4

Maintenance and survey of distribution systems

Dammika Vitanage, Francis Pamminger and Tony Vourtsanis

4.1 INTRODUCTION

Previous chapters have discussed:

- design of pipework and associated facilities to prevent contamination
- system operation to maintain pressure and structural integrity
- design and operation to avoid stagnation and preserve water quality
- prevention of deposits and biofilm by good water treatment.

Succeeding chapters provide guidance on sanitary practices for repairs and construction, and advice on the effects of small animals proliferating in the network. Achieving the objectives given in each of these chapters depends on the distribution system being well maintained and in good structural condition.

Safe Piped Water: Managing Microbial Water Quality in Piped Distribution Systems. Edited by Richard Ainsworth. ISBN: 1 84339 039 6. Published by IWA Publishing, London, UK.

This chapter discusses maintenance and survey procedures that should form part of a water safety plan (see Chapter 7). It looks first at procedures that are applied to readily accessible features such as service reservoirs or valves, and then at procedures applied to the inside of pipework, where condition is inferred from water quality measurements or by inspection, which may be difficult.

In many older systems the condition of the pipework may have deteriorated to such an extent that targeted renovation and replacement is necessary to maintain operability. This can occur where iron pipes have corroded internally to produce hard encrustations that prevent the maintenance of water pressure and disinfectant residuals, or where external corrosion and ground movement have created excessive leakage. Such situations obviously require careful investigation to identify the appropriate engineering solution. This process is usually called rehabilitation planning (Evins et al., 1989; AWWA, 2001) and it incorporates more complex and costly methods than those used for planned maintenance and survey. Rehabilitation planning is not covered in this review, except in this chapter, where there are references to common approaches (e.g. selection of pipe-cleaning methods).

4.2 MAINTENANCE AND SURVEY OF RESERVOIRS, TANKS AND FITTINGS

4.2.1 Sanitary significance

Structural deficiencies in tanks and reservoirs may lead to the direct contamination of water supplies with pathogens. Also, sediments may form in tanks and reservoirs due to the relatively low flow velocities that are a feature of these structures. Although such sediments are unlikely to be of direct health significance, they make it difficult to maintain a disinfectant residual. If the water level of the reservoir drops rapidly, accumulated sediments can be drawn into the pipework, where they are difficult to remove and have an even greater effect on disinfectant residual and general microbial activity than in the reservoir.

Faulty seals, joints or connections on valves, hydrants and washouts may also allow contamination of the system. This is unlikely if the system is operating at design pressures because the leakage flow will be from the pipe outwards. However, low or negative pressures may draw in contamination. The occurrence of low and negative pressures can be extensive during emergencies. For example, surge modelling on three well-operated systems in the USA demonstrated that conditions such as the loss of pumping power, fire flow and pipe breaks created low or negative pressures at up to nearly 30% of the pipe intersection points (nodes) incorporated in the models (AWWARF, 2001).

Where supplies are intermittent, contamination is likely to occur, and it may be difficult to operate the system to reduce the risks of backflow. In managing risks from intermittent supplies, it is important to reduce the hazards that may cause contamination and the risks of ingress of water contaminated with faecal material. Reducing intermittence will require careful analysis of both the causes and the solutions. The management of water demand and the implementation of water conservation measures such as hosepipe bans can provide rapid, long-lasting solutions. However, these measures may be insufficient where the infrastructure needs to be reinforced (e.g. by providing storage tanks and service reservoirs), or repaired, to prevent leakage and wastage in the distribution system.

4.2.2 Service reservoirs and tanks

Table 4.1 provides a typical checklist for external examination of reservoirs to identify potential sanitary deficiencies.

The frequency of internal inspection and cleaning of a reservoir will depend on the rate of deposition of solids, the effect of the solids on water quality and the construction, age and ground characteristics. In many systems, inspection and cleaning will require detailed planning to minimize disruption to supplies and to avoid contamination. Detailed advice is available (Tarbet, Thomas & Brown, 1993). It is vital to observe safety and hygiene requirements during inspection and during any cleaning that is performed. The appropriate safety measures for working in confined spaces should be followed. Minimum hygienic conditions for reservoir entry should include facilities for disinfecting boots, gloves and equipment. These may include foot baths with disinfectant solution and the provision of clean disinfected mats around the hatch. It is also advisable to provide toilet facilities on site. General guidelines about the use of personnel in situations where they could contaminate water supplies are given in Section 5.3. Table 4.2 provides a typical checklist for the internal examination of reservoir structures to identify deficiencies of potential sanitary significance.

