Pressure Dosing: Attention to Detail

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Pressure dosing, in the onsite wastewater industry, may be defined as the intermittent application, by pump or siphon, of a finite volume of liquid effluent to a treatment, disposal, or reuse site. Pumps can dose either uphill or downhill, while a siphon may be used to dose only to a lower elevation. Pressure dosing has become standard methodology for many subsurface absorption systems, excepting basic gravity septic systems.

Why Dose?

Limitations of the site and/or system—such factors may be physical, biological, or monitoring, or some combination of these—may make dosing necessary. In its simplest form, dosing occurs incidentally when a pump is used to lift effluent to a higher elevation. But if the effluent-receiving media needs a "resting" period for infiltration, aeration, or some other process to take place, then dosing is appropriate for its intermittence. Dosing is also a means of achieving equal distribution which may ensure better treatment of the effluent, improve the longevity of the infiltration site, and prevent formation of clogging mats in treatment devices such as sand filters.

Flow Monitoring
In a dosed system, monitoring of flows becomes practical. Water meters can be read directly to measure flows in an onsite system. Elapsed time meters are correlated with the pump discharge rate and cycle counters are correlated with the dose volume to measure flows. Control panels equipped with such devices enable reliable system analysis and facilitate troubleshooting, aiding in detection of orifice or pipe clogging, for example, and excessive water use. Using the devices to reach a meaningful diagnosis, of course, presupposes that someone is available both to read the meters and to interpret their data.

Programmed Dosing
A programmable timer (PT) installed in a control panel allows precise control of dosing by running a pump's "on" and "off" cycles for pre-determined lengths of time. PT's allow flows to be discharged more evenly over a period of time. Typically, for example, peak residential flows occur in the morning, evening, or when clothes or dishwashing machines are operated. In a PT controlled system, effluent is discharged from the tank in small, uniform doses over the course of the day instead of in the peak flow volumes that would be discharged all at once in a system with a "demand" float switch. For most residential onsite systems, PT's can be relatively simple analog or digital devices, having dials for "on" and "off" settings with no reference to the time of day or week. More sophisticated PT's may be required for larger, more uneven flows such as those from churches, flea markets, and other intermittent-use facilities. In such cases, PT's permit design of an onsite system that is based on average daily flow over a period of days rather than on peak daily flow. Additionally, PT's are required for many pretreatment devices which operate on a "batch cycle."

"Automatic" monitoring of water usage is a real advantage of programmed dosing. This may be required, for example, when the site being dosed has limited hydraulic capacity. If a PT is set to dose the maximum expected volume of effluent each day, any additional sewage entering the tank beyond this maximum sets off an alarm, alerting the system user to stop or reduce water usage. Since typical washing machines discharge 40-60 gallons (150-225 liters) per load, washing multiple loads of clothes in a short period of time is a prime cause of hydraulic overloading. Depending on the reserve volume of the tank, a PT will allow a more uniform discharge of effluent or the alarm will sound, alerting the user to the abuse. Where tightly controlling the volume of effluent discharged is less critical, this alarm can be tied to an override function which allows the pump to discharge excess flow, the volume being determined by the drawdown of the alarm float switch. The system then returns to PT control. Figure 1 shows two standard float switch configurations for PT operated panels.

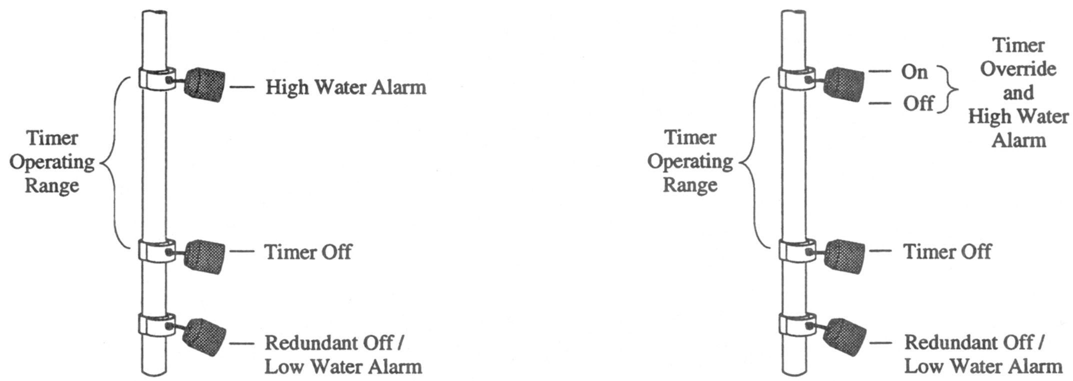

Figure 1: Common float switch configurations used with programmable timers

PT controlled systems are effective in detecting infiltration from leaky tanks, leaky stormwater connections, and leaky plumbing fixtures. Leaking toilet valves commonly run at a rate of several gallons per minute. Even small infiltration rates are readily detectable: a mere one gallon per minute (3.78 L/min) leaking into a cracked tank during periods of high groundwater, for example, will increase daily household flow by 1440 gallons (5450 L)!

