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Field Application Uniformity of Impellicone and Pulse-Width-Modulated Anhydrous Ammonia Manifolds

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Abstract

With the consistently increasing cost and widespread use of anhydrous ammonia (NH3), producers are looking for ways to reduce variability in applicator equipment. One way to improve uniformity in NH3 applicators is the use of a better distribution manifold. Impellicone and pulse-width-modulated (PWM) manifolds are newer design alternatives to a Vertical-Dam manifold. Uniformity measurements during field application were made comparing Vertical-Dam manifolds with several Impellicone manifold designs and also a pulse-width-modulated (PWM) valve design as these manifolds were refined for commercial production. Application rates ranged from 23.7 to 224 kg N/ha (21.2 to 200 lb N/acre) depending on experiment with many applications near 84 kg N/ha (75 lb N/acre; "low" rate) and 168 kg N/ha (150 lb N/acre; "high" rate) during Impellicone tests. Modified Impellicone and PWM manifolds both had better uniformity at a 99% confidence level (as measured by lower coefficients of variation (CVs)) than did Vertical-Dam manifolds tested during the same field conditions. Modified Impellicone manifolds had average coefficients of variation (CVs) 9 and 6 percentage points lower, than the Vertical-Dam manifold at the low rate and high application rates, respectively. The PWM manifold CV was 3 percentage points lower than the Vertical-Dam at application rates of 95 kg N/ha (85 lb N/acre), but 6 and 13 percentage points lower than the Vertical-Dam manifold at application rates of 179 and 22 kg N/ha (160 and 20 lb N/acre, respectively).

Keywords

Application variation, Anhydrous ammonia, Distribution manifold, Impellicone, NH3, Nitrogen, Pulse width modulation

Disciplines

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Comments

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Abstract. *With the consistently increasing cost and widespread use of anhydrous ammonia (NH_3), producers are looking for ways to reduce variability in applicator equipment. One way to improve uniformity in NH_3 applicators is the use of a better distribution manifold. Impellicone and pulse-width-modulated (PWM) manifolds are newer design alternatives to a Vertical-Dam manifold. Uniformity measurements during field application were made comparing Vertical-Dam manifolds with several Impellicone manifold designs and also a pulse-width-modulated (PWM) valve design as these manifolds were refined for commercial production. Application rates ranged from 23.7 to 224 kg N/ha (21.2 to 200 lb N/acre) depending on experiment with many applications near 84 kg N/ha (75 lb N/acre; "low" rate) and 168 kg N/ha (150 lb N/acre; "high" rate) during Impellicone tests.*

Modified Impellicone and PWM manifolds both had better uniformity at a 99% confidence level (as measured by lower coefficients of variation (CVs)) than did Vertical-Dam manifolds tested during the same field conditions. Modified Impellicone manifolds had average coefficients of variation (CVs) 9 and 6 percentage points lower, than the Vertical-Dam manifold at the low rate and high application rates, respectively. The PWM manifold CV was 3 percentage points lower than the Vertical-Dam at application rates of 95 kg N/ha (85 lb N/acre), but 6 and 13 percentage points lower than the Vertical-Dam manifold at application rates of 179 and 22 kg N/ha (160 and 20 lb N/acre, respectively).

Keywords. *Application variation, Anhydrous ammonia, Distribution manifold, Impellicone, NH_3, Nitrogen, Pulse width modulation.*

Since the 1960's anhydrous ammonia (NH_3) has become the most widely used source of nitrogen (N) fertilization in U.S. agriculture. Over 3.7 billion kg (8.1 billion lb) of NH_3 are used in the United States every year (Terry and Kirby, 1997). With the cost and widespread use of NH_3, operators are seeking ways to improve application uniformity. A key component of NH_3 application equipment that affects uniformity is the distribution manifold. Tests have shown that some outlets on manifolds release two to four times as much NH_3 to subsurface distribution knives as other outlets (Fee, 1999).

During application, as NH_3 moves from the supply tank to the distribution manifold, its pressure lowers creating a gas/liquid NH_3 mixture that is difficult to evenly divide across the swath of the applicator. Uneven distribution of NH_3 by the manifold to subsurface injection knives (Schrock et al., 2001b; Hanna et al., 2002) can waste fertilizer for the grower and result in excess N in certain areas of the field. Excess N can increase nitrate-nitrogen leaching into groundwater (Jaynes et al., 2001). To more evenly distribute the gas/liquid NH_3 mixture than a conventional manifold with a simple hollow chamber, newer distribution manifolds have been investigated (Boyd et al., 2004).

One such manifold is the Vertical-Dam (Continental NH_3 Products, Dallas, Tex.), which uses specific orifice rings for certain application rates. Vertical-Dam manifolds have produced coefficients of variation (CVs) of 15% to 18% compared to conventional manifolds producing 30% or higher CVs (Boyd et al., 2004). A drawback is that different rings and housings are required for the Vertical-Dam manifold at different ranges of application rate.