Table 4.1. A checklist for the external examination of reservoirs.

Item	Check
Grounds and banks	Trees, bushes and scrub close to reservoir; localized luxuriant growth of grass (indicative of leakage); wet patches; animal damage; cracks and signs of ground movement
Roof cover	Cracks, animal damage or ponding indicative of poor drainage
Roofing membrane	Where visible check for damage, de-bonding and cracks (especially at joins and edges)
Hatches	Damage to cover, lock, built-in ventilators and seals
Ventilators	Corrosion, dents, cracks, vandalism, integrity and suitability of the mesh, excessive number of ventilators
Overflow or washout	Operability or existence of the flap valve, corrosion of flap valve and pipe, condition of discharge point, protection from backflow and intrusion by vermin
Valve housing or chamber	Security, leakage from reservoir, operability of valves if possible, corrosion of valves, leakage from valves, labelling
Valve gear, telemetry, gauges	All points where cables or spindles pass through into the reservoir
Disinfection system	Security of housing and operation of the equipment

Source: Tarbet, Thomas & Brown (1993).

Table 4.2. A checklist for the internal examination of reservoirs.

Item	Check
Valves	Corrosion and operability, washout blockages.
Pipework	Corrosion, fixings, outlet screens and outlet blockages
Roof, walls and floor	Roof to wall joints, locations where spindles, hatches etc pass through the roof, indications of leakage such as stains and deposits, root intrusion and cracks
Deposits	Depth and location, take samples for analysis

Source: Tarbet, Thomas & Brown (1993).

Cleaning of internal surfaces

Certain aspects of the internal inspection normally require the internal surfaces to be cleaned and freed of deposits. Pressure jetting and chemical cleaning are the two methods commonly used for this.

Pressure-jet washing employs specialized equipment; it may damage weak surfaces and coatings, and expose aggregate on concrete surfaces. Therefore, the jetting pressure should be selected and tested with care, and provisions made for localized repairs. Following jetting, surfaces should be sprayed with a disinfecting solution. A typical solution contains 10–20 mg/l of free chlorine.

Any chemical cleaning system that is used should be suitable for a potable water system. Those that have been employed consist of a dilute solution of hypochlorous acid, or a dilute solution of organic or inorganic acids plus vitamin C (ascorbic acid). Provided the manufacturer's instructions are followed, these chemical cleaning methods should not damage the structure. Whichever method is employed, there will be a requirement to dispose of the deposits, disinfecting solutions and cleaning solutions in an environmentally acceptable manner.

Alternative inspection and cleaning methods may be available, based on diving equipment or robot-based technology. When using these techniques for inspection there are potential advantages of reduced disruption to reservoir operation and safer working conditions. However, if they are being considered for cleaning, then the difficulties of removing packed sediments and effectively disinfecting walls could be a disadvantage.

Frequency of inspection and cleaning

Many water supply organizations undertake the inspection and cleaning of service reservoirs at 1–5 year intervals, depending on factors such as water-quality measurements, the efficiency of water treatment in removing deposit-forming substances, the presence of animals and information from previous inspections.

External sanitary surveys may be undertaken more frequently, using standardized forms designed for the specific reservoir. These surveys should focus particularly on sanitary and structural integrity, and any obvious deviations from good operational practice such as inundated valves, inspection covers left open and damaged vent-pipe mesh. Routine visitors to the reservoir should be encouraged to report any visible defects promptly and operational staff should respond rapidly to identified problems. Where operators visit service reservoirs daily, they should be given the task of regular inspection of the reservoir.

4.2.3 Valves and other fittings

Valves are used to isolate and control flow, regulate pressure or prevent backflow. A range of valve types exists, with various design features to achieve different operating requirements.

