Low Pressure Sprinkler and Fan Cooling System Design for Dairy Facilities

Originally written by
Brian J. Holmes and Leonard R. Massie,
Extension Engineers
Biological Systems Engineering
University of Wisconsin – Madison

Modified by
Kevin A. Janni
Professor and Extension Engineer
Biosystems and Agricultural Engineering
University of Minnesota

INTRODUCTION

The thermal "comfort" zone for most cows is typically between 40 F and 75 F. High producing dairy cows begin experiencing mild heat stress when the air temperature is 75 F or higher and the relative humidity is 70% or higher. More severe heat stress begins when the air temperature is 87 F or higher and the relative humidity is 50% or higher. Minnesota typically experiences 175 hours (approximately seven days) each year when ambient air temperatures are at or above 84 F (ASHRAE, 1997).

Dairy cows that suffer from heat stress will reduce their feed intake, milk production, and reproductive efficiency. And higher producing cows are especially susceptible to heat stress. As a result, many dairy producers are considering and installing supplemental cooling systems to help cows beat the heat. Supplemental cooling can help cows get rid of metabolic heat. Supplemental cooling can be provided using cooling or mixing fans, fans and low-pressure sprinklers, or fans and misters. This article is about low-pressure sprinkler systems.

Before spending money on a supplemental cooling system, make sure that the area is properly ventilated and shaded. Cows should also have access to plenty of fresh cool drinking water. After these are provided, producers can consider adding a supplemental cooling system.

Low-pressure sprinkler and fan cooling systems can be used along feed bunks and in holding areas where there is good ventilation (air exchange) and the floor can be wet without significant consequences. The fans run continuously while the sprinklers turn on and off. The sprinklers are on long enough to wet the cows' hair and coat to the skin. Sprinklers are typically "on" for between 1 to 3 minutes in every 10 to 15 minutes. Excess sprinkling wastes water and does not reduce heat stress. The cows feel cooler because some of their body heat is used to evaporate the water. It is critical that the sprinklers be turned off for evaporation to occur. Adequate air exchange is essential to remove the humidified air.

Low-pressure sprinkler and fan cooling systems can be very effective if the systems are designed and managed properly. The purpose of the article is to present design recommendations and example cases for low-pressure sprinkler and fan cooling systems. Improperly designed systems may not provide the desired cooling effect and they may create wet conditions that lead to increased mastitis.

DESIGN FACTORS

Low-pressure sprinkler and fan cooling system design criteria include: system location, nozzle selection, water supply and sprinkler system sizing, cooling fan selection and location, and controls.

Cooling System Location

Low-pressure sprinkler and fan cooling systems can be used in holding pens and alongside feed mangers in naturally ventilated freestall barns. They can also be used along outdoor shaded feed bunks with a concrete apron. Sprinklers can be used where the floor can get wet without significant consequences. Sprinkler systems installed in freestall barns should be positioned to avoid getting bedded freestalls and feed wet. The area should have adequate drainage (1/8 in. to 1/4 in. per ft slope) to allow excess water to drain away and to avoid water ponding. Some of the cooling water will wet the floor and get into the manure system. Avoid excessive sprinkling to avoid adding excessive water to the manure storage unit.

Nozzle Selection

Nozzle selection is critical to system performance. Use either 180 degree (half-circle) or 360 degree (full-circle) low pressure (20 to 25 pounds per square inch (psi)) sprinkler nozzles that produce large droplets that produce a shower effect, which readily wet the cow's skin. A fine mist should not be used. Irrigation nozzles and solid-cone coarse droplet spray nozzles with flow rates between 0.2 and 0.5 gallons per minute (gpm) work very well. Along a feed manger, the 180-degree nozzles mounted next to the bunk to spray away from the feed bunk minimize wetting of the feed. The 360-degree nozzles work well in holding areas.

Use sprinkler supplied information to determine nozzle spacing based on water pressure. Space nozzles so that the system provides a uniform distribution and apply most of the water in the middle of the cow's back. Provide some overlap. Typical nozzle spacing ranges from 4 to 10 ft. Locate nozzles high enough (about 9 ft) so that cows cannot reach them.

Water Supply and Delivery Capacity

The water supply system must be able to deliver sufficient water at the design pressure throughout the sprinkling system and satisfy all other farmstead water needs (i.e., drinking water, flush water, parlor needs, other) which occur simultaneously. Consider using a reservoir system when the water supply flow rate is limited. A reservoir system accumulates water during off periods. See Figure 31, page 25 of Heating, Cooling and Tempering Air for Livestock Housing (MWPS-34) for a schematic on how to arrange a reservoir system.

