District Highway Maintenance Research On-Call (ROC) 2023-09-Task 2: Evaluation of New Technologies for Tracking the Distribution of Deicing Materials

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Prepared for:
Ohio's District Highway Maintenance
The Ohio Department of Transportation,
Office of Statewide Planning & Research

May 2023

Final Report

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/OH-2023-08		
4. Title and Subtitle		5. Report Date:
District Highway Maintenance Research On-Call Task 2: Evaluation of New Technologies for Tracking the Distribution of Deicing Materials		**May 2023**
		6. Performing Organization Code
7. Author(s)		8. Performing Organization Report No.
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9. Performing Organization Name and Address		10. Work Unit No. (TRAIS)
University of Cincinnati **Department of Civil and Architectural Engineering and Construction Management** **Cincinnati, Oh 45221-0071**		
		11. Contract or Grant No.
		37852
12. Sponsoring Agency Name and Address		13. Type of Report and Period Covered
Ohio Department of Transportation **1980 West Broad Street, MS 3280** **Columbus, Ohio 43223**		**Final Report**
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

This report summarizes the results of a research task that was conducted to analyze Ohio DOT's use of liquid deicing materials and the tracking capabilities of its snowplows' distribution systems. The objective of the task was to identify areas for improvement in terms of tracking the liquid application rates and provide ideas on how to evaluate new technologies that may improve tracking. To achieve this objective, a comprehensive audit of Ohio's current state of the practice was conducted. Areas for improvement were identified and constraints were noted. In addition, a nationwide survey was distributed; the survey served as a metric to compare Ohio's state of the practice as well as providing leads for new technologies to investigate. Then, vendors were solicited for information about liquid tracking systems that could fit into Ohio's infrastructure and offer the enhancements Ohio was seeking. Brief research was done on each of these new technologies. Lastly, an evaluation matrix was developed so ODOT can continue pursuing these options. The evaluation matrix lists criteria that should be examined as well as specific elements within each criteria. It also proposes ideas on how to practically evaluate or measure each criteria element. ODOT can use the information presented in this report to select new liquid tracking technologies to test within their research program, and continue working towards optimizing their response to winter weather.

17. Keywords	18. Distribution Statement
Liquid deicing application, deicing material liquid pumps, snowplow flow meters, tracking brine distribution	**No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161**

19. Security Classification (of this report)	20. Security Classification (of this page)	21. No. of Pages	22. Price
Unclassified	**Unclassified**	**43**	

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May 2023

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Acknowledgments

The researchers would like to thank the Ohio Department of Transportation (ODOT) and the Federal Highway Administration (FHWA) for sponsoring this study. The researchers would like also to thank the technical liaisons: Mr. Doug Burke, Mr. Scott Lucas, Mr. Douglas Riffle, and Mr. Samuel Morrison. Finally, the researchers would like to express their appreciation to Ms. Jacquelin Martindale for her time and assistance.

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1. Project Background

The Ohio Department of Transportation (ODOT) has snowplow trucks that use on-board, truck-mounted liquid pumps for dispensing liquid deicers during winter snow and ice events. There is uncertainty about the accuracy and reliability of these liquid pumps and, consequently, an opportunity to research new technologies that might improve such metrics. Finding a more accurate liquid application system would provide consistent information back to the operator and managers of the county. This would improve productivity, allowing operators to dispense material at values that will guarantee they can complete their routes before running out of material. It would also result in a faster, safer, and more efficient response time to the motoring public during a snow and ice event.

This Research-On-Call task provides ODOT a framework with which to evaluate the available new technologies for tracking the distribution of deicing materials. To accomplish this, researchers analyzed the current state of the practice for ODOT storm management, surveyed other transportation agencies about their winter maintenance programs, identified on-board, truck-mounted liquid pumps and flow meters that would be capable of dispensing and tracking liquid deicers within ODOT's fleet, and developed an evaluation criteria and methodology for testing any systems of interest.

2. Research Context

The objectives of this task are:

1- Summarize ODOT's current practices for deicing liquid distribution, identifying areas for improvement and any relevant constraints for use of new technologies.
2- Review nationwide deicing liquid distribution practices and identify best practices.
3- Conduct a market survey to identify new technologies in the field of distributing and tracking deicing materials, specifically those which would be compatible with ODOT's infrastructure.
4- Develop an evaluation framework for new technologies, including proposals for subsequent testing methodology.

3. Research Approach

3.1 Summarize ODOT Current Practices

This task involved documenting ODOT's current practices in winter weather management. Emphasis was given to their liquid material distribution systems and GPS tracking systems. The research team visited four Ohio counties: Stark, Lucas, Pickaway, and Fairfield Counties. Winter maintenance managers and snowplow operators conducted tours of their facilities and shared information with the research team. Researchers saw ten unique trucks and two main operating systems, and learned about materials, operation and application, pumps, and metering systems. The summary of Ohio's current state of the practice is provided in Appendix A. The tours also resulted in receipt of the state snow and ice guidelines, which detail the materials application guidelines depending on weather conditions, pavement conditions, and equipment. Those guidelines can be found in Appendix B.

Additionally, several individual interviews were conducted with operators. A set of questions was developed based on the preliminary information obtained during the garage site

visits, concentrating on how the current system affects the plow operators. They provided insight into the thought process utilized in winter storms, the advantages and disadvantages of current operating systems, and what features could improve the trucks' distribution and tracking systems. This was valuable because, for any new system that ODOT adopts, operator buy-in will be crucial. The results of operator interviews are in Appendix C.