The most common valve function in a distribution system is to isolate flow, by being either open or shut. Valves at the boundaries of supply zones are shut to maintain a specific pressure within a supply zone, whereas those within a supply zone are generally open. Thus, valves could be in the same operational position for long periods. Distribution valves assist the operation of a water-supply system at times of pipe failures, supply deficiencies, seasonal supply changes and mains cleaning. Their predominant function is to isolate sections or to configure the systems differently to maintain supply. Thus, having all valves locatable and operable is important in minimizing the number of consumers affected during both emergencies and planned maintenance.

Hydrants provide fire authorities with access to sufficient water in case of a fire, and can be used for air release at high points. In practice, hydrants are used for a number of other reasons, such as flushing mains to improve water quality, and filling water trucks and street sweepers. Above-ground hydrants are easier to see, which is useful to fire authorities at critical times. However, placing hydrants below ground avoids the potential for vehicular accidents and reduces the chance of vandalism. Washouts are fittings designed to drain and aid the flushing of mains; they are usually located at the ends of mains or low points along a pipeline.

These valves and other fittings are important for the efficient operation of the system to maintain water quality. They are also potential points of ingress for contaminants, including pathogens. If a burst occurs or there are unusual demands, low or negative pressures may allow ingress through sealing mechanisms. Valves and other fittings should therefore be regularly inspected and maintained to meet the following requirements (Walski, 1994):

- the type and location of all fittings are accurately recorded;
- valves and fittings are accessible and boxes are not buried under asphalt or paved over;
- valve and fittings boxes are clear of debris, well drained and show no signs of leakage;
- valves and fittings are in operable condition, and sealing mechanisms are in good order;
- valves are in the intended position (either open or shut);
- the turning direction and required number of turns for all valves is known.

Exercising or operating valves requires skill and care. It is possible to open or shut valves too quickly, causing surge, which can lead to main breaks or low pressures. Valves that have not been operated for a long time can break if too much pressure is applied. Operation of such valves can also dislodge rust and sediments, adversely affecting water quality. Closing such valves may also be complicated if sediments lodge in the valve seat, requiring operation of a nearby hydrant to dislodge these sediments. It is important that only suitably trained personnel operate valves.

Box 4.1. An outbreak of Norwalk viral gastroenteritis due to backflow between a septic tank and the water supply.

During May 1978, an outbreak of gastroenteritis affected staff and students at a school in Pierce County, Washington State, USA. The main clinical features were nausea, vomiting and abdominal pain. Two of three people from whom paired sera were collected showed a fourfold rise in titre to Norwalk virus. The attack rate in the school was 71.5%, compared to only 6.5% in a control school. There was a very strong correlation between illness and reporting consumption of tap water in the school. Furthermore, two soccer teams from other schools met at the school and players from these teams who drank water were 14 times more likely to be ill than those who did not drink the water.

The water supply to the school came from a 51 m deep well yielding 257 l/m. The water was not chlorinated. The school was not connected to the public sewer and used a septic tank. Well water was pumped to a pressure tank through a ball-check release valve, with the pressure being maintained by on–off cycling of the pump. When the pump switched off, a port in the valve opened to allow air into the system. This air was expelled when the pump switched on again. At this point, it was common for water to spill out of the valve and maintenance staff had therefore attached a pipe from the valve to a floor drain. On 2 May, a baffle to the septic tank blocked and foul water filled the boiler room floor to a depth of 20 cm, completely covering the end of the pipe from the ball-check release valve.

As soon as the outbreak was identified, maintenance staff took samples from five taps in the school and all five showed thermotolerant (faecal) coliforms. It was concluded that the drinking-water had become contaminated with foul water through the pipe from the release valve that had aspirated water up the pipe.

Source: Taylor, Gary & Greenberg (1981).

4.3 MAINTENANCE AND SURVEY OF PIPES

4.3.1 Sanitary significance

Externally-derived pathogens can potentially persist within deposits in a pipeline (see Section 1.3.3), and can present an underlying health concern if resuspended with the deposits and then consumed. Although there are no reports of health effects directly attributed to this mechanism, maintaining the internal cleanliness of the network is a prudent objective. Deposits provide an environment for the proliferation of microorganisms and animals, which may make the water unpalatable. This may result in consumers turning to alternative potentially unsafe sources, and may also make it difficult to identify contamination of hygienic significance by routine monitoring. The deposits also hinder the maintenance of a disinfectant residual, especially in the smaller diameter pipes, which are at greatest risk of low pressures and hence contamination.

