Sprinkler Nozzle Testing Report

Submitted to:

EPA WaterSense Program

By:

Michael D. Dukes, Ph.D., P.E.

University of Florida

Institute of Food and Agricultural Sciences

Agricultural and Biological Engineering Department

Oct. 9, 2023

Table of Contents

List of Tables

List of Figures

Introduction

High efficiency (HE) spray sprinkler nozzles have been reported to reduce irrigation consumption. The term "high efficiency" is used here since manufacturers use terms such as "efficient performance, maximize efficiency, maximum water efficiency" and claim water savings ranging from 30% to 35%. However, the mechanisms for water savings are not fully known. In contrast, the term "standard nozzles" will be used here to refer to those that are typically used in landscapes with fixed radii and arc and include matched precipitation rate. Some HE nozzles offered by manufacturers may be characterized by multistream/multitrajectory (MSMT) characteristics defined by ASABE/ICC 802 as, "Nozzles designed to distribute discharge water in a number of individual streams, of varying trajectories, which rotate across the distribution area."; however, the MSMT characteristics do not of themselves define an HE nozzle.

Solomon et al. (2007) estimated 31% savings potential using HE nozzles compared to standard spray head nozzles. However, this estimate was based on theoretical conservation due to higher application efficiency from increased distribution uniformity. Bijoor (2019, 2021) measured 20% savings from a high efficiency nozzle rebate program in Santa Clara, CA. Dukes and Cardenas (2019) found 17% savings from a Florida utility rebate program pre/post and weather corrected analysis. In 2009, 17 residential and 6 commercial sites were retrofitted with HE nozzles with a goal of reducing peak demand (Petersen, 2013). Irrigation use was reduced 20% to 35% in three study years. A measurement and verification study of HE rebate programs analyzed 117,552 residential and 8,287 commercial customers that had nozzle rebates with a total of 1.2 million nozzles installed. Savings analysis showed a reduction of 1.57 gpd/nozzle aggregate savings (Graham, 2016). For the average lawn with 30 nozzles, the savings would be 17 kgal/yr. Baum-Haley, et al. (2012) measured water savings and cost effectiveness of HE nozzles and showed 11 kgal/yr savings across 82 single family homes. Commercial sites had 104 kgal/yr savings across 148 sites.

Sovocool et al. (2010) documented HE nozzles reducing application rates more than 50% and increasing distribution uniformity. In contrast to rebate programs savings reported above, Sovocool et al. (2013) analyzed pre/post intervention homes compared to non-intervention homes and found no water savings. The difference between the SNWA study reported by Sovocool et al. (2010, 2013) and other studies is that in the SNWA study full irrigation audits were performed and irrigation controllers were reprogrammed to match the new HE application rate. However, it is hypothesized that the typical spray head zone with standard nozzles has excessive time programmed in the timeclock.

Recently, we studied runtimes from mobile irrigation lab (MIL) testing in Florida from 2020-2023. A total of 1,310 spray sprinkler zones and 1,026 rotor sprinkler zones were analyzed. Runtimes averaged 23 min for spray zones with a median of 20 min. Rotor zones averaged 32 min and had a median of 30 min of runtime. However, 44% of spray zones had runtimes of 25 min or greater. On the low end of this range, 25 min equates to 0.83 in of irrigation assuming an non-pressure regulated sprinkler at 2.0 in/hr based on our test data. Furthermore, these zones averaged 2.4 d/wk irrigation intervals resulting in 1.99 in/wk or 104 in/yr of irrigation, nearly 3X more irrigation than needed for turfgrass evapotranspiration in the MIL region. Thus, it is likely that irrigation could be reduced on these zones without a water deficit, particularly in periods of rainfall.

Thus, replacing standard nozzles with HE nozzles that have half the application rate results in an inherent irrigation reduction. In addition, the HE nozzles increase distribution uniformity and reduce runoff and wind drift. These factors resulted in measured savings according to the rebate studies discussed earlier.

The EPA WaterSense program engaged Dr. Michael Dukes of the University of Florida, Agricultural and Biological Engineering Department to perform data analysis of HE nozzles testing. Nozzle test data were collected as part of a grant from the Innovation Conservation Program of the Metropolitan Water District of Southern California. Testing was conducted 2021-2022. The purpose of the testing was to determine performance characteristics of HE nozzles compared to standard spray sprinkler nozzles.

Models Tested

A total of 32 different nozzle selections were tested across four brands (arbitrarily labeled brands A-D), two radii (12 ft and 15 ft) and two patterns (full [F] and half [H] circle; Table 1). Each model had four replicate samples tested. The nozzles and spray sprinklers tested were obtained from commercial irrigation equipment distributors. For most manufacturers, HE nozzles do not have a direct comparison to standard nozzle radii. Most of the HE nozzles on the market offer families of nozzles in the range of standard nozzle radii. For example, a 12 ft standard nozzle radius may be analogous to a 8-14 ft HE nozzle from the same manufacturer. The HE nozzles in Table 1 are labeled for the maximum published radius at recommended pressure from each manufacturer. For convenience throughout this report the 15F or 15H HE nozzle will represent the larger radius and the 12F or 12H will represent the smaller tested radius with the logic that the larger and smaller HE radii tested here would likely be replacements for those standard nozzles.

Table 1. Nozzles and sprinklers tested

Item	Brand	Test	Model	Radius (ft) & Pattern
Nozzles	**Hunter**	Standard model	Pro-Spray Fixed	12-H
				12-F
				15-H
				15-F
		HE Comparison	MP Rotator MP1000-180	14-H
			MP Rotator MP1000-360	14-F
			MP Rotator MP2000-180	19-H
			MP Rotator MP2000-360	19-F
	K-Rain	Standard model	FN	12-H
				12-F
				15-H
				15-F
		HE Comparison	RN100-ADJ-90-270	14-H
			RN100-FIX360	14-F
			RN200-ADJ-90-270	18-H
			RN200-FIX360	18-F
	Rain Bird	Standard model	MPR	12-H
				12-F
				15-H
				15-F
		HE Comparison	R-VAN-14	14-H
			R-VAN-14-360	14-F
			R-VAN-18	18-H
			R-VAN-18-360	18-F
	Toro	Standard model	570 MPR	12-H
				12-F
				15-H
				15-F
		HE Comparison	O-12-H Precision Series	12-H
			O-12-F Precision Series	12-F
			O-15-H Precision Series	15-H
			O-15-F Precision Series	15-F
Spray bodies	**Hunter**		PROS-04	
	K-Rain		Pro-S 78004	
	Rain Bird		1804	
	Toro		570Z-4P	

Procedure

The test procedure was performed based on a modified version of the ASABE/ICC 802-2020 Landscape Irrigation Sprinkler and Emitter Standard as follows:

1. Test conditions
   - (a) All tests shall be conducted at an ambient air temperature between 40 and 120°F (3 and 49°C) and the water supply temperature shall not exceed 78°F (25.5 °C). The water supplies shall be filtered in accordance with the specifications of the manufacturer.
   - (b) Test samples shall be stored at ambient laboratory conditions for a minimum of 12 hours prior to testing. Test samples shall be flushed prior to testing.
2. Modified from the pressure regulation test based on ASABE/ICC 802-2020 Appendix A.
   - (a) For all pressure test points, the pressure shall be adjusted to within 1.0 psig (6.9 kPa) of the specified test point (e.g., 40 psi, 60 psi, etc.) and stabilized. Stabilization is considered achieved when 3 consecutive pressure readings are within +/- 1 psi (+/- 6.9 kPa) of the specified test point.
   - (b) Testing shall be conducted beginning with the lowest test point, and increased incrementally to the highest test point. Upon reaching the highest test point, the inlet pressure shall then be reduced incrementally to the lowest test point. After testing a sprinkler under one pressure, the inlet pressure shall be reduced to 0 psi prior to starting the next test. At each test point, the pressure at the inlet of the test specimen shall be measured and recorded. Inlet pressure shall be logged at no greater than 30 second intervals and the data collection duration at each test pressure shall be a minimum of 3 minutes, not to exceed 5 minutes. Inlet pressure shall be measured at the inlet to the sprinkler body.
   - (c) Test specimens shall be supplied by straight, smooth piping that is free of fittings, except compliant pressure taps, for a minimum length of 20 times the inlet diameter of the nozzle test specimen. Supply piping shall be ¾" nominal diameter SCH 40 PVC. All pressure taps shall comply with ASME PTC 19.2. The average of the readings, minimum, maximum values and standard deviation shall be recorded.
   - (d) Where flow metering devices are utilized, the flow shall be conditioned in accordance with manufacturer instructions and shall be installed in accordance with ASME PTC 19.5. Flowrate shall be measured at no more than 30 second intervals and the test duration shall be a minimum of 3 minutes, not to exceed 5 minutes.

Test Equipment and Setup

Equipment

a. A pressure transducer capable of measuring pressure from 0 to at least 150 psi with at least 0.1 psi resolution. Accuracy (including linearity and hysteresis and repeatability) shall be within 0.50 psig (3.4 kPa) in the range of inlet pressures tested.
b. Data logger capable of measuring the pressure transducer and flowmeter inputs.
c. Flow meter capable of resolving at least 0.05 gpm (0.189 lpm) within a range of at least 1.5 to 15 gpm and accuracy of 100% +/- 1.5% for the range of flow measured.

d. Piping to allow necessary straight pipe runs for the flow measurement and necessary pressure taps as described previously.

The test apparatus (Figure 1) was constructed as described in the ASABE/ICC 802-2020 standard with modifications. The original specification called for ¾” SCH40 PVC piping; however, ½” SCH40 PVC was used. Sprinklers were tested with filters as supplied by the manufacturer. Potable water was used as the water source. Since the supply pressure was not adequate to meet the maximum test pressures, a high pressure, low volume centrifugal pump was used to achieve adequate maximum test pressure. In addition, the pressure transducers used had a full-scale measurement range of 0 to 145 psi which was deemed adequate for the test.

Testing of spray sprinkler nozzles was conducted with a standard spray sprinkler body without pressure regulation or check valves for each of the brands tested. Each test specimen was tested at four or five inlet pressures: manufacturer’s stated regulation pressure, +15 psi for the next increment for 30 psi recommended pressure or +10 psi for 40 psi recommended pressure, then +15 psi increments up to a peak test pressure of 85 psi, +10 psi or +15 psi for the final increment to reach 85 psi. For example, if a nozzle had a recommended pressure of 30 psi, tests were completed at 30, 45, 60, 75, 85, 75, 60, 45, and 30 psi. Alternatively, if a nozzle had a recommended pressure of 40 psi, tests were completed at 40, 55, 70, 85, 70, 55, and 40 psi.

Nozzles with arc adjustment were adjusted to a 180 degree pattern for the applicable test. If a nozzle had a distance of throw adjustment, they were adjusted to the maximum distance.

A Campbell Scientific (Logan, UT) CR1000 datalogger was used to record measurements from the flowmeter and the pressure transducers. The flowmeter was a Seametrics (Kent, WA) PE202-075 low flow magmeter (Figure 2) with resolution of at least 0.01 gpm and accuracy of +/- 1% plus 0.005 gpm of reading across rated range. The pressure transducer was a Campbell Scientific model CS451 (Figure 3) with a resolution of 0.0035% full scale and accuracy of +/- 0.1% full scale range. An adjustable pressure regulator (Watts LF26A, North Andover, MA, Figure 4) was used to set the various pressure test levels. The two manual pressure gauges were used only to assist the getting near the proper test pressure, but all final test conditions were determined with the pressure transducer.

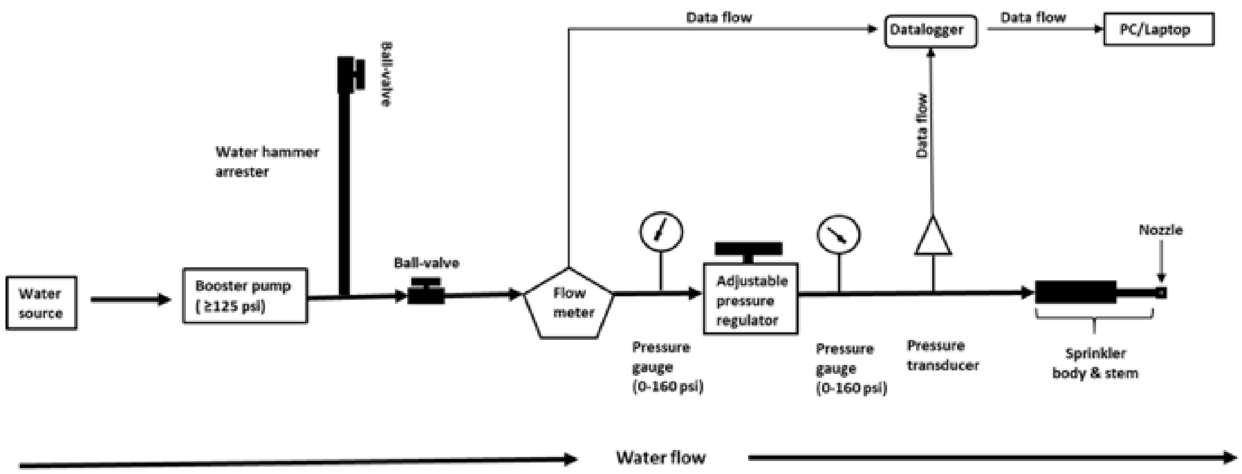


Figure 1. Test equipment schematic

Figure 2. Test apparatus showing flowmeter (credit Michael Gutierrez UF/IFAS)

