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1992

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PERFORMANCE OF CHEMIGATION BACKFLOW PREVENTION ASSEMBLIES

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ABSTRACT

When chemicals are applied using irrigation systems, there is potential for contamination of the water source by backflow if the irrigation system shuts off while unattended. This study was conducted to determine the operating and performance characteristics of new, i.e., unused, chemigation backflow prevention assemblies (CBPAs). Four manufacturer's models were tested in the laboratory. However, two of CBPAs have been modified since the testing was completed. In general, the CBPAs do not meet the standards established for municipal water suppliers and many industries. The backpressures required for the two current models to seal were 0.0 and 6.7 kPa (1.0 psi). Backflow was a function of backpressure for the three check valves that did not seal at zero backpressure. All four valves exhibited a backpressure backflow relationship when artificially fouled with hexagonal bars placed across the valves seat. At the backpressure head of 3.7 m (12 ft), the low pressure drains on all models intercepted 100% of the backflow (leakage) when the check valves were fouled with 0.12 cm (3/64 in.) bars placed across the valves seats. A typical backpressure head after shutoff of a center pivot irrigation system is 3.7 m (12 ft). These findings support the results of field tests of eight used valves where the low pressure drains intercepted 100% of the backflow at all backpressure heads evaluated [3.7 m and less (12 ft)]. KEYWORDS. Chemigation, Backflow, Check valves, Low pressure, Drain.

INTRODUCTION

Chemigation is the process of applying agricultural chemicals by injecting the chemicals into the flowing water and using the irrigation system for chemical distribution (Threadgill, 1985). Threadgill (1985) estimated that in 1983 there were 4.3 million ha (11 million ac) of chemigated land in the United States with sprinkler irrigation systems being used on about

3.6 million ha (8.9 million ac). In the Great Plains region, the majority of the chemigation is done using center pivot sprinkler systems. In essentially all cases, a pump is used to deliver and pressurize the water for application. In Nebraska, the pump normally serves only one irrigation system. As such, in this article, the analysis is concerned with a pumped water supply that serves only one irrigation system.

One potential environmental hazard of chemigation is point source water contamination due to backflow of the water-chemical mixture following an unexpected shutoff of an unattended irrigation pump. This situation can occur due to mechanical or electrical failure of the irrigation or pumping system. The water source can be contaminated by direct backflow from the irrigation pipeline *only when the irrigation pump stops*.

There are two sources of contaminant. One is the chemical in solution with the irrigation water in the irrigation piping (mainline and laterals). The other source is the concentrated solution in the chemical supply tank. Flow of the contaminant to the water source can be prevented using properly designed and adequately maintained safety equipment. A schematic of a typical chemical injection system and safety equipment is shown in figure 1. As presented by Eisenhauer et al. (1988), the backflow prevention equipment on the irrigation pipeline, discussed by Buttermore (1988) and Eisenhauer and Hay (1989), is necessary for two purposes: 1) to augment the safety equipment on the chemical injection system and
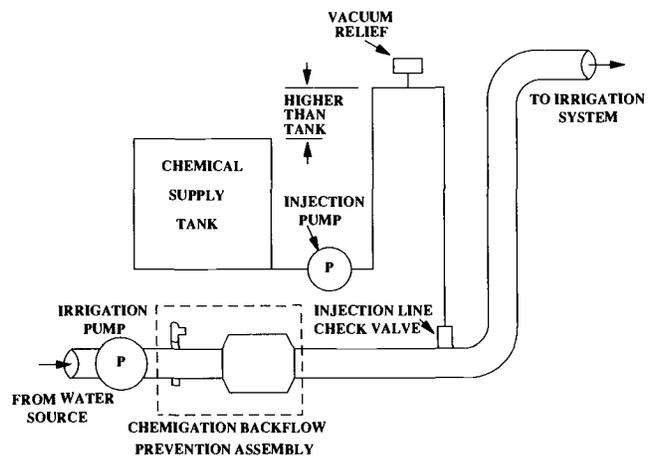

Figure 1–Schematic of chemical injection system and safety equipment.

2) to prevent backflow of the normally dilute water-chemical mixture in the irrigation piping system.

BACKFLOW PREVENTION EQUIPMENT

Backflow prevention, or cross connection control, is common technology in municipal and industrial piping systems. Many of the principles of backflow prevention were developed by the Foundation of Cross Connection Control and Hydraulic Research (FCCHR) at the University of Southern California. Their testing procedures and the suggested specifications for the backflow prevention equipment are given in FCCHR (1988).

Since many of the chemigation applications are installed on center pivots where the best location for the backflow prevention assembly (BPA) is near ground level, backpressure on the BPA is common after system shutdown. According to FCCHR requirements, if a toxic chemical is in the water and if backpressure exists, only one backflow prevention method, the reduced pressure principle device (RP), is acceptable. By FCCHR's definition, most agricultural chemicals used in chemigation are considered toxic.

Even though the basic principles presented by FCCHR were incorporated in ASAE EP 409 (ASAE, 1989), it is uncommon in agriculture to use equipment that meets FCCHR's specifications for two principle reasons. The first, and perhaps the most important, is the relatively high cost of the equipment. The second is the relatively high pressure loss through RP assemblies which can make it difficult to adapt to existing irrigation systems without major modification to the irrigation system and/or pumping system. For chemigation, it is common to use CBPAs (fig. 2) which were first suggested by Fischbach (1973) and later modified by Fischbach et al. (1984) and Eisenhauer and Hay (1989). Nebraska's chemigation regulations, discussed by Buttermore (1988), are based on the principles presented in these publications. Likewise, regulations in several other states follow these guidelines.