4.3.2 Strategies for pipe networks

The most important problems associated with networks are:

- hygienic water-quality problems
- aesthetic water-quality problems
- hydraulic deficiencies
- structural performance problems
- leakage.

Hygienic water-quality problems are clearly the most important of these; however, identifying the best solution requires information about the other problems. This can be a complex process because of the variety of pipe materials and pipe ages usually found in a network, and the fact that a relatively small part of a pipeline may be responsible for a problem.

Many utilities have found that a programme of regular mains cleaning to remove loose deposits and animal infestations has been of great assistance in maintaining water quality in distribution. A range of activities and solutions may be available, such as simple flushing of selected pipe lengths, swabbing, relining pipes with either structural or nonstructural linings and mains renewal. The costs and complexity of these are obviously different and dictate that problems are investigated in a systematic way based on performance data. These strategic investigation and planning procedures, which should also consider the future demands on the system, are beyond the scope of this review. Representative methodologies for systematic rehabilitation planning have been published (Evins, Liebeschuetz & Williams, 1989; AWWA, 2001; Lei & Sægrov, 1998; Herz, 1998).

Three methods are generally used to clean pipes; flushing, air scouring and swabbing with compressible foam swabs. These methods are often referred to as nonaggressive techniques. An important attribute is that they can be used without having to cut into the mains and are therefore suitable for regular maintenance. Some cleaning methods (e.g. pressure jetting, mechanical scraping and abrasive swabs) do require cutting into mains and, if the pipe material is ferrous, also require subsequent relining of the pipe. Complexities like this require systematic rehabilitation planning.

Programmes of regular mains cleaning should not become a substitute for efficient treatment (see Chapter 2). However, even in well-treated supplies, some deposits may form in small diameter pipes and at dead-ends, and animals may be present (see Chapter 6). Deposits may also originate from historically poor water treatment. Some investigational work will be required to ensure that extensive internal encrustations of iron mains are not present. Where these exist, there is the risk that the adoption of an aggressive cleaning method will aggravate the problem by dislodging the encrustations and allowing the iron surfaces to "bleed" corrosion products. In badly encrusted pipes, the use of nonaggressive foam swabs is likely to be ineffective and the swabs could become stuck or disintegrate to create blockage problems.

A general approach to targeting pipes to be cleaned requires analysis of available water-quality information and maintenance records, and integration with other maintenance activities within the distribution system. Monitoring of swater-quality changes in the network can be used to identify baseline conditions and infer where deposits are located. The following parameters have been employed for this purpose (Cossins et al., 2000; Rodgers, Pizzi & Friedman, 1998; Friedman et al., 1998):

- heterotrophic bacteria counts and total coliforms
- residual disinfectant concentrations
- consumer complaints
- turbidity
- dissolved oxygen
- iron, aluminium and manganese concentrations.

The colour of filter-papers used to filter set volumes of water can indicate the internal condition of pipework. The method has been used to distinguish problems caused by corrosion, deposition of treatment chemicals and deposition of manganese (Evins, Leibeschuetz & Williams, 1990a).

Water-quality measurements may indicate the presence of deposits. The selection of a cleaning method (or indeed whether cleaning alone is appropriate) depends on the pipe material (easily identified if not known) and the nature of the deposits. The three nonaggressive methods described in this chapter are not suitable for the removal of:

- hard deposits such as calcium carbonate (downstream of water softening plants or in pipes conveying very "hard" waters);
- corrosion tubercles in iron pipes;
- adhesive deposits, such as those that are rich in manganese oxides.