Water Pressure

Normal operating pressures for low-pressure systems are between 15 and 25 psi. Avoid excessive system pressures to avoid producing a mist or very fine droplets that do not soak the hair coat or drift away more easily in air currents. Consider installing a pressure regulator to keep the water pressure within operating limits for the nozzles.

Water Line Filter

A line filter, usually a Y-filter with a flush valve and a 200 to 500 mesh screen, will protect nozzles from plugging with sand and rust particles. Check and clean filters periodically and prior to system start up each year prior to hot weather.

Flushing and Shutdown

Consider providing a valve or removable plug at the end of each branch or lateral to flush sand and rust from the lines. Make sure that the system and all lines can be drained prior to freezing weather.

Distribution Pipe Selection

Various types of plastic pipes (i.e., PVC and polyethylene) can be used for supply and distribution lines. Check with nozzle suppliers for recommendations. In addition to cost and ease of installation, consider durability, susceptibility to sunlight degradation, and need for mounting support.

Pipe Sizing

Pipe size requirements will depend on line length, number and length of distribution branches, number of nozzles per branch, nozzle flow rates, and number of branches on at one time. For example a line 200 ft long with 19 sprinklers with flow rates of 0.25 gpm/sprinkler will need to supply at least 4.75 gpm of water.

Table 1 gives friction loss factors for smooth plastic pipe for different sized pipes and flow rates. Water velocities were limited to 5 ft per second or less to avoid water-hammer problems. This can be used to size supply and distribution lines. The supply line needs to be sized adequately to limit the pressure drop in the line to 20% of the operating pressure. Table 2 gives a reduction coefficient to account for reduced friction loss in pipes with multiple outlets (i.e., nozzles) due to reduce flow in the pipe.

The head loss through plastic pipe is calculated by:

HL (psi) =
Friction loss factor (psi) /100 ft (Table 1) • Pipe length (ft) • Reduction coefficient (Table 2)

Pipe Sizing Examples

Consider two sprinkler distribution pipe arrangements for a 400-cow, 4-row drive through naturally ventilated freestall barn that is 400 feet long. In both cases the distribution pipes (laterals) are located above the two feeding alleys and all sprinklers operate simultaneously. In the first case, the supply line enters the barn at the center with four distribution lines branching into the four quadrants of the barn. In the second case, the supply line enters at one end of the barn and branches into two distribution lines. Assume sprinklers are spaced at 10-foot intervals and each delivers 15-gph (0.25 gpm) operating at a 20-psi supply pressure. In both cases distribution lines and the supply lines were sized so that the pressure drop in each line is less than 20% of the operating pressure.

Table 1. Friction loss factors for plastic pipe.

Flow Rate (gpm)	1/2	3/4	1	1.25	1.5	2	2.5	3
1	1.41	0.20	0.05	0.02	0.01	0.00	0.00	0.00
2	5.09	0.71	0.17	0.06	0.02	0.01	0.00	0.00
3	10.78	1.50	0.37	0.12	0.05	0.01	0.00	0.00
4	18.36	2.55	0.63	0.21	0.09	0.02	0.01	0.00
5		3.85	0.95	0.32	0.13	0.03	0.01	0.00
6		5.40	1.33	0.45	0.18	0.05	0.02	0.01
7		7.19	1.77	0.60	0.25	0.06	0.02	0.01
8		9.20	2.27	0.76	0.31	0.08	0.03	0.01
9			2.82	0.95	0.39	0.10	0.03	0.01
10			3.43	1.16	0.48	0.12	0.04	0.02
11			4.09	1.38	0.57	0.14	0.05	0.02
12			4.80	1.62	0.67	0.16	0.06	0.02
13			5.57	1.88	0.77	0.19	0.06	0.03
14			6.39	2.16	0.89	0.22	0.07	0.03
15			7.26	2.45	1.01	0.25	0.08	0.03
16				2.76	1.14	0.28	0.09	0.04
17				3.09	1.27	0.31	0.11	0.04
18				3.43	1.41	0.35	0.12	0.05
19				3.80	1.56	0.38	0.013	0.05
20				4.17	1.72	0.42	0.14	0.06
22				4.98	2.05	0.50	0.17	0.07
24					2.41	0.59	0.20	0.08
26					2.79	0.69	0.23	0.10
28					3.20	0.79	0.27	0.11
30					3.64	0.90	0.30	0.12
35						1.19	0.40	0.17
40						1.53	0.52	0.21
45						1.90	0.64	0.26
50						2.31	0.78	0.32
55						2.75	0.93	0.38
60							1.19	0.45
70							1.45	0.60
80							1.86	0.77
90							2.31	0.95
100							2.81	1.16