A prototype manifold using a cone design (Impellicone) reported by Boyd (2002) and Boyd et al. (2004) showed initial promise to evenly distribute NH_3 without the need to change parts. NH_3 flow impacting the point of a cone was divided and the cone spun as external spiral flighting was impacted by the flow. Relatively constant cross-section through the flow path limited expansion and further gas production while the spinning mixed the liquid/gas mixture. Relatively large size and material expense of this initial prototype, however, limited its use in commercial production. After further development as described in this article it is now manufactured and sold by CDS-John Blue (Huntsville, Ala.).

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Trade and company names are included in this article for the benefit of the reader and do not infer endorsement or preferential treatment of the product named by Iowa State University.

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Pulse-width-modulated (PWM) control valves use a PWM electric signal to open and close solenoid operated valves for specific time periods establishing a duty cycle. PWM control valves used to both meter and divide flow have the potential advantage of keeping pressure of the NH_3 immediately upstream of the combination valve and flow divider close to tank pressure and limiting expansion (and resulting gas formation) that normally occurs after a metering valve and before a flow divider. Maintaining NH_3 pressure near tank pressure keeps NH_3 "quality" (ratio of vapor mass to total mass of liquid and vapor) in a more nearly liquid state for easier flow division. A PWM manifold investigated in stationary tests gave improved uniformity as compared with conventional and Vertical-Dam manifolds (Schrock et al., 2001a).

While applying NH_3 in the field, however, distribution manifolds are subject to dynamic vibration and lowered operating temperatures. In steady-state conditions reached in extended operation in the field, manifolds operate at a cooler temperature with a greater percentage of ammonia in liquid form. Measurement of uniformity during field application of a PWM NH_3 manifold and a comparison manifold such as the Vertical-Dam assists in validating the improved uniformity measured in stationary tests. The PWM manifold is now manufactured and marketed by Capstan Ag Systems (Hiawatha, Kans.).

Objectives

Testing was performed to measure and record port-to-port flow rates of NH_3 during actual field application with these objectives:

- To determine and compare manifold distribution uniformity of a Vertical-Dam manifold with: 1) an old (initial) Impellicone prototype manifold and a newer (commercial) Impellicone prototype manifold and 2) with a PWM manifold.
- To evaluate the effect of various design modifications of the newer Impellicone prototype on distribution uniformity.

Methods and Materials

Experimental Design and Other Equipment

A three-point hitch NH_3 applicator (DMI model 3250) was used for application with knives on 0.76-m (30-in.) centers. A John Blue A-3300 Nitropacer (CDS John Blue Co., Huntsville, Ala.) NH_3 regulator was used upstream of the manifold. The applicator was outfitted with a system of valves to temporarily re-direct NH_3 flow from the knives into 19-L (5-gal) collection buckets that were approximately half-full of water to allow head space for the violent combination of NH_3 with water (Hanna et al., 2002). Valves were connected together and were simultaneously opened or closed by a solenoid valve and pneumatic cylinder. Applicator's traveling speed was 8 km/h (5 mi/h). Before using the manifold, it was operated for a short period of time to cool it to operating temperature. Buckets were weighed in the field before application and again after plot application within 10 min of NH_3 filling. Actual weight of NH_3 delivered from each outlet was determined gravimetrically. A detailed description of the application equipment can be found in Boyd (2002) and Hanna et al. (2002).

Collection times were adjusted to allow for an average of 0.45 kg (1.0 lb) of NH_3 to be collected in each bucket. Length of the test plots for the Impellicone tests (June, 2003) was 67.1 m (220 ft). Longer plots, 128 m (420 ft) were used during the PWM test (May, 2002) to accommodate a longer collection time for some of the lower application rates. Manifold treatments were applied in three completely randomized field blocks (three replications each). A datalogger recorder (Omega Om-3000, Stamford, Conn.) was used during Impellicone tests to measure and record temperature and pressure readings in the system before and after the distribution manifold. Temperature and pressure sensors were not used during the PWM test as stationary experiments had indicated that NH_3 remained at high pressure (near 100% liquid) near the upstream side of the PWM valves (Shrock et al., 2001a).

Anhydrous ammonia can cause caustic burns and inhalation problems, so safety equipment was worn when working around the applicator and collection buckets. Unvented goggles, rubber gloves, and long sleeve clothing and pants were worn. The valve operator wore a respirator in addition to the other safety equipment. A livestock tank full of water and water dispenser on the field supply tank were also available in case of an emergency.