Standards for conventional backflow prevention devices and check valves have been set by several organizations, including the American Water Works Association (AWWA, 1982 and 1983), Foundation for Cross Connection Control and Hydraulic Research (FCCHR, 1988), Underwriter Laboratories (UL, 1975), American

Society of Sanitary Engineering (ASSE, 1980), American National Standard Institute (ANSI), and Manufacturers Standardization Society of Valve and Fittings (MSS). Refer to FCCHR (1988) and Zappe (1987) for more information .

The design of CBPAs is different from the conventional backflow prevention devices (RP and double check valve) and therefore, it does not meet the design requirements of FCCHR. The major difference between devices is that the conventional devices consist of two independently acting check valves while CBPAs often have only one spring-loaded check valve. Because the standards for backflow prevention set forth by the FCCHR have not been strictly followed in agricultural applications, there was a need to evaluate the effectiveness of the CBPA.

OBJECTIVE

The objective of this study was to determine the operating and performance characteristics of chemigation backflow prevention assemblies designed to prevent backflow in the irrigation mainline.

MATERIALS AND METHODS

Models of CBPAs from four manufacturers, designated Models A, B, C, and D, were evaluated in the laboratory. All of the models were obtained from the respective manufacturers in the fall of 1986. Two of the models, which did not meet the requirements of the Nebraska Department of Environmental Control (NDEC), have since been modified to meet the NDEC regulations. The regulations require that the check valve should not leak at 14.9 kPa (2.2 psi) backpressure or more. The major change made by the respective companies of the model was in the design of the spring to give a high closing force at the check valve seat. These design changes would change the tests results.

The assemblies were all 200 mm (8 in.) nominal diameter and ranged from 520 to 700 mm (20 to 28 in.) in length. All the assemblies had a spring-loaded swing check valve. Upstream of the check valve, each assembly had an automatically opening low pressure drain to intercept leakage, a vacuum relief valve to prevent subatmospheric pressure conditions on the upstream end, and an inspection port to visualize leakage. All assemblies had a resilient gasket on the check valve flapper which seated against an irreplaceable metal seat.

The area of the seating surface is important when determining the pressure on the seat for the given backpressure. In other words, a valve with a smaller seating area has a higher seating pressure and a greater chance of closing drip tight (zero leakage).

The area of the seating surface was approximated by:

$$A = \pi D t \qquad (1)$$

where D is the inside diameter of the seat; t is thickness of the metal or width of the surface which makes contact with the flapper; and A is an area of the seating surface. All dimensions were measured to the nearest 1 mm (0.04 in.).
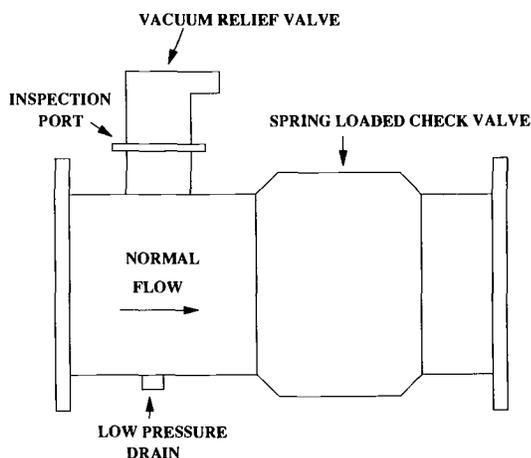

VACUUM RELIEF VALVE

INSPECTION PORT

SPRING LOADED CHECK VALVE

NORMAL FLOW

LOW PRESSURE DRAIN

Figure 2–Chemigation backflow prevention assembly.

OPENING AND RESEALING PRESSURE

The opening pressure was defined as the depth of water above the bottom of the inside surface of the assembly required to open the check valve in the normal direction of flow when the outlet (downstream) pressure was atmospheric. Resealing pressure was defined as the inlet pressure (above the bottom of the assembly) which allows the check valve to be drip tight after shutoff of a normal pumping operation when the outlet pressure was atmospheric.

To determine the opening pressure, the CBPA was installed horizontally in the test stand (fig. 3). The head of water above the bottom of the assembly on the inlet section was increased until the check valve opened and permitted leakage. This depth of water where leakage occurred was converted to forward opening pressure.

To measure the resealing pressure, water was pumped through the assembly for one or two minutes and then shut off. After shut off, the pressure in the upstream section was gradually decreased. When the valve became drip tight, the height of the water surface was measured and the resealing pressure was calculated. Each measurement was repeated three times.

BACKWARD CLOSING AND OPENING PRESSURE

The purpose of this evaluation was to determine the rate of backflow through an unfouled check valve (if it did leak), as a function of backpressure and the backpressure at which the check valve became drip tight or allowed backflow.

Backward closing pressure was defined as the backpressure at which the check valve became drip tight to backflow when the pressure in the upstream portion of the assembly was atmospheric and the backpressure was increasing. *Backward opening pressure* was defined as the backpressure at which backflow through the check valve starts when the backpressure is decreasing.