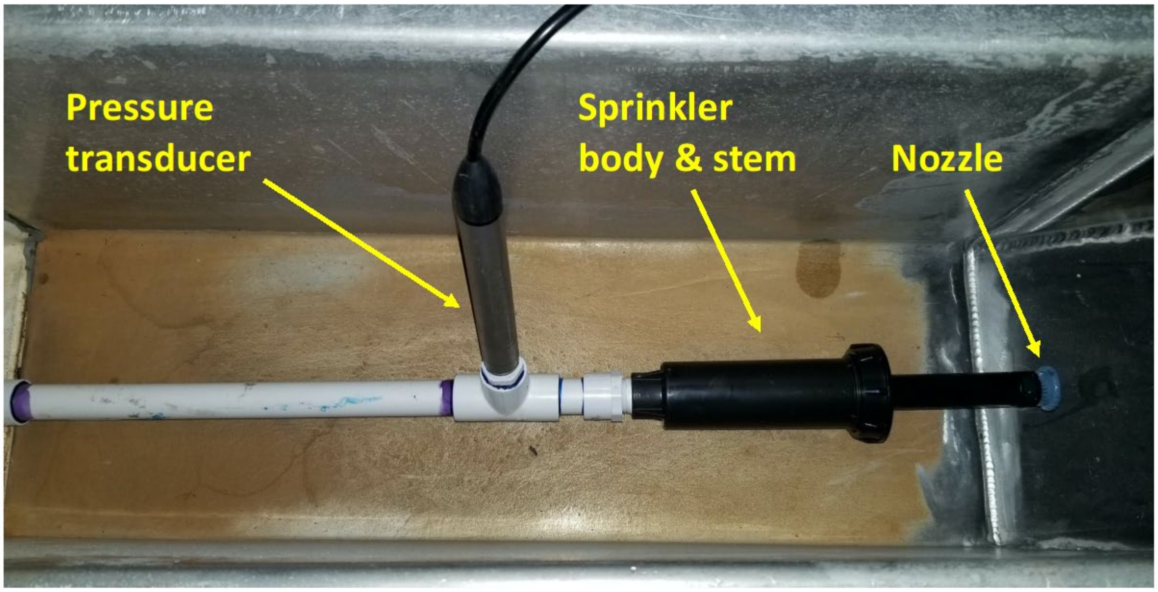


Figure 3. Testing of a sprinkler nozzle affixed to a spray sprinkler body with inlet pressure transducer, nozzle and associated fittings (credit Bernard Cardenas UF/IFAS)

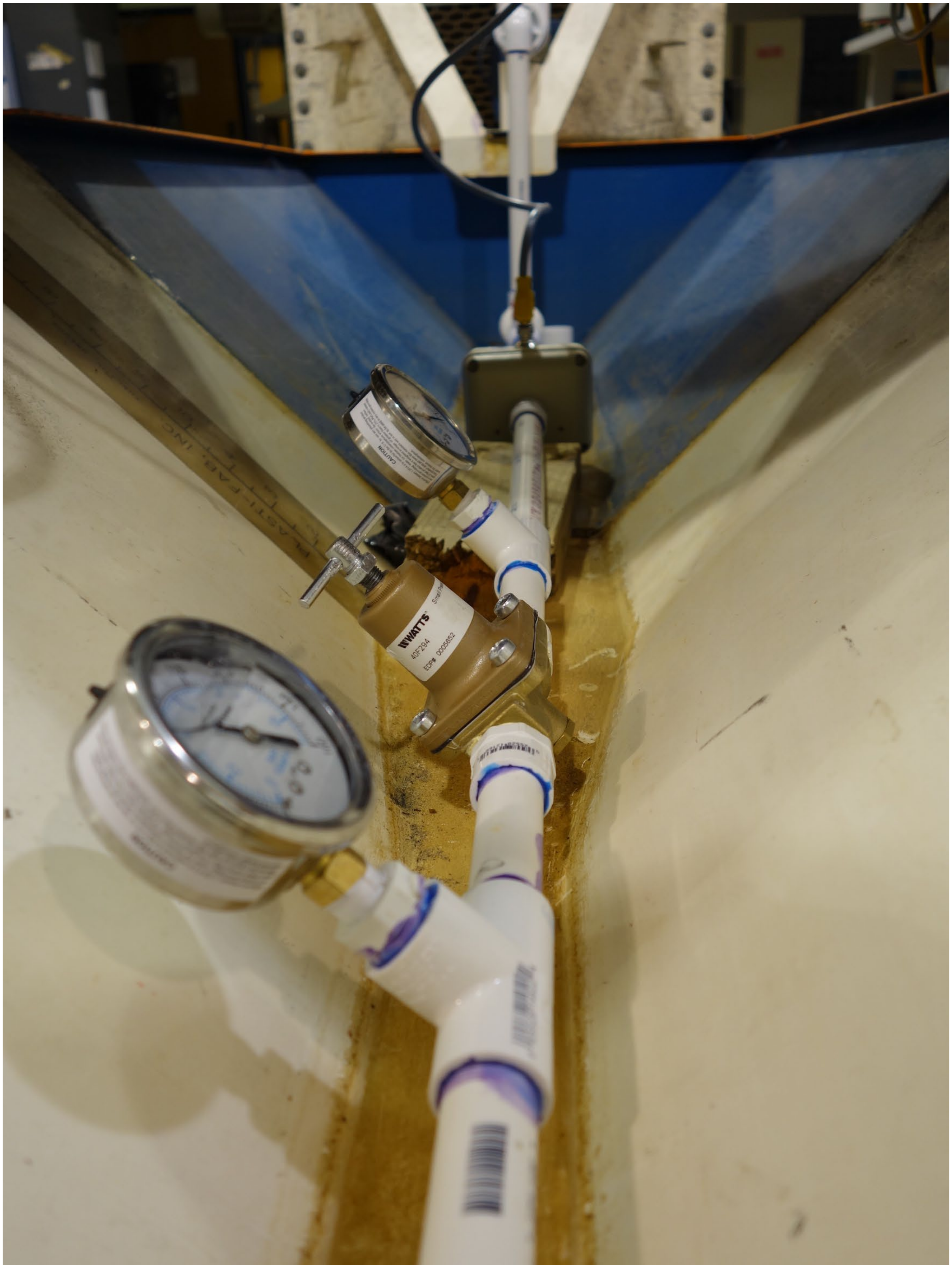


Figure 4. Adjustable pressure regulator and pressure gauges (credit Michael Gutierrez UF/IFAS)

Results and Discussion

Test Consistency

Testing of a type of nozzle in a particular brand generally had low manufacturing variation with nearly zero standard deviation in flowrate across the replicated test samples. Accordingly, the coefficient of variation (CV) in flowrate was 6% or less across all tests (Figure 5). The CV was 3.2% or less for the 360 degree pattern (F). The 180 degree (H) pattern required manual adjustment, which introduced an element of human error.