Programmed dosing is also commonly retrofitted to existing gravity or pressurized systems that are failing hydraulically and/or biologically. By limiting the doses to small incremental volumes spread evenly over a 24 hour period, many "failing" systems can be successfully remediated. This remediation method has been successful on several different types of systems, including gravity and pressurized drainfields, sand filters, and mounds.

Factors to be considered for setting PT cycles include expected daily flow, anticipated peak flows, PT "working volume," maximum desired volume per dose or per orifice, and pump discharge rate. Residential PT cycles ("on" + "off" times) are usually set between 30 and 90 minutes.

Dosing Applications

Gravity Drainfields

Applying effluent incrementally to a gravity drainfield is the simplest form of dosing. Doses may be applied to "equal" distribution boxes, serial distribution boxes, or hydrosplitters. Hydrosplitters—also called pressure manifolds—create the most uniform distribution, allowing predetermined percentages of effluent to be distributed to each gravity line, regardless of line length or elevation (Fig. 2). Differing line lengths are accommodated by fitting the hydrosplitter manifold with orifices sized to permit the percentage of flow desired. A hydrosplitter is normally positioned at a high point so that flow is by gravity in all lines following the hydrosplitter. An anti-siphon valve (swing-check valve installed in reverse) is required if siphoning can occur through the hydrosplitter.

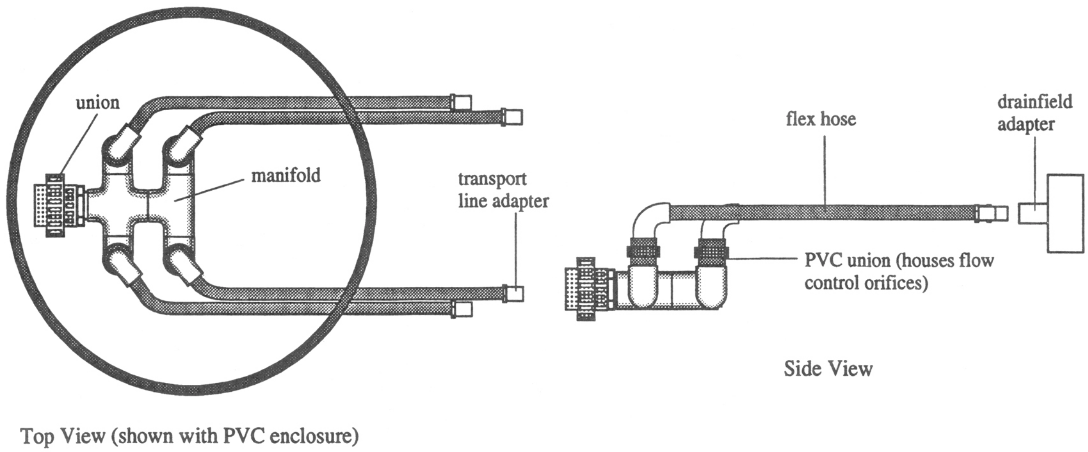

Figure 2: Hydrosplitter

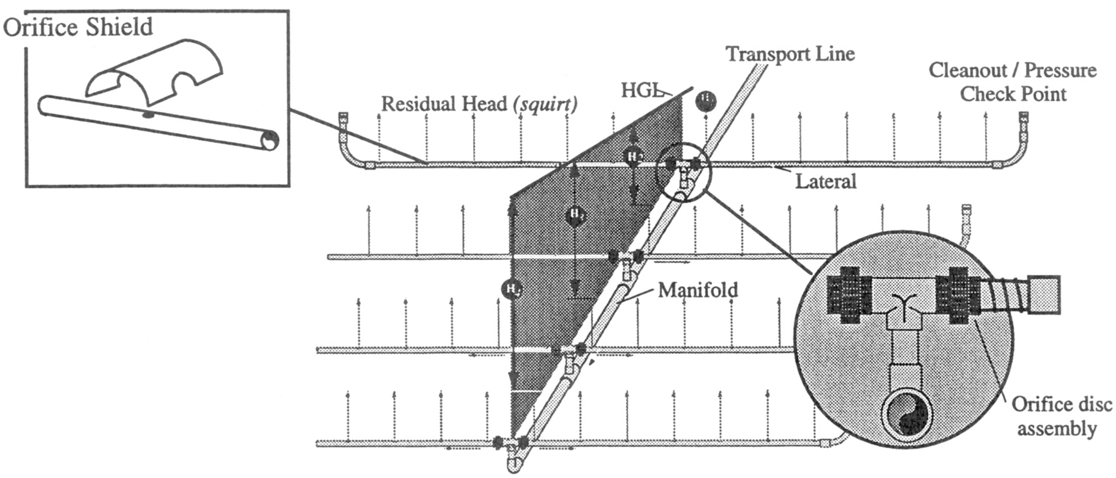

Figure 3: Pressurized Drainfield

Pressurized Networks

Dosing to a pressurized drainfield usually accomplishes more even distribution than a gravity or dosed gravity system can provide. A pressurized drainfield can be laid out in a variety of ways. Figure 3 shows a typical layout with the usual components: transport line, manifold, laterals, orifices, orifice shields, and cleanouts. Details and determination of line sizing are discussed later.