3.2 Review Nationwide Deicing Liquid Distribution Practices

In addition to understanding Ohio's current state of the practice, it was helpful to learn how other agencies respond to snow and ice. A survey was developed in concert with ODOT and the TAC that requested information about other agencies' liquid material application rates, snowplow mechanics, hydraulic pumps, and flow metering systems. It also asked respondents to assess how satisfied they were with their state of practice in terms of accuracy and reliability.

In November 2022, the survey was distributed for responses. The distribution list included contacts from the Clear Roads Pooled Fund, the No Boundaries Pooled Fund, the Transportation Research Board Snow and Ice Committee, FHWA's Local Technical Assistance Program, the National Center for Pavement Preservation, and PIARC World Road Association.

The survey received 15 full responses. (There were several participants who answered some questions but did not complete the survey.) The most pertinent respondents included Michigan and West Virginia, which both share a border with Ohio, as well as Illinois, Iowa, Nebraska, and Delaware, which are located at similar latitudes and therefore exhibit similar winter weather.

The distributed survey and all complete responses are provided in Appendix D.

3.3 Identify New Technologies for Distributing and Tracking Materials

ODOT trucks need to accurately manage the application rates of granular and liquid deicing materials. The hardware and configuration of granular and liquid application systems on ODOT trucks is very different, but all use a series of hydraulic circuits to operate the necessary components. Most trucks are configured to simultaneously apply granular and liquid materials to the roadway, while other trucks have solely dedicated liquid systems for high volume applications. Granular application rates are typically adjusted by modifying the speed of an auger, whose RPM's are monitored by a Hall Effect Sensor attached to the auger shaft. Liquid application rates are adjusted by modifying the speed of a centrifugal or gear pump; however, ODOT's systems are categorized as "open loop" as they do not monitor real-time liquid output (e.g. gallons per minute) and instead use values computed during the calibration process to estimate material usage. The liquid pumps on ODOT trucks typically supply a valve manifold with one or two sections. The first section generally pretreats salt and has a low flow rate requirement (<3.0 gpm). The second section has higher flow requirements (15-30 gpm), and is used for anti-icing or direct liquid applications (DLA), wherein, salt brine is applied directly to the roadway using a boom with high-flow straight stream nozzles. Suitable technologies for ODOT need to easily integrate with the granular and liquid control systems.

The research team combined feedback from the national survey with their own agricultural expertise while investigating new technologies, and identified three primary focus areas for improving the accuracy and tracking of liquid application systems:

1) Configuration of Spraying Systems
    a. Standardize the type, size, and number of nozzles for pretreating, anti-icing, and DLA applications on ODOT trucks
    b. Develop a spray boom or manifold for anti-icing and DLA applications

2) Sprayer Pumps and Plumbing
    a. Evaluate appropriately sized centrifugal, gear, and diaphragm pumps
    b. Identify the optimal plumbing configuration to improve reliability, fleet production, and adaptability
    c. Investigate the use of electric pumps for pretreating-only trucks
3) Technologies for Monitoring and Tracking Liquid Materials
    a. Test flow monitoring systems that are compatible with ODOT trucks
    b. Determine whether rate tracking or real-time rate control systems are needed
    c. Identify technologies that are easily configured and capable of transmitting data via GPS AVL

3.4 Develop an Evaluation Framework for New Technologies

The last step of this project involved developing an evaluation matrix that could be used in the future to analyze the new technologies identified in the previous step. The scope of this project did not include making a specific recommendation on which new technologies to adopt, but rather to provide the means for ODOT to make decisions about what works best for their needs. To that end, the evaluation criteria needed to be broad enough to be applied to any number of new technologies while being specific enough to be actionable.

ODOT and the TAC provided information about what criteria were important to them, which formed the basis of the evaluation matrix. The team was tasked with developing specific elements within each criterion, as well as providing brief ideas on how to tangibly evaluate each element or category of elements. The evaluation matrix can be found in Appendix E.

4. Research Findings and Conclusions

Appendices A, B, C, D, and E present a detailed summary of the results and analysis that researchers performed for this project. The main findings of this task are summarized below.

Main Findings of Ohio State of the Practice Review

- ODOT puts strong emphasis on liquid anti-icing and pre-wetting, which is advantageous. Using liquids within a snow and ice management program helps maximize efficiency.
- ODOT uses mostly salt brine. Some garages also use chloride or organic additives. Both have been shown to increase effectiveness of brine, but chlorides can corrode faster than brine alone and organic products can clog distribution systems.
- ODOT utilizes two main operating systems: Force America or Pengwyn. Force America is slightly more prevalent in ODOT's fleet and very prevalent nationwide. Pengwyn is an Ohio-based company that promises to deliver innovations based on ODOT's specific needs.
- Trucks can run in auto mode or manual mode. Auto mode dispenses a "known" volume per distance and is generally preferred, while manual mode allows the operator to override the rate control system. The tracking accuracy of auto mode has not been confirmed, and accurate tracking in manual mode is nearly impossible.
- For high-volume liquid applications, most garages use a hydraulic centrifugal pump. For low-volume applications, they use an Oberdorfer gear pump.
- The specific pumps viewed at selected garages included the Hypro 1700XL roller pump, the Hypro 9303 145 gpm, the Hypro 9202 103 gpm, and the Oberdorfer N7000 gear pump 18 gpm.

