CHAPTER 19

CHEMIGATION

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Abstract. *Chemigation is the application of water-compatible chemicals by the use of an irrigation system for fertilizing or control of crop pests, or for maintenance of a microirrigation system. Chemigation, in all its forms, is commonly used in irrigated production across the world, and its use can greatly influence the design and operation of farm irrigation systems. Its use must follow regulatory requirements and be done according to the chemical label. A major concern with chemigation is safety, in terms of protecting personnel, the water supply, and the environment. There are numerous ways to apply the various chemicals depending on the volumes and required precision of the injection. These systems must be carefully calibrated and used with great care.*

Keywords. *Chemicals, Crop protection, Fertilizers, Irrigation, Safety, Systems.*

19.1 INTRODUCTION

19.1.1 Definition

Chemigation is the application of various chemicals to a crop through an irrigation system. In agricultural operations the type of chemicals applied may be fertilizers, pesticides, insecticides, fungicides, herbicides, nematicides, and growth regulators (Rolston et al., 1986; Bar-Yosef, 1999). However, injection of water-soluble fertilizers is the most common form of chemigation (Wright et al., 1992; van der Gulik, 1993; Burt et al., 1995; Scherer et al., 1999). Depending on the use and the user, various forms of chemigation are also referred to as fertigation, pestigation, insectigation, fungigation, herbigation, and nematigation, to name just a few.

Chemicals may also be injected into an irrigation system for maintenance purposes, such as algaecides and chlorine in microirrigation systems (Evans and Waller, 2007). Specific details on microirrigation system maintenance with chemical treatments are provided in Chapter 17.

Chemigation has been considered and probably practiced since sprinklers were first used on farms in the first part of the 20th century. One of the first discussions on chemigation in the literature was by Bryan and Thomas in 1958. Threadgill (1985) conducted a survey of chemigation use in 35 states in 1983 and found that about 4.3 million hectares in the U.S. were utilizing chemigation at least once during the season.

The 1998 Census of Agriculture (NASS, 1998) reported that about 4 million hectares were chemigated on more than 35,000 farms across the U.S. at that time. The use of chemigation is expected to increase as producers continue to convert to pressurized irrigation systems because of the convenience and reduction in application costs over more conventional chemical application methods. In addition, it is expected that the current emphasis on precision farming techniques will accelerate the growth of chemigation in the near future.

The application of chemicals is almost universal with most drip systems and a large percentage of sprinkler systems are using this technology. Chemigation is used to a lesser extent on surface-irrigated land. Microirrigation and center pivot systems are well-suited to the use of chemigation because of their high distribution uniformities and ease of operation (Rolston et al., 1986; Threadgill et al., 1990; van der Gulik and Evans, 2006; Evans and Waller, 2007).

Prior to using chemigation an operator must understand federal and local regulations that apply; understand safety issues and environmental protection measures that must be followed; have knowledge of the irrigation system operation and chemical to be applied; be able to determine an appropriate injection rate and timing of application for the area treated and crop grown; and ensure the irrigation system is properly flushed after chemigation has been completed (van der Gulik 1993; Burt et al., 1995; Evans and Waller, 2007).

19.1.2 Benefits

The use of chemigation with irrigation systems has shown steady growth. Benefits include:

- reduced labor and chemical application cost,
- incorporation and activation of fertilizers for crops grown under drip systems in drier climates,
- timely application of chemicals,
- reduction of soil compaction and mechanical damage to the crop,
- improved operator safety when applying pesticides,
- reduction in the amount of chemical use,
- potential reduction of environmental contamination, and
- improved crop production.

The benefits of chemigation do come with extra cost and precautions. Backflow prevention, other safety equipment, and injectors will increase system cost. Irrigation system distribution uniformity must be maximized to ensure best possible chemical distribution uniformity. To ensure proper operation of the system, injector calibration is necessary. Irrigation drift must be minimized and all irrigation systems must be managed to control over- or under-application of chemicals..

The use of microirrigation irrigation systems and fertigation will continue to increase due to the many advantages offered by this technology. Better application efficiencies offer a reduction in the amount of fertilizer used. Fertigation offers the possibility of timely applications of the appropriate amount of fertilizers which will result in less impact on the environment

The proper application of fertilizers imposes minimal health concerns and risks to water purveyors. However, the potential to apply other chemicals is seen as a greater risk. Potential contamination of the water source due to backsiphonage and backpressure are possible if an unexpected shutdown of the irrigation system should occur while injection is taking place. This risk can be minimized by following good chemigation practices and if proper backflow prevention devices are installed and inspected regularly.

19.2 BACKFLOW PREVENTION AND SAFETY

19.2.1 Why Chemigation Is a Potential Hazard

Chemigation is considered a hazard if there is a potential cross-connection between a chemical tank and a potable water source. A cross-connection is any connection or structural arrangement between a potable water system and any nonpotable water system or chemical source through which backflow can occur. The cross-connection can be to a purveyor's main line, stream, lake, or groundwater used as a source of potable water. Injecting chemicals into an irrigation system therefore presents a potential hazard to public health and safety, requiring approved prevention measures.

The safety devices that are required will depend on federal or local laws and the information provided on the chemical label. Some chemical labels require specific backflow prevention devices to be installed before chemigation can be used. Specifications and management of backflow devices may vary between jurisdictions. Applicators should always consult with local officials or experts for information on the required backflow prevention devices for their area.

19.2.2 Regulations and Safety

The first rule of chemigation is always safety. Special chemigation safety devices, check valves, and air relief valves are required for *all* chemical injection systems under federal and local regulations. Well heads must be protected from reverse flows, system drainage, or backsiphoning. Electric and hydraulic interlocks with time delays must be installed between the injectors and irrigation pumps to prevent chemical injection when the irrigation system is not operating. Chemical injection areas should always be securely fenced with appropriate containment facilities in the event of a spill (Shulze and Buttermore, 1994). Special protective equipment, safety showers, and any required chemical neutralizing agents should be readily accessible and clearly marked. Personnel must be specifically trained and, in many areas, licensed for chemical applications. Injection of any pesticide into an irrigation system must be specifically permitted by the pesticide label and may also be subject to additional state regulations. Detailed records of all chemical applications need to be maintained for safety, evaluations, legal, and regulatory requirements.

All chemicals and chemical-water mixtures must be checked to avoid phytotoxic effects before any injection occurs. In addition, it is critical that all the chemicals being injected at one time are compatible with each other and the water chemistry and concentration limits are not exceeded so that precipitates do not form and plug emitters. Some chemical combinations, such as calcium nitrate and phosphoric acid, will immediately form a precipitate creating a severe plugging situation. Emulsifiable pesticide concentrates and wettable powders may require special design and management considerations (e.g., mechanical supply tank agitation) to help ensure uniform applications and reduce plugging. Acidification to lower water pH may sometimes be required prior to injection of a chemical. Precipitation tests should be conducted at the same dilutions, pH, and other conditions of chemical application. Additional information and procedures can be found in Ptacek (1986), Smajstrala et al. (1986), van der Gulik (1993), Burt et al. (1995), Clark et al. (1998), Scherer et al. (1999), and Granberry et al. (2001).

19.2.3 Backflow Prevention Devices

Backflow can occur in a chemigation system by either backsiphonage or backpressure (Smajstrala et al., 1985; Wright et al., 1992; van der Gulik, 1993; Solomon and Zoldoske, 1998; ASABE, 2006). Backsiphonage is caused by low pressure or a reduced pressure in the water supply piping. Principal causes of backsiphonage are:

- failure of the irrigation pipeline main line check valve upon pump shutdown or power failure;
- creation of a severe hydraulic gradient by undersized piping in the supply line;
- pipeline breakages in the water supply main line, which is lower than the customer service point;
- reduced main line pressure due to a high water withdrawal rate, such as for fire fighting or main line flushing; and
- reduced main line supply pressure due to pump or power failure.

Backpressure occurs when the user system is operating at a higher pressure than the water supply system. Major sources of backpressure are:

- booster pumps on the user system used to increase flows and satisfy pressure requirements;
- interconnection with other piping systems operating at higher pressures;
- electric or gas-driven injector systems;
- connections to pressurized systems, such as boilers; and
- elevation differences between the irrigation system and the water supply system or water source.

The following devices can be considered for use on a chemigation system. The device selected will depend the degree of hazard, injector type, and irrigation system setup. All backflow prevention devices should be tested by a certified tester before every irrigation season, and inspected prior to each chemigation event. The backflow prevention device should be installed between the pump discharge and the point of chemical injection.

19.2.3.1 Air gap. A 0.25-m air gap can be an effective backflow prevention device. Air gaps are most commonly used where the water source for the chemigation system is a self-contained pond or reservoir. The air gap must be maintained between the maximum surface elevation of the reservoir and the pipeline used to fill the reservoir. Crops such as cranberries often use reservoirs for irrigation supply and frost protection and can utilize an air gap as a backflow prevention device.