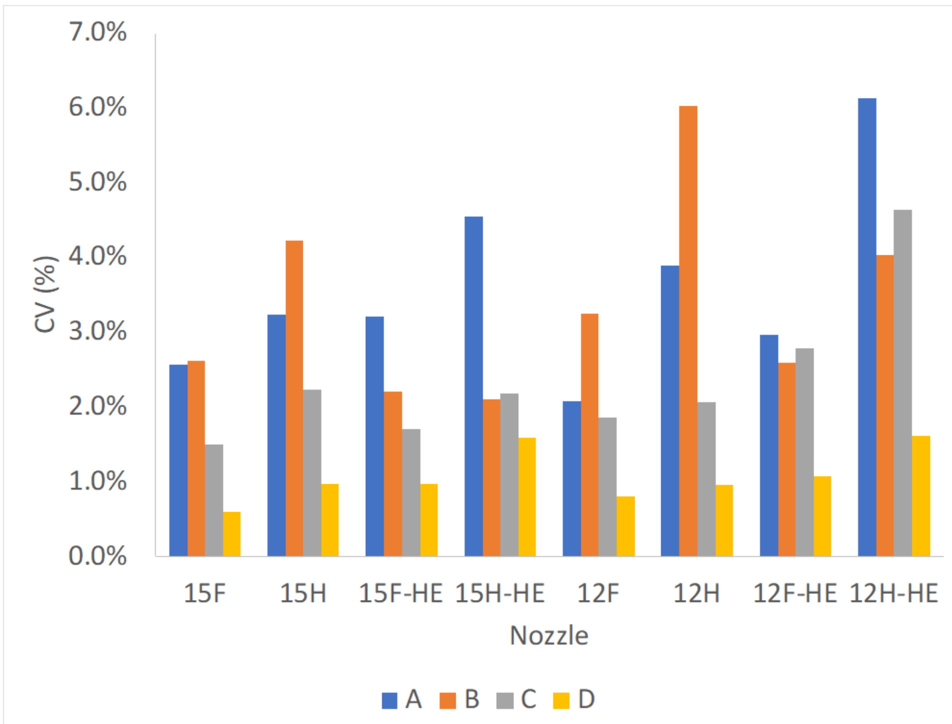


Figure 5. Flowrate coefficient of variation (CV) at recommended pressure across nozzle combinations where 15F, 15H, 12F, and 12H denote radius (ft) and pattern for standard nozzles; HE is high efficiency nozzles

Flowrate Testing

The flowrate for the standard 15F nozzles ranged from 3.4 to 4.0 gpm at recommended pressure. The 15H standard nozzles ranged from 1.7 to 2.0 gpm at the same pressure (Table 2). The HE nozzles had flowrates ranging from 1.1 to 2.2 gpm and 0.6 to 1.1 gpm for 15F and 15H nozzles, respectively. The average flowrate reduction of HE nozzles compared to standard nozzles at recommended pressure was 53% and 49% for 15F and 15H nozzles, respectively. The trend in flowrate reduction for 12 ft nozzles was similar with standard nozzles ranging from 2.1 to 2.6 gpm and 1.2 to 1.4 gpm for 12F and 12H and HE nozzles, 0.7 to 1.6 and 0.5 to 0.7 gpm with a flowrate reduction of 53% to 57%.

At the maximum tested pressure of 85 psi, the standard nozzles flowrate ranged from 5.7 to 6.5 gpm for the 15F and 2.8 to 3.5 gpm for 15H nozzles, while HE nozzles had flowrates of 1.7 to 3.7 gpm and 0.8 to 2.0 gpm for 15F and 15H, respectively (Table 3). Flowrate ranged 3.6 to 4.4 gpm and 1.9 to 2.4 gpm for 12F and 12H standard nozzles, respectively. The respective contrasting flowrate of HE nozzles ranged 0.9 to 2.4 gpm and 0.6 to 1.2 gpm. Flowrate reduction of HE nozzles vs. standard ranged from 54% to 62% across all combinations of distance of throw and pattern at the peak pressure of 85 psi.

The flowrate of the HE nozzles was less consistent than the non-HES nozzles across brand, likely due to differences in the nozzles design. For example, for the 15F equivalent HE nozzles, brands A and B had the highest flowrates of 2.1 to 2.2 gpm at recommended pressure and 2.9 to 3.7 gpm at 85 psi. Brands C and D had flowrates of 1.1 to 1.5 gpm at recommended pressure and 1.7 to 2.1 gpm at maximum test pressure of 85 psi. As an example, the reduction in flowrate at recommended pressure for 15F HE vs. standard nozzles was 43% to 44% and 58% to 68% for brands A/B and C/D, respectively (Figure 6).

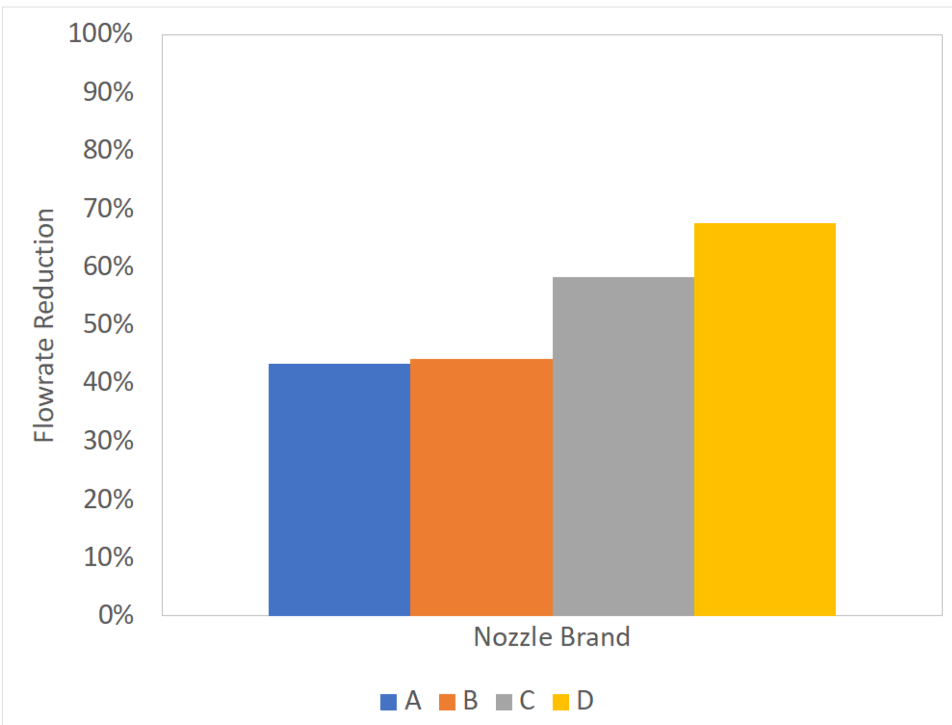


Figure 6. Flowrate reduction of 15F HE nozzles compared to standard nozzles across brand

Across all combinations tested, HE nozzles had 53% lower flowrate at recommended pressure compared to standard nozzles. At maximum pressure tested (85 psi), HE nozzles had 58% lower flowrate.

Table 2. Summary flowrate (gpm) for standard and high efficiency (HE) nozzles tested at manufacturer recommended pressure

