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Cross-Connections: Causes, Consequences, and Cures

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CROSS-CONNECTIONS: CAUSES, CONSEQUENCES, AND CURES

by

William M. Dunne and C. W. Christenson

ABSTRACT

Cross-connections are defined and appropriate remedial measures to eliminate cross-connections are presented. Primary emphasis is placed on cross-connections in an industrial environment.

I. INTRODUCTION

The physical principles involved in interconnecting two plumbing systems operating at different pressures were elucidated many years ago by the earliest students of hydraulics. It is obvious that water, or any other fluid, will flow from a point of higher pressure to one of lower pressure. Unfortunately, many people will create or tolerate cross-connections because of their confidence in continuance of expected pressures in the water distribution system.

A cross-connection is any connection between two systems, one of which contains potable water and the other some nonpotable substance, and the nonpotable substance can enter the potable system. In many cases, the circumstances under which there will be a transfer of adulterants are dependent on a situation not entirely under the control of the scientist, the technician, or the engineer. This discussion is predicated on the assumption that the water supplied by the local water purveyor is of satisfactory quality. Obviously, an industrial plant has no control over the quality of water coming into its plant.

The general reaction to discussions of cross-connections is that they never happen. A review of the literature[1,2] reveals that there have been several significant incidents. An incident, in 1969, had a substantial impact. In Worchester, Massachusetts, the Holy Cross football team was beginning its fall practice sessions. One morning a fire in the nearby town occurred. About a month later, after Holy Cross had played only one game of its scheduled season, it had to cancel the remainder of its schedule because the team had contracted hepatitis. Subsequent investigation by Taylor[3] showed that several children living near the practice field had hepatitis and had used sprinkler boxes in the playing field as toilets. The fire in the nearby town had lowered the water pressure enough to siphon the contaminated water into the water system. When water pressure was restored, the contaminated water was distributed through the system. When the players drank from the water fountain at the edge of the field, they became the unknowing victims of a cross-connection. Note that if the team had not been practicing and one groundskeeper had contracted hepatitis, the medical practitioner would probably not have been able to identify properly the cause of the infection. A situation involving chemical poisoning would not present a difficult tracing problem if the acute effect of ingestion were severe and immediate. However, the statistical association between cause and effect is often difficult with infectious diseases.

II. HAZARDS

A. Types

Hazards may be characterized as falling into the following four categories:

1. Chemical
2. Biological
3. Radiological
4. Physical

The severity of the hazard associated with any of these categories is, in most cases, route-dependent. A cyanide solution contacting the skin is obviously much different from ingestion of the same solution. Assuming that there are no breaks in the skin, biological agents would be a problem only if ingested. Other chemicals, for example, a 30% caustic solution, would constitute a hazard either on ingestion or body contact. Radiological hazard is due to the retention of the isotope and subsequent irradiation of human tissue. A physical hazard may be the connection of a steam line to a water line.

B. Toxicity Evaluation

A question logically arises as to what constitutes a high or low degree of chemical hazard. In this area, the literature is somewhat contradictory since some references differ in reported toxicity levels for the same substance. "Clinical Toxicology of Commercial Products"[4] categorizes materials by toxicity classes ranging from practically nontoxic to supertoxic. Fortunately, there are few materials in the supertoxic category. One also may argue with some of the categorizations, such as common salt being identified as a moderately toxic substance. This does not conform to our preconceived notions about table salt. By its categorization, somewhere between one ounce and one pound would be a probable lethal dose for a 150-pound man. Exposure to a sodium chloride solution appears to be a much less serious matter than exposure to a similarly categorized "moderately toxic" insecticide such as methoxychlor or the "moderately toxic" antifreeze ethylene glycol. Obviously, toxicity data must be interpreted carefully. Toxicity evaluation is critical in the determination of the type of protective device to be installed.