19.2.3.2 Atmospheric and pressure vacuum breaker. Vacuum breakers are effective for backsiphonage situations only. An atmospheric vacuum breaker (AVB) can only be used in situations where the unit is not subject to continuous pressure and therefore does not have shutoff valves downstream of the unit. Unlike an atmospheric vacuum breaker the pressure vacuum breaker (PVB) has an atmospheric vent valve which is internally loaded by a spring. A spring helps open the valve and the PVB can therefore be installed on the pressure side of a shutoff valve and used in situations that are operating under continuous pressure. An AVB and a PVB must be installed 30 cm (12 in.) above the highest sprinkler or dripper on the chemigation system.

Acceptable use of atmospheric and pressure vacuum breakers include situations where nonpotable water is pumped into an irrigation system that is cross-connected to an irrigation district or municipal pipeline where only backsiphonage is likely. Vacuum breakers are not approved for use on irrigation systems that are applying chemigation.

19.2.3.3 Check valve with low-pressure drain and vacuum relief valve. Typically, the check valve low-pressure drain and vacuum relief valve are combined with an inspection port, whether manufactured as a single unit or assembled as separate components. When combined, these devices constitute an approved backflow prevention device for chemigation systems. The check valve and appurtenant devices should be installed in accordance with the manufacturer's specifications and maintained in a working condition.

Check valve. A check valve consists of a single internally loaded flapper capable of closing and preventing backflow of the irrigation back into the water source. The term is used generally to include all types of elements regardless of shape and method of function. The check valve should provide for a watertight seal against reverse flow.

The check valve should contain a quick-closing and tight sealing mechanism that will close the moment water ceases to flow in the downstream direction. The check valve construction should allow for easy access for internal and external inspection and maintenance. The preferred installation method for the check valve is to be installed horizontally above ground with adequate space to provide ease of maintenance, testing, and inspection. The check valve should be inspected and tested after installation to ensure it is installed correctly and operating satisfactorily.

The irrigation line and check valve should be drained in the fall and protected from freezing. The manufacturer can provide recommendations on how to drain each water-trapping cavity of the device.

Low-pressure drain. The automatic low-pressure drain is used with the check valve and consists of a spring-loaded or hydraulically actuated valve located on the bottom of the irrigation line between the valve and the water source. The automatic low-pressure drain is designed such that if the check valve leaks after system shutdown, the automatic low-pressure drain will allow the water-chemical mixture to be drained away from the water source rather than into it.

The automatic low-pressure drain must be installed between the water source and the check valve so that any fluid which seeps past the check valve back toward the water source will automatically drain out of the irrigation pipe. The drain should be at least 2 cm (3/4 inch) in diameter and should be located on the bottom of the horizontal irrigation pipe between the water source and the check valve. The outside opening of the drain should be at least 5 cm (2 inches) above grade. The flow from the drain should be controlled by a pipe, trough, ditch, and slope of soil surface or other means so that it will drain away from the water source.

Vacuum relief valve. The vacuum relief valve is combined with the check valve and low-pressure drain. The device consists of a spring-loaded or hydraulically actuated atmospheric vacuum breaker valve. An atmospheric vacuum breaker allows air to enter the irrigation pipeline when the line pressure is reduced to a gauge pressure of zero or less. The vacuum relief device is typically located on the top of the horizontal irrigation pipeline between the check valve and the water source.

The vacuum relief device should be installed in such a position and in such a manner that insects, animals, floodwater, or other pollutants cannot enter the irrigation pipeline through the vacuum relief device. The vacuum relief device may be mounted on the inspection port as long as it does not interfere with the inspection of the other antipollution devices including the check valve and low-pressure drain.

Inspection port. An inspection port allows for easy access to the internal components of the check valve, automatic low-pressure drain, and vacuum relief device for the purposes of testing, inspection, and maintenance. The inspection port should allow for visual inspection to determine if leakage occurs past the check valve, seal, seat, and any other components of the backflow prevention device. The port should have a minimum 10-cm (4-in.) diameter orifice or viewing area. For diversion works with irrigation pipelines too small to install a 4-in, diameter inspection port, the check valve and other appurtenant devices should be mounted with quick disconnects, flange fittings, dresser couplings, or other fittings that allow for easy testing, inspection, maintenance, and removal.

19.2.3.4 Double check valve assembly. A double check valve assembly (DCVA) consists of two approved check valves, internally loaded either by a spring or weight, installed as a unit between two tightly closing shutoff valves. The DCVA is an approved backflow prevention device effective against backflow caused by backpressure or backsiphonage. The DCVA must be installed upstream of the chemical injection system at a location that is readily accessible for testing.

The irrigation lines should be thoroughly flushed before installation of the DCVA. Most failures during testing are due to debris fouling either the first or second check valve seats. The DCVA should be installed above ground with adequate space to simplify maintenance and testing. It shall be inspected and tested after installation to ensure it is installed correctly and operating satisfactorily. A strainer with a blow-out tapping should be installed ahead of the DCVA. The DCVA must be drained in the fall and protected from freezing. The manufacturer can provide recommendations on how to drain all water-trapping cavities of the device. The DCVA must be tested by a Certified Tester before every irrigation season.

If possible, a DCVA should not be installed in a pit, because any leaky test cocks would then become cross-connections when the pit is flooded. If the unit must be installed in a pit, provisions for pit drainage must be provided. Test-cock taps should also be plugged to reduce the danger of leaks if the device does become submerged. The vault should be large enough to provide free access for testing or repairing the device. DCVAs larger than 6.4 cm (2.5 in.) shall have support blocks to prevent damage.

19.2.3.5 Reduced-pressure device. A reduced-pressure backflow device (RPBD) consists of two independently acting, internally loaded check valves separated by a reduced-pressure zone. The device should be installed as a unit between two tightly closing shutoff valves. The RPBD is effective against backflow caused by backpressure and backsiphonage and is designed to be used in situations that are considered very hazardous. The RPDB, while slightly more costly, is considered the best protection for backflow prevention. The main reason is that the unit will leak water when it is not operating properly, allowing a quick visual inspection to inform the operator if the unit is malfunctioning. The unit can then be fixed prior to chemigation proceeding. An RPBD must be installed upstream of the chemical injection system and preferably above ground with adequate space to ease maintenance and testing. A strainer with a blow-out tapping should be installed ahead of the RPBD. The lines should be thoroughly flushed before installation of the RPBD. Most failures during testing are due to debris fouling either the first or second check valve seats. *If possible, the RPBD should not be installed in a pit below ground level.* Flooding of the pit could cause a direct cross-connection through the relief valve. If installation in a pit is absolutely necessary, adequate drainage *must* be provided. Devices that are larger than 6.4 cm (2.5 in.) shall have support blocks to prevent damage. A RPDB is susceptible to fluctuating supply pressures on an extreme low flow or static flow condition, which may cause nuisance dripping and eventual fouling of the device. The RPBD shall be inspected and tested after installation to ensure it is installed correctly and operating satisfactorily, and it must be tested by a Certified Tester before every irrigation season. The RPBD must be drained in the fall and protected from freezing. The manufacturer can provide recommendations on how to drain each water-trapping cavity of the device.

19.2.4 Safety Equipment

A chemigation system should also contain additional antipollution and safety devices on the irrigation system and the chemical injection system (Smajstrala et al., 1985; Wright et al., 1992; Burt et al., 1995; Solomon and Zoldoske, 1998; Evans and Waller, 2007). These devices are used to reduce hazard to the environment and the operator during the chemigation application.

19.2.4.1 Injection-line equipment. *Injection-line check valve.* An injection-line check valve should be installed to prevent the flow of water from the irrigation system into the chemical supply tank, possibly overflowing the supply tank. A check valve is also used to prevent gravity flow from the chemical supply tank into the irrigation system if the opening pressure of the check valve is sufficient. The opening or cracking pressure of the chemical injection-line check valve should be at least 70 kPa or greater to prevent gravity flow. The injection-line check valve should be located downstream from any backflow prevention equipment and fresh water supply valves.

When physically possible, the point of chemical injection should be higher than the chemical supply tank and lower than the lowest sprinkler or outlet on the irrigation system. This will prevent siphoning from the chemical supply tank. The point of chemical injection should also be located as far as possible from the water source to protect the water source in the event of a chemical leak or spill to the ground.

Flow sensor. An injection-line flow sensor installed on a high-pressure injection-line upstream of the chemical injection-line check valve can assure system shutdown if flow in the injection line ceases. This device guards against continued operation after a rupture or disconnection of injection line, injection pump failure, loss of prime, empty chemical supply tank, or plugging of the injection port.

Manual valve. A manually operated valve should be installed on the chemical supply tank. Installation of a manual valve will allow the operator to manually stop the flow of chemical from the supply tank during equipment maintenance, or in case of accidents.

Strainer. A strainer should be installed on the suction side of the chemical injection pump. A strainer located upstream of the calibration tube, injection pump, air bleeder valve, and injection-line check valve is essential to prevent foreign materials from clogging or fouling these devices or other safety equipment.

Injector calibration device. A calibration device of sufficient volume should be installed on the suction side of the injection pump to accurately calibrate the injection pump. The installation of a calibration tube provides an easy way to check and fine tune the injection pump output. The calibration tube volume and graduation markings should be sufficient to provide for a minimum 5-min calibration period. Calibration tube markings should be large enough for the user to easily read the scale. Chemical compatibility is a key to preventing the calibration tube from being discolored or degraded.