Sand filters, trickling filters, peat filters, mounds, and many other fixed media treatment units rely on pressure dosing for proper performance.

Designing A Pump-Fed Pressurized System

Careful attention to details of system design and to the components specified is essential to reliability and longevity of a system.

Septic Tank

In a pressurized system, the septic tank is one of the most important and, unfortunately, most overlooked components. Without a properly designed, structurally-sound, watertight septic tank, a system is doomed from the start. Infiltration into a leaky tank can cause washing of solids out of the tank, waterlogging or damage in downstream components, excessive wear on the pump, and unnecessarily high electrical costs. Exfiltration from a leaky tank reduces the biological activity which breaks down solids and thus increases the need for sludge removal. Exfiltration also lowers the scum layer in the tank, allowing scum to plug the pump and/or pump vault inlets. Scum that escapes the tank inevitably corrupts the downstream portion of the system. Perhaps most insidious of all, exfiltrated septic tank contents may go directly into the ground without any treatment and contaminate groundwater and surface waters.

With the advent of the Screened Pump Vault, the use of single compartment dosing septic tanks has become widespread, eliminating the need for a secondary dosing tank in most situations. When dosing directly from a single compartment dosing septic tank, maintaining a liquid level approximately equal to 90 percent of the tank's working volume is recommended. If extra reserve volume is needed, a larger tank should be used. For most residential applications, a 1500 gallon (5678 L) tank furnishes 300 to 500 gallons (1136 to 1893 L) of reserve capacity. The discharge rate from a single compartment dosing septic tank should be limited to approximately 30 gallons per minute (114 L/min) or less. Figure 4 shows a pump system in a single compartment dosing septic tank.

If a discharge rate greater than 30 gallons per minute (114 L/min) is necessary, pumping from the second compartment of a two compartment tank or from a separate dosing tank is recommended. In that case, the temptation to use the pump chamber for all the reserve capacity by pumping from its bottom should always be resisted. The liquid level in the pump chamber should be kept as high as possible to maintain effluent quality: scum and sludge layers develop even in a second chamber—less rapidly, of course, than they do in the main septic tank—and effluent quality will suffer if the pump is not protected from these solids. The appropriate way to maintain reserve capacity, when needed, is to oversize a single tank rather than to introduce a second tank and pump off its bottom. Exceptions are systems for processing high strength wastes or those expected to have very large, uneven flows. These require an experienced designer to establish proper protocol.