Identifying the nature of the deposits in mains is difficult because they are relatively inaccessible. A number of water suppliers have used fibrescopes (fibre optic instruments), which allow visual inspection via mains tappings or hydrants under mains pressure (Carruthers & Evins, 1985). A more direct approach is the examination of pipe samples, exhumed deliberately for this purpose, or obtained opportunistically during repairs and system modifications. Other techniques involve controlled flushing via hydrants and washouts to estimate the quantities and measure the composition of loose deposits and the populations of animals (Evins, Liebeschuetz & Williams, 1990b).

4.3.3 Planning mains-cleaning programmes

Pipe-cleaning programmes require careful planning to be effective and to prevent flow conditions that may allow system contamination. For all three techniques, a basic principle is that water must enter the length of main being cleaned from a length of main that has been previously cleaned or is known to be clean. It is important to assess normal flow velocities and pressures, and the effects on these of the work being planned. An important hygiene requirement is to avoid low or negative pressures in adjacent parts of the network. A network model will help in this assessment and can be used to identify whether the planned operations will create flushing conditions in adjacent pipework. Planning will normally follow the eight steps listed below (Stephenson, 1989).

(1) Determine where cleaning is required (as described in Section 4.3.2) and which method to use (see Section 4.4 below).
(2) Prepare plans of the area(s) to be cleaned.
(3) Assess potential contamination hazards (low pressures, pipe environment, air valves, etc) and which preventative measures to adopt.
(4) Determine the timing of works and labour; determine plant and material requirements including those for good hygienic practice (see Chapter 5).
(5) Assess on-site traffic problems, access and condition of mains and valves.
(6) Review and, if necessary, modify, step 4.
(7) Brief operators, notify consumers, and arrange system modifications (e.g. tappings) if required.
(8) Monitor progress and effectiveness of the work.

The environmental impacts of an extensive pipe-cleaning programme should always be assessed beforehand. For example, the large volumes of water and deposits that are discharged will require careful disposal and dechlorination to avoid contamination of watercourses and land. It is prudent to inspect the site environment and address issues such options for discharge of dirty water, dechlorination, erosion, and potential scenarios for ingress and contamination.

Further to this, mitigation and protection measures should be considered, such as stormwater drain protection, temporary detention or off-site disposal.

Good consumer relations and information are critical to the success of a pipe-cleaning programme. Consumers, especially critical ones such as hospitals and other utilities, need to be informed of maintenance activities via a suitable communication strategy, which could include the following features:

- advance notification letters informing the community of forthcoming work; reasons and benefits to the water supply;
- shutdown notification (if required);
- handling of complaints and enquiries specific to the cleaning programme.

4.3.4 Monitoring effectiveness of mains cleaning

The parameters used to identify the parts of the network requiring cleaning should be measured after cleaning. Indicator organisms should be included, to verify that the working practices were hygienic (Ashbolt, Grabow & Snozzi, 2001). Existing operational and verification monitoring can be used to assess how the pipes have responded to cleaning in the long term (> 1 month). Data collection before and after cleaning is essential for understanding the benefits, costs and secondary impacts of the cleaning programme (Friedman et al., 1998).

4.4 NONAGGRESSIVE PIPE CLEANING METHODS

4.4.1 Introduction

The most commonly used cleaning methods for routine maintenance are flushing, air scouring and swabbing. Other, more abrasive, methods are available for cleaning pipes before the renovation of water mains by coating with spray-on protective linings such as cement mortar or epoxy resin, or before the insertion of pipe liners such as polyethylene. Examples are high pressure water jetting, power boring with metal flails, and abrasive pigging devices (AWWA, 2001). However when these abrasive methods are used to clean iron pipe surfaces they should always be followed by a lining method, otherwise corrosion will continue apace, causing extensive water discolouration and deterioration. The characteristics of each of these nonaggressive cleaning methods are described in the following sections and are summarized in Table 4.3.

Table 4.3. Characteristics of the nonaggressive pipe cleaning methods.

	Flushing	Air scouring	Swabbing
Pipe sizes	Up to 150 mm in high-pressure areas	Up to 200 mm	Normally up to 1000 mm
Plant and materials	Hoses for disposal of large water volumes	Air scouring rig and compressor	Swabs, swab locators
System modifications	Existing hydrants usually employed	Additional hydrants, valves and injection points may be needed	Insertion points on larger pipes
Comments	Of limited use in low-pressure areas, potential to create extensive disturbance that may not be removed via flushing hydrant	More effective than flushing and can be used in low-pressure areas	Blockages may occur if swab lost

Sources: WRc (1994), Stephenson (1989).