Air-bleeder valve. An air-bleeder valve should be installed on the high-pressure side of the chemical injection pump immediately upstream of the chemical injection-line check valve. The air-bleeder valve can be used to relieve trapped air and pressure in the high-pressure injection line, which might otherwise affect the calibrated injection rate. Pressure within the line should be relieved any time the injection line is to be disconnected. This prevents the operator from being sprayed with the chemical in the line. The valve is especially helpful while making equipment inspections.

Supply tanks. Chemical supply tanks should be constructed of chemically resistant materials. Supply tanks that remain in the field throughout the year should also be constructed of sunlight-resistant materials. The supply tanks should be designed so that they can be easily drained after each use. The capacity of the tanks will depend upon the type of chemical injected. A containment system helps guard against site contamination in the event that a supply tank leaks or ruptures. Containment structures can be made of chemically resistant plastics, painted metal, or concrete.

Chemical supply tanks should be located as far away from the water source as is possible. The slope of soil surface should be graded to force drainage away from the water source in the event of a chemical leak or spill.

Solenoid valve. For further safety, a normally closed solenoid valve on the chemical suction line can be electrically interlocked with the engine or motor driving the injection pump. This valve, which is located on the suction side of the chemical injection pump, provides for a positive shutoff of the chemical injection line. The chemical cannot flow if the injection pump is stopped. The solenoid valve should be constructed of chemically resistant materials since it will be in contact with the chemical concentrate.

19.2.2. Injector pump interlocks. An interlock system should be used between the power system of the injection unit, the irrigation pumping plant, and the irrigation system, if it is electrically controlled. Interlocks can be accomplished electrically, hydraulically, and mechanically. The interlock should function so that if the irrigation pump stops, the injection pump will also stop. This type of interlock is referred to as a *one-way* interlock. A disadvantage to the one-way interlock is that some motorized irrigation systems may continue to run if the injection pump stops. In this situation, it may be difficult for the operator to determine where the chemical treatment ended in the field.

A two-way interlock ensures that both systems shut down simultaneously and, for non-electrical systems, can be accomplished by installing a flow or pressure sensor on the high-pressure injection line. A loss of pressure in the chemical injection line due to injection-line breakage, an empty chemical tank, a plugged strainer, or injection pump failure would then trigger a simultaneous shutoff of both the irrigation system and the chemical injection system.

19.3 INJECTION SYSTEMS

There are four basic types of injection systems used for chemigation. These are centrifugal pumps, positive displacement pumps (piston, diaphragm, gear, lobe, peristaltic, and others), pressure differential injectors, and Venturi injectors. Some injectors may be a combination of these types. Pressure differential systems are often the least expensive and are also the least accurate. The basic costs of Venturi injectors and water-drive systems are lower than the other alternatives; however, the cost of these injectors with feedback and control systems is in the range of the cost of positive displacement pumps. Positive displacement pumps are generally preferred for most chemigation applications due to their accuracy in metering chemicals into the system, and backflow prevention.

Chemicals injected can be gases or liquid; however, this discussion will focus on water-based injection systems. Injected gases such as chlorine and anhydrous ammonia have their own special requirements, and producers should work with their chemical supplier for these unique applications. Several companies manufacture liquid injection pumps for chemigation systems. These devices are used to apply water-soluble fertilizers, pesticides, plant growth regulators, wetting agents, soil amendments, mineral acids, and various other chemicals.

19.3.1 Injector Selection

The primary selection criteria for injectors are durability, accuracy, ease of operation and repair, service life, flow-rate range, and resistance to corrosion by the chemicals being used. Other important considerations are the cost, available power source, chemicals to be injected, and the number of chemicals to be injected simultaneously.

Injection systems should be able to inject any water-soluble chemical, acid, emulsifiable concentrate, or wettable powder at low concentration levels (e.g., 1 to 100 mg/L). Solutions may have a wide pH range or other corrosive index that may require multiple injectors made from different materials. Separate injectors may also be required for fertilizers and pesticides as fertilizers typically require a higher injection rate than the other chemicals. It is often not possible to accurately adjust an injector of the type required for fertilizer to inject at the low flow rate required for pesticides or acids.

The choice of an injector will depend on consideration of the following factors:

- What is the size of field, pesticide and fertility programs, and types of crop(s) to be covered?
- What are the irrigation system water flow rates?
- What chemicals will be injected, at what desired concentrations (particularly if acid injection is desired)?
- Are multiple injection heads needed (for incompatible chemicals)?
- What are the pressure and flow requirements for proper operation of the injector?
- Is a portable or stationary injector desirable?

Once the size and type of injector are determined, consider the ease of repair and reported longevity of the unit. Growers should also consider the manufacturer's reliability, technical support, service, and other qualifications. Much of this information is available on the Internet, and by talking to other growers and extension personnel.

Injection of multiple chemicals at the same time requires careful planning to ensure compatibility, separation distances, and flexible pump operations over a range of conditions. Some positive displacement pumps are available that can drive multiple, separate heads for each different chemical.

Feedback and control systems are available that measure irrigation pipeline flow rate and automatically adjust Venturi or positive displacement pump injection flow rates. For example, drip irrigation systems may have several different sizes of blocks or blocks with different water requirements. A feedback and control system could adjust the rate of injection as the irrigation system is automatically changed from block to block. Controllers can also manage variable speed drives to provide a broad range of injection rates, which is advantageous with large (e.g., center pivots) or multi-zone systems with either constant or varying flow rates.

19.3.2 Centrifugal Pump Systems

Small radial-flow centrifugal pumps (booster pumps) are often used to inject chemicals into irrigation systems. The pump draws water directly from the chemical reservoir and delivers a pressure that is higher than the pressure in the irrigation line to inject the chemical. Consequently, the flow rate of the chemical from the pump depends on the pressure in the irrigation line at the time of injection. To accurately determine the amount of chemical being injected requires calibration while the system is operating. Because these systems are sensitive to irrigation system pressure fluctuations and changes, they are not recommended for the injection of toxic chemicals where the injection rates must be precisely controlled.

19.3.3 Positive Displacement Pumps

Positive displacement pumps are the most recommended injection system. They are generally classified as reciprocating (piston and diaphragm), rotary (gear and lobe), or a miscellaneous type (e.g., peristaltic, progressive cavity), depending on the mechanism used to transfer energy to the fluid. Few rotary and other types of positive displacement pumps are used for chemical injections into irrigation systems. Gear-and-lobe rotary pumps and peristaltic pumps can be used when only small injection rates are required. This discussion only covers piston pumps, diaphragm pumps, and combination piston/diaphragm pumps, which are the most commonly used types for chemical injection into irrigation systems.

Positive displacement pumps are recommended where precise control of injection flow rate of chemicals is required, as with pesticides. They are also the pump of choice for highly viscous materials. They are easy to monitor and calibrate, and most can be adjusted while in operation (preferred).

Piston, fluid-filled diaphragm, and piston/diaphragm pumps come closest to being ideal positive displacement pumps. These systems can typically control injection flow rates with a range of error of ±1% to ±2%. Injected flow rates remain constant over a range of chemical viscosities and irrigation pipeline pressures as long as there is minimal pressure in the irrigation pipeline. Both piston pumps and diaphragm pumps are adjustable; however, some pumps cannot be adjusted while the system is running.

A piston or a diaphragm displaces a given amount of chemical with each stroke. Both piston and diaphragm pumps consist of a pumping device and two check valves (Figure 19.1). As the diaphragm or piston is retracted, chemical is drawn into the chamber from the tank through the first check valve. As the diaphragm or piston is pushed out, the chemical is forced out the second check valve into the irrigation pipeline. Diaphragm pumps have a small flexible Teflon or rubber diaphragm that is moved in and out of a small chamber. Diaphragm pumps are thus less prone to corrosion than piston pumps, because they have less contact with the chemical. For piston pumps, which draw chemical into a long metal cylinder, care must be taken to select a piston and cylinder that will not be corroded by the chemicals.

Positive displacement pumps can be purchased that cover a wide range in flow rates and chemical properties. For example, piston pumps can be purchased with two different sized cylinders on either side of the pump in order to provide a range of injection flow rates. Diaphragm pumps generally have a fixed operating range, but different injector heads can be purchased to provide a broader range of flow rates as well as chemicals.