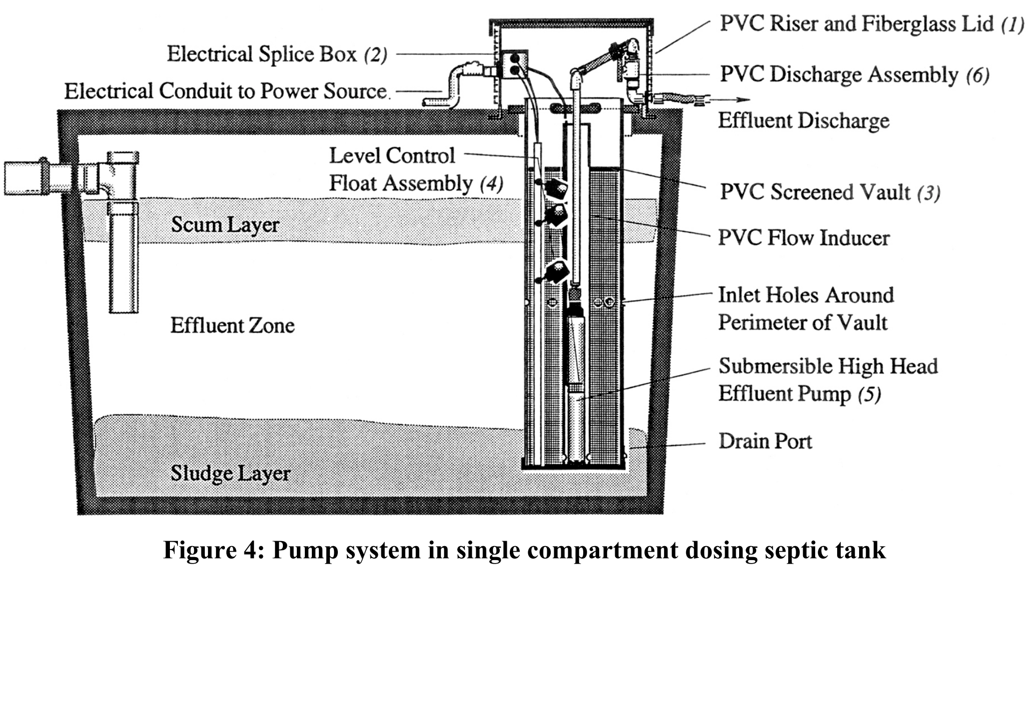

Figure 4: Pump system in single compartment dosing septic tank

Pumping System

A pumping system for a septic tank or dosing chamber has seven main components. All of them except the control panel are shown in Figure 4. (1) A riser and lid attached to the top of the dosing tank is essential for access to the pumping equipment. (2) An electrical splice box is recommended for installation inside the riser to allow splicing of wires from the control panel with the cords from the pump and float switches. (3) A pump vault is recommended for housing the pump in a dosing tank. Merely setting the pump on a concrete block or in a bucket on the bottom of the pump chamber is a guarantee that sludge, fats, oils, grease, and floc will end up downstream in the system. (4) Liquid level float switches are mounted in the tank to control and/or monitor the liquid level inside the tank. (5) An effluent pump is required to move the effluent to a distribution point. (6) A discharge assembly connects a pump to the point of discharge from the tank. Headlosses through discharge assemblies are very difficult to calculate theoretically because of the interdependence of the various types and positions of fittings and valves. Simple addition of K values for fittings and valves gives very inaccurate results. Empirically derived equations and curves for specific types of discharge assemblies are much more accurate. Equations for headlosses through discharge assemblies of four diameters and of construction similar to that illustrated in Figure 4 are shown in Table 1. These equations are developed by measuring actual headlosses that occur under operating conditions. (7) A control panel to govern the operation of the pump should be mounted within sight of the pump system.

Table 1: Headloss equations for selected discharge assemblies.

Size	Model #	Equation
1"	HV100B	$H_L=0.023Q^2$
1 1/4"	HV125BC	$H_L=0.005Q^2$
1 1/2"	HV150BC	$H_L=0.003Q^2$
2"	HV200BC	$H_L=0.002Q^2$

Transport Line

The transport line provides a means of moving the effluent to the distribution network. The length and profile of this line influences how it is sized and laid out. PVC pipe is the most common material used for piping, although HDPE may also be used, particularly in extremely cold climates and areas plagued with unstable soils or earthquakes. Lines should be laid out in a consistent grade to avoid unwanted air trapping. In some cases, air release assemblies at high points are necessary.

The Hazen Williams equation is a popular and accurate method for determining head losses in a transport line. For PVC pipe with a roughness coefficient "C" of 150, the equation may be written in a converted form as Equation 1.

$$H_L = \frac{0.000995(L)\left(Q^{1.85}\right)}{D^{4.87}} \qquad (1)$$

where HL is the head loss in feet; L is the length of pipe in feet; Q is the flow rate in gallons per minute; D is the inside diameter of pipe in inches. (Note: Actual inside diameter of pipe may be substantially different than the "nominal size.")

Manifold

A manifold is usually considered to be that portion of transport line which has side connections for laterals or other distribution piping. Because the volume of effluent flowing through the manifold is reduced each time a lateral connection is passed, the pipe size along the length of a long manifold may be reduced. However, there must be a minimal amount of head loss across the length of the manifold to ensure equal distribution. The method using the Hazen Williams equation which is outlined in the following section on laterals can be used in a similar fashion to calculate headlosses in the manifold.

Laterals

Laterals are the distribution lines that actually disperse the effluent into or on the media to be dosed. Most laterals are constructed of PVC pipe in which small orifices, 1/8 inch to 3/16 inch (3.2 to 4.8 mm) in diameter, are drilled. The lateral should be sized so that there is no more than 10% difference in flow from the first to the last orifice, which is generally considered to be "equal distribution." At the same time, velocity in the lateral should be as high as possible to allow "scouring" to limit the biological growth that occurs on the interior of the pipe walls. Such buildup on the pipe sidewalls has the potential to slough off and plug distribution orifices.

The Hazen Williams equation is used for determining headlosses in the lateral. The loss of head occurring between each two successive orifices must be figured independently. Setting up a spreadsheet on a computer allows quick, simple calculations of such parameters as head loss, velocity, and flows. An orifice equation must be incorporated into the spreadsheet to adjust the flows between any two orifices.

Orifices

The general equation for flow through an orifice can be written as Equation 2.

$$Q = Ca\sqrt{2gh} \tag{2}$$

where Q is the discharge flow rate; C is the orifice coefficient; a is the cross sectional area of the orifice; g is the gravitational constant; h is the driving head

The orifice coefficient C is variable depending on many factors, which may include the size and shape of the orifice, sharpness of the orifice edge, the roughness of the orifice wall, the driving head, and temperature [King(1)].

A modified version of equation 2 for orifices drilled in PVC pipe is shown as equation 3.

$$Q = 12.38d^2\sqrt{h} \tag{3}$$

where Q is the flow in gallons per minute; 12.38 is a combination of the orifice coefficient and units conversions; d is diameter of orifice in inches; h is residual pressure in feet.