The CBPA was installed horizontally to a test stand, designed for maintaining a wide range of backpressure (fig. 4). The assembly was checked for backflow against a minimum backpressure of 0.5 kPa (0.07 psi) at the bottom of the assembly. If the assembly was found drip tight against this backpressure, backward closing pressure was considered as zero, otherwise the rate of backflow was
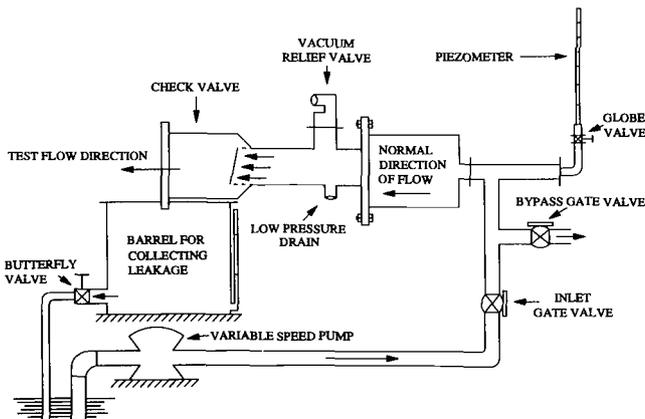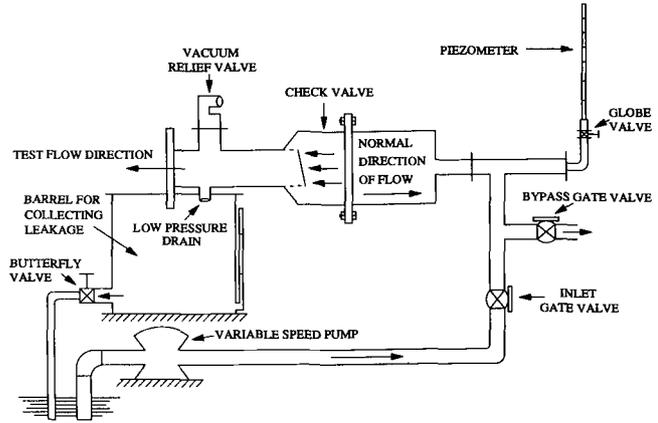
Figure 4—System for maintaining backpressure.

measured by collecting a certain volume of backflow in a graduated cylinder or graduated tank over a specific time period. Backflow rates were determined with the increasing backpressure until the check valve became drip tight against backflow. Each reading was taken three times. After each change in backpressure, two to six minutes were allowed to stabilize the backflow. The backpressure at which the check valve became drip tight was considered as the backward closing pressure.

After measuring the backward closing pressure, the backpressure was decreased in the same increments as during the increasing phase while the upstream section of the assembly was inspected for backflow. The backpressure at which the backflow started was considered the backward opening pressure.

BACKFLOW THROUGH A FOULED CBPA

The backflow through artificially fouled check valves was measured over a range of backpressures. The check valves were artificially fouled by placing a hexagonal-shaped bar across the bottom side of the valve seat. Four bar sizes were used: 0.12 cm (3/64 in.), 0.20 cm (5/64 in.), 0.278 cm (7/64 in.), and 0.32 cm (1/8 in.). Backflow was determined by measuring the leakage in a graduated tank or cylinder over a certain time. Backpressure ranged from 0.5 kPa (0.07 psi) at the bottom of the assembly to 97 kPa (14 psi) at the gauge point. Each measurement was taken three times.

BACKFLOW INTERCEPTED BY THE LOW PRESSURE DRAIN

The amount of backflow intercepted by the low pressure drain was determined over a range of backpressures for the assemblies when fouled with each size of bar. The rate of backflow not intercepted by the low pressure drain was measured in the graduated tank or cylinder. The backflow intercepted by the low pressure drain was determined by subtracting the amount of backflow not intercepted by the drain from the total backflow, as measured in the previous test for the corresponding backpressure.

Figure 3—Test stand used for the measurement of forward opening and resealing pressure.

LOW PRESSURE DRAIN CAPACITY AND ITS CLOSING PRESSURE

The low pressure drain closing pressure was defined as the pressure, on the inlet side, at which the flow through the drain stopped. The CBPA was installed in the system for measuring drain capacity (fig. 5). During the test, the check valve was maintained in the fully opened position using a brace. A plexiglass plate was placed at the end of the assembly to insure that all flow went through the drain valve. Pressures ranged from 0.5 kPa (0.07 psi) above the bottom of the assembly to 97 kPa (14 psi) at the gauge point. The drain capacity was determined at various pressures until the drain sealed.

The design of the low pressure drain for Model D precluded the use of the above procedure because this model required a velocity head in the CBPA to initiate closure. Thus, a flow of 50.5 L/s (800 gpm) through the CBPA was chosen to determine drain capacity. The assembly was installed in the system for measuring head loss at various flow rates (fig. 6). The pressures were maintained from 6.9 kPa (1.0 psi) to 97 kPa (14 psi) at the centerline of the assembly. The flow rate through the low pressure drain was determined at several different pressures until the drain closed or the pressure reached 97 kPa (14 psi). Each flow rate was measured three times. The pressure was increased in 6.9 kPa (1.0 psi) increments.
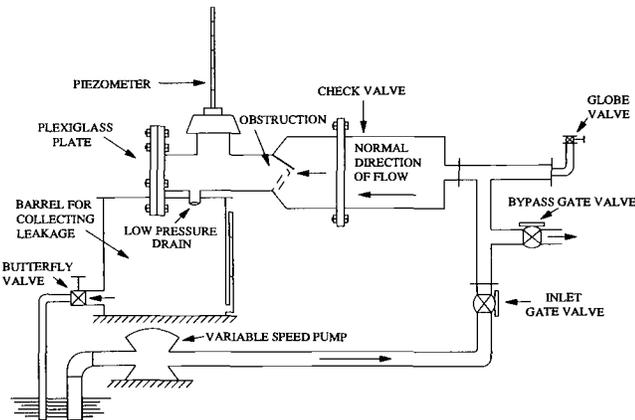

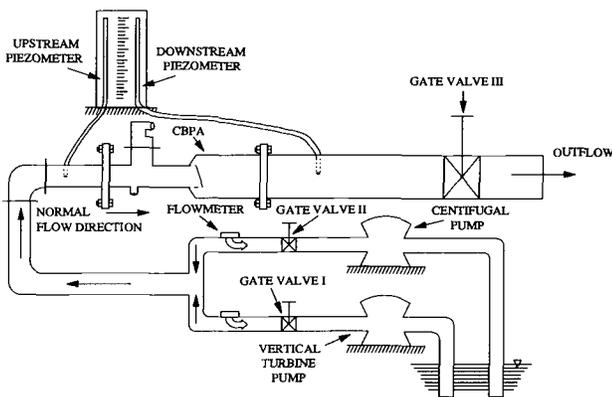**Figure 5–Test arrangement used for measuring drain capacity.**

Figure 6–System for maintaining various flow rates and measuring head loss.

