
WASTEWATER ENGINEERING: COLLECTION AND PUMPING OF WASTEWATER

METCALF & EDDY, INC.

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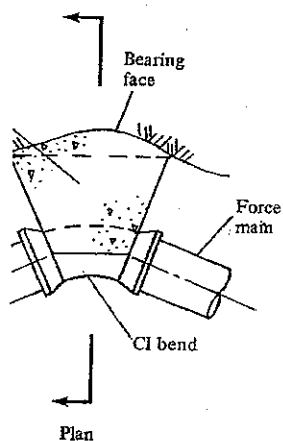
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Concrete material.
1 plane bend.

It should be given to the horizontal to minimize turbulence not only smells bad but would severely attack the some cases, the sewer may be intensified by pressure in the force main during a. 7.

to align the crown of the receiving manhole. The between the force main higher than about 2 m/s it may be necessary to provision for energy dissipation.

normal elevation of the rock, the force main may be at the low-level sewer standard drop inlet. If the other structure, an inside

As a further precaution against hydrogen sulfide problems, especially in hot climates, it may be desirable to seal the outlet of the force main pipe. The sewer can be sealed by placing the crown of the force main pipe outlet at the same elevation as the invert of the gravity sewer, with the manhole invert sloping upward from the force main outlet to the sewer. The seal may also be provided with a trap formed with pipe fittings.

Force Main Appurtenances

Common force main appurtenances include blowoffs, access manholes, and air and vacuum valves.

Blowoffs. A blowoff is a controlled outlet on a pipeline, so arranged that it can be used to drain or flush the pipeline. Blowoffs normally are not required on force mains. However, where the force main contains a long depressed section between high points, a blowoff may be desirable in case the force main must be drained and pumped out.

A suitable blowoff might consist of a valved connection in a manhole at the low point, discharging to a manhole or vault that would serve as a wet well for a portable pump. The size of the blowoff should not be less than 150 mm (6 in). It should, if possible, be large enough to provide flushing velocities in the force main.

Air valves. Force mains are usually constructed at approximately uniform depths below the ground surface. This practice often results in high and low points along the course of the pipeline. In such cases, it may be necessary to provide valves for the release of trapped air when putting the line in service (filling) and during regular operation, or for admitting air should it be necessary to drain the force main. The release or admittance of air for filling or draining can be accomplished by use of a manually operated air valve. Specially designed automatic air release valves have been used for bleeding air from high points while the force main is under pressure.

If possible, force mains should be designed without high points, and with the top of the force main below the hydraulic grade line at the minimum pumping rate so that air-relief valves will not be needed. If the elimination of high points is not feasible, a manual air-release valve should be installed at each significant high point where air could become trapped. A high point may be considered significant if it is 0.6 m (2 ft) or more above the minimum hydraulic grade line or, when pumping is intermittent, above the static head line. Air-release valves should not be less than 20 mm (3/4 in) nor more than 50 mm (2 in) in size. Larger sizes should be used with larger-diameter force mains. Preferably, these valves should be located in vaults, but a valve of 40-mm (1 1/2-in) diameter or larger may be buried in the ground and operated with a wrench through a box. An air-release valve may discharge to a sewer manhole, a vented dry well, or other suitable place. Consideration should be given to

providing a means of rodding out or back flushing the valve. A typical air valve installation for a force main is shown in Fig. 9-12.

Automatic air-release valves should not be installed if their use can be avoided. From past experience it has been found that automatic air-release valves require frequent maintenance in order for them to function as intended. Inadequate maintenance causes these valves to clog and malfunction, often soon after they are installed. In most cases, manual air valves could be used instead of automatic air valves. For example, if after the force main has been put into service, the need develops for frequent use of a manually operated valve to relieve entrapped air or gas, the valve may be left at a part-open setting for continuous bleeding of air or sewage. As a last resort, an automatic air-release valve may be installed.

Automatic air-release valves, if used, must be specially designed to keep the valve operating mechanism free from contact with sewage to inhibit clogging and resulting malfunction. They must be located in a manhole or vault and protected against freezing. Automatic air valves should be installed on top of the force main with a shutoff valve close to the force main. A 25-m (1-in)

blowoff valve should be installed on the valve body. A back-flush valve should be installed on the valve body. A back-flush valve should be installed on the valve body.

Automatic air and automatic admission of air to the pipeline during the fast main, or during water hammer, have been used for venting these valves are subject to problems. Furthermore, these valves are subject to problems.