Impellicone Experiment 1 Manifolds

Each manifold tested distributed NH_3 through 11 outlet ports for 11 knives unless otherwise noted. N was applied at 84 and 168 kg N/ha (75 and 150 lb N/acre) rates for most treatments. A 25.4-mm (1.0-in.) diameter 254-mm (10.0-in.) long pipe nipple with two threaded ports for pressure and temperature sensors was used to direct incoming NH_3 into the manifolds. An Acme NH_3 fitting at the entry end of the pipe was used for attaching the regulator hose to the manifold.

The old Impellicone was an initial prototype (fig. 1; Boyd, 2002). This manifold had 13 distribution ports. Of these ports, 11 were used for NH_3 application and the other two ports were spaced out evenly and used for holding pressure and temperature sensors. The old Impellicone had a large central housing that would accommodate a free-spinning cone. External spiral flighting grooves on the cone were cut to act as a pathway for the NH_3. Flow pressure causes the cone to spin, evenly spreading NH_3 across the ports. The cone had

Figure 1. Old Impellicone manifold.

9.53-mm (0.375-in.) grooves in a spiral shape to achieve the desired affect.

Several subsequent versions of this design were also tested (new Impellicone prototypes). Designs were based on the old Impellicone design, but were much smaller and more practical for commercial production (fig. 2). NH_3 entered the bottom of the manifold (bottom entry had improved uniformity in some previous tests; Hanna et al., 2002) impacting the point of the cone, which was pointed down. The housing had 12 outlet ports. In testing, 11 of these outlet ports were used for application to 11 knives and a pipe tee for temperature and pressure sensors was inserted in the 12th port. The new Impellicone prototypes used in experiment 1 had a smooth flattop lid with an o-ring seal fastened to the housing with four allen-head screws. Two different cones were used in experiment 1. One cone had four spiral paths with 3.18-mm (0.125-in.) square grooves cut into the cone. This cone was narrower than the original cone and had a flat or blunt end. The second cone was similar, but with just three grooved spiral paths. Cones used in experiment 1 are shown in figure 3 along with altered versions used in the later experiment 2. In addition, several objects were used above the cone to help limit upward displacement of the cone during NH_3 flow:

- a 15.37-mm (0.605-in.) tall and 15.88-mm (0.625-in.) diameter (corner-to-corner) nut including a solid threaded shaft,
- a 25.4-mm (1.0-in.) diameter nylon pipe bushing with a height of 15.37-mm (0.605-in.),
- a 25.4-mm (1.0-in.) diameter nylon pipe bushing with a height of 23.06-mm (0.908-in.) (double-height bushing).

Separate tests at both the high and low rates were made using the three-grooved cone and plugging distribution ports 3, 6, and 9.

Both small- and large-housing Vertical-Dam manifolds were used for comparison in the tests. The small housing (part MVD) Vertical-Dam with ring (LG 12” = 75#N min/acre @ 6 mph max cap. @ 65% tank psi) was used for the lower application rate of 84 kg N/ha (75 lb N/acre). The large housing (part SVD-01) Vertical-Dam manifold with corn ring (corn 30” = 75# N min/acre @ 6 mph max. cap. @ 65% tank psi) was used for the higher application rate of 168 kg N/ha (150 lb N/acre). A pipe-tee was used in the top of the manifold housing for holding pressure and temperature sensors.

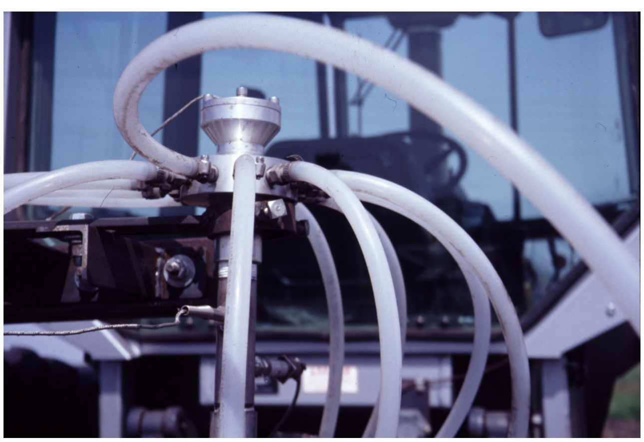

Figure 2. Modified Impellicone manifold.

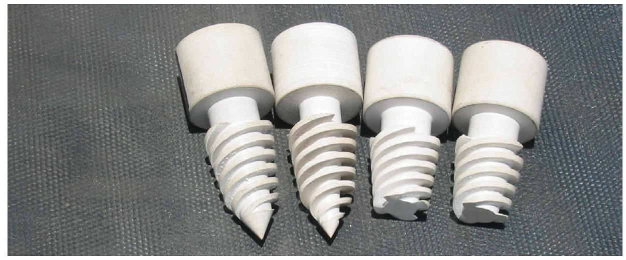

Figure 3. Cone styles (left to right): shallow groove, deep groove, four-groove, and three-groove cones.