Two similar designs of the low pressure drain for the Model D were tested.

HEAD LOSS THROUGH THE CBPA

Head loss was determined by measuring differential head between fittings immediately upstream and immediately downstream of the CBPA. Open-top manometers scaled to the nearest 1 mm (0.04 in.) were connected to the upstream and the downstream side of the assembly at an approximate distance of 61.0 cm (24 in.) and 30.5 cm (12 in.), respectively. Selected flow rates ranging from 12.6-101 L/s (200-1600 gpm) were maintained within an accuracy of 2%. The head loss through the CBPA and piping between the piezometers for each flow rate was calculated by the difference of the corresponding upstream and the downstream heads. The CBPA was then removed from the test stand and the head loss between the piezometer fittings was determined for the same flow rates. The head loss of the assembly was determined by subtracting the test piping head loss from the total head loss. Head loss through the assemblies was measured at an average downstream head of 85.0 cm (33.5 in.) relative to the bottom of the outlet section of the CBPA.

RESULTS

DESIGN FEATURES OF THE TEST ASSEMBLIES

The general design features of the assemblies are summarized in Table 1. Models A and B were similar in design with the following primary differences: 1) Model B had a small sector-shaped dam in the bottom of the pipe upstream of the low pressure drain to divert backflow to the drain, 2) there was less distance from the flapper to the

TABLE 1. Design features of the chemigation backflow prevention assemblies

Design Features	Models			
	A	B	C	D
Length of the assembly (cm)	55.9 (22.0)*	52.0 (20.5)	69.8 (27.5)	67.3 (26.5)
Internal diameter of the assembly (cm)	20.0 (7.87)	19.4 (7.64)	20.3 (7.99)	19.4 (7.64)
Inside diameter of the low pressure drain opening (cm)	1.9 (0.75)	1.9 (0.75)	1.9 (0.75)	2.2 (0.87)
Area of the check valve seating surface (cm²)	10.0 (1.55)	9.7 (1.50)	60.8 (9.42)	60.5 (9.38)
Distance of low pressure drain from check valve seat (cm)	19.7 (7.76)	14.0 (5.51)	20.3 (8.19)	36.8 (14.5)
Seating angle relative to vertical axis (degrees)	0.0	0.0	8.0	42.3
Presence of dam	no	yes	yes	no
Seating pressure at 3.7 m backpressure head (kPa)	1195 (173)	1128 (164)	225 (33)	226 (33)

* Numbers in parenthesis are in inches, square inches, or psi for length, area, and pressure, respectively.

low pressure drain in Model B, and 3) the low pressure drain of Model A was in a sump on the bottom side of the pipe. Model C also had a sector-shaped dam upstream of the low pressure drain. Model D had the highest seating angle and the largest distance from the flapper to the low pressure drain.

OPENING AND RESEALING PRESSURES OF NON-FOULED ASSEMBLIES

The opening and resealing pressures of the assemblies are summarized in Table 2. Only Model A had opening and resealing pressures greater than zero. With Models B, C, and D, water leaked past the check valve as soon as it touched the bottom of the flapper.

All of the assemblies had opening pressures less than the 6.9 kPa (1.0 psi) required by the FCCHR for an "approved check valve." An increase in the closing force, and hence seating pressure by hydraulic or mechanical means, would reduce the backward opening and closing pressures of the valves.

The relationships between backflow (Q) and backpressure (P) for Models B, C, and D are shown in figures 7-9, respectively, for the cases of decreasing backpressure. Since Model A had an opening and resealing pressure greater than zero, there was no backflow at any backpressure.

Typically, the backflow rate first increased as backpressure increased until it reached a peak. It then decreased with further increases in pressure until the valve sealed. The backward opening and closing pressure were estimated by linear interpolation between the last two data points.

Figure 8–Opening backflow–backpressure relationship for non-fouled Model C.

The opening backflow–backpressure (Q-P) relationship is more important than the closing Q-P relationship for chemigation applications because the backpressure usually decreases with time after the irrigation pump stops.

Except for Model A, the CBPAs required some backpressure to become drip tight against backflow and thus do not comply with the requirements of FCCHR. However, Models A and B would pass the requirements of Underwriter Laboratories (UL) 312 and the Nebraska Department of Environmental Control regulations which specify that the check valves should be drip tight at 14.9 kPa (2.2 psi) backpressure or more. Model A did not leak at any backpressure. Thus, it would meet the zero leakage with backpressure requirement of FCCHR. The backflow rate and the backward opening and closing pressures for Model B were much lower than those of Models C and D. The backward opening and closing pressure was highest for Model D.

A non-linear regression analysis was performed on the backflow rate data for each model, using PLOTIT - Interactive Graphics and Statistics and the Marquardt's Compromise method for the parameter estimation (Draper and Smith, 1966). The fitted equations were of the form:

TABLE 2. Opening, resealing, and closing pressures [kPa (psi)] of the assemblies

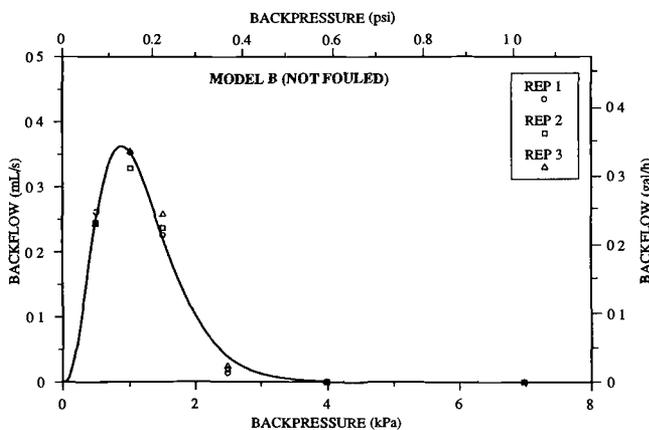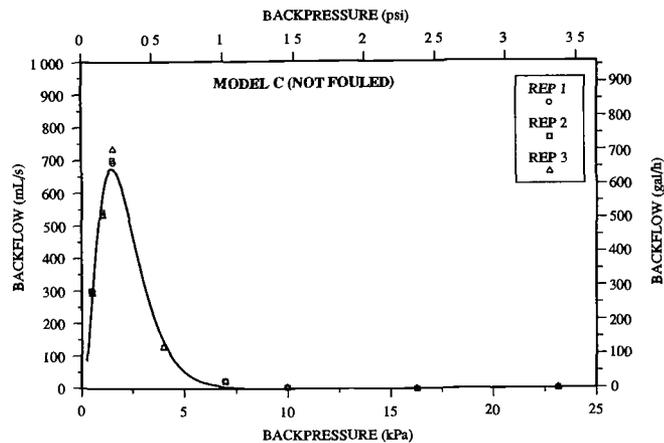| Model | Forward | | Backward | |
	Resealing Pressure	Opening Pressure	Resealing Pressure	Opening Pressure
A	1.2 (0.2)	1.0 (0.1)	0.0 (0.0)	0.0 (0.0)
B	0.0 (0.0)	0.0 (0.0)	6.7 (1.0)	3.4 (0.5)
C	0.0 (0.0)	0.0 (0.0)	23.2 (3.4)	23.2 (3.4)
D	0.0 (0.0)	0.0 (0.0)	50.7 (7.4)	50.5 (7.3)

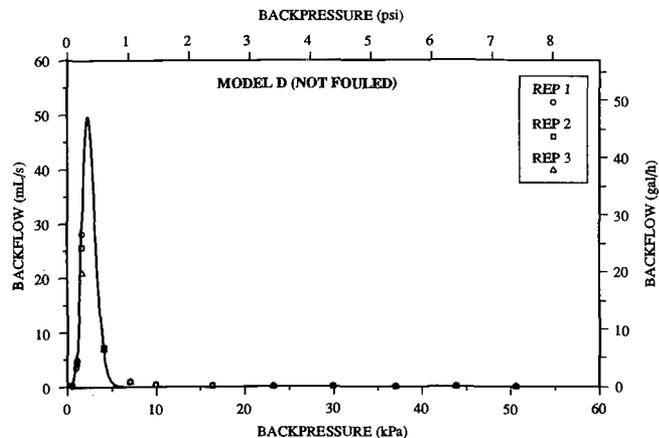Figure 7–Opening backflow–backpressure relationship for non-fouled Model B.

Figure 9–Opening backflow–backpressure relationship for non-fouled Model D.

TABLE 3. Peak backflow rate, Q_p (mL/s), and backpressure, P_p (kPa) at Q_p, for various models and bar sizes

| | Bar Size, cm (in.) | | | | | | | |
| | 0.12 (3 / 64) | | 0.20 (5 / 64) | | 0.278 (7 / 64) | | 0.32 (1 / 8) | |
Model	Q_p	P_p	Q_p	P_p	Q_p	P_p	Q_p	P_p
A	8.2 (7.8)*	1.0 (0.1)	210.5 (201.2)	1.5 (0.2)	762.5 (725.2)	4.0 (0.6)	1247.0 (118.6)	7.0 (1.0)
B	140.3 (133.4)	1.5 (0.2)	538.4 (511.9)	4.0 (0.6)	1285.3 (122.2)	10.0 (1.5)	1956.6 (186.1)	23.2 (3.4)
C	884.9 (841.6)	1.5 (0.2)	1130.0 (107.5)	4.0 (0.6)	1200.0 (114.1)	4.0 (0.6)	1459.5 (138.8)	4.0 (0.6)
D	65.2 (62.0)	1.5 (0.2)	116.2 (110.5)	1.5 (0.2)	268.0 (254.9)	4.0 (0.6)	357.9 (34.0)	4.0 (0.6)

* Numbers in parenthesis are in gal / hr and psi for backflow rate and backpressure, respectively.

$$Q = AH^B \exp(CH) \qquad (2)$$

where Q represents backflow rate (mL/s or gal/min); H is backpressure (kPa or psi); and A, B, C are constants with A and C having units mL/s/kPa^B (gal/min/psi^B) and 1/kPa (1/psi), respectively. Both the observed and predicted data obtained for the backward opening pressure test by using the fitted equation for each model are shown in figures 7 through 9.

BACKFLOW THROUGH FOULED CBPAs

The backflow rate through artificially fouled CBPAs was dependent upon the degree that they were fouled, the backpressure, and the model. Like the unfouled case, the backflow rate first increased with an increase of backpressure until it reached the peak rate (Q_p). It then decreased with further increases in backpressure. The backpressure at which Q_p occurred is denoted as P_p and was dependent on the model and the degree to which it was fouled (Table 3). For Models A and B, P_p increased as the bar size increased. For the 0.12 and 0.20 cm 3/64 and 5/64 in.) bars, the peak flow through Model C was the highest of all models. For the 0.278 and 0.32 cm (7/64 and 1/8 in.) bars, Model B had the highest Q_p The model with the next highest peak flow was Model C. Except for the 0.12 cm (3/64 in.) bar, the peak flow rates through Model D for all bar sizes were the smallest of all models.