4.4.2 Flushing

Flushing involves the discharge of water from pipes, generally through hydrants and washouts, to generate velocities in the pipe capable of removing accumulated material and biofilms inside the pipe and attached to its walls. This is the simplest of the pipe-cleaning techniques. The velocity required to suspend and flush out the deposits depends on particle size and specific gravity. Although most small animals are of low specific gravity (about 1), inorganic deposits may have a specific gravity of up to 3. Table 4.4 provides the volumetric flow rates required to transport loose particles of 0.2 mm diameter. Below this diameter, the minimum flow rate required falls quickly with particle size. Above this diameter, the effect of flushing diminishes rapidly.

Table 4.4. Flow rate required to suspend and transport solids of 0.2 mm particle size in water mains.

Pipe diameter (mm)	Flow rate (l/s) for specific gravity 1.5	Flow rate (l/s) for specific gravity 3.0
50	1.5	2.7
75	3.8	7.2
100	7.6	15.0
150	20.0	41.0
200	42.0	83.0

Source: Stephenson (1989).

Many water suppliers have a long history of implementing flushing programmes in one form or another, and to varying extents within the distribution system. Flushing may be used routinely to expel contaminants or in response to consumer complaints. These latter unplanned operations often involve opening hydrants in an area and leaving them open until certain water quality objectives are met (e.g. reduction or elimination of discolouration of water, or decreased turbidity of water). Flushing velocities are not necessarily maximized and the water used to flush a particular pipe may not have originated from clean or preflushed pipework.

For planned maintenance it is important to adopt a systematic approach based on unidirectional flushing. This means working to ensure that water enters from a previously cleaned main and water approaches the discharge point from one direction only. A particular section of pipe is isolated, typically by closing valves. The hydrants are then opened in a sequential manner, with the aim of increasing the velocity of water flowing through the pipe, thereby suspending sediments and flushing them out. In calculating flushing times it is important to remove at least twice the nominal volume of each main, because the suspended particulate matter moves more slowly than the water.

Advantages of flushing:

- simple to perform because it requires only 1 or 2 persons;
- relatively inexpensive to carry out in comparison with other cleaning techniques.

Disadvantages of flushing:

- uses a lot of water;
- limited effectiveness unless high flow velocities are achieved;
- unlikely to remove all the biofilm from the pipe;
- not suitable for larger diameter mains because it is usually not practicable to achieve the desired flushing velocity.

4.4.3 Swabbing

The swabbing process involves driving a cylindrical foam sponge (known as a swab) through pipes using water pressure. The swab has a diameter approximately 25% greater than the pipe it is being forced through. Various grades of swab are available, depending on the particular manufacturer's specifications. Typically, they come in three grades: soft, hard and scouring (WRc, 1994).

In practice, swabbing will be effective when the velocity of the water in the pipe is between 0.8 and 1.5 m/s. If the swab travels too fast it will remove less material and will suffer from wear and tear. To prevent the swab from tumbling, the ratio of length to diameter should be 2 for small diameters (< 100 mm) and 1.5 for larger diameters.

Swabbing will remove soft deposits but not the hard scales or corrosion products that may be present. It is usual to send between three and six swabs through a pipe to achieve adequate cleaning.

Swabs are normally inserted into pipes using existing fixtures such as hydrants, or insertion points such as swept-tees (T-branched connections, with the middle branch sweeping in at a shallow angle) specifically installed for this purpose. The insertion method will depend on the local engineering practices. However, all methods involve gaining access to the pipe interior and inserting a swab that will be in contact with both drinking-water and surfaces that are exposed to drinking-water. It is therefore essential that staff apply the same working practices and disinfection procedures as described in Chapter 5 for all equipment and materials (e.g. swabs) used in swabbing operations.