- Low-volume applications usually exhibit an issue with accuracy, while high-volume applications may be subject to limitations based on the pump flow curves.
- ODOT is unique in using an open loop system for its liquid application. There is no flow meter.
- In the past, ODOT county garages have been hesitant to incorporate flow meters due to durability issues. Minimal maintenance effort is desired.
- Each year, ODOT snowplow trucks are required to perform a "dry run" in the late fall. The liquid and granular application systems are calibrated yearly in preparation for the dry run. It was common to see modifications made to the systems. One such modification was changing the pre-wetting system to treat at the auger instead of the spinner, which seemed to work well.
- The team constructed a diagram of current systems, as shown in Appendix A2.
- Based on interviews (see Appendix A3), operators seem to prefer using Force America systems, although they noted that whatever system they use quickly becomes second nature. Many operators do not believe they are utilizing the Force America technology to its full potential in terms of tracking.
- Typical routes are anywhere from 15 to 60 miles. Typical operating speed is about 30 to 40 miles per hour. Variances are based on location, current weather conditions, size of the truck, and how long the truck dispenses in auto mode versus manual mode.
- Operators estimate that they are away from their route for about 45 minutes when refilling. This time includes driving without treating, putting more material in their trucks, taking necessary food or restroom breaks, and sometimes cleaning equipment parts.
- Operators feel that they can more effectively address winter weather by analyzing conditions for themselves and making judgement calls, rather than scrupulously following written guidelines. This ability is developed after a few years of experience but written guidelines are helpful at the beginning.
- The ability to treat in manual mode is a feature that operators are unlikely to relinquish.

Main Findings of National Survey

- Survey responses indicated a wide variety in agencies' approach to winter weather. However, they encounter many of the same issues with liquid pumps that ODOT does.
- Force America hydraulic systems are common, usually paired with Varitech pumps. Other commonly used pumps included Hypro, Oberdorfer, and Danfoss.
- Pengwyn hydraulic systems are unique to Ohio and therefore no other agencies reported using them.
- Hydraulic and pump systems are often integrated. These systems are reportedly capable of modifying the pump speed based on truck speed, but respondents said the accuracy of these systems was uncertain.
- Operating in manual mode versus automatic mode is known to complicate tracking efforts.
- Low-volume pumps are prone to clogging, so regular cleaning and calibration are critical aspects of owning this type of equipment. Those agencies who have had success with them report being very attentive to regular cleaning and maintenance.
- Tracking liquid distribution may be more accurate if a system can measure output via a flow meter fed to the spreader control rather than the pump.
- The survey asked respondents to indicate if any formal research or testing had been conducted in order to select hydraulic systems and pumps; three agencies said yes, but upon further investigation the team learned that their research was not relevant to this project.

Main Findings from Identification of New Technologies

- Different plumbing configurations will be required for centrifugal, diaphragm, and gear-type pumps.
- Centrifugal pumps are well suited for anti-icing and DLA applications but oversized for pretreating.
- Currently, 12-volt electric pumps are only capable of meeting the flow requirements for pretreating systems.
- Electro-magnetic flow meters provide greater reliability compared to impeller-style.
- Pressure-based rate control may be better suited for ODOT operations compared to flow-based rate control due to turbidity and viscosity of deicing solutions.
- Force America controllers and wiring harnesses are preconfigured to receive input from a pulse-style flow meter.
- The current spray bar utilized by ODOT is unable to maintain a consistent pressure across all the nozzles at higher flow rates.
- A sprayer manifold with multiple sections (e.g., pretreat, anti-icing, DLA) could provide greater application accuracy and versatility during the manufacturing process.
- Changing nozzle sizes is an effective way to meter materials based on road conditions and/or truck configurations.

5. Recommendations

Based on the results of this study, the following recommendation are made:

- ODOT should consider standardizing its fleet and management guidelines. Making and assessing improvements will be difficult without first standardizing the fleet statewide. If statewide standardization is not possible, define an example "typical" scenario in which improvements can be measured from. Based on this project and the discussions with the Task advisory committee, the following points are recommended for standardization.
    - For direct liquid application, a spray bar with 10 straight stream nozzles and quick disconnect nozzle bodies.
    - For pre-wetting, a spray boom with two nozzles strategically positioned to spray granular salt as it falls from the auger plate.
- Identify the specific elements of the snow and ice management program where improvement will provide the greatest value.
    - This will be mostly subjective but should incorporate feedback from a variety of stakeholders including state-level coordinators, garage managers, and snowplow operators. Some preliminary decisions may be made based on the information provided by this research task, specifically the current state of the practice in Appendix A1 and operator interviews in Appendix A3.
- Explore the prospective hydraulic systems that were introduced in this project (Appendix E, Section 2) Twenty new technologies were identified in this task. The research team specifically recommends further study of the following:
    - Cab mounted screens or dials for displaying and tracking liquid and granular applications.
    - Electromagnetic flow meters for monitoring the real-time flow of liquid systems.
    - 12V liquid pump for liquid pretreating systems.

    - Solid stream nozzles for spray bars used during anti-icing and DLA applications.
- Evaluate the list of pump systems recommended in Appendix E, Section 2. It is recommended that the evaluation be performed according to criteria provided in the Evaluation Matrix in Appendix E1. The evaluation matrix includes four criteria: accuracy, durability/reliability, cost, and ease of use. The matrix includes several factors within each criteria, as well as ideas for how to measure or test those factors. The Evaluation Matrix may be modified to fit the parameters that ODOT is most interested in improving or may include all elements.

Some guidelines for conducting testing needed for the evaluation were provided in Appendix E1. These ideas may require further refinement before actual testing can commence; therefore, it is recommended to allow time for development of protocols used as part the testing and evaluation of different pump systems.