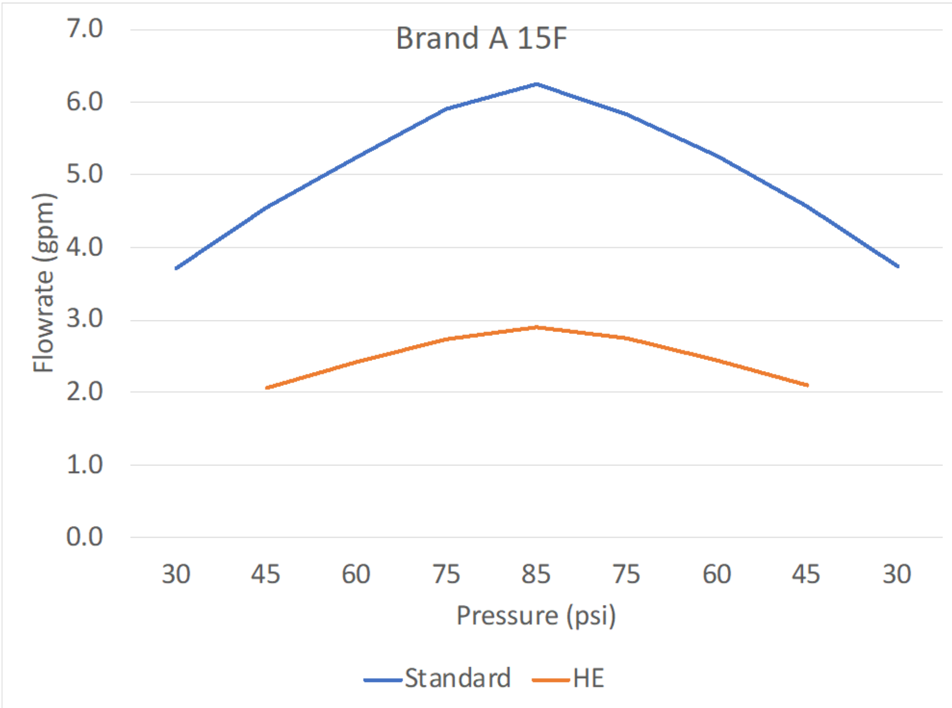
	Standard				HE			
Brand	15F	15H	12F	12H	15F	15H	12F	12H
A	3.7	1.7	2.5	1.4	2.1	1.1	1.6	0.6
B	4.0	1.8	2.1	1.2	2.2	1.2	1.4	0.7
C	3.6	2.0	2.6	1.3	1.5	0.8	0.9	0.5
D	3.4	1.7	2.5	1.4	1.1	0.6	0.7	0.5
Avg	3.7	1.8	2.4	1.3	1.7	0.9	1.2	0.6

Table 3. Summary flowrate (gpm) for standard and high efficiency (HE) nozzles tested at 85 psi

	Standard				HE			
Brand	15F	15H	12F	12H	15F	15H	12F	12H
A	6.2	2.8	4.1	2.3	2.9	1.6	2.2	0.8
B	6.5	3.0	3.6	1.9	3.7	2.0	2.4	1.2
C	6.1	3.5	4.4	2.3	2.1	1.1	1.3	0.6
D	5.7	2.8	4.2	2.4	1.7	0.8	0.9	0.8
Avg	6.1	3.0	4.1	2.2	2.6	1.4	1.7	0.9

Figures 7 and 8 show an example of the tested flowrate for HE and standard nozzles for brand A across the tested combination of radii and arc. The apparent HE nozzle compensation of flowrate across increasing pressures can be observed due to the flatter slope of the curve on the HE nozzles vs. the standard nozzles. The other three brands had similar trends.

A summary comparison of all four brands was created to show the flowrate reduction at peak pressure, recommended pressure and the best case scenario (for a nozzle replacement) of flowrate reduction of HE nozzles at the recommended pressure vs. standard nozzles at peak test pressure of 85 psi. Brand A had a flowrate reduction of 43% to 66% at peak pressure, 34% to 58% at recommended pressure and 60% to 75% for the best case scenario (Figure 9). Brand B had respective flowrate reductions of 32% to 42%, 33% to 44% and 60% to 66% (Figure 10). Brand C had respective flowrate reductions of 65% to 73%, 59% to 66%, and 76% to 80% (Figure 11). Brand D had respective flowrate reductions of 68% to 78%, 63% to 74%, and 78% to 85% (Figure 12). Finally, to assess the impact of pressure regulation on flowrate, a comparison was created with flowrate reduction of HE nozzles alone and HE nozzles tested at manufacturer recommended pressure which is analogous to pressure regulation (Figure 13). Adding pressure regulation to HE nozzles increased flowrate reduction on average 14% and ranged 7% to 28%. Aside from flowrate reduction this testing did not assess the benefit of pressure regulation on nozzle pattern performance or function, both of which would be expected to increase with manufacturer pressure regulation.



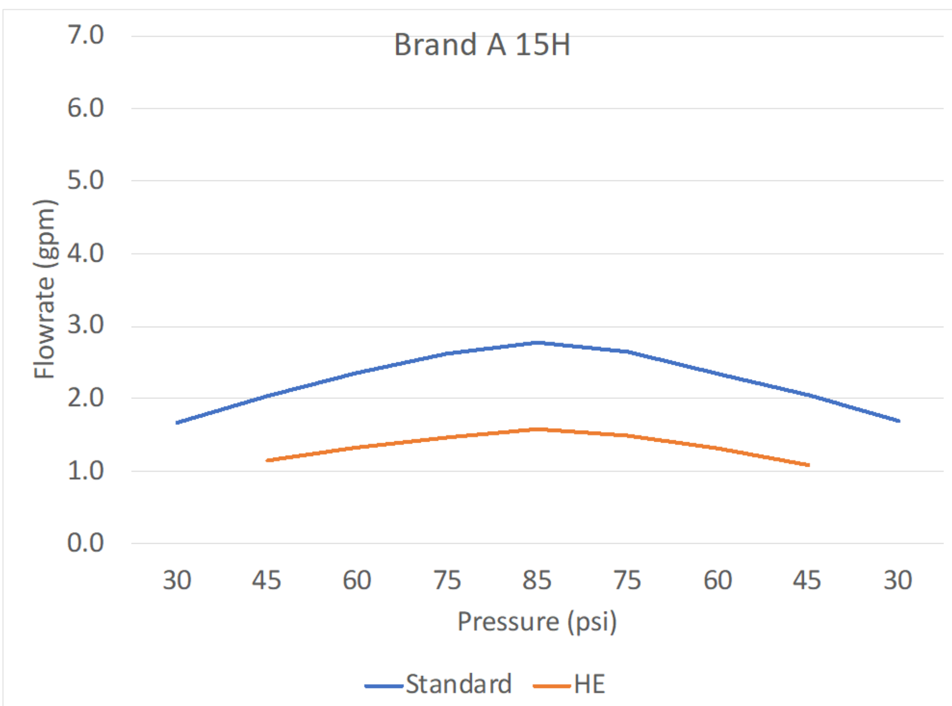


Figure 7. Flowrate curve from Brand A 15F and 15H standard nozzles and analogous radii HE nozzles

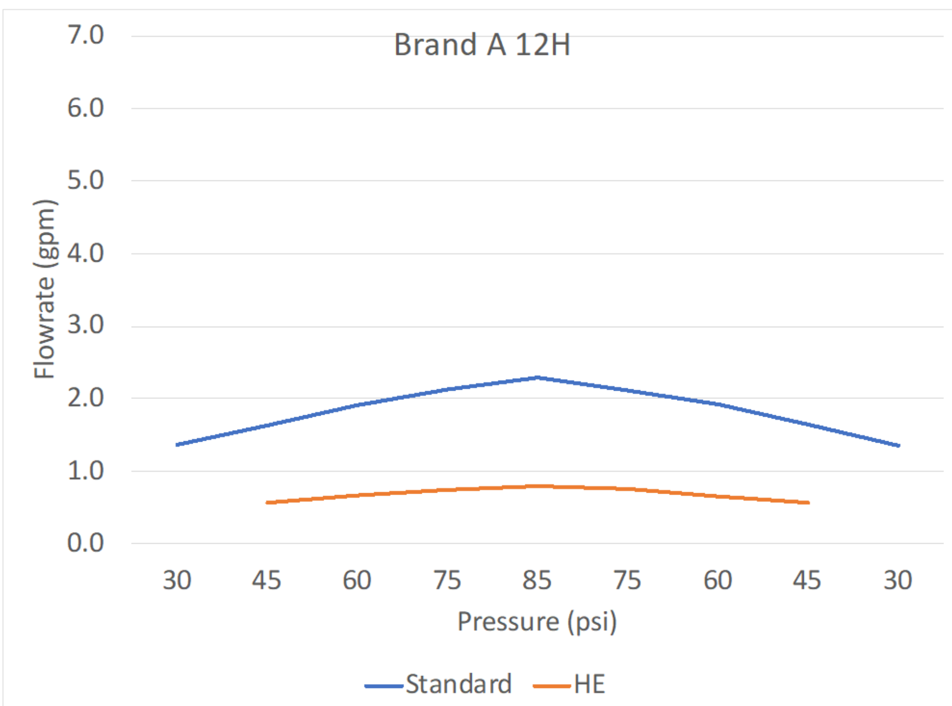


Figure 8. Flowrate curve from Brand A 12F and 12H standard nozzles and analogous radii HE nozzles