The backflow rates through a fouled assembly at 3.7 m (12 ft) of head (36 kPa or 5.2 psi), which is typical after shut off of a center pivot system, are listed in Table 4. At this backpressure, the backflow rate through the assembly for the 0.12 cm (3/64 in.) bar was highest in Model D. For the 0.20 cm (5/64 in.) bar, Model C had the largest backflow rate and for the 0.278 and 0.32 cm (7/64 and 1/8 in.) bars, Model B had the highest backflow.

TABLE 4. Backflow rates (mL/s) at a backpressure head of 3.66 m (12 ft) for various models and bar sizes

| | Fouling Bar Size, cm (in.) | | | |
Model	0.12 (3 / 64)	0.20 (5 / 64)	0.278 (7 / 64)	0.32 (1 / 8)
A	0.3 (0.3)*	2.1 (2.0)	92.0 (87.5)	600.0 (570.7)
B	1.6 (1.5)	5.0 (4.8)	800.0 (760.9)	1510.0 (1436.2
C	4.3 (4.1)	10.9 (10.4)	15.0 (14.3)	120.0 (114.1)
D	7.5 (7.1)	9.2 (8.8)	36.0 (34.3)	55.0 (52.3)

* Numbers in parenthesis are in gal / hr.

LOW PRESSURE DRAIN CAPACITY

The flow capacities of the low pressure drains for Models A, B, and C are shown in figure 10 and for Model D it is given in figure 11. As expected, the capacity of the low pressure drain was dependent upon the water pressure at the drain and the design of the drain. The low pressure drain capacity for Model A was generally higher than all the other units at all pressures. The drain closed abruptly at a pressure of 22 kPa (3.2 psi) after reaching the peak flow rate of approximately 1.42 L/s (23 gal/min). Model A required the lowest pressure to become drip tight (fig. 10). For Model B, the maximum flow rate, 1100 mL/s (17.4 gal/min), occurred at a pressure of 12 kPa (1.8 psi). The flow rate then decreased gradually as pressure increased. The drain became drip tight at 67 kPa (9.8 psi). The low pressure drain of Model C was spring loaded and it closed at a pressure of 32 kPa (4.6 psi). The maximum flow of 795 mL/s (12.6 gal/min) occurred at a pressure of 11 kPa (1.6 psi) (fig. 10).

Two designs of the low pressure drain for Model D were tested. The flow rate through both drains was maximum at a pressure of 8 kPa (1.1 psi) and decreased gradually as pressure was increased. Drain Design No. 1 became drip tight at a pressure of 98 kPa (14.1 psi) but the Drain No. 2 had not yet closed at that pressure (fig. 11).

None of the low pressure drains meet the flow capacity of 3.8 L/s (60 gal/min) at a differential pressure of 10 kPa (1.5 psi) as required by the FCCHR and AWWA for the differential relief valves on RP devices.

BACKFLOW INTERCEPTED BY THE LOW PRESSURE DRAIN

The percent of backflow intercepted by the low pressure drain was dependent upon the backflow rate through the
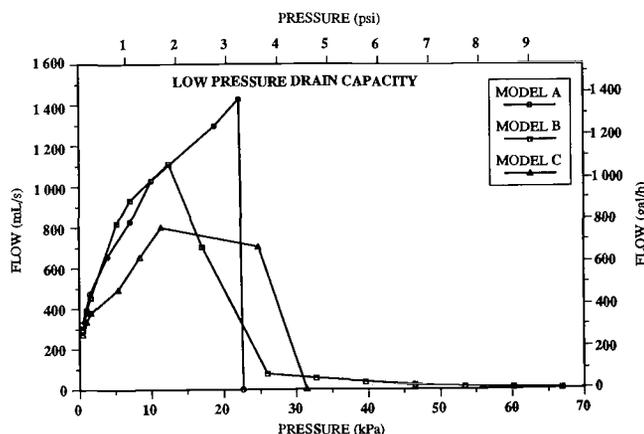

Figure 10–Low pressure drain capacity for Models A, B, and C.
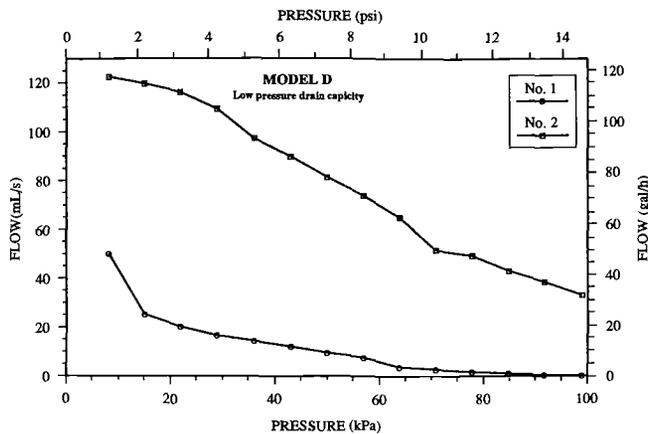
PRESSURE (psi)

Figure 11–Low pressure drain capacity for Model D.

fouled CBPA, the pattern of the flow, design of the drain valve, the distance of the drain from the flapper, drain inlet condition (dam vs. sump), and the drain capacity.

Except for Model D, backflow interception generally followed the same pattern; an initially high percentage of interception was followed by a decrease in percent intercepted as backpressure increased. This was followed by an increase in interception as the pressure was increased further. For the 0.32 cm (1/8 in.) bar with Model B, the interception decreased after reaching a second peak in percent intercepted at a backpressure of 72 kPa (10 psi). Above 72 kPa (10 psi), the leakage sprayed over the drain. The pattern of backflow interception for the two smaller bars with both drains used in Model D were similar to the flow characteristics of the other models. However, for the 0.278 and 0.32 cm (7/64 and 1/8 in.) bars, the percent intercepted was initially low; it reached a maximum with an increase of backpressure and then decreased with a further increase in pressure.