Developing a Testing Methodology for Granular and Liquid Application Systems

To apply liquid and granular deicing materials accurately and effectively to the roadway, ODOT trucks need electrical, hydraulic, and mechanical systems that can adapt to changing road conditions and vehicle configurations. Objectively evaluating these interconnected application systems requires testing procedures that mimic the typical usage during winter maintenance activities (e.g. changing of vehicle speeds, start-stop events, modifying application rates). Conducting short, "snap-shot" style testing procedures may fail to identify shortcomings of the interconnected systems or properly assess the accuracy over a range of operating conditions. To provide efficient and robust testing methodology of the entire material application system we suggest the following:

- Identify a testing area where the trucks can continuously apply liquid and/or granular materials for a minimum of five miles.
- Modify the application speed by 5 mph increments for predetermined distances throughout the continuous testing.
- Incorporate multiple stop-start events into the testing procedures to simulate intersections.
- Evaluate the accuracy of the prewetting, anti-icing, and granular systems at a low, medium, and high application rate.
- Recommend comparing the pre- versus post-testing liquid volume and/or granular material weights to determine the effective application rates.
- Attempt to test various vehicle configurations on the same day to reduce variability amongst environmental conditions and materials.
- Use a single operator when conducting tests on different configurations.

Appendix A Ohio Current State of the Practice

The Current State of the Practice document explains the equipment that ODOT uses, highlights the strengths of the program, and notes any obstacles to improved tracking. This information is based on in-person site visits to four county garages as well as interviews with ODOT personnel.

A.1 Current State of the Practice

General Approach

- Ohio places a strong emphasis on liquid anti-icing and pre-wetting. Research has proven that anti-icing practices increase the efficacy of subsequent deicing, saving money and time while improving safety.
- The state's total fleet consists of about 1500 trucks across all counties.
- Ohio has 43,000 lane miles to treat.
- ODOT spends $50 million annually on labor, equipment, and materials for winter maintenance activities.

Materials

- Salt brine is the primary liquid used for snow and ice management. Salt brine is 23.3% NaCl in water. It can be mixed and stored prior to use.
- Occasionally, facilities will add chloride-based additives (such as calcium chloride and magnesium chloride) or organic products (Beet Heat) to the salt brine.
- There are drawbacks to both: chlorides corrode the equipment, but organic products clog the spray system.

Application and Operating Notes

- *Pretreating* is introducing a liquid enhancement to a stockpile. The liquid can be pumped in, lanced into the pile, or sprayed over the material.
- *Prewetting* is applying the liquid enhancement at the truck level. There are many variates of nozzle configuration and orifice sizes (when present) for this purpose.
    - Most trucks *prewet* with liquid at the spinner. A few do it at the auger (Stark Co.).
- *Anti-icing is* applying liquid to the roadway using a spray bar
    - Different variations in spray bar configuration were observed. For example, there were various numbers of nozzles and orifice sizes across Ohio's fleet.
- Application rates vary across the state but typically are in the ranges shown below:
    - Anti-icing 20-40 gal/mile
    - Pre-wetting at spinner 6-12gal/ton
    - Prewetting at table 20-40 gal/ton
    - Direct application 60-100 gal/mile
    - Granular material 100-200 lb/mile (up to 400 for bad storm)
- Trucks can be run in auto mode or manual mode. Auto mode dispenses a "known" volume per distance and is generally preferred. Manual mode allows operator to override the rate control system and apply as much as they deem necessary. Manual mode will also dispense material while the vehicle is stopped. An additional drawback to operating in manual is that it will complicate any sort of material distribution tracking the truck can do with GPS/AVL.
- Operators know their routes well, can analyze the weather quickly, and will often make their own decisions about how to best distribute materials. The use of auto vs manual modes seems to be a regional/personal choice.
- Operators report they often run out of liquid before running out of granular material. Different garages had different attitudes about this. In Lucas County, they considered it a positive aspect because it meant they were applying sufficient amounts of liquid. Other counties pointed out the waste involved with using that metric (extra materials, extra truck weight, deadhead time, etc.). The ideal situation is to be able to track material distribution well enough that both materials are used up at the same time and an operator can adjust application rates to optimize their route.

- Incorporating GPS AVL will be important. Right now they get feedback from it but do not trust it, so one goal is to improve actual measurements.
- If any new system is introduced, buy-in from maintenance managers and operators will be crucial.

Pumps and Pump Systems

- Ohio is unique in using an open loop system as opposed to most states who utilize closed loop systems. This means they do not have a flow meter anywhere in the system.
- ODOT trucks currently use a hydraulically-powered centrifugal pump for high-volume applications and a hydraulically-powered Oberdorfer 7000 gear pump for low-volume applications.
    - Low-volume applications usually see problems with accuracy
    - High-volume applications may be problematic according to pump flow curves (e.g. Oberdorfer has maximum flow of 19 gpm @ 1700 rpm)
- Flow from the hydraulic system can be indirectly measured via the size of the valve being used, although accuracy of this "measurement" is unclear. Flow from the brine is not measured.
- ODOT is hesitant to use flow meters due to durability issues; operators want to minimize maintenance efforts.
- Force America and Pengwyn are the manufacturers ODOT is primarily interested in.
- Currently ODOT trucks use mostly Force America: the 6100 model is the most common, and they may have some 5100EX models.

Other

- Select ODOT trucks use stand-alone, gas powered Honda GX engines to operate centrifugal pumps for high volume applications and they have minimal problems with them.
- The mechanical across ODOT is 280 series.
- Road class designations for routes (i.e. primary, secondary) vary by county.