In general, automatic air valves should not be used on force mains. Instead, they should be used on low-pressure lines, because of internal pressure of pipe having walls sufficient to withstand the load.

9-5 WATERHAMMER

The rapid changes in pressure in a pipe can be caused by a sudden change in flow and can result in a condition known as water hammer. This can be either positive (above normal pressure) or negative (below normal pressure) and is accompanied by a hard condition in force main pipes. This is the most severe water hammer condition and can result in pipe failure or power failure. The theory of water hammer is discussed in this section.

Theory of Waterhammer

In the case of rapid pumping, the force main is initiated and the pump motor is cut off, causing a rapid decrease in speed, causing a rapid decrease in pressure. This negative-pressure wave travels from the pump back toward the pumping station as a positive-pressure wave during its passage.

A cycle of pressure wave reaches the pump and the cycle repeats.

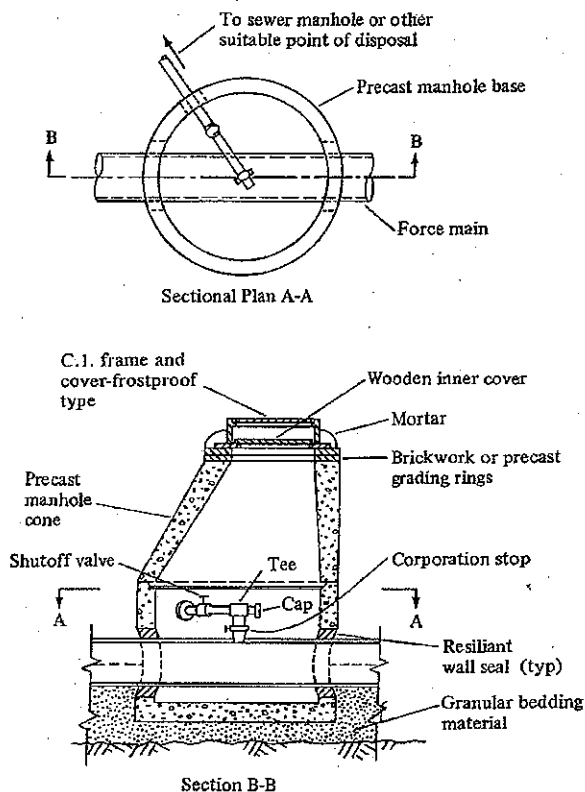


Figure 9-12 Typical air valve installation for wastewater force main.

live. A typical air valve

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blowoff valve should be installed either above the shutoff valve or on the air valve body. A back-flushing connection should be provided by the valve manufacturer.

Automatic air and vacuum valves have been used to allow the quick automatic admission of air that might be needed to prevent collapse of a thin-walled pipeline during the fast drainage that would take place through a broken force main, or during water-column separation following a power failure. They also have been used for venting air during the filling of the force main. However, these valves are subject to maintenance problems similar to those of air-release valves. Furthermore, their malfunction could create additional waterhammer problems.

In general, automatic air and vacuum valves should not be used on sewage force mains. Instead, the problem of possible collapse of force main pipes because of internal pressures less than atmospheric should be solved by the use of pipe having walls sufficiently strong to withstand the induced added crushing load.

9-5 WATERHAMMER IN WASTEWATER FORCE MAINS

The rapid changes that can occur in the velocity of flow in force mains and pressure pipe can be caused by pump startup, pump shutdown, or power failure and can result in a considerable change in pressure. The change in pressure can be either positive (above normal) or negative (below normal) and is sometimes accompanied by a hammering-type noise. This transient pressure and flow condition in force mains and pressure pipes is known as *waterhammer*. The most severe waterhammer conditions generally result during pump shutdown or power failure. The theory, analysis, and control of waterhammer are discussed in this section.

Theory of Waterhammer

In the case of rapid pump shutdown or power failure, the flow and velocity in the force main are initially steady. However, when the power supply to the pump motor is cut off, the pump rapidly decelerates from full speed to zero speed, causing a rapid decrease in the pump discharge into the force main. This decrease creates a negative-pressure wave (below normal pressure) that rapidly travels from the pumping station end of the force main to its discharge end. This negative-pressure wave decelerates the flow in the force main in accordance with Newton's second law of motion. When this negative-pressure wave reaches the discharge end of the force main, it is reflected back toward the pumping station as a positive-pressure wave, which further decelerates the flow during its passage.