The maximum backflow rates and maximum flow intercepted for each model are shown in figure 12. The drain valve in Model A was able to intercept 100% of the backflow for the non-fouled condition and for the 0.12 and 0.20 cm (3/64 and 5/64 in.) bars. The low backflow rates and the drain location were probably the reasons for reaching 100% interception. For the other models, the drain valve was unable to intercept all the backflow rates for any sized bars. However, the drain of
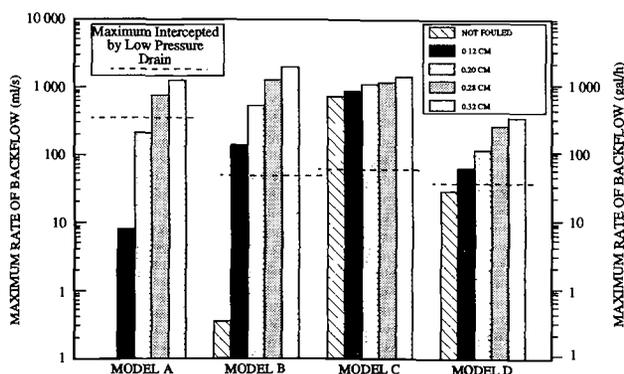
Models B and D did intercept 100% of backflow with the non-fouled condition.

Models A and B had similar designs but Model A intercepted a higher percentage of the backflow than Model B, probably due to the sump. In Model B, the interception reached 100% of the backflow for the 0.12, 0.20, and 0.278 cm (3/64, 5/64, and 7/64 in.) bars at high backpressures. Model C intercepted 100% for all bars after reaching the minimum interception. For Model D, the performance of Drain No. 1 was better than Drain No. 2.

For all the assemblies, the pattern of the backflow and the distance of the low pressure drain from the check valve flapper were important factors in the backflow interception. It appears that increasing the distance from the drain to the flapper enables the drain to intercept a higher portion of the backflow when backpressure causes the backflow to spray above the bottom of the pipe. In some cases the drain was unable to intercept the flow, not only due to its capacity, but also because of the leakage pattern. This was especially true for the 0. 278 and 0.32 cm (7/64 and 1/8 in.) bars in both Models A and B, as the backflow was spraying over the drain.

The percent of backflow intercepted at a backpressure head of 3.7 m (36 kPa) (12 ft) and the approximate backpressure at shut off of a center pivot sprinkler irrigation system is summarized for each model in Table 5. Except for Drain No. 2 of Model D, all the models intercepted 100% of the backflow at the shut off head for bar sizes of 0.12 and 0.20 cm (3/64 and 5/64 in.). Also, except for the 0.32 cm (1/8 in.) bar, Models A and C had intercepted 100% of the backflow. For the 0.32 cm (1/8 in.) bar, the interception percentage was highest for Model C. The maximum intercepted backflow rates through various models are also listed in Table 5.

HEAD LOSS

The head loss through each of the assemblies at all flow rates was relatively small (fig. 13). The maximum head loss of 55.4 cm (22 in.) of water was measured through the Model D at a flow rate of 101 L/s (1600 gal/min).

The initial shape of the head loss curve for Models A and B was caused by the closing force of the flappers. Models C and D had head loss curves that increased monotonically with flow rate. The reason for similarity may be because spring design of the two models were similar. Head loss was maximum at 101 L/s (1600 gal/min) for both models.

Each of the assemblies met the requirement of FCCHR and AWWA with regard to allowable head loss.

Figure 12–Maximum backflow of CBPAs and interception of the low pressure drain.

TABLE 5. Percent of backflow intercepted by low pressure drain at a backpressure head of 3.66 m (12 ft) for various models and bar sizes

| | Bar Size, cm (in.) | | | | Maximum Backflow |
Model	0.12 (3 / 64)	0.20 (5 / 64)	0.278 (7 / 64)	0.32 (1 / 8)	Rate Intercepted
	Percent				(mL / s)
A	100	100	100	43	323.7 (307.9)[*]
B	100	100	35	17.5	45.5 (43.3)
C	100	100	100	98	58.9 (56.0)
D No. 1	100	100	87	52.5	37.0 (35.2)
No. 2	100	96.7	76	60	45.6 (43.4)

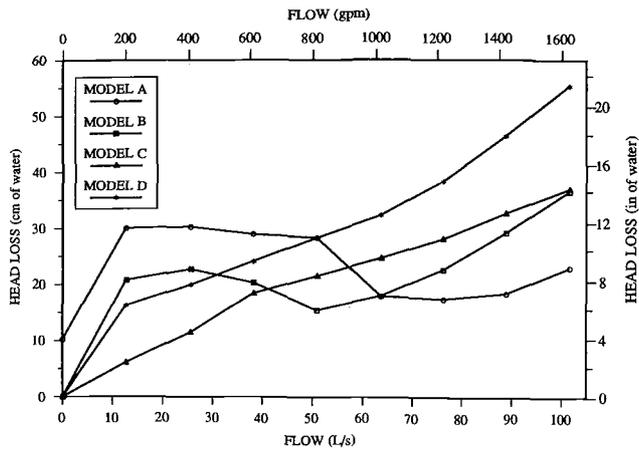* Numbers in parentheses are in gal / h.

Figure 13–Head loss through the CBPAs.

DISCUSSION

It is unfortunate that Models C and D were tested prior to modifications in their design. Obviously, any design changes in these models would affect the characteristics presented here. The backward opening and closing pressures for Models C and D were decreased to meet the Nebraska DEC regulations. The required design changes would have probably caused a decrease in backflow for the fouled and non-fouled conditions. Also, it is hypothesized that the head loss through the assemblies would increase if a spring that gave a higher closing force at the check valve seat were used to meet zero leakage requirement. However, another alternative would be the use of a more resilient gasket material on the valve seat or flapper facing.