Advantages of swabbing:

- superior to flushing and air scouring in terms of removing sediments and biofilm from the pipe wall;
- has the potential to remove almost all biomass and sediment;
- uses less water than flushing;
- no diameter limitations because foam swabs can be manufactured for practically all pipe sizes;
- swabs can be manufactured with abrasive surfaces to assist in removing harder deposits from the pipe wall (but see comments above concerning corroded and tuberculated iron mains).

Disadvantages of swabbing:

- consumers may have to be isolated from supply during the cleaning operation;
- swabs may break up in the pipe, particularly in pipes with a high degree of internal corrosion or encrustations;
- more expensive than flushing;
- problems with collecting and disposing of contaminants — swabbing can produce a large amount of discoloured water that requires careful environmental planning for its disposal;
- swabs may become stuck in any unforeseen bore restriction, such as inserted length of smaller diameter pipe or tuberculated section;
- requires suitable points for insertion of swabs;
- swabs and any other materials or equipment used in the insertion process must be disinfected.

4.4.4 Air scouring

Air scouring involves the controlled injection of filtered, compressed air into pipes, usually via a hydrant (Stephenson, 1989). Given a continuous supply of water and air in the right proportions, discrete "slugs" of water are formed in the main and driven along by the compressed air at high velocity. There is no need to turn the water or air on and off to achieve this effect. This is illustrated in Figure 4.1. The high velocity slugs tend to lift up silt and sediment from the base of the pipe. Air-scouring companies do not claim that the process removes much, if any, biofilm from the walls of the pipe. Achieving the right conditions whereby high velocity 'slugs' are propelled through the pipework is a skilled task, and normally undertaken by a specialist team. Alternate slugs of air and water, along with loose sediments, are ejected from the hydrant (or other fixture) at the end of the pipe being cleaned. It is very important to get all the compressed air out of the pipe before it is returned to service, to avoid unstable flows and cloudy water.

The fact that pipeline fixtures will be used as air injection points dictates that the same hygienic working practices will be required as described above for swabbing. The additional complication is that ambient air is normally injected after being pressurized in an air compressor, which will almost certainly release oil into the air stream. Therefore, the compressed air should be passed through an air cooler and suitable filters to ensure removal of both oil droplets and oil vapours. The nature of the ambient air and its potential to contaminate the pipework should also be considered: for example, the proximity of a cooling tower generating aerosols could be considered potentially hazardous if the aerosols contain chemicals or microorganisms.

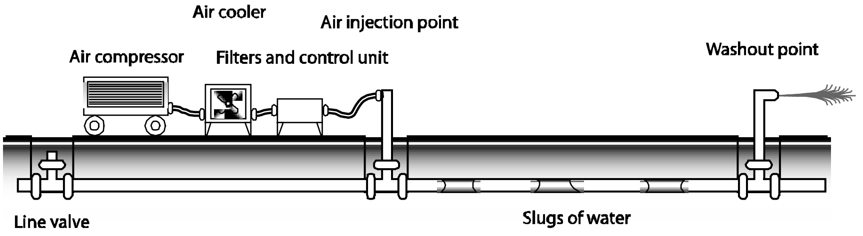

Figure 4.1. Achieving slug flow during air scouring.

Advantages of air scouring:

- about 40% less water is used during air-scouring than during swabbing or flushing;
- removes more deposits from pipes than flushing;
- the likelihood of a pipe break is very low as air pressure is kept below the static operating pressure of the pipe.

Disadvantages of air scouring:

- only effective in pipes with a diameter of less than 200 mm (also reported to lose its effectiveness in very small diameter pipes);
- not as effective as swabbing for removing biofilms;
- operators must be skilled, to ensure that the correct proportions of air and water are used;
- as with swabbing, consumers need to be isolated from the water supply during air scouring to ensure that discoloured water does not enter the house service pipes;
- precautions must be taken to prevent air contaminated with pathogens and chemicals (such as compressor oil) entering the pipework.

4.5 SUMMARY

Structural deficiencies in tanks, reservoirs, valves, fittings and pipework may offer direct routes for the contamination of water supplies with pathogens. This will depend on the environment surrounding the different components of the distribution system and the water pressure. Emergencies will generate low pressures in most conventional distribution systems.