Because of recent renewed interest in orifice coefficients in the onsite industry, Orenco Systems, Inc. (OSI) began testing dozens of orifices at its hydraulics station. When varying results were obtained on seemingly identical orifices, more investigation led to microscopic examination of the orifices, and a review of the methods and tools used to drill the orifices. Under a microscope it was discovered that what appeared to the naked eye to be a perfectly clean hole was really a fairly rough, crude hole with many burrs on both the inside and outside orifice edges. It was also noted that brand new drill bits are often not completely true and straight, causing holes to be enlarged. Using a machinist's reamer to produce a more accurate orifice repeatedly produced orifice coefficients equal to or lower than the

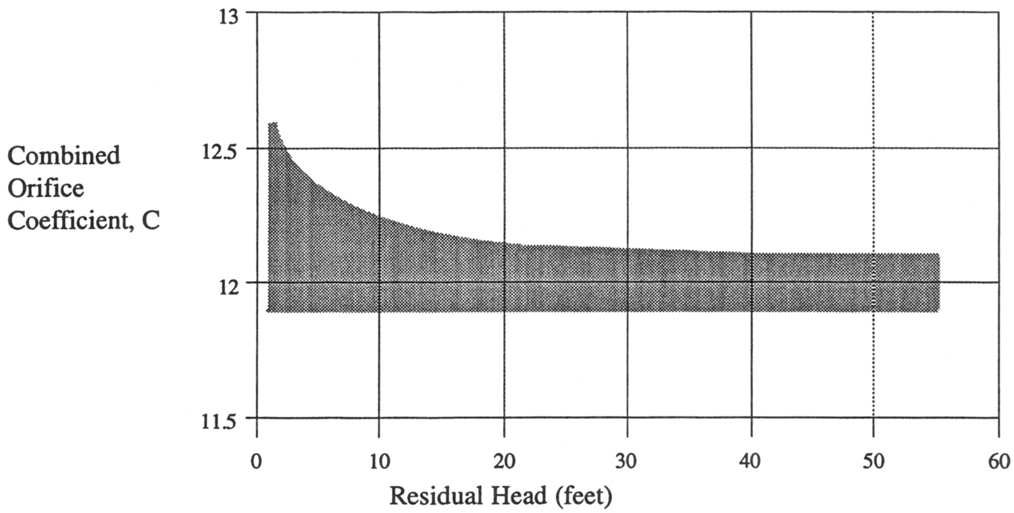

Figure 5: Range of orifice coefficients from preliminary test of 1/8 and 3/16 inch diameter orifices

smallest coefficient produced by a standard drill bit. The average value for the coefficient (as shown in Equation 3) in OSI's initial testing was 12.22 for heads varying from 2 feet to 7 feet on 1/8 and 3/16 inch diameter orifices. Coefficient values consistently dropped with increasing driving head. Figure 5 gives a coefficient value range versus driving head for OSI's initial tests. These results follow the same general pattern as have other orifice tests over the past 100 years [King(1)]. The value 12.38 given in equation 3 is derived from averages of testing performed by engineering students at Umpqua Community College in Roseburg, Oregon [Ball(2)] over a 10 year period and is considered sufficiently accurate for onsite systems if orifices are drilled with care. Optimally, holes should be drilled using a drill press or guide instead of "freehand." Using the correct size drill bit is essential and one must meticulously avoid enlarging the hole if deburring is required. As an example, the flow from a 1/8 inch (3.2 mm) orifice with a 5 foot (1.52 m) residual head is 0.43 gallons per minute (gpm) (1.63 L/min). But if the hole has been misdrilled or enlarged by only 1/64 inch (0.40 mm), the flow required to achieve the same five foot (1.52 m) residual head increases by 0.12 gpm (0.45 L/min) or 27%.

To get accurate residual head measurements in the field, a clear pipe must be attached to the pipe with the orifice. The true residual head is measured from the top of the orifice to the height of the water column. Measuring the squirt height out of the orifice into to the atmosphere will give heads lower than the true residual head. Tests at OSI's lab produced the results in Table 2, which compares squirt height with true residual head. These tests were done in still air. Tests done in the field with wind speeds of 5 to 8 miles per hour (8 to 13 km/hr) resulted in up to 18 inches (46 cm) lower measured residual head with a true residual head of 5 feet (1.52 m).

Table 2: Actual residual head versus observed squirt height

ACTUAL RESIDUAL HEAD	MEASURED SQUIRT HEIGHT
24 inches	21.5 inches
36 inches	33 inches
60 inches	56 inches
84 inches	77 inches
120 inches	96 inches

Orifice shields (Fig. 2) are recommended for installation over orifices that are encased in media which may impede flow through the orifices. A University of Wisconsin study [Falkowski(3)] reported that directly covering orifices with small gravel media caused the same reduction in flow that clogging of 25% of the orifices produced. Orienting orifices up instead of down prevents settling of solids in them and allows air to escape more readily during the filling cycle. Orifices may be pointed down if freezing of the lateral is a major concern. Tests done at OSI's laboratory in 1993 showed that 4 inch (10 cm) diameter orifice shields, while clearly protecting orifices from the surrounding media, did not provide significant spreading of effluent compared to unshielded orifices.