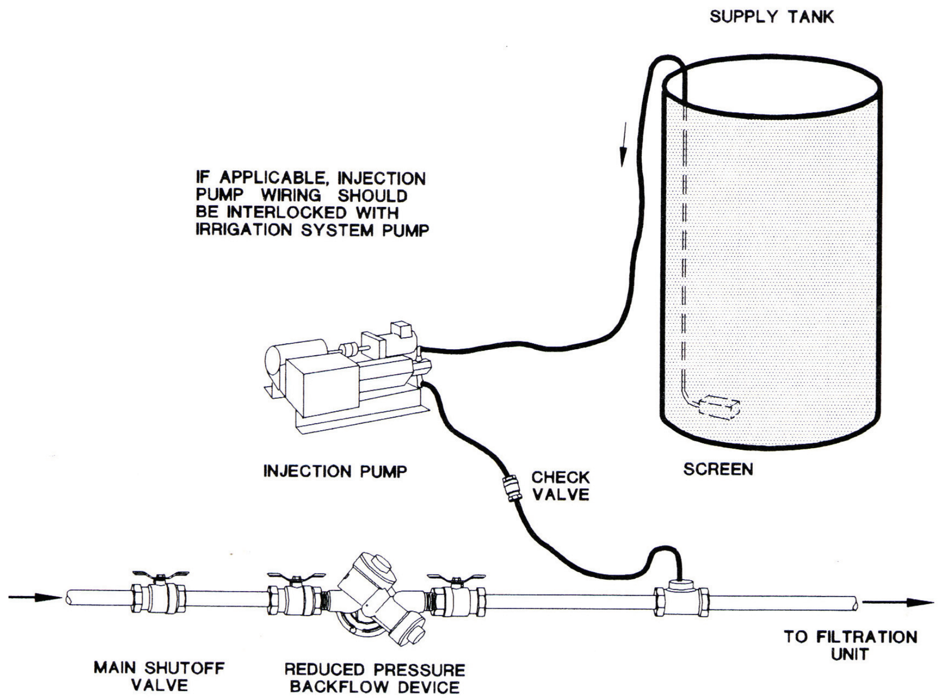

Figure 19.1. Schematic showing a typical layout for positive displacement injection pump systems (from van der Gulik, 1993).

Positive displacement pump systems are especially adaptable to feedback and control systems, which provide additional management flexibility. Variable frequency, electric motor drives are often used with control systems.

Since positive displacement pumps displace a fixed volume of fluid with each stroke, they can produce very high injection pressures. This situation should be avoided (e.g., trying to operate against a closed valve in a discharge line) since this will often result in pump or injection line damage.

Three-phase electric motors are the most common source of power for piston and diaphragm pumps. Some injection pumps are driven by belt power, compressed gases, or a water motor. Another problem with electric injector pumps is that they can continue to inject chemical once the irrigation system is shut down. Preventing independent operation requires electrical and mechanical interlocks and careful monitoring.

A variation of positive displacement pumps are water-pressure driven injectors. As is the case with Venturi systems, the water-driven systems are installed on a parallel bypass line that draws water from the main line above a flow constriction through the device to inject the material. However, in this case, the water powers a small turbine or piston device. The injection rate is controlled by regulating the amount of water going to the drive unit. Water-driven injection devices generally operate at injection ratios from 0.2% to 2% of the total flow. The turbine uses system pressure to drive a small cam and piston rod unit to move a diaphragm or piston injector. Piston water drives use as small amount of water (about 3 times the amount injected), but do not lower system pressure due to their operation. A drain needs to be provided for disposal of water from the water-powered piston drives since the water is not returned to the system.

Water-powered injectors are often referred to as ratio or proportional feeders because the quantity of material injected depends on the flow rate through the injector, which is a function of the pressure in the main line. Thus, the concentration of chemical in the irrigation water will remain the same because it is always proportional to the system flow rate. This characteristic can be an advantage in situations where the system automatically changes from one zone to another with variable flow requirements, as long as the concentration in each zone remains the same.

19.3.4 Venturi Injection Systems

Venturi injectors rely on the Venturi pressure drop principle to draw chemical from the tank into the irrigation pipeline. A small Venturi (Figure 19.2) can be used to inject chemicals into a relatively large mainline by shunting a portion of the flow through the injector. To assure that the water will flow through the shunt and injector, a pressure drop must occur in the main line. This is created by a partially open valve, an orifice, or other obstruction. These obstructions are located between the mixing water supply fitting and the injection point. It serves to increase water velocity and decrease pressures to values below atmospheric pressure in the throat of the Venturi device.

Most chemical stock tanks in Venturi systems are vented to atmospheric pressure and the pressure differential between the atmosphere and the throat of the Venturi device forces the chemical solution into the irrigation pipes at this reduced-pressure zone. Mixing of chemical with irrigation water is facilitated by the flow velocity in the Venturi device. Because chemical is sucked into the irrigation system after the main or

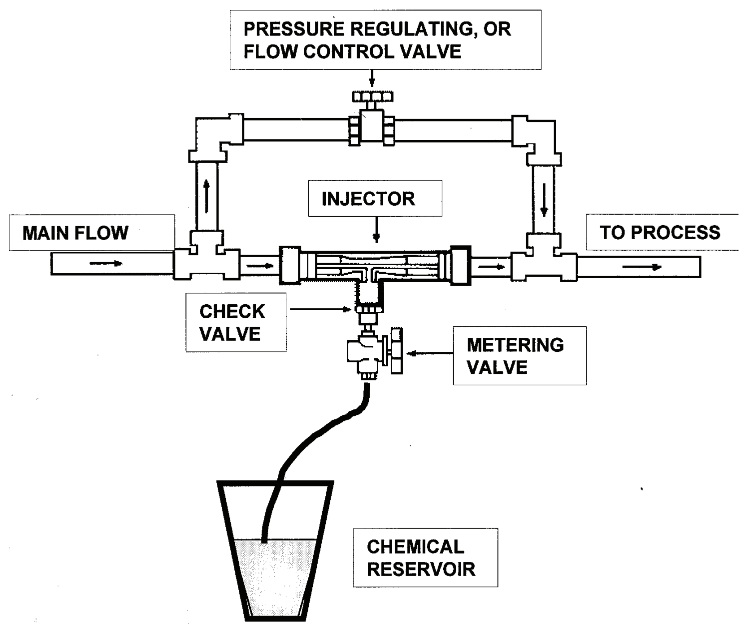

Figure 19.2. Schematic of the basic Venturi injector system. Courtesy of Mazzei Injector Corporation (MIC).

booster pumps, there is no contact between the chemical and the pump; thus, Venturi injection systems are less susceptible to corrosion than some other types of injectors.

Venturi injectors come in various sizes and can be operated under different pressure conditions. Suction capacity (injection rate), head loss required, and working pressure range will depend on the model. Venturi injection systems, with or without feedback and control, can be purchased in units with injectors of different sizes to provide a broad range of injection flow rates. A large chemical stock tank may be required because the proportion ratios are low (typically in the range of 1:15). This tends to limit the use of Venturi-type injectors to relatively small areas.

A Venturi injector does not require external power to operate, although ancillary equipment (e.g., control systems, booster pumps) may require power. It does not have any moving parts, which increases its life and decreases probability of failure. The injector is usually constructed of plastic and it is resistant to most chemicals. It requires minimal operator attention and maintenance. Since the device is very simple, its cost is low as compared to other equipment of similar function and capability.

The flow rate of a Venturi injector can vary dramatically due to changes in irrigation pipeline pressure. Most Venturi injectors require at least a 20% differential pressure to initiate sufficient vacuum for proper operation. However, as long as the pressure differential across the upstream and downstream side of the Venturi is greater than 200 kPa, the injection flow rate is relatively insensitive to irrigation pipeline pressure. This situation creates a minimum pressure within the Venturi throat that is slightly above the limit of zero absolute pressure. The pressure differential at which each Venturi injection system reaches a minimum can be observed on the manufacturer's flow rate vs. pressure differential curves. If a constant chemical injection flow rate is required throughout the event, then a high pressure differential across the Venturi must be maintained or a centrifugal pump is used to boost pressure in the Venturi bypass line. The piping system shown in Figure 19.1 is not suitable for accurate calibration and constant injection rate. Thus, Venturi systems may also feature a pressure regulator for more precise control of injection rates.

The flow rate of a Venturi injector can be quite sensitive to temperature changes because the viscosity of some chemicals can vary substantially with temperature. For example, the change in injection flow rate can be in the range of 5% to 10% over a 20°C temperature range for relatively viscous fertilizers such as UAN32 or CAN17. However, there is basically no change in flow rate due to temperature for chemical solutions with viscosities in the range of water because these viscosity changes with temperature are minimal. When chemical viscosity is an issue, a good method to keep flow constant over a temperature change is a control system with feedback from a flow sensor.

It is also important to realize that the suction capacity depends on the liquid level in the supply tank. As the liquid level drops, the suction head increases, resulting in a decreased injection rate. To avoid this problem some manufacturers provide an additional small tank on the side of the supply tank, where the float valve maintains the fluid level relatively constant. The fluid is injected from this smaller auxiliary tank.

Often the injection criterion is that a known volume of chemical must be pumped during a specified period for each irrigation zone, but the concentration does not have to remain constant. One commonly used alternative for pressurized irrigation systems is the combination of a Venturi device with a pressurized chemical tank. Since the water flowing through the tank is under pressure, a sealed airtight pressure-supply tank (constructed to withstand the maximum operating pressure) is required. However, the injected concentrations will change gradually due to the dilution of the chemical in the tank as the water enters the tank during injection.

19.3.5 Pressure Differential Systems

Mixing-tank injectors and proportional mixers located on the discharge side of the irrigation pump are two approved pressure differential injection systems. Various metering or proportioning valves are used with mixing and proportioning tanks that operate on pressure or flow changes in the irrigation system. Frequently, these devices are an application of a Venturi meter or an orifice with changing diameter.