District 2: Lucas County Trucks

Large Capacity Liquid Pre-Treater

- 6 of these tanker trucks in fleet
- Capacity 5000 gallons
- Pre-treat at traffic speeds
- 50 gal/mile (could do up to 300 gal/mile)
- Can use on all roads, up to three lanes width
- Cost $2300 for unit (engine = $900 + pump = $1400)
- $40k to build entire system including personnel and everything
- Force America hydraulics
- Standalone hydraulics, which they see as a huge advantage because it's easier to diagnose and fix problems. Disadvantage is having two separate hydraulics on one truck is cumbersome.
- Flomax 15 Centrifugal pump powered by Honda GX390
- Seals within pump must be replaced about every 1.5 years
- Controller shows output values in gal/acre but they do a calculation to convert to gal/mi

- Raven 450 spray controller providing rate control; they do not like working with Raven. Zane suggests Trimble may be a compatible alternative.
- Currently uses Raven M200 flow meter (impeller style) with Raven flow control valve
    - Noted issues with flow meter, but regular cleaning/maintenance extended lifespan
- On back of truck: spray bar with small nozzles and large pipes called the "flood line"
- Experimenting with other liquids (including Aquasalina and Beet Heat) has not seemed to affect viscosity and flow rate output
- Clogging is sometimes an issue in the smallest valves

Regular Tandem 15 foot bed

- About 40 of these in fleet
- Capacity 800-900 gallons
- Can perform prewetting, anti-icing, and granular applications.
- Application rates: 50 gal/mile
- Force America hydraulic system, same as the large capacity trucks

Saddle Tank Trucks

- Two liquid tanks on either side of bed for granular material
- Tanks store 90-120 gallons
- No liquid tracking, but side tanks are clear so operator can just look back and see liquid levels
- Bed of the truck rises as truck empties
- Oberdorfer gear pump, good for low flow, made of bronze
- Pump costs about $800
- Originally had issues with leaking and salt buildup, but turning it upside down has reduced leaking
- Auger is at back drivers side of truck

Live Bottom Trucks

- Have a material conveyor system (auger-powered) built into the floor of the bed of the truck. Allows for material unloading without raising truck bed.
- These focus more on solid salt; did not explain much at this visit as focus was on their more advanced liquid systems. They do have liquid tanks just like the saddle trucks, but depending on needs, they may or may not choose to employ them.

District 6: Pickaway County Trucks

Saddle Tank Trucks

- 35 mph apply rate
- Capacity: 200-400 lbs solid salt, about 800 gal liquid
- Force America
- Auger controls salt application based on speed
- Torque speed 1500-1700 rpm; loses accuracy below 1500 rpm
- Operator can roughly calculate application rates after their route based on distance and amount of material, but does not track exactly
- Calibrate once per season or when replaced
- This garage keeps covers off of the pump system so they get rinsed and sprayed with oil (Zane noted that they were cleaner and more well-maintained than others we have seen)
- Treating up at auger improved things; drawback is if they hit blast a lot it clogs

Experimental Pengwyn Prototype:

- Fixed Displacement Liquid Pump
- Electronic hydraulic manifold controls on current configuration
- Hydraulic cylinder strokes a piston inside a PVC sleeve to create a known flow
- Can be used with any Pengwyn
- Has different sized poppet valves that correspond to different hydraulic flow rates (0.25, 0.5, 1, 2, 4, 8 gpm)
- Pumps on both strokes (this is the first time this has been attempted)
- Noted that it is difficult to switch between spray bar and treating salt

District 5: Fairfield County Trucks

- 4 main types of trucks, 15 total in fleet
- This county puts strong focus on liquids, used 300-500k gallons last year
- Use GeoMelt ($2/gal) and Beet Heat ($1.50/gal), usually 20% beet to 80% brine
- Typical route is 30 miles (22-35 range)

840 Gallon Tandem

- This truck is most similar to Pickaway typical trucks
- Used Hypro 9303 pump
- Unijet 11020 nozzles for pre-wetting
- Spray bar const

450 Gallon Tandem

- (Some debate whether this truck's capacity was 450 gals or 560 gals)
- Pengwyn, electric
- Ace FMC-150F-HYD-206 pump holding up well, not sure of material it's made of
    - 7 GPM hydraulic motor,
- Sometimes use smaller nozzles in order to get more out of them, make the route last longer

Live Bottom Truck

- Force America

Liquid Dispensing Truck

- Issue with centrifugal pump is that you can't manage the flow
- Don't often use side sprayers here
- Used Hypro 9306