Cleanouts

Cleanouts should be placed at the ends of all laterals to allow cleaning of the pipe and orifices (Fig. 2). Using a sweep ell rather than a sharp ell makes it easier to use cleaning devices such as snakes and bottle brushes if necessary. An alternative is to clean laterals and orifices by connecting a vacuum to the end of each lateral. An access riser over each cleanout makes it easy to find when maintenance is required and eliminates a need for digging.

Developing a System Curve

When designing a pressurized system, it is necessary to know the flow rate and head at which the pump needs to operate. Plotting on a graph the head versus flow rate for a particular system yields a system curve. When a system curve is plotted alongside a pump curve, the approximate operating point of the pump will be where the system curve intersects the pump curve. A system curve can be drawn by plotting the total dynamic head (TDH) produced by the system at various desired flow rates. TDH can be calculated as the summation of the static lift, discharge piping headlosses, and desired residual head. The use of the equations given previously—Hazen Williams equation, the empirical discharge assembly equations, and the orifice equation—allow fairly accurate TDH calculations. Computerized graphical spreadsheets make plotting of system curves quick and easy.

Sloping Sites

Maintaining equal distribution on a sloping site is more difficult than on a level one for several reasons: the uneven residual pressure at the lateral orifices, uneven distribution of effluent during the start of a dose cycle, and draining of effluent to the lower lines.

Described below are five basic methods for equalizing distribution in spite of residual pressure differences. (1) Orifice spacing can be increased in the lower lines to accommodate the larger flow rate per orifice. Although this method equalizes distribution between laterals, distribution within a single line will be uneven. (2) A globe or gate valve installed at the beginning of each line may be used to adjust residual pressure. However, adjustment of valves is a trial and error procedure and is susceptible to misadjustment once the system has been put into operation. Quarter-turn ball valves are not designed or recommended as a means of flow control. (3) An orifice disc assembly (Fig. 2) may be installed at the beginning of each lateral to adjust residual pressure. The advantage is that trial and error and the potential for misadjustment are eliminated. Orifice discs installed in unions also allow easy inspection and cleaning of the orifice restriction. Calculations based on this method are discussed later. (4) A hydrosplitter or pressure manifold may be used to feed and control pressure to each individual lateral. The hydraulic analysis is more difficult than with the orifice disc assembly method. A trial and error method of equalizing residual head may be used if gate valves are installed on each line of the hydrosplitter, but valves have the same cleaning and misadjustment problems discussed previously. Positioning the hydrosplitter below the lowest line and installing a check valve at the beginning of each line can reduce uneven distribution during the beginning of the cycle. (5) Electrical or mechanical distribution valves may be used to dose at the same time only the lines that are at the same elevation. With each cycle, the valve rotates to a new line(s). A more detailed description of distribution valves is discussed later.

Even if residual pressure has been accommodated for, uneven distribution of effluent may still occur on a sloping site at the beginning of the cycle until laterals are fully pressurized. Additionally, at the end of the cycle, effluent in the upper lines and manifold may drain into the lower lines. Of the five methods described here, only the hydrosplitter and distributing valve will eliminate these beginning and ending cycle problems. There are, however, other ways to mitigate them in systems without hydrosplitters or distributing valves.

Carefully leveling the entire manifold will help minimize unequal distribution at the beginning of the cycle and drainback at the end of the cycle. Of course, lower laterals will always fill first, but placing check valves in the manifold directly after each lateral connection prevents drainback at the end of each cycle and allows the achievement of equal distribution more quickly at the beginning of the cycle. Using check valves in that way also means that the transport line must feed the manifold from below the lowest lateral. Unfortunately, check valves used in this manner are difficult to test and maintenance. Alternatively, “humps” or high spots at the beginning of each lateral may be designed in to prevent effluent from draining out of the lateral, although unequal distribution can still occur at the beginning of the cycle.

Sometimes equal distribution through pressurized laterals is just not feasible. Then dosing gravity trenches with a hydrosplitter often becomes the method of choice on sloping sites, particularly when dosing downhill.

Distribution Valves

Electric ball valves and mechanical distribution valves are used to divide distribution networks into two or more zones. Reasons to do so are various: to provide equal pressure distribution on a sloping site, to allow resting of zones, to permit dosing large areas with small pumps, to allow reduction in pipe sizes, and to increase residual pressures.

Electric ball valves must interface with a control panel so that they open and close at the appropriate times. Irrigation-type solenoid valves are not normally recommended as they tend to clog and corrode easily when used with typical septic tank effluent.