Impellicone Experiment 2 Manifolds

A second experiment was performed using several different types of lids and cones based on observations from initial tests [uniformity was improved with a pointed cone (old Impellicone manifold) and some limit in upward cone movement]. For this experiment the actual manifold housing was not changed. Further design modifications were tested for cones and lids. Cone style was modified with a pointed end similar to the old Impellicone and shallow- and deep-grooved styles (fig. 3) were evaluated. Both of these cones had a hole centered in the top and drilled 34.9-mm (1.38-in.) deep with a pointed end. The shallow-grooved cone had 3.18-mm (0.125-in.) square-cut grooves cut in a spiral. The deep-grooved cone had rectangular cut grooves 3.18-mm (0.125-in.) wide and 4.76-mm (0.188-in.) deep. Adding lid height reduced headspace above the cone, reduced the travel of the distribution cone, and improved performance with certain lid heights. One-piece lids had spacers that fit with tight tolerances down into the manifold housing and limited the upward displacement of the cone in the manifold during NH_3 flow. A shaft protruded down from the center of each lid into the middle of the cone. This shaft went through the hole in the top of the cone. One ball bearing was inserted into the needle to allow a surface for the shaft and cone to spin on. An exploded view of the manifold assembly is shown in figure 4. Lids with added space heights of 27.56, 20.68, 18.54, and 16.38 mm (1.085, 0.814, 0.730, and 0.645 in.) were tested (fig. 5). Some lids were tested

Figure 4. Exploded view of new Impellicone manifold showing lid, ball bearing, cone, and body (left to right).

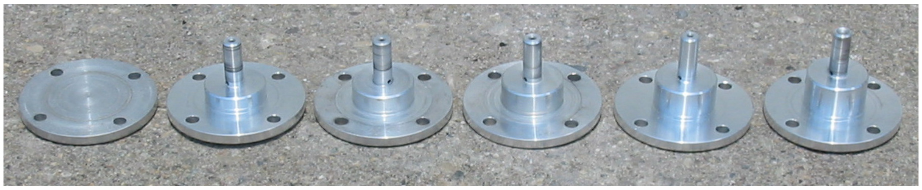

Figure 5. Lid styles (left to right): smooth lid, 16.38-mm (0.645-in.), 18.54-mm (0.730-in.), 20.68-mm (0.814-in.), 24.13-mm (.950-in.) (not used in this experiment), and 27.56-mm (1.085-in.) lids.

with no ball bearing in the top of the cone. Additional N rates of 224 kg N/ha (200lb N/acre) and 43 kg N/ha (38lb N/acre) were each tested for one manifold style.

PWM Experiment

A multi-valve PWM manifold (May 2002; Capstan Ag Systems; Topeka, Kans.) and a Vertical-Dam manifold (Continental NH3; Dallas, Tex.) were compared. Five treatments of the PWM manifold were made with runs at valve duty cycles of 10%, 30%, 50%, 70%, and 100% (percentage of time that the fixed-orifice valve is open). For PWM manifold treatments, the upstream regulator (Nitro-pacer #A-3300-H, CDS John Blue Co., Huntsville, Ala.) was wide open (approximately 7000-lb/h capacity). There were three treatments of the Vertical-Dam manifold with runs made at corresponding low [22 kg N/ha (20 lb N/acre)], middle [90 to 101 kg N/ha (80 to 90 lb N/acre)], and high [179 kg N/ha (160 lb N/acre)] application rates. The Vertical-Dam manifold used a MVD housing with a "LG:18"=130#N/acre" model ring for the low and middle application rates, and a SVD-01 housing with a "Corn:30"=75#N min/acre" model ring for the high application rate.

Analysis

Measures of uniformity included average outlet difference (i.e. the average of the absolute values of the differences in kg (lb) NH_3 of all outlet outputs from the mean outlet output), average percentage difference (as a percentage of the mean), high/low ratio (ratio of highest to lowest outlet port), and coefficient of variation (CV; standard deviation divided by the mean and expressed as a percentage). A 95% probability level was used for statistical analysis unless otherwise noted. Statistical contrast is a measure used to determine if a statistical difference exists between treatment means of two different groups within an experiment using a pooled experimental error from the experiment. For comparison purposes statistical contrasts were used in the second Impellicone experiment as it was desired to evaluate if specific design attributes (e.g. shallow- vs. deep-grooved cones; newly revised designs vs. Vertical-Dam manifold, etc.) had different uniformity. Statistical contrasts were also used as the comparison technique in the PWM experiment between the PWM and Vertical-Dam manifolds at both selected application rates and in overall testing. Because the statistical measurement for contrast difference is only meaningful between the two selected group means that are being contrasted, separate letter groups by least significant difference are not shown in results tables for these two experiments but instead specific contrast differences are noted within results.