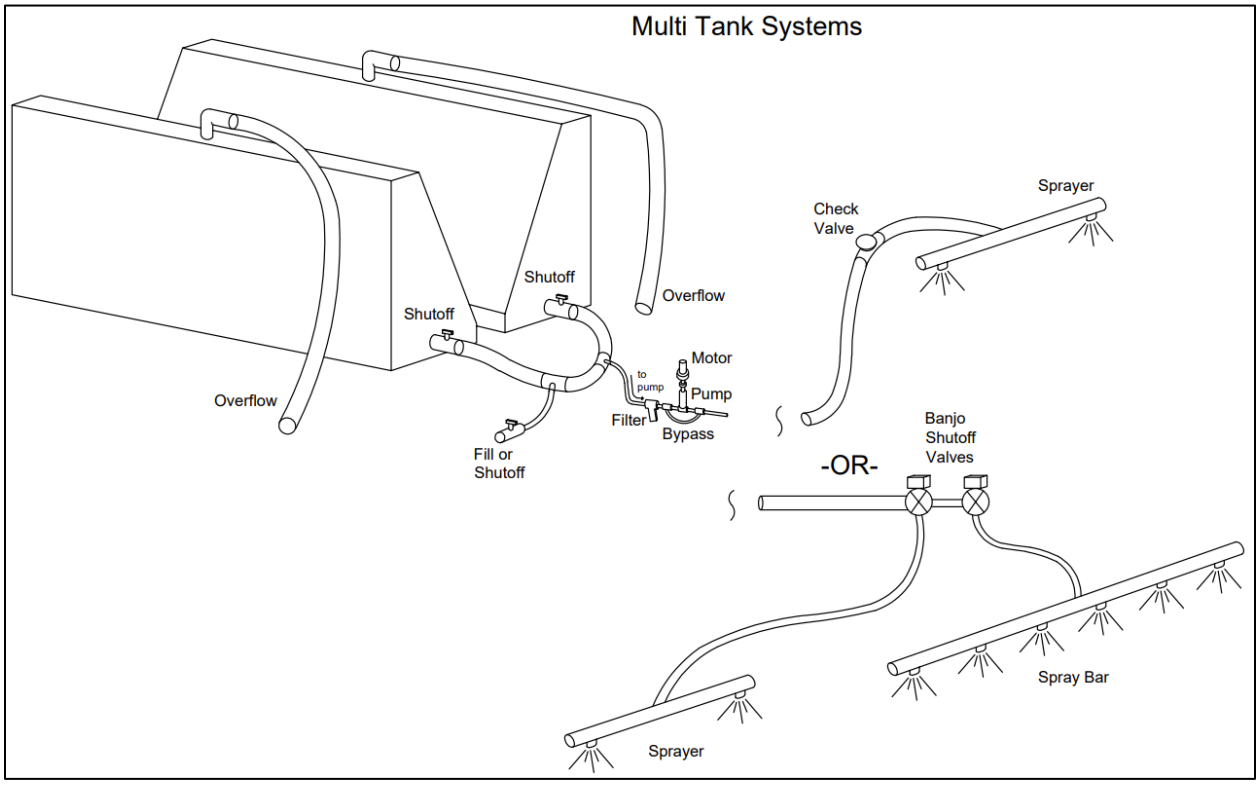
District 4: Stark County Trucks

- Combination of direct mount and slide-in units
    - Preferred direct mount trucks come equipped with broom circuit for roadway clean up
- Several pre-wetting systems were modified to treat at the auger vs. spinner
    - Preferred pre-wetting at auger because of superior clinging of granular salt
    - Teejet 11020 nozzles were most common, but significant number of machines did not have nozzles
    - Treating at 40 gal/ton at auger
- Typically operating speed is 25-45 mph (40 mph was standard)

Direct Mount Tandem Axle w/Force 6100 controller

- Live bottom truck with two, 400 gallon saddle tanks
- Pre-wetted at the auger was 3, teejet 11020 nozzles with centers drilled out
    - Operator noted the straight stream helped the brine penetrate the granular salt as it moved through the auger
- Custom built spray bar with ½ barbed elbows for nozzles
- Two pumps:
    - Varitech Centrifugal Pump (model #: 93140) w/microtrak flow sensor (PN: 14689) for anti-icing and DLA
    - Hypro 1700 XL Roller pump for prewetting w/flow meter (no serial numbers)

A.2 Diagram of Common Liquid Application System Components



Appendix B Ohio Snow and Ice Guidelines

Ohio Department of Transportation											
Materials Application Guidelines											
Conditions			Equipment	Pre-Storm		Light Snowfall*		Heavy Snowfall**		Freezing Rain	
Pavement Temperature Range, and Trend	Pavement Surface at Time of Operation	Recommended Maintenance Action	Recommended Snow Removal Equipment	Anti-icing with Salt Brine or Other Winter Liquid Blends (gallons/mile)	Comments	Pre-wet*** Rock Salt (#/mile)	Comments	Pre-wet*** Rock Salt (#/mile)	Comments	Pre-wet*** Rock Salt (#/mile)	Comments
Above 32ºF Steady or Rising	Dry, Wet, Slush, or Snow Cover	Monitor Road and Weather Conditions and Treat as Needed	Anti-Icing System, Plow, Salt Spreader, and Pre-wetting	20 -40	3, 6	Max 200	1,2,7	Max 200	1,2,4		
Below 32ºF to 20ºF Steady, Rising, or Falling	Dry, Wet, Slush, or Snow Cover	Apply Pre-wet Salt and Salt Brine as Needed	Anti-Icing System, Plow, Salt Spreader, and Pre-wetting	20 -40	3, 6	Max 400	1,2,7	Max 200	2,4	Max 400	1,7
Below 20ºF Steady or Falling	Dry, Wet, Slush, or Snow Cover	Apply Pre-wet Salt and Salt Brine with Other Winter Liquid Mixtures as Needed	Plow, Salt Spreader, and Pre-wetting		3	Max 400 #	1,2,5,8	Max 200 #	2,4,5	Max 400 #	1,5,8

* Light snowfall: less than 1" per hour

** Heavy snowfall: more than 1" per hour

*** 8 to 12 gallons of salt brine per ton minimum (preferred: maximize deicing liquid output)

8 to 12 gallons of salt brine mixture per ton minimum (preferred: maximize deicing liquid output)

Comments:

1) Monitor temperatures and road pavement conditions for icy spots. Plow and treat areas as needed.
2) Modify salt treatment on secondary routes only between 11:00pm and 5:00am (or 2 hours prior to rush hour) to 200 #/mile maximum.
3) Do not apply chemicals and maintain dry pavement during windy conditions.
4) Plowing is recommended during heavy snowfall events. Treat areas as needed.
5) Salt brine mixed with other winter liquids as per manufacturer recommendations should be used when temperatures fall below 20ºF.
6) Apply anti-icing pre-storm to prevent frost or black ice conditions. Do not anti-ice if leading edge of storm is rain.
7) Utilize direct salt brine application 40 to 90 gallons/mile as conditions warrant. Follow DLA guidance chart.
8) Utilize direct salt brine mixture application 90 gallons/mile minimum as conditions warrant. Follow DLA guidance chart.