Using the irrigation pump's suction line is not an approved method of injection in most jurisdictions. The reason is that it is difficult to prevent contamination of surface water sources in the event of an unexpected pump shutdown. Chemical solution can then easily be siphoned out of the tank and into the water supply. It is also difficult to monitor or determine the chemical flow rate as it depends on the amount of the pump's suction at the injection point, the length and size of the suction line, and the level of chemical in the supply tank. It is also difficult to adjust the injection rate in these systems. In addition, the chemical solution is drawn through the pump and could result in significant corrosion and breakdown of seals and bearings. This method of injection is not recommended.

A mixing-tank injector operates on the discharge side of the main pump and operates on the same pressure differential concept as Venturi systems. They are installed on a similar bypass shunt that runs parallel to the main irrigation line. However, in these simple, low-precision systems the chemical reservoir is sealed instead of being vented to the atmosphere. Water from the main line enters the reservoir and displaces the same volume of the chemical mixture into the irrigation system. This results in a constant rate decrease in the chemical concentration in the reservoir, requiring that specific chemical batches be prepared for each and every zone to ensure that each zone receives approximately the right amount of material. The injection into the main line is often controlled by a metering device installed on the inlet side of the injector.

Proportional mixers are a modification of pressurized mixing tanks and operate on a volume water displacement principle. It is commonly used in irrigation systems where flow fluctuations are expected, perhaps due to varying set sizes or sharing water with other users. Sufficient concentrated chemical for one injection event is contained in a collapsible, impermeable bag that is placed into the pressure tank. The chemical remains separated from the water and feeds chemical solution into a proportioning valve that injects it into the irrigation system. Chemicals in the bag are forced into a proportioning valve by the pressure differential and injected into the irrigation system. The volume of chemical is displaced by water entering the tank at the same rate the chemical is injected. This makeup water does not mix with the chemical and is not returned into the system. Injection is completed when the bag is totally collapsed and the tank is full of water. The proportioning valve responds to the changes of flow, but not pressure changes in the irrigation system. Thus, as long as the pressure and the flow rate in the system do not vary significantly, the injection rate will remain relatively constant. To insert a new bag of chemical the tank is isolated with valves and drained.

19.3.6. Operation and Maintenance of Injector Systems

It is highly recommended that injector systems utilize some method (mechanical or liquid) to agitate the injector supply tank to keep the chemicals in solution, especially when working with many pesticides and dry chemicals. In addition, if large fertilizer tanks are not used for extended periods, water-soluble fertilizers can accumulate in the bottom of stock tanks due to density differences, resulting in large differences in fertilizer concentrations during the injection event. Also, dilution ratios higher than 1:200 require agitation as fertilizer may not dissolve completely due to exceeding the solubility limits of the chemical.

The following practices are recommended in most installations:

- Chemical injections should be made in the center of a water stream (e.g., center of a pipe diameter), whenever possible, for better mixing.
- Keep the injector's suction line as short as possible (1.5 m or less),
- The suction hose on the injector should also have a strainer to prevent precipitated and non-water soluble materials from entering the injectors and the irrigation system.
- Stock tanks should be covered to prevent algae and/or debris buildup, contamination, or evaporation of stock solution.
- Stock tanks need to be opaque since the chelating agents in some micronutrient fertilizers tend to break down if they are exposed to light.
- Injectors should not be exposed to freezing temperatures as cracking and/or warping may result.
- Suction and discharge tubing needs to be replaced regularly (e.g., every couple of years).
- Intake strainers should be suspended 7 to 10 cm (3 to 4 in.) from the bottom of the solution tank to avoid pulling up undiluted concentrate.
- Inject clean water after use to flush the system.
- Regularly clean the solution tanks (weekly or biweekly, depending on frequency of use) to prevent dirt and scale buildup that might plug or abrade the injectors.
- Suction tube strainers should be cleaned using clean, clear water and inspected regularly for clogs and/or cracks.
- Inspect and service O-rings. Petroleum-based lubricants such as Vaseline, lanoline, WD-40, or motor oil should never be used on dosage pistons or seals.

19.4 INJECTION SYSTEM CALIBRATION

The balance between chemical injected and irrigation water flow rate are critical for proper chemigation. If there is too little water in the chemical and water mixture there will be uneven chemical distribution, high volatilization (chemical loss), or chemical buildup in irrigation lines. On the other hand, too much water in the chemical mixture will result in possible dilution of chemical below effective concentrations or loss of the applied chemical to groundwater (Smajstrala et al., 1986; Clark et al., 1998; Scherer et al., 1999; Werner, 2002; Evans and Waller, 2007).

Consequently, calibration of the injector flow rate is very important. In this process, how much chemical is being injected using different settings is determined. Periodic calibration during the irrigation season is needed to ensure that an injector is operating properly. Calibration methods are focused on either mass or volume determinations of injection rates, and are independent of concentrations that must be determined separately. Adjustments may be done by adjusting the injection rate (e.g., in a Venturi), or by adjusting the concentration of the chemical stock solution.

There are numerous ways to calibrate injection systems depending on the type of system and chemical involved. Many chemicals are supplied as either a percentage by weight of a dry or liquid mixture. Therefore, the mass of chemical mixture required will depend on the concentration of raw chemical in the mixture. When chemicals are supplied in liquid form, as is often the case with chemigation, it is more convenient to measure volumes rather than masses or weights, so volumetric calibrations are the most common. The owner's manual for the injector system should recommend ways to test a specific injector.

For supply tanks that are vented to the atmosphere, it is possible to calibrate injectors by weighing tanks with scales or load cells. This is also the recommended procedure for gaseous chemical injector systems. Where other techniques are impractical, fluorescent tracer techniques can also be an accurate means to calibrate injectors.

The injection rate of the chemical injection pump should be determined for a particular setting of the injection rate control knob, with the irrigation system operating, so the injection pump is working against the water pipeline pressure. Otherwise, the tested injection rate will be higher than when the injection pump is injecting into a pressurized irrigation pipeline. Calibrations should be done at constant pressure with clean water and no chemicals. The injector should also be operated prior to the test to remove any air bubbles in the lines.

Volumetric calibrations are based on letting the injection pump draw from a calibrated container on the suction side of the injector pump. Usually, a calibrated sight tube is used to determine the volume extracted from the chemical supply tank. Flow meters on the injection lines may also be used to indicate volumetric injector flow rates.

The water volume being injected is measured over a given time at each particular injector setting (usually expressed on a dial as a number) for a predetermined amount of water (making sure that the volume is appropriate for the container). The container should be filled to a known volume. The injector and a stop watch or timer are turned on simultaneously. Record the time, line pressure, and volume when the volume in the container is reduced by the predetermined amount. This process is repeated for different dial settings. There are some special considerations for stationary, continuous move and surface irrigation systems.

19.4.1 Stationary Irrigation Systems

Stationary irrigation systems include hand move and wheel move sprinklers, permanent solid set sprinklers, and microirrigation systems (includes drippers and microsprinklers.) Chemigation with stationary systems is a relatively simple procedure if the chemigation begins and ends within the duration of a single set as the chemical is applied to a given area. Application through sprinkler systems will only be as spatially uniform as the overlap water application pattern. The injection is repeated at the same rate and duration for each set until the entire field has been covered

Microirrigation applications generally do not have overlap from adjacent water application devices, and uniformities are primarily a function of time and the coefficient of uniformity of the individual devices. Under good management, this is usually highly efficient with few losses because the plants' roots have developed over time to fully utilize the applied water and chemicals in the wetted soil volume. Some new systems have long microirrigation laterals with large diameters to prevent excessive friction loss. Chemigation uniformity and duration can then be especially difficult because of the length of time it takes for water and chemical to reach the last emitter.

19.4.2 Continuous Move Irrigation Systems

Continuous move irrigation systems include center pivots, linear moves, and travelers. For these systems injections must be at a constant concentration over the entire irrigation to ensure the same amount of chemical is applied to the whole field. If the rate varies as the machine moves, variations in chemical applications will be exacerbated. The injection rate must be calibrated so that the full application continues for the entire duration of the irrigation event (e.g., one complete revolution). The grower does not want to run out of material before the end of the irrigation nor does he or she want to apply an additional application to lands that were previously covered in that pass.

End guns and corner systems present some unique chemigation challenges. Intermittent end gun operation and the variable irrigation system flow rates as a corner system swings out and back in again changes injection flow rates and may also affect pressure and application uniformities. In these situations, chemigation most commonly utilizes a flow-meter feedback controller system tied to the angle resolver at the pivot (through the control panel) and/or a GPS system to regulate injection rates as irrigation system flow rates change. Calibration of the injection system must consider the full range of flow rates and the pump's response characteristics as both flow and pressure vary. End guns may be turned off in certain areas of the field to prevent potential safety or environmental problems.

19.4.3 Injection Flow Verification

Once the actual chemigation operation is started, the injection rate should be rechecked and the meter readjusted (if necessary) at least once during the chemigation process. A flow indicator installed on either the suction or outlet tubing of an injector is an outstanding diagnostic tool. Some will allow the grower to tell with a glance if the pump is working properly.