III. PROTECTIVE MEASURES

Before defining protective measures two other definitions must be presented, namely, those of backpressure and backsiphonage. Figure 1 identifies these conditions. The horizontal axis is gauge pressure at sea level. With backpressure, as shown above the horizontal axis, pressure in the nonpotable and potable systems is above atmospheric, and pressure in the nonpotable system exceeds pressure in the potable system. In a backsiphonage condition, as shown below the horizontal axis, pressure in the potable system is less than atmospheric, that is, it is operating under a vacuum. Pressure in the nonpotable system may range from subatmospheric to above atmospheric (although only the subatmospheric pressure case is shown here).

The greatest danger in cross-connection control is to assume that a gate valve, single-check valve, or similar valve, constitutes a cross-connection control device. Such devices can pass a measurable quantity of water when they are thought to be closed. What then are some of the devices which can be used to provide the required separation between potable and nonpotable systems? These devices will be presented in the order from the device providing the least amount of protection to that providing the greatest degree of protection.

A. Atmospheric-Type Vacuum Breaker

An atmospheric-type vacuum breaker is an adequate protective device if the system is not subject to pressurization (or

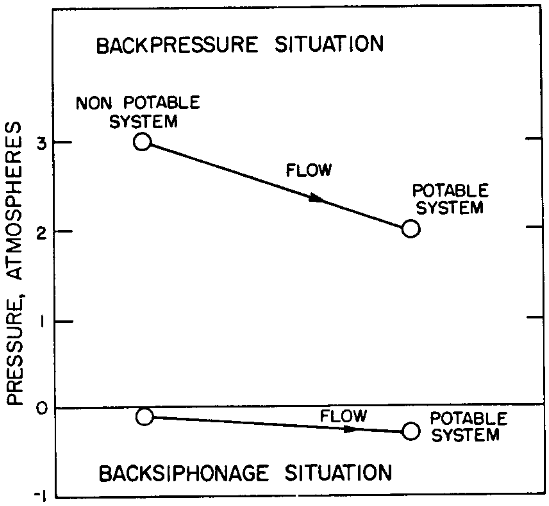

Fig. 1. Conditions allowing backflow.

backpressure) on the downstream side of the vacuum breaker. These devices function by allowing air to be introduced into the water system if pressure in that system falls below atmospheric pressure. A laboratory sink is a fairly typical installation example. If the materials handled there are not hazardous, a vacuum breaker will provide adequate protection because it will prevent water from being siphoned out of the lab sink through a hose connected to the water service fixture. If, however, the hazard is substantial - as in the case of cyanide solutions - a more sophisticated device will be required. Two important restrictions on this type of device are that they must be installed in a vertical position at least 6 in. above the highest use point, and there must be no shut-off downstream of the device. In many cases, suppliers have available as stock items water fixtures complete with vacuum breakers and it is recommended that such water fixtures be purchased. A vacuum breaker may be installed after a sink is in place.

B. Pressure-Type Vacuum Breaker

A pressure-type vacuum breaker similarly is subject to the restriction that it will not prevent backflow due to backpressure. However, it may be located with a shut-off valve downstream. If materials handled downstream of the device are not hazardous, this type of device may be used. Two important restrictions on this type of device are that they must be installed vertically at least 12 in. above the highest use point, and nearby equipment must be protected from any splashing.

The device should be located in an area where it is accessible for testing and the test cocks should not be used as a water source.

C. Double-Check Valve

A double-check valve may have all the appearances of two single-check valves assembled in series. One significant difference between the single-and double-check valves is the provision of test cocks to permit testing to determine proper operation of the device. These devices, unlike others mentioned previously, can be used with downstream pressures in excess of the upstream pressure. These devices should not be used in plumbing systems containing hazardous materials.

D. Reduced Pressure Principle Type Backflow Preventer

These devices can be used safely between potable water lines and lines containing hazardous materials and they provide satisfactory protection against both backpressure and backsiphonage conditions. Units come in a wide range of sizes adequate to meet most industrial requirements. A 3/4-in. device will pass a maximum of 34 gal/min (2.1 x 10^{-3} m^3/s). Larger devices such as a 6-in. device will pass a maximum of 1 000 gal/min (6.3 x 10^{-2} m^3/s).