Note: Friction losses are shown for water velocities of 5 ft/s or less so water hammer will not be a problem. Nominal I.D. = inside pipe diameter

Table 2. Reduction coefficients for adjusting friction loss in pipes with multiple outlets.

Number of Outlets	Reduction Coefficient
1	1.00
2	0.64
3	0.53
4	0.49
5	0.46
6	0.44
7	0.43
8	0.42
9	0.41
10 – 11	0.40
12 – 14	0.39
15 – 20	0.38
21 – 35	0.37
> 35	0.36

CASE 1

In the first case, each of the four distribution lines is about 200 feet long with 19 sprinklers. Each distribution line must receive 4.75 gpm (19 sprinklers @ 0.25 gpm/sprinkler). To limit the pressure drop in the line to 20% of operating pressure the line head loss must be 4 psi or less (0.20 • 20 psi = 4 psi). Using 4.75 gpm and Table 1 (interpolating between 4 and 5 gpm), a 3/4-in. line would have a pressure loss of 3.53 psi/100 feet. With 19 outlets, Table 2 gives a reduction coefficient of 0.38. The head loss (HL) for each distribution line is:

HL = (3.53 psi/100 ft) • 200 ft • 0.38 = 2.68 psi (< 4 psi).

The head loss is less than the allowed 4-psi limit. This means that the 3/4-in. distribution line is adequate for this case.

The supply line must provide 19 gpm (4 distribution lines • 4.75 gpm/line). If the operating pressure will be in the 30 to 40 psi range, the maximum head loss could be 6 to 8 psi. A 1.25-in. line would lose 3.80-psi/100 ft (Table 1). If the supply line is 200 feet or less and the supply pressure is 40 psi, the pressure loss is acceptable. If the supply pressure is lower or the supply line is longer than 200 ft, the line diameter needs to be increased to 1.5 in.

CASE 2

In Case 2, the water supply line enters the barn from one end. The two distribution lines, each 400 feet long, must receive 9.5 gpm (38 sprinklers @ 0.25 gpm/nozzle). The line head loss again must be 4 psi or less. Using 9.5 gpm and Table 1 (interpolating between 9 and 10 gpm), a 1-in. line would have a pressure loss of 3.13 psi/100 ft. With 39 outlets, pressure loss coefficient from Table 2, is 0.36. The head loss HL for both distribution lines is:

HL = (3.13 psi/100 ft) • 400 ft • 0.36 = 4.5 psi.

This is more than the allowed 4-psi loss. The 1-in. distribution line is not adequate for this case.

Selecting a 1.25-in. line yields a pressure drop of:

HL = (1.06 psi/100 ft) • 400 ft • 0.36 = 1.52 psi.

A 1 1/4-inch diameter pipe is satisfactory for both distribution lines.

The water supply line selected in Case 1 carries the same total flow rate as in Case 2. The total pressure loss for the system is 4.64 psi (1.52 psi + 3.12 psi) which is less than the desired 5 psi total.

It will take 9 gallons to fill the laterals in Case 1 and 25 gallons in Case 2. In both cases, the water supply must be able to deliver 19 gpm for 1- to 3-minute intervals every 15 minutes. If this is not possible, options for reducing the demand on the water supply system include:
1. Controlling each branch of the system separately with multiple timer/solenoid valves that are scheduled to operate at different times. The flow then becomes 4.75 gpm for Case 1 or 9.5 gpm for Case 2.
2. Using a reservoir and a separate pump. The reservoir could be filled at a steady pace from the water supply system and from clean wastewater sources (i.e., plate cooler).
3. Using another source of water. Examples include a farm pond or rainwater cistern. When a pond is used, a chlorinating system may be needed to control algae in the sprinkling system.