There are many types of flow meters to measure chemical injection rates, including variable-area (called tapered-tube or rotometer), positive displacement, paddlewheel, pitot tube, ultrasonic, and mass flow meters. Each type has its special features and there is a wide range in cost. The variable-area flow meter offers many advantages over some more costly and technical types, making it the meter of choice for many chemical flow measurement applications. Some manufacturers offer various flow indicators as standard equipment.

Another indicator of the fertilizer injector output is by measuring the electrical conductivity (EC) of the dilute fertilizer solution. Good estimates of fertilizer concentrations can be obtained using a portable EC meter where the water is applied in the field. Permanent EC monitors, which may also measure pH, can be installed a suitable distance downstream of the injection point. Alternatively, the concentration of a sample of the water-fertilizer mixture can be analyzed by a reputable testing laboratory.

19.5 IRRIGATION SYSTEM CONSIDERATIONS

The design and operation of irrigation systems will impact the effectiveness of a chemigation system. There are many operation characteristics that need to be considered, but the main concern is the distribution uniformity of the system. It is virtually impossible to achieve good chemical application uniformity if the irrigation system is not designed to operate at a high uniformity. Center pivot systems with drop tubes and trickle/drip systems provide the best uniformity. Sprinkler and gun systems are susceptible to wind drift, pressure variations, and crop interference, which often reduces the achievable uniformity.

19.5.1 Irrigation System Characteristics

The physical characteristics of the irrigation system will determine the type of injection system, selection of chemicals that can be applied, application rate, and duration of application.

Irrigation systems are either stationary and continuous move systems. Stationary systems include handlines, wheel move, solid set sprinklers, trickle, and microsprinkler systems. These systems irrigate a block of land at a constant application rate over time. A batch of chemicals can therefore be mixed and applied during the irrigation interval. The duration of application will be determined by the type of chemical being applied. Some chemicals must be incorporated to be effective, requiring application of enough water to move the chemical into the soil. Other chemicals, such as nitrate nitrogen, are very mobile and should be left near the soil surface to avoid potential groundwater contamination. Chemicals intended for foliar applications should only be applied by overhead sprinkler systems during the end of an irrigation set with a minimum amount of flushing.

Continuous move systems include center pivots, lateral move, traveling guns, and overhead boom systems used in nursery and greenhouse operations. These systems irrigate a block of land with a predetermined amount of water but at varying application rates (the application rate will be greater at the last tower, especially on those systems using an end gun, than the application rate at the pivot point). The rate of chemical injection must therefore be matched with the rate of travel. Batch application of chemicals cannot be used with these types of irrigation system.

Table 19.1 provides some general guidance on the uniformities that can be achieved. Depending on design, installation, and operation some systems may be rated higher or lower than what is shown. Chapter 5 provides more detailed information on irrigation system uniformities.

All system components must be able to withstand the effects of corrosion from injected basic and acidic chemicals at the expected concentrations at each location. Consult material compatibility tables and match materials with the chemicals. For example, concentrated sulfuric acid is not compatible with PVC tubing and will quickly

Table 19.1. Irrigation system uniformities.

Irrigation Method	Uniformity
Wheel move system	fair
Handline	fair
Solid set over-tree sprinkler	fair
Solid set under-tree sprinkler	poor
Solid set gun	poor
Microsprinkler	fair
Traveling gun	poor
Center pivot	good
Surface systems	fair
Trickle/drip	good

create a hazardous situation, but PVC is acceptable when the acid is greatly diluted. As a general rule, uncoated metallic components (except specific stainless steels) should be used as little as possible.

19.5.2 Site Considerations

Proximity of the irrigation system to dwellings, neighboring crops, roadways, playgrounds, and residential areas, and surface water sources such as ditches, streams and lakes, must be carefully considered. The safety of people, wildlife, domestic animals, and other non-target areas must be considered.

19.5.2.1 Topography. Field topography can cause pressure differences along an irrigation lateral, which affects application uniformities. Low-pressure center pivot and trickle systems are most susceptible to pressure differences caused by elevation or friction loss. Sprinkler irrigation systems can also be affected if the elevation changes are in excess of 5 m. Pressure or flow regulators on each individual sprinkler head may be required to ensure uniform discharge for each sprinkler along the lateral. Pressure-compensating emitters are recommended to maintain system uniformity for trickle systems.

19.5.2.2 Crop. The crop grown often determines the type of irrigation system that will be used. Trickle irrigation systems are often used for tree fruits, grapes, strawberries, and other horticultural crops because of water application efficiency and the ability to control fertilizer application directly to the plant roots (Doerge et al., 1991; Burt et al., 1995; California Fertilizer Association, 1995; Rosen and Eliason, 1996). High-density orchard plantings require quick tree response after planting and early fruit development to realize a return on capital investment. However, the injection of some pesticides through a trickle system may not be effective.

Cranberries and forage crops are well suited for sprinkler irrigation systems. Overhead and under-tree sprinkler systems are also popular on orchards and vineyards for a variety of reasons. Overhead sprinkler systems used for irrigation, frost protection, or crop cooling on tree fruits or cranberries can be adapted to chemigation. A minimum application uniformity of 80% should be achieved.

Center pivot and lateral move overhead sprinkler irrigation systems are commonly used for corn and forages, but can be used on any crop providing that the fields are large enough to accommodate a pivot.

19.5.2.3 Soil type. The maximum infiltration rate of water into the soil and available water storage capacity of the soil differ with soil type. Soil types can vary significantly over an entire field requiring a change in the operation of the irrigation system. Coarse-textured soils can have high infiltration rates but can store very little water within the root zone. Conversely, fine-textured soils can store large amounts of water but have low infiltration rates. High application rates on fine-textured soils increase runoff potential, while excessive amounts of irrigation on coarse-textured soils increase the potential for leaching of chemicals below the crop root zone and into groundwater.

Chemigation systems must be operated within the limits of the soil types present to reduce the potential for runoff and for leaching. An understanding of soil water-holding capacity is also important to ensure that the chemical added is moved into the soil to an appropriate depth with respect to the plant rooting volume.

19.5.2.4 Drift and runoff potential. Drift and runoff are two leading causes of chemical losses from chemigation systems. Leaching can also be a cause of chemical losses. Environmental conditions during application, sprinkler types, type of chemical being applied, and climatic conditions after application all affect the magnitude of chemical losses.

Water discharged from some sprinkler nozzles under pressure emerges as a fine spray. The amount of physical drift will depend upon the sprinkler type, system pressure, wind speed, and crop height and density. Part of the spray is evaporated within the wetted area, intercepted by vegetation and soil, or carried away by wind outside the intended target area. Wind drift can cause a potentially hazardous situation. Chemigation should not be carried out if wind conditions are strong enough to cause significant drift to non-target areas. Some pesticide labels carry statements prohibiting application when wind speeds are sustained above a certain limit.

Many center pivot systems will turn off high-pressure end gun sprinklers as they move around the field to avoid water applications to roads, buildings, or waterways. In these cases, the end guns are often turned off during the whole chemigation event to avoid changes in system pressure as these sprinklers cycle on or off in various sectors of the field, as that could cause poor uniformities along the entire lateral length. Combining the high pressures, small droplets produced, and the end guns being mounted 3 to 4 m high directly on the lateral piping creates a greater chance of chemical drift beyond the intended application area.

Runoff depends not only on the irrigation system application rate and soil infiltration rate but is also influenced by factors such as field slope, surface vegetation, crop cover, and soil surface residue. Irrigation systems applying chemicals should be designed and operated to prevent any runoff from occurring. Some regions will require runoff to be contained before it leaves property boundaries or the place of use. Treated water may be required to be reused on the crop or site treated. Chemical label restrictions may prohibit the use of treated water on crops or sites other than those listed on the chemical label.

19.5.3 Design Considerations for Sprinkler Systems

Sprinkler irrigation systems used to apply chemicals should be designed with a coefficient of uniformity of at least 80% and preferably 90% whenever possible. Even for uniformities of 90% the ratio of the depth of irrigation applied on one part of the field compared to another can be as high as 3:1. A coefficient of uniformity of 80% can only be obtained by designing sprinkler systems to the following minimum standards:

- The maximum pressure variation along the lateral must not exceed 20% of the sprinkler operating pressure and 10% (or less) pressure variation is desirable. Flow-control nozzles must be used if pressure fluctuations exceed the 20% allowance. Another option is to use pressure regulators at sprinkler heads operating at pressures exceeding the normal operating range.
- For stationary sprinkler systems the sprinkler spacing along the lateral and the lateral spacing should not exceed 50% of the sprinkler wetted diameter. If the predominant wind speed exceeds 5 km/hour then the spacing should be reduced to 40% of the wetted diameter.
- The sprinkler should be operated within the manufacturer's recommended pressure range to provide adequate stream breakup for proper dispersal.
- The sprinkler should have a rotation time of less than 1 min and the system operated for at least 15 min when chemigating to improve uniformity.

19.5.4 Microirrigation System Design Considerations

Microirrigation systems include drip or trickle systems that apply irrigation directly to the soil surrounding plant roots rather than the entire field. All microirrigation systems should be designed so that biocides, fertilizers, and other chemicals can be injected and uniformly applied through the irrigation system. Microirrigation inherently offers tremendous benefits for chemical injection and applications. Consistent soil water contents and wetted soil volumes tend to increase plant uptake efficacy of many chemicals. Water-soluble nutrients can be injected to closely match crop requirements, increase nutrient use efficiencies, and reduce costs.