Ohio Department of Transportation

Route Application Guidelines and Goals

Treatment of Routes During an Event	
Primary Routes	Plow and/or apply materials as determined by the materials application guidelines to eliminate hazardous areas, obtain clear pavement, and keep traffic moving throughout the event.
Secondary Routes	Plow and/or apply materials as determined by the materials application guidelines to eliminate hazardous areas and keep traffic moving throughout the event. Modify operations between 11:00pm and 5:00am (or 2 hours prior to rush hour) by plowing and reducing salt application rates to 200 #/mile maximum.

Critical Success Factor Measurement	
Primary Routes	Event recovery time is to be met within 2 hours following the end of the weather event as signified by traffic speeds recovering to within 10 mph of the expected speed for that route segment.
Secondary Routes	Event recovery time is to be met within 4 hours following the end of the weather event as signified by traffic speeds recovering to within 10 mph of the expected speed for that route segment. The hours of 11:00pm to 5:00am shall be excluded from the recovery time calculation due to the reduced salt treatment maximums during that time frame. For example: -Weather event ends at 2:00am, the 4 hour recovery time would start at 5:00am and end at 9:00am. -Weather event ends at 10:00pm, the 4 hour recovery time would start at 10:00pm and end at 8:00am (excludes the overnight

Cleanup After an Event	
Primary Routes	Obtain clear pavement as soon as practical by following material application guidelines.
Secondary	Obtain clear pavement as soon as practical by following material application guidelines.

Materials			
	Above 32°F	**32°F to 20°F**	**Below 20°F**
Pre-wet Salt	Recommended	Recommended	Recommended
Salt Brine	Recommended	Recommended	
Mixture*			Recommended
	*** Follow manufacturer recommendations.**		

Ohio Department of Transportation

DIRECT LIQUID APPLICATION RATES (DLA)

Guidelines

	(Gallons per Lane Mile)		
	Pavement Temperature		
Event Type	Above 30°F	Below 30°F to 20°F	#Below 20°F
Light Snow (Less Than 1" / Hour)	40	50 to 80	90+

Below 20°F: Utilize salt brine mixture and salt treatment as needed.

Ohio Department of Transportation

Anti-Icing Guidelines

PURPOSE

Anti-ice any identified trouble spots with liquid material for black ice, unexpected winter events, frost control, and forecasted winter events when conditions warrant.

MATERIALS

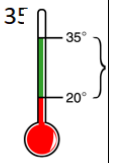
Salt Brine or equivalent

APPLICATION

Anti-ice trouble spots when conditions or forecast warrants. On higher volume roads where material may be tracked away by traffic, anti-ice as close to the onset of an event as possible.

CONDITIONS

- ☑ Roadways are dry.
- ☑ Rain is not forecasted for the next 24 hours.
- ☑ Forecasted low temperature to fall within the range of 20 to 35 degrees Fahrenheit or within critical dew point range.
- ☑ Sufficient time exists for pavement to dry before pavement temperature falls below 20 degrees Fahrenheit.
- ☑ Blowing snow is not anticipated.
- ☑ Visual observation indicates sufficient material residue does not exist.



Appendix C Snowplow Operator Interviews

C.1 *District 5: Scott, Cody, and Christopher*
Tuesday, February 14th

- All three interviewees are HT3 operators. Scott has 9 years of experience operating this type of truck; Cody has 5 years of experience; Christopher has 27 years of experience (12 of which have been specifically focused on winter operations.)
- They are most familiar with tandem trucks, but also have experience operating single axle trucks, saddle tank trucks, and others.
- Typical truck has 500- to 1200-gallon liquid capacity and 6- to 12-ton granular capacity.
- These trucks do pre-wetting and anti-icing applications. The spray bar is behind the truck and sprays right on the spinner for salt application.
- They use brine a lot, especially on bridges.
- Typical application rates are 3 to 24 gal/mi for brine and 100 to 250 lb/mi for granular.
    - Application rates are determined by guidelines and personal experience.
    - Most difficult part is knowing *when* to put down materials, rather than how much.
    - Speed can be difficult to control. Too fast means bounce, but too slow is dangerous on interstates.
- All interviewees operate trucks with Force America hydraulic system
- Pumps they use include Hypro (with 130 psi and 3000 rpm), Hypro (with 120 psi and 4600 rpm), Oberdorfer, and Ace pump.
- Routes range from 28 to 38 miles (round trip total). In operator opinions, not much time is lost during refills because they often run out of material close to the garage.
- Granular material is currently tracked by counting the number of buckets go in the truck during refills and totaling that number for each shift.
- Liquid material is currently tracked via a system called Outback that records what truck you have and how many gallons you put in at a time, activated via key fob.
- Running out of material happens sometimes. Operators report that this becomes less of an issue as they gain experience. One interviewee said he usually runs out of granular salt before brine, while the other two said they run out of liquids before granular.
- All three operators are satisfied with the pumps, but do note that valves have durability issues because they freeze up occasionally.
- One operator said they spend 80% of their time in automatic mode and 20% in manual mode, while the other two operators said they operate almost exclusively in automatic mode.
- All three interviewees indicate that they do not believe there would be significant time or material savings if the truck had more accurate material control. They trust the current rate control system and they are checked/calibrated at least twice each season.