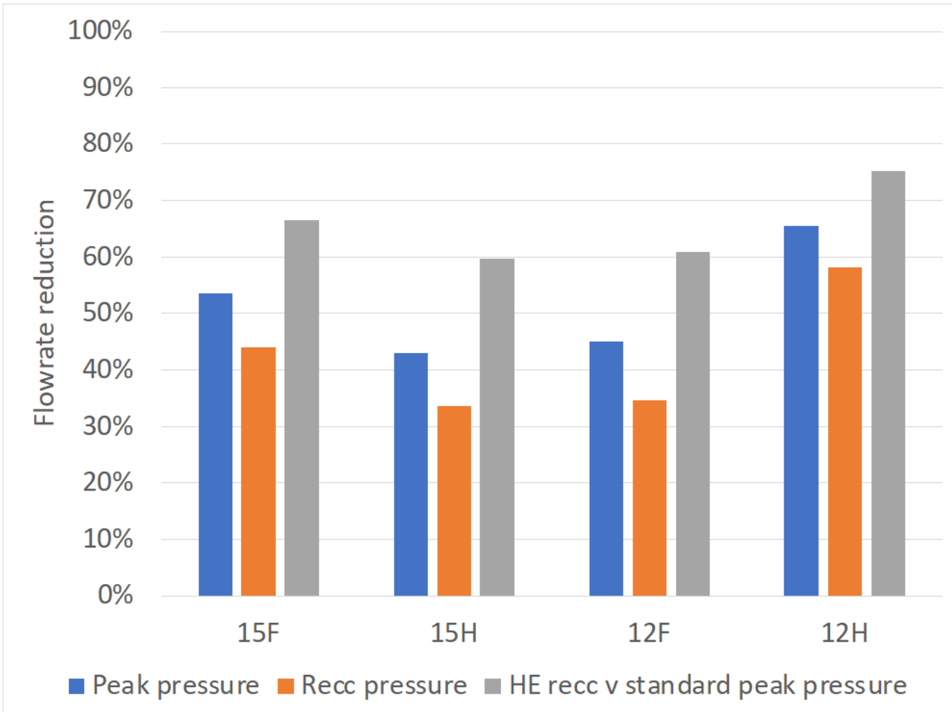


Figure 9. Flowrate reduction of Brand A HE nozzles at peak pressure (85 psi) tested, manufacturer recommended pressure, and HE at recommended pressure vs. standard nozzle at peak pressure

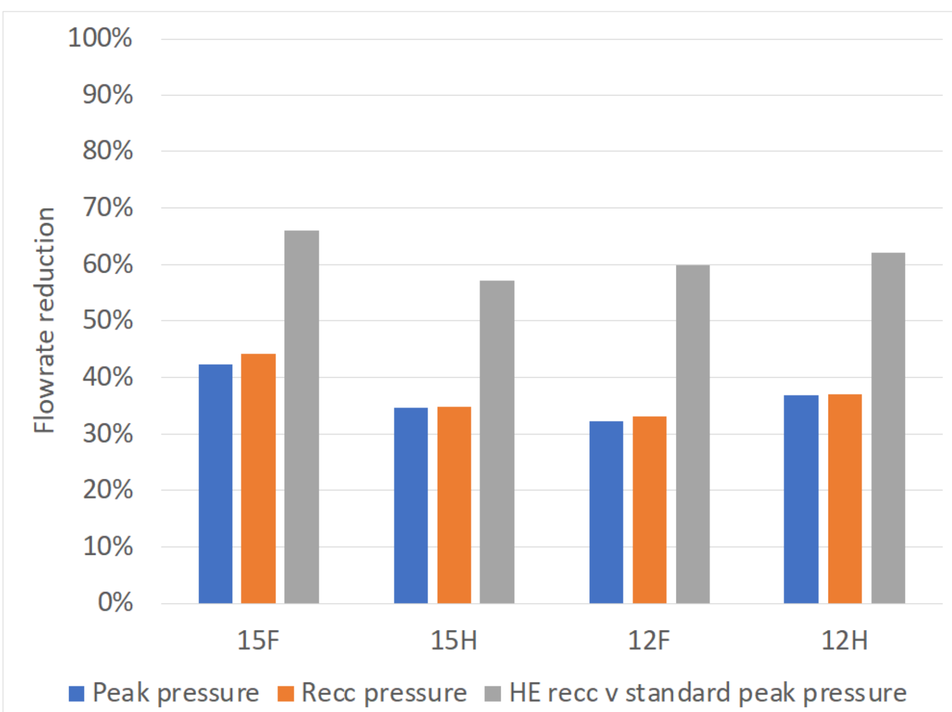


Figure 10. Flowrate reduction of Brand B HE nozzles at peak pressure (85 psi) tested, manufacturer recommended pressure, and HE at recommended pressure vs. standard nozzle at peak pressure

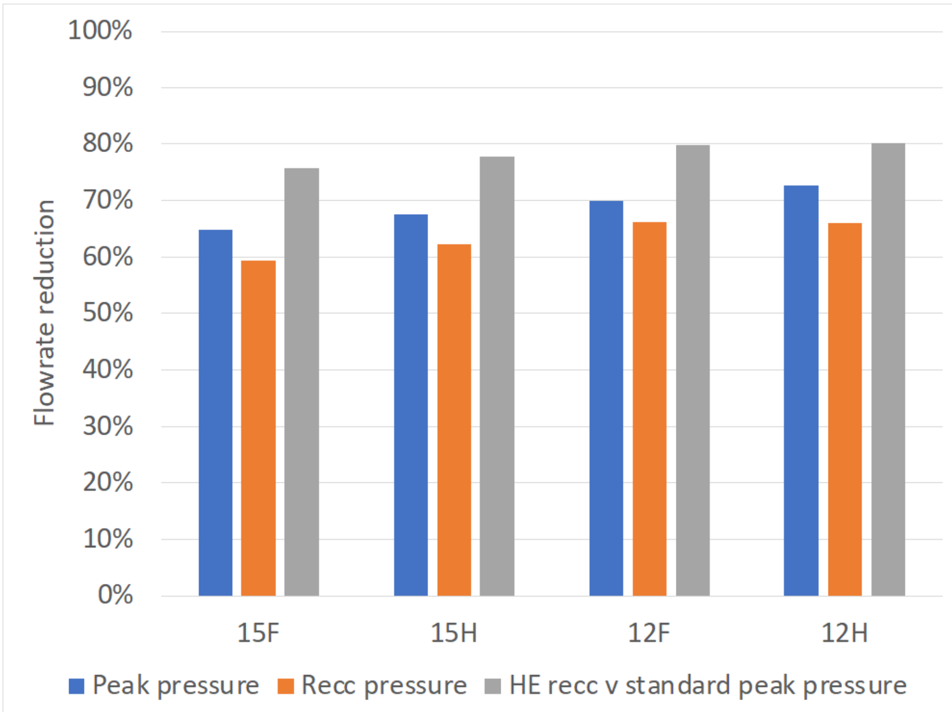


Figure 11. Flowrate reduction of Brand C HE nozzles at peak pressure (85 psi) tested, manufacturer recommended pressure, and HE at recommended pressure vs. standard nozzle at peak pressure