Microirrigation systems can be operated to achieve an emission uniformity of 90% if care is taken in the layout and design of the system. The system should be designed and operated to achieve these high application uniformities to avoid undesirable leaching and ensure good application uniformity since the chemical application uniformity cannot exceed the water application uniformity.

Microirrigation systems operate at efficiencies in the 85% to 95% range compared to sprinkler systems that are only 60% to 80% efficient. Microirrigation systems are therefore much superior chemigation systems compared to most sprinkler systems. Low-pressure center pivots systems with drop tubes are the only systems that can come close to matching the performance of drip/trickle systems for fertigation. However, these systems are limited in their ability to apply herbicides and insecticides effectively.

Factors that should be considered in the design of microirrigation systems for chemigation are:

- Emitter spacing should ensure that at least 60% of the plant root area is irrigated during drier seasons.
- The emitter selected should provide good uniformity and match the terrain, crop type, and available water quality. Emitter flow characteristics and product durability should be considered. The manufacturer's variance coefficient should be less than 0.05 and preferably 0.03. Testing of emitter flow rates at the beginning and end of the zone will confirm that flow rate uniformity is within acceptable limits.
- If pressure compensating emitters are not used the emitter operating pressure range should be kept within ±10% of the emitter operating pressure.
- All chemical injections should be filtered. Injection should occur after the pump and before the media or final screen filters to trap any undissolved material. Injection installations should always provide for complete mixing and uniform concentrations before the chemicals reach the field. Materials should be injected into the center of the water flow to ensure quick dilution to reduce deterioration of the filter tanks, piping, valves, or other components. Generally, injection rates should not exceed 0.1% of the system water flow rate although concentration limits (e.g., for chlorine) and label requirements for pesticides are usually less.
- The injection of chemicals often increases the susceptibility for emitter plugging. There are numerous products being promoted as universal line or emitter cleaners, biocides, and fertilizers. These products should be used only if these claims can be proven with unbiased, high-quality research. Many of these materials are costly, only treat symptoms without addressing the underlying problems, and eventually fail.

19.5.5 Design Considerations for Surface Systems

Chemigation with surface irrigation systems usually involves only fertilizers or other soil amendments (e.g., PAM). Pesticides are rarely injected into surface systems due to environmental concerns due to runoff.

Irrigations should be designed and managed to ensure distribution uniformities as high as possible during chemigation. Options for high uniformity include surge flow and reducing the length of runs, especially on cracking soils. There should be provisions for the collection and reuse of all tailwater. The tailwater should be reused on the same set as much as possible. Injections should not exceed the time needed for each set so that each set receives the correct amount of chemical. Chemicals are typically injected only for about half of the total set time, and there are various alternatives available.

One option is to start injection after the water has advanced half the length of the furrow or border to reduce excess leaching at the head of the field. However, tailwater management and ensuring uniform applications is quite difficult. More commonly, each set is irrigated for the same duration at the same flow rates and concentrations.

Chemicals must be injected continuously into the incoming water supply at a constant rate at sufficient distance upstream to ensure adequate mixing for the duration of each injection period. Liquid or powdered fertilizers and soil amendments can be added to the incoming water supply by gravity or battery-powered devices. Gases such as anhydrous ammonia are often injected by a hose inserted in the ditch or pipe using the tank pressure to power the process.

19.5.6 Operation Considerations

In addition to system selection and design there are many operational considerations to be taken into account to ensure an effective chemigation program is carried out in a safe manner.

19.5.6.1 System inspection. Injection and safety equipment should be flushed to prevent the accumulation of precipitates in the injection equipment. The injection pump, injection lines, and the injection-line check valve should be flushed after each use. This equipment should be flushed with clean water or other solvent as specified by the chemical label.

All injection and safety equipment should be inspected prior to each chemigation event. The operator should follow the manufacturer's recommendations for cleaning and maintenance of this equipment. Inspection of these devices will minimize the potential for failure. Moving parts should be lubricated as necessary before each chemigation event and before storage during the off season to preserve the equipment.

The irrigation-pipeline check valve should be repaired or replaced if leakage is found. Operators should not chemigate if the check valve leaks. Remember, the low-pressure drain is for backup only.

The low-pressure drain should be inspected before each chemigation event. If the drain is functioning properly, some water should discharge from the outlet immediately after start-up. The drain valve should eventually close as the system pressure increases.

The injection-line check valve should be inspected for backflow prevention. Remove the injection line from the inlet side of the chemical line check valve and observe whether back leakage occurs when the irrigation system is pressurized. Remember to bleed any trapped air or pressure from the injection line prior to removal. You may also inspect the chemical injection-line check valve for leakage in the normal direction of flow by removing the check valve from the injection port. To inspect the valve, insert the discharge end of the injection-line check valve into a bucket and start the injection pump. Pump some chemical or water through the system, then shut off the injection pump and observe whether leakage occurs through the chemical injection-line check valve.

The interlock system should also be inspected before each use as switches and other items could fail after weathering and wear.

Finally, inspect the irrigation system joints, fittings, and nozzles. Check system nozzles and outlets for wear and function ability. Check all fittings and connections on the system to avoid leaks and possible over application.

Operators should chemigate only with reliable, well-maintained injection and safety equipment. Chemigation can be a relatively safe practice provided proper precautions are taken.

19.5.6.2 Irrigation operation characteristics. Physical characteristics of irrigation systems that affect the uniformity of chemical injection include the following:

- Solute dispersion occurs as the chemical travels along the irrigation pipeline. The friction affect of the pipe walls on the fluid motion causes this dispersion. A slug of chemical injected into an irrigation system becomes diffuse as the chemical travels along with the irrigation water.
- The irrigation main line contains a significant amount of water. The travel time for the chemical to reach the discharge point and the time required to flush the system must be considered. The irrigation system should be flushed after the injection is complete. The operator should flush the irrigation system for at least 10 to 15 min after each chemical injection period.
- The operating flow rate for each zone will be different.
- For stationary systems, uniformity of application generally increases with the length of set time. Chemicals that require a short application duration may be difficult to apply uniformly.
- For continuously moving irrigation systems such as center pivots the amount of chemical that can be applied is dependent on the travel speed and concentration of the chemical solution. The available chemical solution may dictate the irrigation travel speed. Check to ensure that the speed chosen will provide good application uniformity.

19.5.6.3 Operation guidelines. The following steps can be used to ensure that a chemigation system is operating properly.

1. Prepare a worksheet showing zones, flow rate per zone, area covered or plants per zone, injection rate, and injection time. This is useful for future reference.
2. The irrigation lines should be completely filled and pressurized before starting chemigation.
3. Solid set sprinkler systems should, preferably, be operated for 1 h to achieve good application uniformity. This may not be possible for all chemigation applications, but the minimum application duration suggested is 15 min.
4. Fertilizers and other agrichemicals (except chlorine) should never be left in the pipeline when the system is not operating. The general "one-fourth" rule of thumb is that chemigation should start after one-fourth of the irrigation set time, injection should occur during the middle two-fourths, and the lines flushed with clean water during the last one-fourth of an irrigation event. (See the following

section for additional information.) Pesticide and fertilizer injections should be made in small, frequent doses that fit within scheduled irrigation intervals that match plant water use to avoid unnecessary leaching. Likewise, excess water applications for leaching soil salts should never be done when chemicals (except chlorine) are being injected.

5. The system should be flushed after chemigation has been completed. The irrigation system must be operated long enough to clear all lines of the chemical being applied. If the irrigation system is shut down before all the chemicals have exited the lateral lines, extra chemical will be applied at low spots where water drains through emitters, sprinklers, or system drains. Chemical that was intended for the end of the lines will then not reach the target area. Some chemicals may plug nozzles or emitters if not thoroughly flushed from the system. A flushing time of 30 min should be sufficient for most systems, depending upon system design, although systems with lengthy and large main lines may require longer durations for system flushing.
6. A dye test can be conducted to determine the length of time required for the last of the chemical to exit the final sprinkler or emitter. The amount of flush time can be reduced by injecting the chemical at the zone control on some systems.
7. Mixing a solution separately for each zone reduces the likelihood of error during the application process and allows for proper flushing of the irrigation system to increase application uniformity. If a controller with the capability of programming injections during scheduled irrigations is used, a large batch tank of chemical can be mixed for all zones. The amount of chemical applied to each zone will then be controlled by adjusting injection times.
8. If applying chemicals that may damage the crop foliage, the irrigation system should be operated long enough after chemigation to ensure that the chemical is washed off.
9. Post-injection treatments may be required to prevent the accumulation of algae, slimes, or precipitates that may plug microirrigation systems. High carbonate and/or iron concentrations in some irrigation waters may react with fertilizers and cause insoluble calcium or iron compounds. Certain bacteria can also fix iron as a byproduct of metabolism and produce slime or jelly-like material inside the irrigation lines. Algae growth may also be enhanced by the addition of nutrients in the water. Special maintenance procedures such as chlorination, adding algaecides and bactericides, and pre-treating water with chelating agents may be required when performing fertigation with irrigation systems.
10. The acidity of the soil should be monitored, especially when applying ammonium fertilizers through a trickle irrigation system. Acidity will be dependent on the buffering capacity of the soil. Selection of an appropriate fertilizer source will reduce acidity problems. Treatment with lime may also be an alternative.