A cycle of pressure wave travel is completed when the positive-pressure wave reaches the pumping station, where it is again reflected and a second

Pumping Station Design

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Air in Pipelines

Dissolved air (or other gas) is a serious problem in pipelines that have intermediate high points or are nearly flat. If air comes out of solution, it forms bubbles that accumulate, reduce the water cross-sectional area, and increase resistance to flow—sometimes greatly—and the air-moisture environment is conducive to corrosion. In sewer force mains, air and consequent corrosion is disastrous. Various ways to deal with air in pipelines include (1) designing the pipeline profile to rise all the way to the exit; (2) installing air release valves at high points in the pipeline (or at frequent intervals for flat profiles); or (3) designing for velocities high enough to scour air bubbles to the exit. Obviously, the first is preferred if possible. Air release valves are risky because of uncertain maintenance. They should not be used at all on wastewater force mains because maintenance must be done so frequently (for example, monthly) and without fail. (See Sections 5-7 and 7-1 for an exception.) If the valves are not maintained properly, they are worse than useless because they then engender a false sense of security. Designing for scouring velocities in large pipes may result in excessive headlosses and energy needs. The required scouring velocities are given in Table B-9.

Some consultants customarily install manways at 450-m (1500-ft) intervals in water pipelines equal to or larger than 900 mm (36 in.) in diameter to permit worker entry and inspection of, and repairs to, the lining and to fix leaks. Air release valves are required in the manway covers to prevent the accumulation of air under them.

3-4. Headlosses in Pipe Fittings

Pumping stations contain so many pipe transitions (bends, contractions) and appurtenances (valves, meters) that headlosses due to form resistance (turbulence at discontinuities) are usually greater than the frictional resistance of the pipe. The simplest approach to design is to express the headlosses in terms of the velocity head, $v^2/2g$, usually immediately upstream of the transition or appurtenance. The equation for these losses is

$$h = K \frac{v^2}{2g} \quad (3-16)$$

in which K is a headloss coefficient (see Appendix B, Tables B-6 and B-7). The few exceptions to Equation 3-16 are noted in the tables.

The headloss coefficient, K , is only an approximation, and various publications are not always in agreement and may differ by 25% or more. The values in Tables B-6 and B-7 have been carefully selected from many sources and are deemed to be reliable.

In Equation 3-16, K varies with pipe size as noted in Table B-6. Furthermore, published values are for isolated fittings with a long run (for example, 20 pipe diameters) of straight pipe both upstream and downstream from the fitting. The headloss is measured between one point a short distance upstream from the fitting and another point at the downstream end of the piping system. This piping ensures symmetrical flow patterns. The difference in headloss with and without the fitting is used to compute K . Headlosses for a series of widely separated fittings are therefore directly additive.

Part of the headloss is due to the turbulence within the fitting, but probably about 30% (less for partially closed valves) is due to eddying and turbulence in the downstream pipe. So if one fitting closely follows another (as in a pumping station), the apparent K value for the first fitting is, probably, reduced to about 70%. For example, because K for a 90-degree bend is 0.25 (see Table B-6), K for two 90-degree bends would be 0.50 if the bends were separated by, say, a dozen pipe diameters. But if the bends were bolted together to make a 180-degree bend, K for the entire bend could be figured as $0.70 \times 0.25 + 0.25 = 0.43$, which is within 8% of the K value for a 180-degree bend in Table B-6. As another example, K for a 90-degree bend consisting of three 30-degree miterers can be determined directly from Table B-6 as 0.30 or indirectly by adding reduced K values for each miter except the last. Thus, $0.70 (0.10 + 0.10) + 0.10 = 0.24$ —an error of 20% (one publication lists the K for the mitered fitting as 0.20).

Pumps, especially when operating on either side of their best efficiency point, usually cause swirling (rotation) in the discharge pipe. Swirling sometimes also occurs in inlets and suction pipes. The effect of such swirling is to increase eddy formation and turbulence; consequently, the headloss in fittings can be doubled or even tripled. If swirling is likely to occur and if headloss within the pumping station is critical (which is often true in suction piping), the safe and conservative practice would be to design for headloss without swirling and again for headloss using, say, 200% of the fitting losses. Because there is no definitive body of literature about this complex subject, designers must either rely on experience or guess at headlosses.

Another method for computing headlosses is to use an "equivalent length" of straight pipe. This

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and all controls in a hermetically sealed, corrosion-resistant and submersible or explosion-proof enclosure.