Results And Discussion

Impellicone Experiment 1

At the 84-kg N/ha (75-lb N/acre) application rate, the manifold with the greatest uniformity (6.6% CV) was the new Impellicone prototype with a three-groove cone and three evenly plugged ports at the distribution outlets (table 1). This plugged-port manifold was not statistically different than the old Impellicone, new Impellicone three-groove with nut, and new Impellicone three-groove with bushing manifolds. The new Impellicone manifold with the most uniformity excluding the three-groove plugged-port manifold, was the new Impellicone three-groove with nut (11.0% CV). This manifold was not statistically different from all of the manifolds except the new Impellicone four-groove and new Impellicone three-groove cone with double-height bushing manifolds. The Vertical-Dam small housing manifold (15.5% CV) was statistically no different than all versions of the new Impellicone manifold with three grooves and using 11 outlets. The new Impellicone prototype with a four-groove cone had statistically lower uniformity (23.5% CV) than all other manifolds at the 84-kg N/ha (75-lb N/acre) rate.

At the higher N application rate of 168 kg N/ha (150 lb N/acre), the new Impellicone three-groove with three plugged ports had the greatest uniformity (3.8% CV) of manifolds tested although it was not statistically different to the new Impellicone three-groove manifold with nut, old Impellicone, new Impellicone three-groove manifold with bushing, and new Impellicone three-groove with double height bushing. The new Impellicone three-groove with nut had the second best uniformity (6.2% CV). The Vertical-Dam manifold with corn ring had the least uniformity of all manifolds (15.6% CV), however it was not statistically different from the new Impellicone with three-grooves, new Impellicone with four-grooves, and new Impellicone three-groove with double height bushing manifolds. All of the manifolds produced lower CV's at the higher rate application except for the Vertical-Dam corn ring (0.1% increase).

Impellicone Experiment 2

The lower 84-kg N/ha (75-lb N/acre) application rate was used only with a deep-grooved cone for the redesigned manifolds. The new Impellicone prototype with deep-grooved cone and 16.4-mm (0.645-in.) lid had the lowest CV (6.8%) of all manifolds tested at the lower application rate (table 2). This treatment also produced the lowest average percent outlet difference (5.4%) and the lowest high/low ratio (1.23). The manifold with the next best uniformity (8.0% CV) was the new Impellicone deep-grooved cone with 18.5-mm (0.730-in.) lid. The Vertical-Dam small housing produced the highest CV (18.6%) of manifolds tested at the 84 kg-N/ha (75-lb N/acre) application rate. It also had the highest average percent outlet difference and high/low ratio. The second highest CV was for the new Impellicone with

Table 1. Tank and manifold pressure, application rate, and distribution of various manifolds during initial test.[a]

Treatment	Tank Pressure[b] kPa (psi)	Pressure before Manifold[b] kPa (psi)	Pressure after Manifold[b] kPa (psi)	N Application Rate[c] kg/ha (lb/ acre)	Avg. Outlet Difference NH_3,[d] kg (lb)	Avg. % Outlet Difference[e]	High/low Ratio[f]	Coefficient of Variation %
84 kg N/ha (75 lb N/acre)								
Vertical-Dam (SH)	655 (95)	345 (50.0)	324 (47.0)	90 (80)	0.056 (0.124)bcd	12.2cd	1.66bcd	15.5bcde
Old Impellicone	682 (99)	241 (35.3)	202 (29.3)	98 (87)	0.036 (0.079)ab	7.1a	1.37a	8.9a
New Impellicone 3 groove	613 (89)	184 (26.7)	165 (24.2)	95 (85)	0.052 (0.115)bcd	10.6bcd	1.83de	14.8bcd
New Impellicone 4 groove	689 (100)	212 (30.7)	184 (26.7)	89 (80)	0.071 (0.157)d	15.6e	2.07e	23.5g
New Impellicone 3 groove with nut	724 (105)	254 (36.8)	203 (29.5)	90 (81)	0.042 (0.093)abc	8.8ab	1.41ab	11.0ab
New Impellicone 3 groove with bushing	744 (108)	262 (38.0)	221 (32.0)	98 (87)	0.049 (0.108)bc	9.7bc	1.43abc	11.5abc
New Impellicone 3 groove double height bushing	675 (98)	358 (52.0)	218 (31.7)	88 (79)	0.062 (0.138)cd	13.7d	1.78bcde	17.0cdef
New Impellicone 3 groove with 3 plugged ports	689 (100)	241 (35.3)	223 (32.3)	85 (76)	0.023 (0.051)a	5.1a	1.23a	6.6a
168 kg N/ha (150 lb N/acre)								
Vertical-Dam (corn ring)	682 (99)	336 (48.7)	322 (46.7)	176 (157)	0.058 (0.128)c	12.3f	1.72d	15.6d
Old Impellicone	682 (99)	379 (55.0)	324 (47.0)	185 (165)	0.026 (0.058)ab	5.3ab	1.29ab	7.1ab
New Impellicone 3 groove	613 (89)	317 (46.3)	288 (42.0)	179 (160)	0.041 (0.092)bc	8.7bcdef	1.49abcd	11.6bcd
New Impellicone 4 groove	646 (94)	322 (46.7)	296 (43.0)	169 (151)	0.037 (0.083)bc	8.4bcde	1.44abcd	11.7bcd
New Impellicone 3 groove with nut	724 (105)	436 (63.3)	356 (51.7)	184 (165)	0.025 (0.056)ab	5.2a	1.20a	6.2a
New Impellicone 3 groove with bushing	744 (108)	422 (61.3)	372 (54.0)	195 (174)	0.042 (0.094)bc	8.2bcd	1.34abc	9.7abc
New Impellicone 3 groove double height bushing	675 (98)	501 (72.7)	342 (49.7)	174 (155)	0.034 (0.076)ab	7.4bc	1.42abcd	9.8abcd
New Impellicone 3 groove with 3 plugged ports	689 (100)	395 (57.3)	374 (54.3)	206 (184)	0.016 (0.035)a	2.9a	1.12a	3.8a