The most significant finding is the relationship between backflow and backpressure of the check valves in the CBPA assemblies. This Q-P curve has two important implications. First, this relationship is important when developing criteria for inspecting and testing CBPAs. For example, if the CBPAs are used mainly for center pivot systems, a high percentage of the assemblies would pass a field evaluation if the inspection procedures given by Eisenhauer and Hay (1989) were used. Their suggested procedure is: (1) start the irrigation pump and pressurize the irrigation system to normal operating pressure, (2) shut off the irrigation pump, and (3) open the inspection port and observe for leakage from the check valve. Since most of the inspections where center pivots are used would have a backpressure head of 3.7 m (12 ft) immediately after shutoff, many of the CBPAs would have zero leakage and thus would pass the field inspection. However, if the same CBPAs were applied on irrigation systems that would have a low head upon shutoff, such as a sideroll system or a gated pipe system, the CBPAs may fail the field inspection and indeed allow leakage through the check valve. This would mean that the only mechanism for preventing backflow would be the low pressure drain. The low pressure drain should be considered as a secondary device, not the primary device for preventing backflow.

A second aspect of the Q-P relationship is that even though the CBPA may pass a field inspection immediately after shutoff, anything that causes the backpressure head to be reduced over time, such as leaks in the irrigation piping

system, could cause the head to be lowered to the point where the check valve opens and allows leakage. Therefore, it is highly desirable to use check valves that do not open or allow backflow within a realistic range of backpressure. A valve with a forward opening pressure greater than zero, such as Model A and as required by FCCHR and AWWA, guarantees that there will not be any backflow at any backpressure unless the valve was fouled.

The important question is: Will CBPAs with a single check valve prevent backflow with a high degree of certainty? The work reported in this article only gives an initial answer to this question. Obviously, if you refer to figure 12, a concern is raised since the low pressure drain did not intercept 100% of the backflow in many of the situations illustrated. However, it is important to realize that the information in this graph is dependent upon the size of bars that were used to artificially foul the check valves. The question then remains: Were the bar sizes that we selected realistic? At this time, we are unsure.

Another important question is: How will the CBPAs perform after they have been used in the field? Eisenhauer et al. (1988) reported testing results for eight CBPAs that had been in the field for three to five years. Two had check valves that did not leak at any backpressure, all eight were sealed at a backpressure head of 3.7 m (12 ft), and six were leak proof at a backpressure head of 1.5 m (5.0 ft). It is encouraging that the low pressure drains on these assemblies intercepted 100% of the backflow regardless of the backpressure head. A summary of the field tests are given in Table 6.

Finally, an important function of the CBPA is to backup the safety equipment on the chemical injection system. As illustrated by Eisenhauer et al. (1988), the greatest threat of chemical contamination comes from the concentrated chemical in the chemical supply tank, not from the more dilute chemical water mixture in the irrigation piping system. Therefore, not only is further evaluation of current and alternative designs in CBPAs needed, the performance of the safety equipment on the chemical injection system needs to be scrutinized.

SUMMARY AND CONCLUSIONS

The overall objective of this study was to evaluate the performance of new, i.e., unused, chemigation backflow prevention assemblies (CBPAs) for their effectiveness in preventing contamination of water source. Four manufacturers models designated Models A, B, C, and D, were tested in the laboratory. All of the models were

TABLE 6. Performance of valves that had been used in field
(after Eisenhauer et al., 1988)

Number tested	8
Number that did not leak at 3.66 m (12 ft) backpressure head	8
Number that did not leak at 1.52 m (5 ft) backpressure head	6
Number where 100% of backflow would be intercepted by low pressure drain at all pressure heads from 0 to 3.66 m (12 ft)	8

obtained in the fall of 1986. Experimental equipment and procedures were developed to determine the opening and resealing pressures of the assemblies, the backflow through non-fouled and artificially fouled CBPAs, the capacity of low pressure drains, the backflow intercepted by the low pressure drains, and the head loss through the assemblies.

Except for Model A, the forward opening and resealing pressures of all the assemblies were zero. The performance of new CBPAs was compared with various standards for backflow prevention devices and the Nebraska Department of Environmental Control requirements. None of the assemblies complied with the forward opening and resealing pressure requirements of FCCHR. Only Model A met the backward opening pressure requirement of FCCHR. In addition, Models A and B would pass the backward opening pressure requirement of Underwriter Laboratories (UL 312) and Nebraska DEC regulations. Subsequent to testing, Models C and D have been redesigned to meet the backpressure leakage requirement of UL 312 and Nebraska DEC regulations.

Hexagon bars were placed across the check valve seats to simulate fouling. For the smaller bars, 0.12 and 0.20 cm (3/64 and 5/64 in.), the peak backflow rate through Model C was highest and for the 0.278 and 0.32 cm (7/64 and 1/8 in.) bars, Model B had the largest flow. For backflow interception, the pattern of the backflow, backflow rate, distance of the low pressure drain from the flapper, and the sump design were important factors. At a backpressure of 3.7 m (12 ft) of head (i.e., a typical head after shut off of a center pivot), Models A and C intercepted 100% of the backflow from the 0.278 cm (7/64 in.) bar and smaller bars. Except for Drain No. 2 of Model D, each of the other models intercepted all the backflow for the 0.12 and 0.20 cm (3/64 and 5/64 in.) bars at 3.7 m (12 ft) of head.

Thus, with a backpressure head of 3.7 m (12 ft), all four of the new CBPAs would prevent backflow to the water source if they were not fouled or were fouled only to a small degree.

The capacity of the low pressure drain for Model A was highest of all the assemblies tested, however, none of the drains meet the requirements of FCCHR and American Water Works Association (AWWA) for the pressure differential relief valve used in RP devices. All the assemblies meet the head loss specifications of FCCHR and AWWA.

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