Mechanical distribution assemblies (Fig. 6) are a simpler, less costly means for zoning distribution networks. These valves are activated by the water pressure in the transport line. Each time the pump is turned on, the valve rotates to dose the next zone. A good mechanical valve assembly has the following features: unions to allow easy removal of the valve, clear sections of pipe for visual inspection of valve operation, and a ball valve on the inlet for quick, easy testing of valve operation.

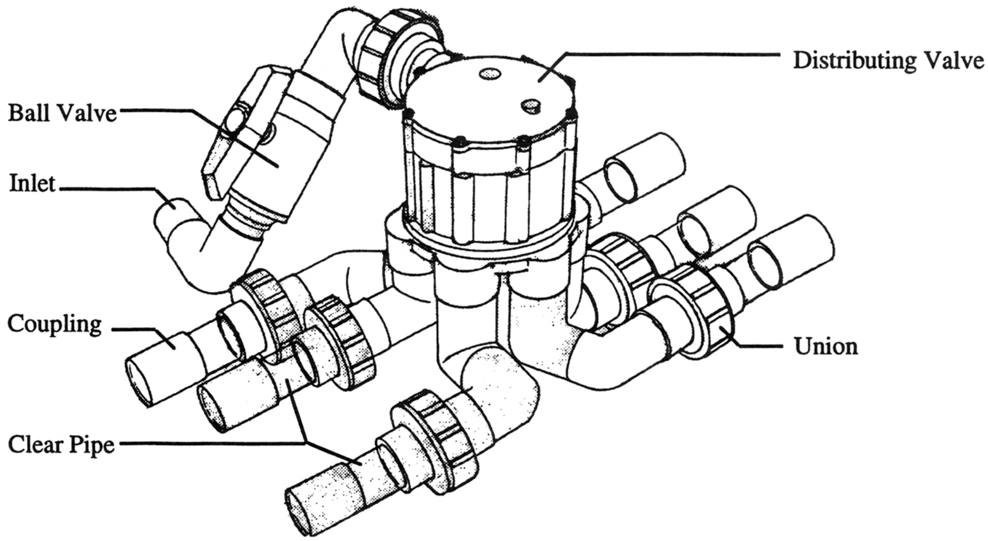

Figure 6: Mechanical distribution valve assembly

Designing Downhill Dosed Systems

Dosing downhill, whether by pump or by siphon, requires that additional criteria to be considered. Pressurization of the distribution system does not occur until the transport line is backfilled with effluent. At the beginning of each cycle, the transport line is empty and the air that is in the pipes must be displaced to achieve proper pressurization. Trapping air during filling of the transport line is a

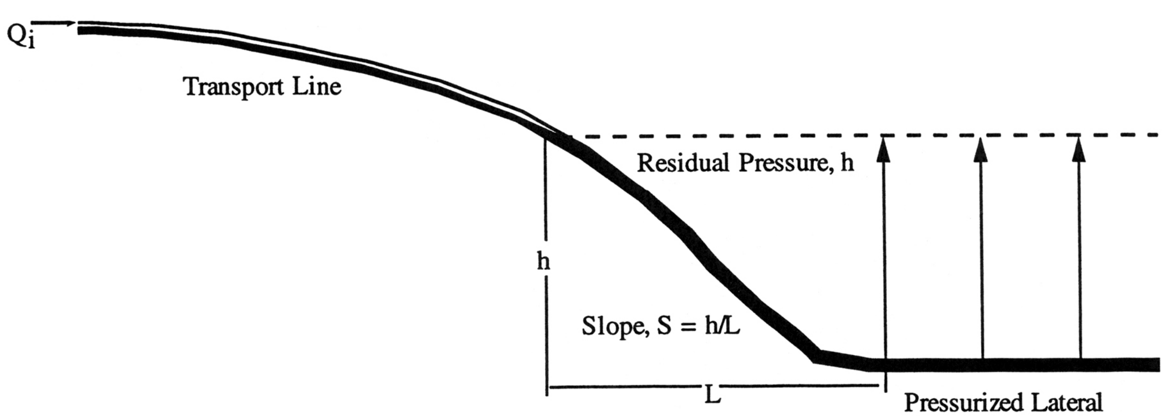

Figure 7: Downhill dosing

critical factor when dosing downhill, particularly when using siphons as there is no additional pressure available to push air out of lines. Oversizing lines to allow open channel flow is a practice commonly used to eliminate this problem. Because it takes time to backfill the transport line to get to the desired residual head, the dose volume must be large enough to reach design pressures. Oversizing the discharge flow rate from the pump or siphon allows quicker pressurization to occur. Time to pressurization can be calculated with Equation 6 based on Figure 7.