Pressure drops vary considerably among the same size devices supplied by different manufacturers. Some pressure-drop curves are sharply rising when approaching the maximum rate of flow, while others are uniformly flat. If pressure drop is critical in proposed installation then manufacturers' published curves should be consulted.

Some of the precautions which must be observed in the installation of these devices are as shown in Table I.

The first requirement of a locked and heated enclosure is applicable to installations where the device is located in a climate with subfreezing temperatures. Obviously, it is prudent to lock any kind of utility installation if it is subject to tampering. Manufacturers' installation directions should be observed scrupulously. Adequate clearances between adjacent piping systems, equipment, and parallel units are a necessity.

The four cocks located on the device and the associated valve are test cocks. These test cocks are to be used solely for testing the functioning of the device. That counsel applies equally to pressure vacuum breakers and double-check valves. These devices have a relief port to discharge water from between the two internal check valves if there are pressure surges in the supply line. If the relief port should discharge water continuously, the device is not functioning properly and should be repaired immediately. Manufacturers' literature describes the operation of these devices in detail. Tests at Oak Ridge, Tennessee, have shown that RP devices are extremely reliable.[5]

TABLE I

RP INSTALLATION REQUIREMENTS

A. A heated, locked enclosure located above the highest possible water pool level

B. Installed to facilitate maintenance; i.e., no less than 12 in. above floor, no more than 4 ft above floor, and adequate clearances all-round to allow for disassembly

C. No connections to the test cocks

D. An unobstructed relief port

Bypasses should never be installed around any of these devices. Parallel units should be installed if noninterruptible water service is a "must." This applies to all methods of backflow prevention.

E. Air Gap

The devices mentioned heretofore are mechanical devices which may be unfamiliar to plant personnel. An air-gap installation is as common as a bathroom sink. Scientists recognized that plumbing fixtures could allow water to be siphoned out of sinks if the faucet outlet were close enough to the water surface. Plumbing fixtures are now designed so that the distance from the water surface to the bottom of the inlet fixture must be a minimum of twice the internal diameter of the supply fixture. In some cases the air-gap requirement may be either three or four and one-half pipe diameters.[6]

A properly installed air gap from the foregoing description is the most foolproof of all backflow prevention systems. The price one pays for the added protection is loss of pressure.

The conditions under which these various devices may be used are as shown in Fig. 2. Note that both the air gap and the RP device may be used in high-hazard situations involving both backpressure and backsiphonage. (For the sake of clarity the double-check valve has been omitted from the backsiphonage area.)

Table II shows some of the more important characteristics of various backflow prevention devices.

IV. RECOMMENDED PROGRAM

Since cross-connections often are designed unknowingly into plumbing systems and maintenance of devices is required, the obvious solution may be to incorporate a system for cross-connection control into the plant engineering department or some

TABLE II

CHARACTERISTICS OF VARIOUS BACKFLOW PREVENTION DEVICES

	Suitable For Degree of Hazard	Prevent Back-flow due to Backpressure	Size Range (in.)	Cost
Atmospheric-Type Vacuum Breaker	Low	No	3/8 - 2	Low, $5 Smaller sizes
Pressure-Type Vacuum Breaker	Low	No	1/2 - 8	Moderate
Double-Check Valve	Low	Yes	2 - 10	High
Reduced Pressure Principle device	High	Yes	3/4 - 10	High
Air Gap	High	Yes	N/A	High (>$1,000) Tank and pump or elevated storage tank

similar organization. At the Los Alamos Scientific Laboratory, such responsibility has been placed within the Health Division. Some of the essential elements of a cross-connection control program are as shown in Table III.