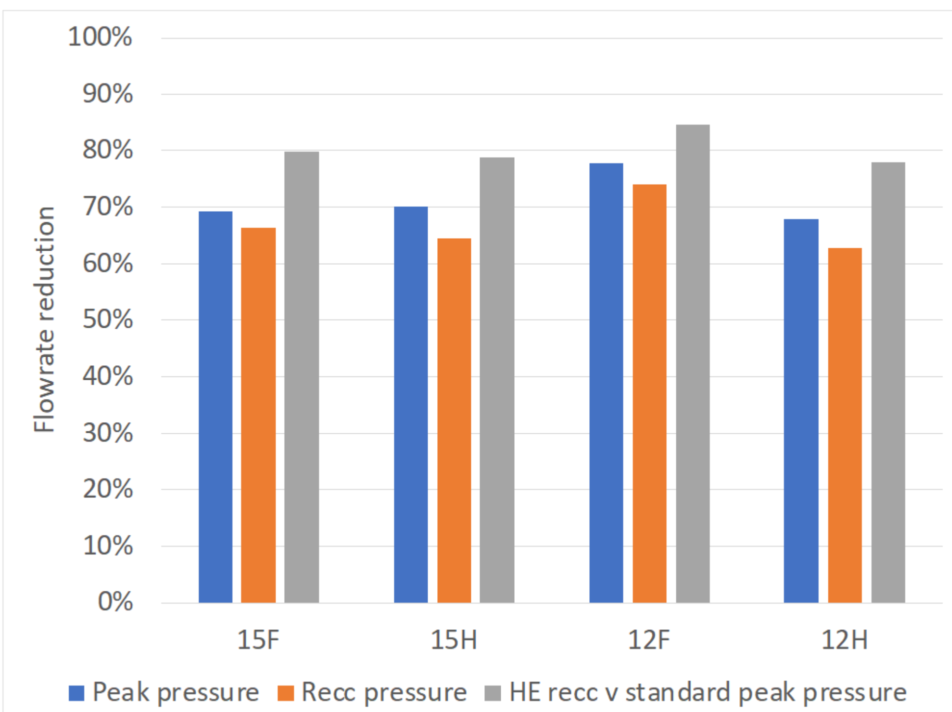


Figure 12. Flowrate reduction of Brand D HE nozzles at peak pressure (85 psi) tested, manufacturer recommended pressure, and HE at recommended pressure vs. standard nozzle at peak pressure

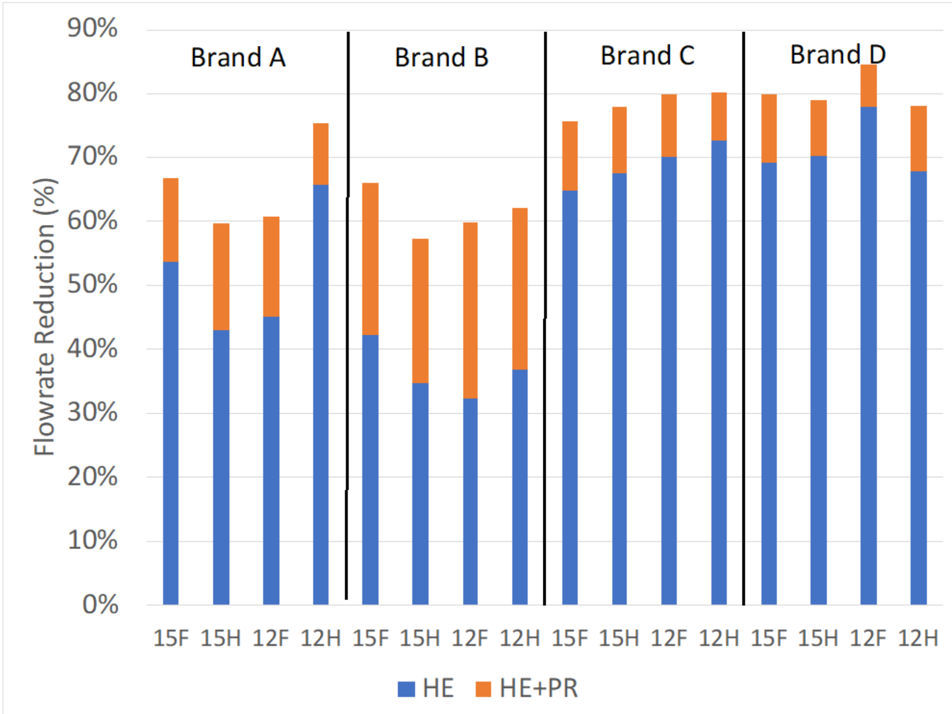


Figure 13. Flowrate reduction of HE nozzles and HE nozzles with pressure regulation (HE+PR) relative to standard nozzles at 85 psi supply pressure

Application Rate

Application rate is determined based on the volumetric output in a given amount of time (e.g., flowrate such as gpm) over a defined wetted area. Using appropriate unit conversions, the flowrate measured in this study along with manufacturer published distance of throw was used to estimate application rate at manufacturer recommended pressure (Figure 14) and at 85 psi peak test pressure (Figure 15). At manufacturer recommended pressure, application rate of HE nozzles tested were all less than or equal to 1 in/hr. When the pressure was increased to 85 psi, the estimated application rates increased, but three of four tested HE nozzles still maintained application rate less than or equal to 1 in/hr.