With a 3-minute on time and a 12-minute off-time (15-minute interval) and a flow of 19 gpm, the amount of water entering the barn is 288 gph (19 gpm + 12 min/hr) or 1995 gallons in a 10-hour operating period. Not all of this water will enter the manure, but 30 to 50% may. This could be an additional 90 to 150 ft^3/day. For comparison, the manure produced by the 400 cows could be about 760 ft^3/day. Using larger flow rates will increase the amount of water in the manure storage. 7

CASE 3 -- HOLDING AREA
The 400-cow barn is divided into 4 quadrants with 100 cows in each group. The parlor is designed to milk each group in an hour. Therefore, cows are in the holding area for 4 hours per milking. Using 15 ft^2/cow in the holding area, the holding area is 1500 ft^2. A 20-foot wide holding area would be 75 feet long. Using a 360 nozzle with a 90(apex angle located 10 feet above the floor, a 10-foot spacing can be used between rows of nozzles. Using two rows of nozzles located 5 feet from each side of the holding area and 7 rows along the length of the holding area, a total of 14 nozzles are needed. At 0.5 gpm/nozzle, 7 gpm must be supplied to the holding area. If the supply line is 100 feet long, a 1-inch line will have a pressure drop of 1.77-psi (Table 1) when the flow rate is 7 gpm. Each of the two rows of nozzles is a distribution line receiving 3.5 gpm. The pressure drop in a 1/2-inch line will be:

HL = (14.57 psi/100 ft) • 75 ft • 0.43 = 4.7 psi.

The total pressure loss becomes 6.47 psi (1.77 psi + 4.7 psi). This is larger than the 5-psi desired, so select a larger distribution pipe. Selecting a 3/4- inch pipe, the pressure loss becomes:

$HL = (2.78 psi/100 ft) \cdot 75 ft \cdot 0.43 = 0.9 psi.$

The total pressure loss is then 2.67 psi (1.77 psi + 0.9 psi), well below the 5 psi desired. The 7 gpm will be an additional demand on the water supply system. Additional water in the holding area floor must also be handled.

Fan Selection and Installation

Low-pressure sprinkler and fan cooling systems include mixing fans to create a draft across or past the cows. Direct-drive axial-flow fans are preferred, primarily because they retain their performance over time better than belt-driven fans. Most mixing fans are 36 or 48 inches in diameter and normally installed about 10 to 12 feet above the cow feeding alley, or high enough to clear equipment operating below the fans. Fans over freestalls are usually mounted 8 feet above the cow alley or higher if necessary to keep cows from reaching the fans. The fans are angled downward at between 15 to 20 degrees. The goal is to create air velocities around 200 to 300 feet per minute across the cows' backs. The recommended distance between fans is 30 feet for 3-foot diameter fans and 40 feet for 4-foot diameter fans. All fans should be blowing air in the same direction. Most cooling fans in naturally ventilated barns are mounted to blow air toward the east or north.

In holding areas where clearance may be limited, fans can be mounted along the side of the holding pen with the airflow directed across the animals. Again, all fans should be blowing air in the same direction. Avoid blowing the air toward the milking parlor. Mount the fans securely and provide guards and screens to prevent cows from reaching moving parts and electrical wiring.

Controls

Controls are very important for effective cooling. It is essential that controller keep the cooling fans running whenever the sprinkler system is operating. It also is essential that the water sprinklers be shut off to allow the cows' hair to dry. This means that the water sprinklers are on a short period of time to wet the cows' skin and off a longer period of time to allow the water to evaporate from the cows' hair coat.

Plan to have the sprinklers on for 1 to 3 minutes out of every 10 to 15 minutes. The sprinklers will spray water for 1 to 3 minutes and are shut off for 12 to 14 minutes over a 15-minute cycle. Select an adjustable 30-minute cycle timer. Longer sprinkler on times may be needed in the holding area. Some trial and error may be needed to find best sprinkler on time in each application. Excessive on-times waste water. Excess water will create puddles, add extra water to the manure storage, and possibly wet the feed and freestalls.

The controls for low-pressure sprinkler and fan cooling systems include thermostats, timers, and solenoid valves to control the cooling fans and the sprinkler system. The simplest system has a thermostat in series with a timer. The thermostat activates the cooling fans and the timer when the air temperature exceeds the set point temperature. Typically cooling systems are set to start operating when temperatures reach 75 to 80 F and above. A two-stage thermostat can be used to have the cooling fans turn on at a lower temperature than the sprinkler system. Use thermostats with switches designed to close on temperature rise (i.e., ventilating fan or air conditioning type applications).

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