Pneumatic Actuators

Pneumatic actuators are available for both linear and rotary motions. The disadvantages of pneumatic operators include (1) noise; (2) poor operating characteristics because the powering fluid, a gas, expands on change of pressure; (3) a tendency to freeze because of expansion on release to atmospheric pressure; and (4) corrosion (with compressed air systems) because of water entrained in the gas.

A pneumatic actuator system generally has a lower initial installed cost than a motorized actuator system. However, the maintenance costs for the pneumatic actuators and associated equipment (compressors, receivers, traps, separators, filters, and piping) are usually much higher than they are for a motorized actuator system.

Pneumatic actuator systems are especially attractive for pumping stations because they can actuate valves when a power failure occurs. A receiver (tank) provides the compressed air to operate the actuator. A solenoid valve, energized to close (de-energized to open), is placed in the air line connecting the receiver to the pneumatically actuated valve. Upon power failure, the solenoid valve opens and the pneumatic actuator causes the valve to close. This system allows some control over the time of closure of the valve so that excessive surge pressures can be avoided. Size the receiver to hold twice as much air as needed to operate all of the valves through one cycle.

In most pumping stations requiring only a few powered valves (no more than three or four), an electric actuator system generally has the lowest installed cost. However, electric actuators are not usually considered fail-safe devices. Hydraulic systems are usually the most expensive, with pneumatic systems in the middle. The cost of the hydraulic and pneumatic actuators themselves may be cheaper than the electric actuators, but the cost of the necessary auxiliary equipment—such as receivers, compressors, dryers, filters, and relief valves—rapidly increases the cost of small pneumatic systems. However, self-contained actuators that use the pumped water for power (so that auxiliary equipment is not required) are relatively inexpensive and low in maintenance labor.

Similarly, electric actuators require less maintenance than pneumatic and hydraulic actuators. Again,

it is the maintenance associated with the auxiliary equipment that usually causes electric systems to be selected.

5-7. Air and Vacuum Valves

Air release and vacuum relief valves are often needed along transmission mains and may sometimes be unavoidable in wastewater force mains. Air must be expelled when the pipeline is being filled. During operation, air (or sewer gas) accumulates along flat pipelines and especially at high points, and must be bled slowly to prevent (1) "air binding" due to the reduction of the cross section of the pipe at high points; and (2) corrosion at the soffit of the pipe. Vacuum conditions must be prevented when the pump head drops quickly (as in power failures) to prevent the shock of colliding water masses in column separation. Vacuum relief valve openings must be large—as much as one-sixth of the diameter of the transmission main, whereas air release valves must be small—as small as one-fiftieth of the diameter of the pipe. Although such valves are outside of the pumping station, their presence in the transmission main has a profound effect on surge and, hence, on the whole system.

A pipeline designed for fluid velocities high enough to scour air to the exit is an alternative approach that does not require the use of air release valves. Such velocities are within the normal design range for pipes 300 to 375 mm (12 to 15 in.) in diameter or smaller, as shown in Table B-9. Elimination of air and vacuum valves in favor of high velocity is not objectionable and may be of some benefit (by eliminating air bubbles altogether) *but only if there is assurance that catastrophic failure is precluded by air-scouring velocities* in pipes on flat or downward slopes. Excessive headloss can be prevented by the use of larger pipe for upward slopes. Note, however, that air-scouring velocities must be reached frequently enough to prevent large air bubbles from forming. Also, note that large pockets of air may greatly increase the head on the pumps. Design such combination systems on the assumption that the air release valves will sometimes fail to operate.

Air Release Valves

Air release valves slowly release the pockets of air that accumulate at high points in piping systems. In pumping stations, they are recommended on the discharge of vertical turbine pumps, especially when

pumping from wells and sumps. A conventional valve has a float that drops to vent the air that accumulates in the body. Valves smaller than 19 mm ($\frac{3}{4}$ in.) usually have a float-activated compound lever with a linkage mechanism to provide a tight closure.

The valve body contains an orifice, usually 5 mm ($\frac{3}{16}$ in.) or smaller, through which the air escapes.

Combination Air Valves

A combination valve combines the functions of air release and vacuum relief. It allows the use of one valve and one connection to the piping instead of two connections. Conventional valves contain linkage mechanisms for float assemblies as shown in Figure 5-16. The large venting orifice exhausts large quantities of air from a pipeline being filled and admits large quantities of air into a pipeline being drained. Some valves include a perforated water diffuser on the inlet to prevent the water column from rapidly entering the valve and slamming the float shut, thereby possibly causing a severe water hammer problem.