Most tanks, reservoirs and fittings are accessible for inspection and planned maintenance. They should be prioritized according to sanitary risks, and surveyed and maintained in accordance with those risks. The survey and maintenance of service reservoirs is especially important because of the large populations served by these structures and the absence of internal water pressure at potential contamination points.

There are sound hygienic reasons for maintaining the internal cleanliness of pipework. Although there are no reports of health effects directly attributed to deposits in pipes, they do provide conditions for proliferation of microorganisms and animals. This may make the water unpalatable and make it difficult to identify contamination of hygienic significance by routine monitoring. The deposits also hinder the maintenance of a disinfectant residual, especially in the smaller diameter pipes which are at greatest risk of low pressures and hence contamination.

Pipe cleaning programmes can be used to maintain the internal cleanliness of a network. They require careful planning to be effective and to prevent flow conditions that may allow system contamination. It is important to assess normal flow velocities and pressures, and the effects on these of the work being planned. A network hydraulic model will help in this assessment. An important hygienic requirement is to avoid low or negative pressures in, and adjacent to, those parts of the network being cleaned. When using swabs or injected air to clean pipework, the materials and fixtures are potential sources of contamination and therefore the hygienic practices described in Chapter 5 should be followed.

4.6 REFERENCES

Ashbolt NJ, Grabow WOK, Snozzi M (2001). Indicators of microbial water quality. In: Fewtrell L, Bartram J, eds. *Water quality: guidelines, standards and health: risk assessment and management for water related infectious diseases*. IWA Publishing, London, UK.

AWWA (2001). *Rehabilitation of water mains*, 2nd ed. American Water Works Association, USA.

AWWARF (2001). *Pathogen intrusion into the distribution system.* American Water Works Association Research Foundation, Denver, USA.

Carruthers FB, Evins C (1985). *Fibre optic instruments for the internal inspection of water mains. A source document for the water mains rehabilitation manual.* Water Research Centre, Swindon, UK.

Cossins F et al. (2000) The Cincinnati water works' unidirectional flushing programme results and alternative approaches for full-scale implementation. In *American Water Works Association Conference Proceedings*, ISBN: 1583210733.

Evins C et al. (1989). *Planning the rehabilitation of water distribution systems. Principal document of the water mains rehabilitation manual.* Water Research Centre, Swindon, UK.

Evins C, Liebeschuetz J, Williams SM (1990a). *Aesthetic water quality problems in distribution systems. A source document for the water mains rehabilitation manual.* Water Research Centre, Swindon, UK, Appendix H.

Evins C, Liebeschuetz J, Williams SM (1990b). *Aesthetic water quality problems in distribution systems. A source document for the water mains rehabilitation manual.* Water Research Centre, Swindon, UK, Chapter 2.

Friedman M et al. (1998). Developing and implementing a distribution system flushing programme. *American Water Works Association Conference Proceedings*,16.

Herz RK (1998). Exploring rehabilitation needs and strategies for water distribution systems. *Journal of Water Supply: Research and Technology — Aqua*, 47(6):275–283.

Lei J, Sægrov S (1998). Statistical approach for describing failures and lifetimes of water mains. *Water Science and Technology*, 38(6):209-217.

Rodgers ML, Pizzi NG, Friedman M (1998). Distribution flushing to improve corrosion control and water quality. *American Water Works Association Conference Proceedings*, 9.

Stephenson G (1989). *Removing loose deposits from water mains: operational guidelines. Source document for the water mains rehabilitation manual.* Water Research Centre, Swindon, UK.

Tarbet NK, Thomas BJ, Brown JA (1993). *Service reservoirs operation, repair and maintenance.* Report No. 1409 UM, Water Research Centre, Swindon, UK.

Taylor JW, Gary GW Jr, Greenberg HB (1981). Norwalk-related viral gastroenteritis due to contaminated drinking water. *American Journal of Epidemiology*, 114:584–592.

Walski TM (1994). Valves and distribution system reliability. *Proceedings of American Water Works Association Annual Conference*, New York, 1994. American Water Works Association, USA, 599–613.

WRc (1994). *Water mains cleaning handbook.* Water Research Centre, Swindon, UK.