A. Review of "New Construction" Drawings

Review of pre-construction drawings and specifications will save hours of headache over the alternative strategy of allowing a contractor to install a cross-connection and then having him remove it later as an "extra" to the construction contract. A uniform pipe labeling system should be adopted. One of the more frustrating occurrences is to find contradictory legends on several different sets of drawings. One example was a building which had been built in four increments. Drawings for the earliest section showed "PW" as potable water; in the adjacent section, "PW" represented Process Water.

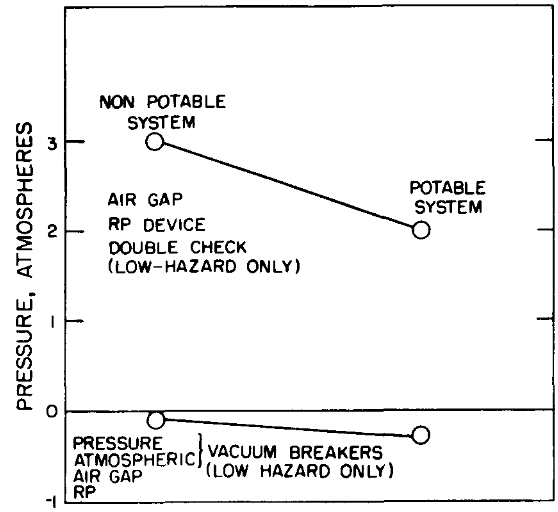

Fig. 2. Appropriate backflow prevention for backpressure and backsiphonage conditions.

TABLE III

CROSS-CONNECTION CONTROL PROGRAM ELEMENTS

A. Review of "New-construction" Drawings

B. Inspection of Existing Facilities

C. Correction of Existing Deficiencies

D. Routine Maintenance of Installed Devices

E. Compliance with Local/State Ordinance and Records Maintenance

F. "In-House" Education Program

B. Inspection of Existing Facilities

The inspection of existing facilities is the most tedious phase of all. The difficulty of inspection of existing facilities is determined by a number of circumstances, such as:

1. Is the piping exposed and readily visible?
2. How many times has the building been modified, expanded, or cannibalized?
3. Are floor plans and the original construction drawings available and are they truly "as-built" drawings?

The most difficult inspection involves the modified, multi-story building with concealed piping. This type of facility becomes almost impossible to inspect if there are no "building veterans" available to advise of changes that have been made. The entire lengths of all water lines must be checked to assure absence of cross-connections. In some cases, it may be necessary to decide whether isolation of one activity from another within the same building is desirable or whether interconnections between segments of the industrial water system are acceptable.

C. Correction of Existing Deficiencies

Inspection of existing facilities implies correction of the deficiencies which are found. Extensive changes may require substantial budgetary commitment because they may include complete segregation of lines now used for potable and industrial water supply. Various methods of cross-connection elimination should be evaluated by traditional engineering economic studies.

D. Routine Maintenance of Installed Devices

Maintenance costs may be estimated on the basis of a 15-min test at least once per year for each backflow prevention device, except for the atmospheric type vacuum breaker, and unless a more stringent maintenance program is required by plant policy or applicable codes.

The manufacturers' literature provides details describing test methods for these devices. Either the Foundation for Cross-Connection Control and Hydraulic Research at the University of Southern California or local/state health departments may sponsor courses that provide training in how devices should be tested. Testing)of these devices should be performed by someone trained in backflow preventer testing and maintenance. Casual observation of the fact that there is no discharge from the relief port is no guarantee that a reduced pressure principle type device is functioning properly.

E. Compliance with Local/State Ordinances and Records Maintenance

Since there are no federal laws (although there are EPA recommendations[7] and OSHA regulations[8]) dealing with this problem, all plant programs should at least be in conformance with local and state codes, if there are any. A logical starting point is to discuss the matter with the local health department or water purveyor. In some jurisdictions, lists of approved devices may have been prepared and the use of only these devices is mandated. The absence of local/state programs is not a waiver of responsibility to the industrial plant. Liability will extend to the plant despite the lack of a local program. Therefore, the plant program should provide a safe water distribution system within the plant by providing backflow prevention devices as necessary and an adequate maintenance and inspection program and adequate records-keeping.