The volume of transport line filled to a height, h, can be written as Equation 4:

$$V = 7.48A_p h\sqrt{1+\left(\frac{1}{s^2}\right)} \tag{4}$$

where:

V is the volume of filled transport line in gallons
7.48 is a units conversion factor
A_p is the transport pipe's area in square feet
h is the vertical fill height in feet
s is the slope of the transport line, h/L in ft/ft

Liquid is stored in the transport line and the liquid level rises until the discharge rate of the distribution system, Qo, equals the inflow rate, Qi. The rate at which the stored volume increases may be expressed as the differences between the inflow and discharge rate in Equation 5.

$$Q_{fill} = Q_i - Q_o = \frac{dV}{dt} = 7.48A_p\sqrt{1+\left(\frac{1}{s^2}\right)}\frac{dh}{dt} \tag{5}$$

where:

$\frac{dV}{dt}$ is the rate of volume change in gpm
$\frac{dh}{dt}$ is the rate of change in liquid height in feet
Q_o is the discharge rate of the pump or siphon in gpm
Q_i is the inflow rate in gpm

Solving Equation 5 for time, t, and substituting the orifice equation for Qo, with n equal to the total number of orifices, yields Equation 6:

$$t = \frac{14.96A_p\sqrt{1+\frac{1}{S^2}}}{\left(12.38nd^2\right)^2}\left(Q_i \ln\left|\frac{Q_i}{Q_i - 12.38nd^2\sqrt{h_1}}\right| - 12.38nd^2\sqrt{h_1}\right) \tag{6}$$

which is the time, in minutes, necessary for the residual head to reach h1, in feet. Since Figure 7 may be a simplified version of what is in the field, Equation 6 should be used with discretion and only as a rough calculation.

Maintenance

Proper operation and maintenance of dosed systems is essential for long-term reliability. Septic tank scum and sludge levels should be measured periodically to determine when solids removal is needed (devices are available that make it simple), and tanks should be pumped before maximum allowable solids levels are exceeded. Pump and siphon systems should be inspected at least annually to ascertain whether they're functioning properly.

Distribution lines or laterals should also be inspected annually and flushed to ensure proper distribution. Inspecting pressurized distribution networks for signs of clogged orifices is most accurately done by checking the current residual head and comparing it to what the system originally produced. Comparing current pump run time or cycle time to original time values is not nearly as sensitive. OSI ran tests

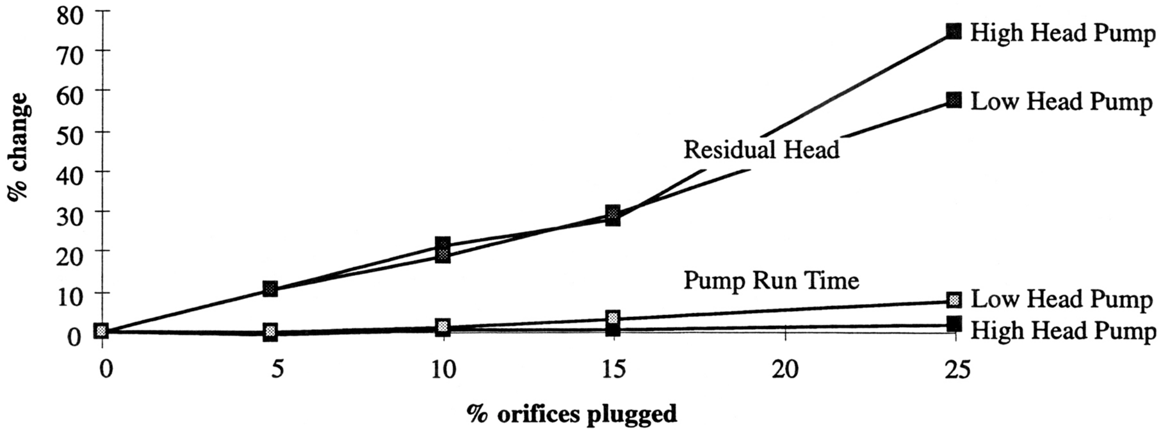

Figure 8: Effects of orifice plugging on pump run time and residual head

simulating clogging of a sand filter manifold having 60 1/8 inch (3.2 mm) diameter orifices to illustrate this point. The tests were conducted with both a high head turbine pump having a shut off head of 105 feet (32 m) and a low head pump having a shut off head of 24 feet (7.3 m). Figure 8 illustrates the percent change in values of both residual head and run time versus the percentage of orifices plugged. It is evident from this study that the change in residual head offers maintenance personnel much more sensitivity than does pump run time when monitoring pressure distribution systems for plugged orifices.

Performing proper maintenance of a dosed onsite system requires substantial knowledge of the particular design and site. An as-built drawing should be kept at the site for reference. Because homeowners are not usually knowledgeable about their systems or inclined to perform the necessary maintenance, maintenance agreements or contracts are highly recommended for all onsite systems.

As it becomes apparent that traditional sewers will never be universally accessible, onsite wastewater treatment must be looked upon as a permanent solution. In fact, there is a growing trend worldwide supporting the notion that onsite systems are more economical and better for the environment than are traditional collection systems and centralized treatment. Water reuse, groundwater recharge, and water conservation are reachable goals with onsite systems. Because pressure dosing is so important in today’s onsite technologies, proper design, construction, and long-term maintenance of dosing systems is essential to assure protection of groundwater, surface waters, and public health.

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