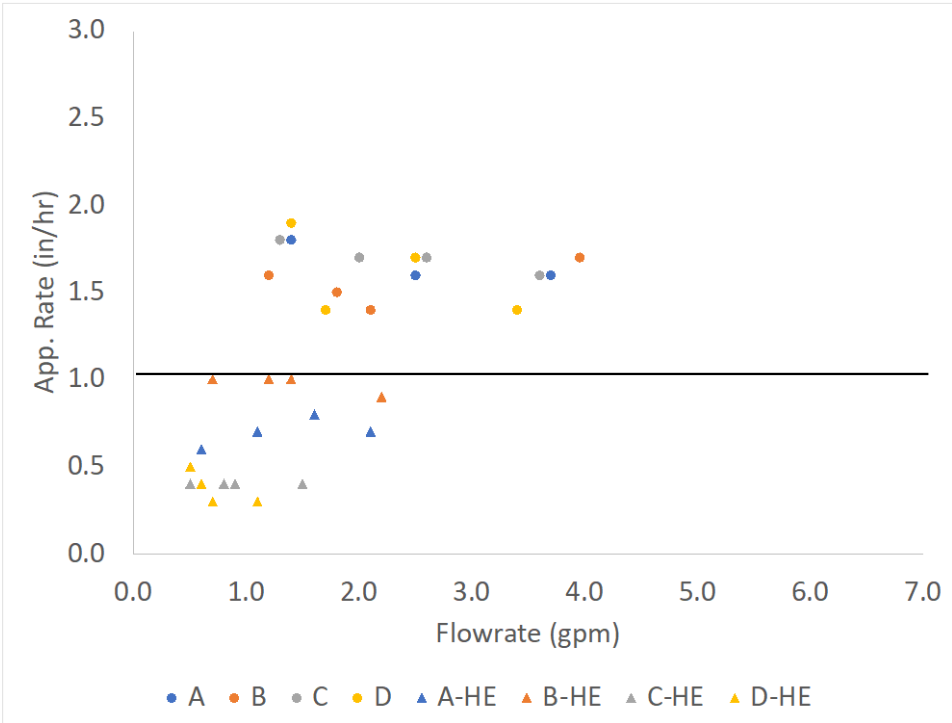


Figure 14. Relationship between application rate and flowrate at manufacturer recommended pressure where A-D are standard nozzles and A-D "HE" are the comparable HE nozzles

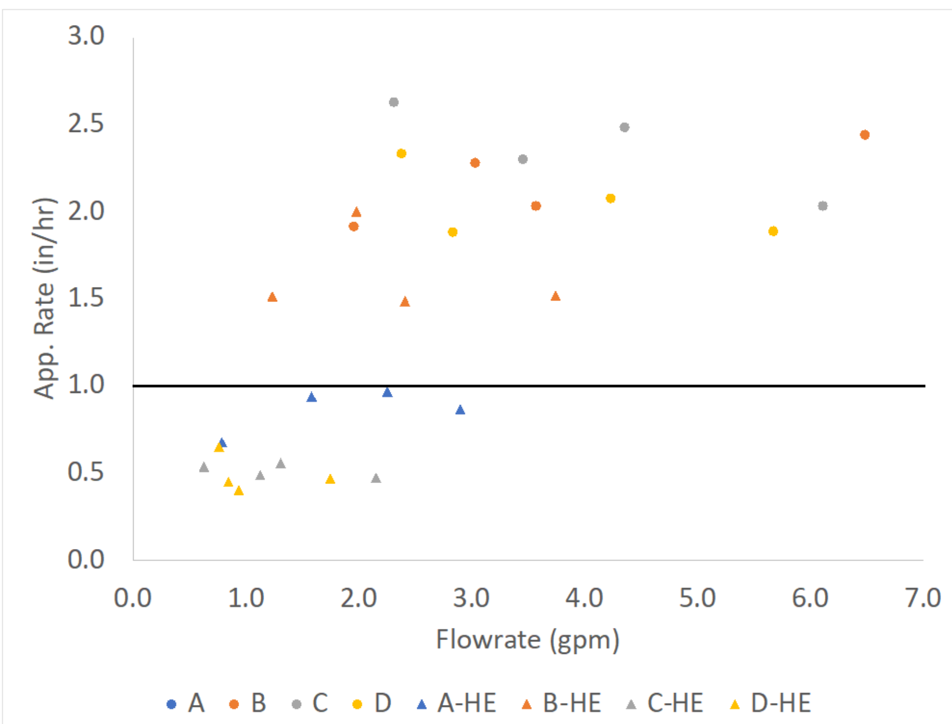


Figure 15. Relationship between application rate and flowrate at 85 psi peak test pressure. Note that the maximum published distance of throw was used to estimate application rate; however, most manufacturers do not publish 85 psi distance of throw

Conclusions

A variation of the WaterSense Spray Sprinkler Body test was used to assess the performance of spray sprinkler nozzles. Test results were consistent across test samples with less than 6% variation across all tests and averaging 2.6% at manufacturer recommended pressure. At manufacturer recommended pressure, flowrate of HE nozzles compared to standard nozzles across all combinations tested here was reduced by more than half (53%). When compared at the peak test pressure of 85 psi, the reduction was 58%. In many situations, pressure regulation is not used with standard nozzles. When standard nozzles at 85 psi were compared to HE nozzles at manufacturer regulated pressure, the flowrate was reduced on average 71% and ranged from 57% to 85% across brands. Application rate of HE nozzles tested here was 1 in/hr or less at recommended pressure for all brands and estimated as 1 in/hr or less for three of four brands at the peak test pressure of 85 psi. Savings studies indicate these nozzles reduce irrigation in the field. Given the flowrate reduction of HE nozzles, it appears that in retrofit situations, end users do not fully increase irrigation runtimes to compensate for lower application rates. In addition, runtimes for standard spray sprinkler zones may have excessive runtimes.

References

International Code Council (ICC). 2020. ASABE/ICC-802-2020. Landscape Irrigation Sprinkler and Emitter Standard. ICC, Washington, D.C.

Baum-Haley, M., J. Berg, & T. Chesnutt. 2012. Measured Water Savings and Cost-Effectiveness of Smart Timers and Rotating Nozzles. WaterSmart Innovations, Las Vegas, NV. https://ceregportal.com/wsi/documents/poster_sessions/2012/P-06.pdf.

Bijoor, N. 2019. Water savings from turf removal and irrigation equipment rebates. Santa Clara Valley Water District, San Jose, CA. https://www.valleywater.org/sites/default/files/Bijoor_Landscape%20Rebate%20Program%20Savings%20Study_VW%20Format.pdf.

Bijoor, N. 2021. Saving water with a landscape conservation rebate program. *Journal AWWA*. https://doi.org/10.1002/awwa.1651.

Dukes, M.D., B. Cardenas, and N. Taylor. 2020. Evaluation of high efficiency sprinkler nozzles and rain sensor rebate program. WaterSmart Innovations, Las Vegas, NV. https://watersmartinnovations.com/webinars/.

Graham, M. 2016. High efficiency nozzle evaluation, measurement and verification. WaterSmart Innovations, Las Vegas, NV. https://ceregportal.com/wsi/documents/sessions/2016/T-1616.pdf.

Petersen, J. 2013. Reducing peak hour demand with nozzle retrofits: Three year evaluation. WaterSmart Innovations, Las Vegas, NV. https://ceregportal.com/wsi/documents/sessions/2013/2013-T-1304.pdf.

Solomon, K.H., J.A. Kissinger, G.P. Farrens, and J. Borneman. 2007. Performance and water conservation potential of multi-stream, multi-trajectory rotating sprinklers for landscape irrigation. *Applied Engineering in Agriculture*, 23(2):153-163. https://elibrary.asabe.org/abstract.asp?aid=22608.

Sovocool, K., M. Morgan, and M. Drinkwine. 2013. Observed long-term results of multi-stream rotational spray heads and associated product retrofits. WaterSmart Innovations, Las Vegas, NV. https://ceregportal.com/wsi/documents/sessions/2013/2013-T-1312.pdf.

Sovocool, K., M. Morgan, and M. Drinkwine. 2010. Field study of uniformity improvements from multi-stream rotational spray heads and associated products. Preliminary results – Distribution uniformity improvements. WaterSmart Innovations, Las Vegas, NV. https://ceregportal.com/wsi/documents/sessions/2010/10-T-1029.pdf.