F. In-House Education Program

There are several important elements to the In-House education program, as shown in Table IV.

Convincing management of the need for elimination of cross-connections is of paramount importance. Obviously, with hazardous materials it is easier to convince management of the importance of such

TABLE IV

IN-HOUSE EDUCATION PROGRAM

A. Management - the importance of elimition of cross-connections

B. Plumbers - how to avoid installing cross-connections; recognition of cross-connections

C. Staff - what cross-connections are; no connections to water system unless installed in accordance with applicable plumbing codes, and no tampering with backflow prevention devices.

a program. Regrettably, there is a dearth of good educational materials for presentation to administrative but nontechnical personnel. Despite the fact that plumbing codes prohibit cross-connections, many maintenance personnel acquiesce in their installation, especially by avoiding the air-gap requirements. With an adequate pipe labeling system, undesirable plumbing alterations can be minimized. One of the most difficult aspects of an in-house education program is to educate the staff to make only competently supervised water system connections. The installation of backflow prevention devices within experimental areas requires constant reminders not to use the test cocks on the devices as sources of water. Without the last two elements in a cross-connection control program, any survey work will often be negated by someone installing a cross-connection as soon as one thinks he has eliminated the cross-connection.

Some industrial facilities may require a noninterruptible source of water and in such cases parallel backflow prevention devices may be required.

The greatest danger in any cross-connection control program is indifference, to assume that "everyone knows that it is our policy not to install cross-connections." The Environmental Protection Agency pamphlet "Cross-Connection Control Manual"[7] cites examples of cross-connections of public health significance and provides added advice on the administration of a cross-connection control program. Publications by the American Water Works Association, such as "Cross-Connections and Backflow Prevention"[9] and "Backflow Prevention and Cross-Connection Control"[10] provide added insights into typical cross-connections, degree of hazard, and recommended type of backflow prevention devices for various circumstances. Other materials are included in the "Handbook of Laboratory Safety"[11] and in the "Accident Prevention Manual for Industrial Operations,"[12] published by the National Safety Council.

REFERENCES

1. G. Craun and L. McCabe, "Review of the Causes of Waterborne Disease Outbreaks," J. Am. Water Works Assoc. 65, 74-84 (1973).
2. G. Craun, L. McCabe, and M. Hughes, "Waterborne Disease Outbreaks in the U.S. - 1971-1974," J. Am. Water Works Assoc. 64, 420-424 (1976).
3. F. Taylor, "The Holy Cross Episode," J. Am. Water Works Assoc. 64, 230-232 (1972).
4. M. Gleason, R. Gosselin, H. Hodge, and R. Smith, Clinical Toxicology of Commercial Products (Williams and Wilkins Co., Baltimore, 1969).
5. J. Baird, W. Sanford, and G. Cristy, "Reduced Principle Backflow Preventer Evaluation and Use at Oak Ridge National Laboratory," Health Physics 11, 743-757 (1965).
6. American National Standards Institute, Standard for Air Gaps in Plumbing Installations, ANSI Standard 112.1.2 (New York, 1973).
7. Environmental Protection Agency, Cross-Connection Control Manual, EPA-430/9-73-002, US Government Printing Office, Washington, DC, 1973.
8. "Air Gaps in Plumbing Systems," American Society of Mechanical Engineers, ANSI 112.1.2. (1973).
9. G. Angele, Cross-Connections and Backflow Prevention (American Water Works Association, Denver, 1974).

10. G. Angele, Backflow Prevention and Cross-Connection Control. (American Water Works Association, Denver, 1966).

11. N. Steere, Ed., Handbook of Laboratory Safety, (The Chemical Rubber Co., Cleveland, 1971).

12. F. McElroy, Ed., Accident Prevention Manual for Industrial Operations (National Safety Council, Chicago, 1974).