[a] Values in each column within each rate followed by a different letter are significant at the $\alpha = 0.05$ level.
[b] Gage pressure.
[c] Application rate as measured into collection buckets.
[d] Average kg (lb) NH_3 difference of an outlet from mean of outlets.
[e] Average difference of outlet from mean of outlets expressed as a percentage of mean.
[f] High/low ratio = maximum single outlet weight/minimum single outlet weight.

three-groove cone and smooth lid. Noting CV's of these last two manifolds used in both experiments, the new Impellicone three-groove with smooth lid had CV's of 13.2% and 14.8% and Vertical-Dam small housing 18.6% and 15.5% in experiments two and one, respectively.

The best performing manifold at the 168-kg N/ha (150-lb N/acre) application rate as indicated by low CV (8.7%), high/low ratio, and average percent outlet difference was the new Impellicone prototype three-groove and smooth lid. Manifolds with the next lowest CV (9.3%) were the new Impellicone deep groove with 18.5-mm (0.730-in.) lid with and without ball bearing. There were no significant differences in application uniformity between these two manifolds among other uniformity measurements. The Vertical-Dam corn ring manifold produced the least uniformity (16.1% CV). The new Impellicone deep groove prototype with 18.5-mm (0.730-in.) lid with no ball bearing had a statistically lower absolute difference, percentage difference, high/low ratio, and CV than Vertical-Dam treatment at a 99% confidence level. The deep-grooved cone treatments statistically had a lower absolute difference, percentage difference, and CV than shallow-grooved cone treatments at the 168 kg N/ha (150 lb N/acre) application rate at a 95% confidence level and a lower high/low ratio at a 90% confidence level. When tested by statistical contrast the group of new Impellicone manifolds as a whole (i.e. all new Impellicone manifold treatments combined) had lower absolute differences, percentage differences, high/low ratio, and CV's than the Vertical-Dam treatments with a 99% confidence level at both 84- and 168-kg N/ha (75- and 150-lb N/acre) rates.

Tests were also conducted at 224- and 43-kg N/ha (200- and 38-lb N/acre) application rates with the new Impellicone deep grooved cone with 18.5-mm (0.730-in.) lid and no bearing manifold (table 2). This manifold had a CV of 6.1% at the 224-kg N/ha (200-lb N/acre) rate. This CV was lower than all other treatments in experiment two and in the low rate tests of experiment one. At the extreme low rate of 43 kg N/ha (38 lb N/acre) this manifold produced a CV of 16.7%. Low manifold pressure at this extreme low rate (just 10.9% of tank pressure) has commonly decreased application uniformity of other manifolds (Boyd et al., 2004).

Temperatures and Pressures

Pressure was recorded at: 1) the NH_3 nurse tank, 2) between the regulator and manifold, and 3) at the manifold. These readings were used to check the percentage of tank pressure near the entry to the manifold and near the manifold exit port. Temperature sensors during the experiment produced unreliable results and were excluded from analysis as a result.

PWM Experiment

Table 3 summarizes NH_3 output variability for different manifold treatments. The maximum application rate at 8-km/h (5-mile/h) travel speed and the PWM valve open 100% of the time (duty cycle = 1) was about 180 kg N/ha

Table 2. Tank and manifold pressure, application rate, and distribution of various manifolds during follow-up test.