Air and Vacuum Valves in Water Service

Wherever possible, select a profile that minimizes the number of air valves because they constitute an onerous maintenance problem. In water service, the short valve body (Figure 5-16) is appropriate for combin-

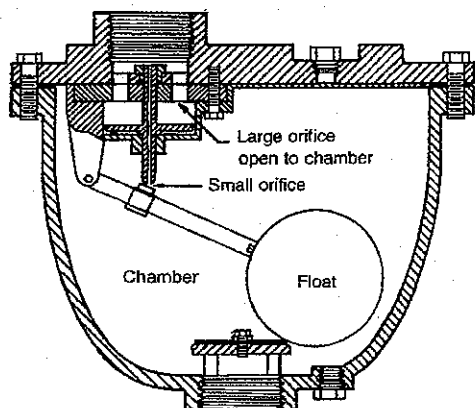


Figure 5-16. Conventional combination air valve for water service. After APCO Valve & Primer Corp.

ation air valves. Lescovich [15] has discussed the use of air valves in transmission mains.

Air and Vacuum Valves in Wastewater Service

Historically, conventional air release and vacuum relief valves for wastewater service have been expensive to maintain and are prone to jamming either open or closed due to grease and debris. In side-by-side tests in two systems [16, 17] known for considerable difficulty with conventional combination air-vacuum valves, a new design, Vent-O-Mat® series RGX [18], was found to be both reliable and to require little maintenance. The period between cleanings of conventional air-vacuum valves is typically one to three months, whereas the permissible period between cleanings of the RGX valve was found to be at least six times longer. In one of the tests, a Vent-O-Mat® series RGX valve was still functional after 18 months of service without cleaning. A somewhat different style, Series RBX, is intended for water service. Product information comes with software to help engineers select the proper size valve for a specific application.

The operation of the valve is illustrated in Figure 5-17. When a pipeline is being filled, the floats are at the bottom of the cylinder, and (as shown in Figure 5-17a) air is exhausted freely through passageways that are unchanging in cross-sectional area. If the column of water moves rapidly, however, the higher air velocity lifts the anti-surge float and reduces the passageway to a small orifice (Figure 5-17b) that releases air slowly and keeps the surge pressure to the level shown in Figure 5-17c. Conventional combination air-vacuum valves do not have such features. Small amounts of air or gas reduce the buoyancy of the lower float and allow the nozzle to separate slightly from the nozzle seat (Figure 5-17d) and release small quantities of air or gas. When a pump stops and part of the pipeline empties, or if column separation occurs, the floats fall and air rapidly enters the pipeline (Figure 5-17e).

Regardless of the proven reliability of air release and vacuum relief valves (or combination valves), if the equipment is to be used to protect pipelines, prudence dictates that two valves, connected to the pipeline with a trans-flow-type three-way valve (that can block either air valve but not both) be installed for the added insurance that the surge control system will function 100% of the time. The valves must be installed in a flood-protected location to assure that air, not water, will enter the valve when a vacuum occurs. See Figure 7-2 in Section 7-1 for a proper installation schematic.

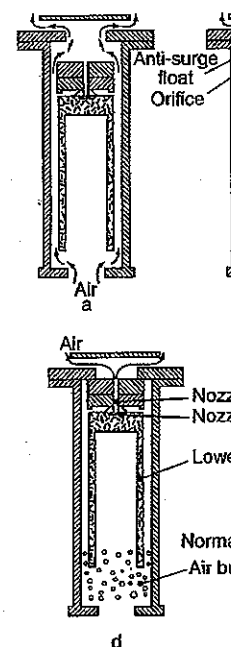


Figure 5-17. Vent-O-Mat vacuum relief valve, Series RGX, for subcritical wastewater filling at supercritical (c) pipeline fully charged of air under pressure; (d) Vent-O-Mat® literature

5-8. Materials of Construction

Bodies

Most valves in water, including air valves, are not subject to high pressure conditions. Bodies are usually cast steel (ASTM A395 or A53), larger, and bronze (ASTM A126) for smaller. Fabricate valves sometimes used in (72 in.), especially in cales, however, water service to iron and steel bodies should be product complying with standards. Also, some valves contain high percentages of carbon [19]. There is a

B.16 Appendix B Data for Flow in Pipes, Fittings, and Valves

Table B-9. Velocities Required to Scour Air Pockets from Pipelines. Values computed by Wheeler [10] using Equation B-1 developed by Wisner, Mohsen, and Kouwen [11].

