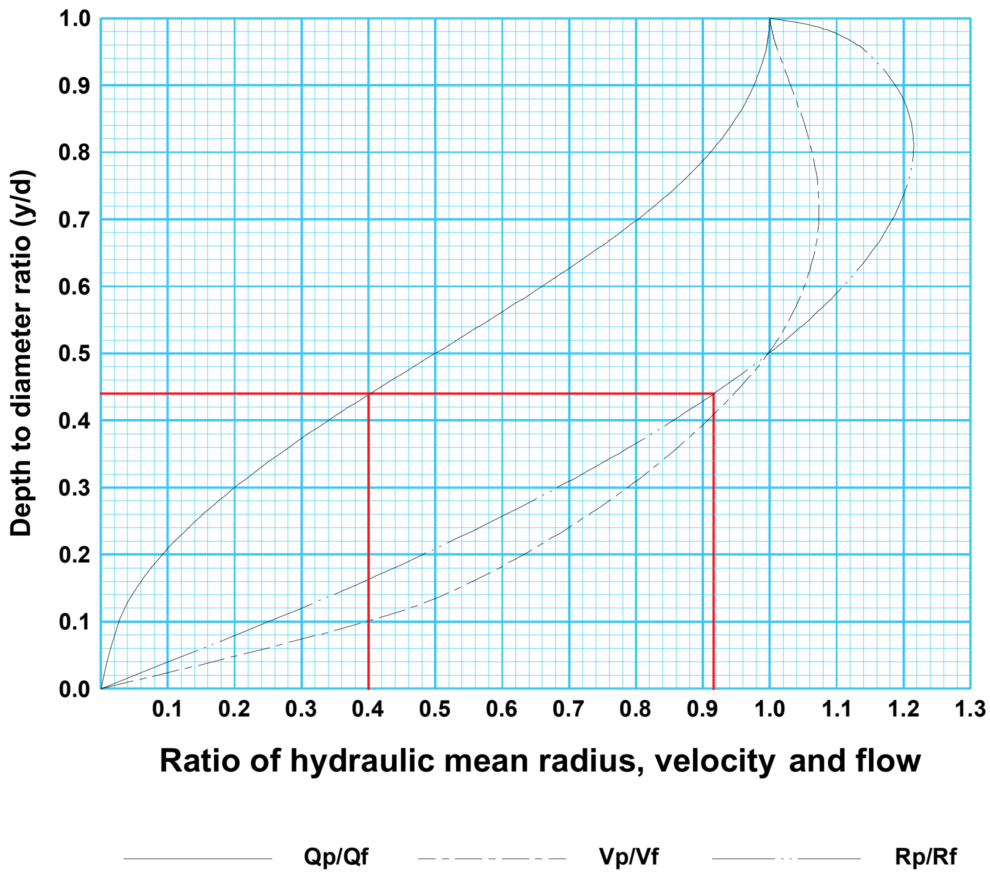

Figure 1.5 - Proportional velocity and discharge in part-full pipes

EXAMPLE

Problem:

A DN1000 FLOWTITE® sewer carrier laid at a 0.068% gradient, with an assumed Colebrook-White roughness k = 0.06mm, will carry 800L/s when flowing full. The probable daily peak dry weather flow is estimated at 320L/s.

Will this sewer be self-cleansing?

Solution:

From the flow resistance chart Figure 1.5, it can be seen that a DN1000 FLOWTITE® pipe has a hydraulic gradient of 0.68m/1000m when flowing at 800L/s.

The ratio Q_p/Q_f = 320 / 800= 0.40

From Figure 1.5;

y/D = 0.44 and for this depth ratio R_p/R_f = 0.92

Substituting for R_p/R_f in Equation 1.2 (with τ ≥ 1.5Pa) = 0.000674 or 0.067%.

As this required grade of 0.067% is less than the 0.068% proposed, the pipeline will be self-cleansing.