Treatment	Tank Pressure[a] kPa (psi)	Pressure before Manifold[a] kPa (psi)	Pressure after Manifold[a] kPa (psi)	N Application Rate[b] kg/ha (lb/acre)	Avg. Outlet Difference NH_3[c] kg (lb)	Avg. % Outlet Difference[d]	High/low Ratio[e]	Coefficient of Variation %
84 kg N/ha (75 1b N/acre)								
Vertical-Dam (SH)	1000 (145)	494 (71.4)	455 (66.0)	98 (87)	0.072 (0.160)	14.3	1.78	18.6
Deep groove 20.7-mm (.814-in.) lid	821 (119)	330 (47.8)	227 (32.9)	101 (90)	0.045 (0.101)	8.8	1.36	10.4
Deep groove 18.5-mm (.730-in.) lid	821 (119)	310 (44.9)	229 (33.2)	101 (90)	0.028 (0.063)	5.5	1.32	8.0
Deep groove 16.4-mm (.645-in.) lid	841 (122)	301 (43.7)	241 (35.0)	98 (86)	0.027 (0.059)	5.4	1.23	6.8
New Impellicone 3 groove	869 (126)	261 (37.8)	235 (34.1)	99 (88)	0.053 (0.118)	10.7	1.54	13.2
Deep groove 18.5-mm (.730-in.) lid no bearing	952 (138)	281 (40.7)	239 (34.7)	101 (90)	0.043 (0.095)	8.3	1.33	9.7
168 kg N/ha (150 lb N/acre)								
Vertical-Dam (corn ring)	1000 (145)	432 (62.7)	400 (58.0)	172 (153)	0.059 (0.132)	13.1	1.66	16.1
Shallow groove 20.7-mm (.814-in.) lid	979 (142)	496 (71.9)	444 (64.4)	178 (159)	0.050 (0.110)	10.4	1.54	12.9
Shallow groove 27.6-mm (1.085-in.) lid	979 (142)	594 (86.1)	463 (67.1)	178 (159)	0.040 (0.088)	8.3	1.37	10.0
Shallow groove 16.4-mm (.645-in.) lid	986 (143)	489 (70.9)	448 (64.9)	182 (162)	0.045 (0.100)	8.0	1.47	10.8
Deep groove 27.6-mm (1.085-in.) lid	1014 (147)	770 (111.7)	421 (61.1)	176 (157)	0.034 (0.076)	7.3	1.42	9.8
Deep groove 16.4-mm (.645-in.) lid	1020 (148)	546 (79.2)	451 (65.4)	183 (163)	0.040 (0.089)	8.1	1.38	10.0
Deep groove 20.7-mm (.814-in.) lid	960 (139)	592 (85.8)	437 (63.4)	172 (153)	0.034 (0.075)	7.5	1.39	9.7
Deep groove 18.5-mm (.730-in.) lid	841 (122)	523 (75.9)	412 (59.8)	188 (168)	0.037 (0.083)	7.4	1.39	9.3
New Impellicone 3 groove	869 (126)	416 (60.4)	386 (56.0)	182 (162)	0.033 (0.074)	6.9	1.32	8.7
Deep groove 18.5-mm (.730-in.) lid no bearing	869 (126)	434 (63.0)	373 (54.1)	174 (155)	0.033 (0.074)	7.3	1.35	9.3
224 kg N/ha (200 lb N/acre)								
Deep groove .730” lid no bearing	1032 (150)	602 (87.3)	551 (58.0)	241 (215)	0.023 (0.051)	4.6	1.24	6.1
43kg N/ha (38 lb N/acre)								
Deep groove .730” lid no bearing	1048 (152)	139 (20.1)	114 (16.5)	49 (44)	0.071 (0.158)	14.0	1.70	16.7

[a] Gage pressure.
[b] Application rate as measured into collection buckets.
[c] Average kg (lb) NH_3 difference of an outlet from mean of outlets.
[d] Average difference of outlet from mean of outlets expressed as a percentage of mean.
[e] High/low ratio = maximum single outlet weight/minimum single outlet weight.

(161 lb N/acre). This was a practical maximum application rate during the test with tank pressure at 590 kPa (85 psi) and average daily temperature of about 13°C (55°F). Higher application rates would be possible with slower travel speed or perhaps greater NH_3 pressure (warmer temperatures, larger fittings) at the PWM valve or larger ports in the valve (2002 version tested).

At the low [22 kg N/ha (20 lb N/acre)] rate, the PWM manifold had a statistically lower average outlet difference, lower average percentage outlet difference, lower high/low ratio, and lower CV than the Vertical-Dam manifold. At the high [179 kg N/ha (160 lb N/acre)] rate, the PWM manifold had a statistically lower average outlet difference, lower average percentage outlet difference, and lower CV than the Vertical-Dam manifold. At the mid-application rate [90 to 101 kg N/ha (80 to 90 lb N/acre)], the PWM manifold had a lower average percentage difference and lower CV than the Vertical-Dam manifold if the statistical confidence level for making such a claim was reduced to 90%.