Pipe diameter, mm	Velocities, m/s					Velocities, ft/s					Pipe diameter, in.
	Slope					Slope					
	0%	5%	25%	45°	90°	0%	5%	25%	45°	90°	
25	0.4	0.4	0.5	0.5	0.5	1.4	1.4	1.6	1.7	1.8	1
50	0.6	0.6	0.7	0.7	0.8	1.9	2.0	2.2	2.4	2.5	2
75	0.7	0.8	0.8	0.9	0.9	2.3	2.5	2.7	2.9	3.1	3
100	0.8	0.9	0.9	1.0	1.1	2.7	2.9	3.1	3.4	3.5	4
150	1.0	1.1	1.2	1.3	1.3	3.3	3.5	3.8	4.2	4.3	6
200	1.2	1.2	1.3	1.5	1.5	3.8	4.1	4.4	4.8	5.0	8
250	1.3	1.4	1.5	1.6	1.7	4.3	4.6	4.9	5.4	5.6	10
300	1.4	1.5	1.6	1.8	1.9	4.7	5.0	5.4	5.9	6.1	12
350	1.6	1.6	1.8	1.9	2.0	5.1	5.4	5.8	6.3	6.6	14
375	1.6	1.7	1.8	2.0	2.1	5.2	5.6	6.0	6.6	6.8	15
400	1.6	1.8	1.9	2.1	2.1	5.4	5.8	6.2	6.8	7.0	16
450	1.7	1.9	2.0	2.2	2.3	5.7	6.1	6.6	7.2	7.5	18
500	1.8	2.0	2.1	2.3	2.4	6.0	6.5	6.9	7.6	7.9	20
525	1.9	2.0	2.2	2.4	2.5	6.2	6.6	7.1	7.8	8.1	21
600	2.0	2.2	2.3	2.5	2.6	6.6	7.1	7.6	8.3	8.6	24
675	2.1	2.3	2.5	2.7	2.8	7.0	7.5	8.1	8.8	9.2	27
750	2.3	2.4	2.6	2.8	2.9	7.4	7.9	8.5	9.3	9.6	30
825	2.4	2.5	2.7	3.0	3.1	7.8	8.3	8.9	9.7	10.1	33
900	2.5	2.7	2.8	3.1	3.2	8.1	8.7	9.3	10.2	10.6	36
1050	2.7	2.9	3.1	3.4	3.5	8.8	9.4	10.1	11.0	11.4	42
1200	2.9	3.0	3.3	3.6	3.7	9.4	10.0	10.8	11.8	12.2	48
1500	3.2	3.4	3.7	4.0	4.1	10.5	11.2	12.0	13.1	13.6	60
1800	3.5	3.7	4.0	4.4	4.5	11.5	12.2	13.2	14.4	14.9	72

- Air problems do not occur where the pipe gradient is positive in the direction of flow [4].
- Avoid excessive head loss by using smaller-diameter pipe (to obtain higher velocities) only where gradient is flat or slopes downward.
- For air scouring to be effective, the tabular velocities must occur frequently (e.g., daily or more often).
- Air release valves in small pipes may be of little or no value.
- Blowback from clearing air in large pipes may cause surges that cannot be estimated. See Wisner, Mohsen, and Kouwen [4].
- Before designing piping systems for air scouring, it is advisable to read "Air Binding in Pipes" by Edmunds [5], the chapter on closed conduit flow in Falvey [7], and, for wastewater, "Hydraulics of Corrosive Gas Pockets in Force Mains" by Walski et al. [6].

Table B-10. Maximum Velocities Required to Scour Air Pockets from Pipelines. Values computed by Wheeler [10] using Equation B-1 developed by Wisner, Mohsen, and Kouwen [11].

True pipe	
D_p , mm	Area, mm ²
254	0.0
304	0.0
381	0.1
457	0.1
533	0.2
610	0.2
686	0.3
762	0.4
838	0.5
914	0.6
1067	0.8
1219	1.1
1372	1.4
1524	1.8
1676	2.2
1829	2.6

^a Eschritt's assumption: 1 assumption is roughly
 D_p is inside diameter
 y is depth of flow.
 A_p is inside cross-sectional area
 A_t is total inside cross-sectional area
For $n = 0.009$, mult
For $n = 0.011$, mult
For $n = 0.012$, mult
For $n = 0.013$, mult