19.5.6.4 Determining depth of chemical application. To be effective, fertilizers applied through the irrigation system must be stored within the plant's root zone. Irrigation applications that exceed the holding capacity of the soil will cause leaching beyond the plant's rooting depth. The specific depth in the soil to which fertilizers or chemicals are applied can be determined from the application rate of the irrigation system, the duration of irrigation, soil texture, and soil moisture content before the chemigation is applied. Table 19.2 presents a guide to determining the approximate soil moisture content of the soil using the hand feel method. Many other soil monitoring methods and products are available to determine soil moisture content, some of which are discussed elsewhere in this monograph.

Table 19.2. Soil moisture, appearance, and description (B.C. Ministry of Agriculture and Lands, 2006).

Available Water[a]	Feel or Appearance of Soil			
	Sand	Sandy Loam	Loam/Silt Loam	Clay Loam/Clay
> 100% (approaching saturation)	Free water appears when soil is bounced in hand.	Free water is released with kneading.	Free water can be squeezed out.	Puddles; free water forms on surface.
100%	Upon squeezing, no free water appears on soil, but wet outline of ball is left on hand. (80)[b]	Appears very dark. Upon squeezing, no free water appears on soil, but wet outline of ball is left on hand. Makes short ribbon. (125)[b]	Appears very dark. Upon squeezing, free water appears on soil, but wet outline of ball is left on hand. Will ribbon about 1 in. (170)[b]	Appears very dark. Upon squeezing, no free water appears on soil, but wet outline of ball is left on hand. Will ribbon about 2 in. (210)[b]
75% to 100%	Tends to stick together slightly, sometimes forms a weak ball with pressure. (70 to 80)[b]	Quite dark. Forms weak ball, breaks easily. Will not slick. (100 to 125)[b]	Dark colored. Forms a ball, is very pliable, slicks readily if high in clay. (125 to 170)[b]	Dark colored. Easily ribbons out between fingers, has slick feeling. (160 to 210)[b]
50% to 75%	Appears to be dry, will not form a ball with pressure. (40 to 70)[b]	Fairly dark. Tends to form a ball with pressure but seldom holds together. (70 to 100)[b]	Fairly dark. Forms a ball, somewhat plastic, will sometimes slick slightly with pressure. (80 to 125)[b]	Fairly dark. Forms a ball, ribbons out between thumb and forefinger. (100 to 160)[b]
25% to 50%	Appears to be dry, will not form a ball with pressure. (20 to 40)[b]	Light colored. Appears to be dry, will not form a ball. (30 to 70)[b]	Lightly colored. Somewhat crumbly, but holds together with pressure. (40 to 80)[b]	Slightly dark. Somewhat pliable, will ball under pressure. (50 to 100)[b]
0% to 25%	Dry, loose, single-grained, flows through fingers. (0 to 20)[b]	Very slightly colored. Dry loose, flows through fingers. (0 to 30)[b]	Slightly colored. Powdery, dry sometimes slightly crusted, but easily broken down into powdery condition. (0 to 40)[b]	Slightly colored. Hard, baked, cracked, sometimes has loose crumbs on surface. (0 to 50)[b]

[a] Available water is the difference between field capacity and permanent wilting point.
[b] Numbers in parentheses are available water contents expressed as millimeters of water per meter of soil depth.

19.6 CALCULATING INJECTION RATES

Calculating the injection rate will help to ensure that the operator can complete the chemigation in the time frame that has been allotted, determine that all of the chemical can be applied, and confirm whether the injector will be able to apply the dosage that is desired. To ensure the best performance the injection rate used should not be at the low end or high end of the injection system.

The injection time will often dictate the injection rate. In the case of the center pivot example discussed in Section 19.6.3 the injection time is the time it takes for the center pivot to make one complete revolution. For traveling gun systems the time it takes for the gun to cover one set would be the injection time. Drip systems that change from one zone to another while chemigating will have the injection time set by the zone operating time.

The following three methods—weight, volume, and injection rate formula—can be used to determine an injection rate. The type of irrigation and injection system and type of chemical being applied will often determine the method that is used.

19.6.1 Weight Injection Method

The weight injection method is often used for granular fertilizers and pressure differential or Venturi injectors. This method works well for handline, wheel move, and other stationary sprinkler systems being used to apply fertilizers. The following steps are required to determine the injection rate for fertilizers using the weight method:

1. Determine the amount of nutrient that has to be applied to a hectare.
2. Using the percent of available nutrient available in the fertilizer calculate the total amount of fertilizer that has to be applied per hectare. For example, if 50 kg of N is required per hectare and the fertilizer has a concentration of 15% N then 333 kg of fertilizer must be applied per hectare.
3. Calculate the area that is being covered by each set of the irrigation system. This calculation can be done by using the sprinkler spacing and determining the number of sprinklers operating on the set to be treated. It is important to remember that the same amount of chemical must be applied during each set of the irrigation system in order for the entire field to obtain uniform coverage.
4. Determine the total amount of fertilizer to be applied by multiplying the amount to be applied per hectare by the area covered during one set of the irrigation system. Dissolve this amount of fertilizer into a tank ensuring that the solution will stay in suspension. All of this solution will be applied during the irrigation set.
5. Determine the length of injection time desired, but make sure that there is sufficient time built in for proper system start up and system flushing. If the fertilizer is to be applied to a certain depth in the soil check the information above, in Section 19.5.6.4.
6. The injection rate will be the amount of solution that is in the tank divided by the injection time selected.

If using a pressure differential injector without a diaphragm, the concentration of fertilizer inside the tank will diminish as the solution is displaced by incoming water. Care should be taken to ensure there is sufficient time to apply all of the fertilizer solution.

19.6.2 Volume Injection Method

The volume injection method is similar to the weight method but is used for a nutrient solution rather than granular fertilizer. This method is often used for stationary sprinkler and drip/trickle irrigation systems. All types of injectors can be used with this method, but pump and water driven injectors as well as Venturi injectors are more common. The following steps are required to determine the injection rate for fertilizers using the weight method:

1. Similar to the steps in the weight method, calculate the amount of nutrient to be applied to every hectare and the area covered by the irrigation.
2. The density of the solution must be known to determine the amount of fertilizer that is contained in the solution. For example, a solution with a density of 1.3 kg/L will have 1.3 kg of fertilizer dissolved in each liter of water.
3. The concentration of nutrient in the fertilizer must also be known to determine the amount of solution that must be applied.
4. The amount of solution that must be applied per hectare can be calculated using the fertilizer concentration and the solution density. For example, if 50 kg of N is required per hectare and the solution density is 1.3 kg/L with a nutrient concentration of 25%, then the amount of solution will be (50 kg/ha)/1.3 kg/L = 37.6 L /ha. Applying a concentration of N of 0.25 will result in 37.6 L/0.25 = 150 L to be applied per ha.
5. The total amount of solution to be applied can be calculated by using the actual area covered by the irrigation system multiplied by the amount of solution required per hectare.
6. The amount of solution to be applied during the selected time will determine the injection rate.

19.6.3 Injection Rate Formula

For continuously moving irrigation systems, such as a center pivot or a drip system that will automatically change from one zone to another during chemigation, an injection rate formula can be used. A well-calibrated injection system will be required for these types of systems. An electrically driven injection pump or pump-assisted Venturi system is usually used. Since this method usually results in the entire field being treated, a large storage tank is required for sufficient chemical.

If all of the parameters are known the injection rate can be determined by:

$$I_c = \frac{Q_c \times A}{C \times T} \tag{19.1}$$

where I_c = chemical injection rate (L/min)

Q_c = quantity of nutrient to be applied to the target area (kg/ha)

A = area that is to be treated and covered by the irrigation system (ha)

C = concentration of injected solution (kg/L) (this is the actual concentration of the nutrient or chemical in solution to be applied)

T = length of time the injector is operating (min).

For example, a pivot with a wetted radius of 410 m (1350 ft) is to apply 50 kg of nitrogen per hectare. The travel speed of the end tower is 1.67 m/min (5.5 ft /min). A urea solution of 23% N and a density of 1.14 kg/L is to be used as the fertilizer source. Calculate an injection rate as:

1. The quantity of nutrient to be applied (Q_c) is 50 kg/ ha of N.
2. The area (A) covered by the pivot can be determined from the wetted radius and is 53 hectares.

3. The concentration of N in the solution (C) is 1.14 kg/L × 0.23 = 0.26 kg /L of N.
4. The length of time is the time it takes the pivot to make one complete revolution. This will be the circumference of the pivot divided by the travel speed and therefore the injection time is 1336 minutes. Thus, the injection rate is:

$$I_c = \frac{50\ \text{kg/ha} \times 53\ \text{ha}}{0.26\ \text{kg/L} \times 1336\ \text{minutes}} = 7.63\ \text{L/min}$$

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