Comparing all pulse-width-modulation (PWM) manifold treatments as a group with all Vertical-Dam manifold treatments, the PWM manifold had a statistically lower average outlet difference, lower average percentage outlet difference, and lower CV (99% confidence level).

Lower variability of the PWM manifold was particularly noticeable at very low application rates [22 kg N/ha (20 lb N/acre)]. This may have been due to very small NH_3 flow rates having significantly more room for expansion within the small, but fixed-chamber Vertical-Dam housing (part MVD). This housing is normally used with application rates four times this value. Because high/low ratio is a ratio of outlet ports with the single highest and lowest flows within individual plot runs, extraordinarily high or low output precluded finding as many differences between treatments.

Conclusions

Impellicone

Measurements in the initial experiment support:

- Greatest uniformity was produced by a new Impellicone manifold using a three-groove cone and having three evenly spaced ports plugged [CV = 6.6% and 3.8% at application rates of 84 kg N/ha (75 lb N/acre) and 168 kg N/ha (150 lb N/acre), respectively].

Table 3. Anhydrous ammonia output variability for manifold outlets on a 10-knife applicator.

Treatment[a]	N Appl. Rate[b] kg/ha (lb/acre)	Avg. Outlet Difference, NH_3[c] kg (lb)	Avg. % Outlet Difference[d]	High/low Ratio[e]	Coefficient of Variation %
PWM10	23.7 (21.2)	0.016 (0.035)	7.08	1.26	5.94
VD20	26.8 (23.9)	0.039 (0.085)	15.54	1.93	19.25
PWM30	65.0 (58.0)	0.021 (0.046)	4.44	1.20	5.65
PWM50	101.2 (90.4)	0.024 (0.054)	4.67	1.28	6.60
VD80	93.3 (83.3)	0.037 (0.082)	7.74	1.35	10.03
PWM70	134.5 (120.1)	0.027 (0.059)	4.85	1.22	6.24
PWM100	180.0 (160.7)	0.024 (0.052)	4.83	1.22	6.01
VD160	181.6 (162.1)	0.046 (0.102)	9.47	1.43	12.09

[a] Letters indicate manifold (PWM or Vertical-Dam) and numbers indicate percentage of duty cycle for PWM or approximate application rate for Vertical Dam.
[b] Application rate as measured into collection buckets.
[c] Average kg (lb) NH_3 difference of an outlet from mean of outlets.
[d] Average difference of outlet from mean of outlets expressed as a percentage of mean.
[e] High/low ratio = maximum single outlet weight/minimum single outlet weight.

- A new Impellicone four-groove manifold had the least uniformity (CV = 23.5%) at an application rate of 84 kg N/ha (75 lb N/acre) and the Vertical-Dam manifold had the least uniformity (CV = 15.6%) at an application rate of 168 kg N/ha (150 lb N/acre).
- Although the old (original) Impellicone prototype was better than the Vertical-Dam manifold, uniformity of many new Impellicone manifolds was inconsistent and not statistically different than the Vertica-Dam except in isolated treatments.

After revisions were made to the new Impellicone manifolds based on results of the initial experiment measurements in the follow-up experiment support:

- Revised new Impellicone designs had lower absolute difference, percentage outlet difference, high/low ratio, and CV (99% confidence level) than the Vertical-Dam manifold. The Impellicone design had average CVs 9 and 6 percentage points lower, respectively than a Vertical-Dam manifold at the low rate and high application rates.
- The Vertical-Dam manifold had the least uniformity at both application rates [16.1% CV at 168 kg N/ha (150 lb N/acre) and 18.6% CV at 84 kg N/ha (75 lb N/acre)].
- A deep-grooved cone used in the new Impellicone manifold had better uniformity than shallow grooved cone.
- There was no statistically significant difference in application uniformity whether or not a ball bearing was used during testing of the new Impellicone with deep grooved cone and 18.5-mm (0.730-in.) lid.
- Impellicone manifold treatments with the 16.4, 18.5, and 18.5 mm (0.645, 0.730, and 0.730 in.) with no ball bearing lids had consistently good uniformity at both 84- and 168-kg N/ha (75- and 150-lb N/acre) application rates.

PWM

Measurements support:

- At very low application rates of 22 kg N/ha (20 lb N/acre) the PWM manifold had considerably less variability (CV = 6%) than a Vertical-Dam manifold (CV = 19%).
- At high application rates of 179 kg N/ha (160 lb N/acre) the PWM manifold had less variability (CV = 6%) than a Vertical-Dam manifold (CV = 12%).
- At moderate application rates, 90 to 101 kg N/ha (80 to 90 lb N/acre), variability between the manifolds was somewhat closer (CV_{PWM} = 7%, CV_{VD} = 10%), but the difference was still significant at a reduced confidence level of 90%.
- Comparing variability measures of both manifold styles across all application rates, the PWM manifold had considerably less variability than the Vertical-Dam manifold (confidence level of 99%).

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