C.2 *District 2: Josh and Alex*
Friday February 17th

- Josh and Alex have been with ODOT for about 10 years
- They operate the same truck on separate shifts: a tandem axle dump truck with a Force America operating system.
- Their garage has both Force America and Pengwyn (roughly 2:1 ratio.) They noted that switching between the two is difficult because a lot of their job is muscle memory so typically drivers will stick with one truck/system. They commented that Pengwyn does not run very well in auto mode so they choose to run in manual if they have to drive a Pengwyn. Force America is better at auto mode.
- Capacity is about 600 gallons liquid, 9-10 tons granular
- Maximum application rate is 100 gal per lane mile
- Typical route is 50-60 miles
- They are away from their route for about 45 minutes while refilling
- Unsure of pump manufacturer but it is a "fin style pump rather than a squeeze style pump"
- They replace the pump about every 3 years
- They have dual augers on their truck (a form of live-bottom truck), which allows for more efficient spreading. Both augers are running at the same time. Sometimes single auger gets jammed more easily.
- They do both pre-treating and direct liquid application, but tend to focus on ramps for the pre-treating. They have been pre-treating less in recent years because a lot of storms are starting as rain and that will wash away any early treatments. Estimate that they pre-treat for about 15% of storms.
- They were unsure of exact application rates because their computer systems tells them a percentage rather than a specific amount. They think the maximum application rate is 10 gal/mi and they usually apply at 25%, so best guess is 2.5 gal/mi. They will go up to 30-50% during a bad storm.
- There are written guidelines for choosing an application rate, but they find it more helpful to analyze the situation themselves and choose accordingly. After 3 or 4 seasons, operators get really good at making that choice for themselves and their route.
- They rarely run out of material unexpectedly. Usually they would run out of granular before liquid, but depends on the operator.
- They do not track material application. Hydraulic resistance sensors in the valve body are the closest they get to tracking. They sense the weight and give you a warning when you're low. Not always accurate, but work well when they receive regular maintenance.
- They don't think they are using the Force America system to its full potential, especially regarding material tracking. But operators would benefit from accurate tracking and think it could potentially save time and money. In general, their attitude is that the more information operators have, the better.

Appendix D Nationwide Survey Results

A nationwide survey was distributed to document current practices and experiences with snowplow hydraulic systems and liquid pumps. The survey was drafted by the research team, with modifications made based on input from the TAC. The survey is below in Section D1. The survey was distributed on November 21, 2022 and stayed open for one month. There were 15 full responses, which are provided individually in Section D2.

D.1 Survey

Do you use any liquid ice melters in your snow and ice program (including pre-wetting liquid treatments applied directly to the road and/or liquid additives applied to solid salt)?

- Yes
- Sometimes
- No (if no, the survey ends)

How are solid and liquid ice melters distributed?

- Solid in one truck, liquid in separate truck
- Solid and liquid together in one truck
- Some of both

What pump or pump system is used in your liquid application truck?

- Free answer

How long have you used this pump/system?

- 1-2 seasons
- 3-5 seasons
- 6+ seasons

Rate your overall satisfaction with the pump/system you use.

- 1-5
- Optional comments

Rate the overall accuracy of the pump/system in terms of gauging how much liquid deicer is being dispersed.

- 1-5
- Optional comments

Rate the overall reliability/durability of the system in performing during winter weather events.

- 1-5
- Optional comments

Have you done any formal testing of this equipment to evaluate its performance?

- Yes, some sort of formal research or organized evaluation was performed
- No, have relied on field experience and personnel feedback

Have you tried any other systems?

- Yes
- No
- If yes, please specify type of system and reasons for not using it anymore

D.2 Responses

Survey 1
Agency: UDOT
State/Province: Utah

Q2 Do you use brine or any liquid ice melters in your snow and ice program (including pre-wetting liquid treatments applied directly to the road and/or liquid additives applied to solid salt)?
Yes
Q3 How are solid and liquid ice melters distributed?
Selected Choice: Solid and liquid together in one truck, Liquid-only truck
Q4 What is your agency's typical liquid application rate?
For direct liquid application (Prefer answer in gallons/mile): 30
For anti-icing (Prefer answer in gallons/mile): 30
For pre-wetting (Prefer answer in gallons/ton): 30
Q5 What type of hydraulic systems do you use in trucks used for snow and ice removal?
Selected Choice: FORCE America, please specify model
Text: 5100EX 6100
Q7 Is your liquid pump or pump system integrated into the hydraulic system or is it a stand-alone system that feeds into the hydraulic system data?
Selected Choice: Pump and hydraulic system integrated
Q9 Please tell us about the pump(s) you use in your fleet, how many you have, and how long you have used them. If you have multiple, use a new row for each one.
Left blank
Q8 Are the pump outputs collected by the truck's hydraulic system?
Selected Choice: Don't know
Q12 Does your system automatically modify the pump speed to adapt to changes in truck operating speed?
Selected Choice: Yes
Q13 Please rate the following attributes of the pump/pump system you use. (5 is best)
Overall satisfaction: 4
Accuracy in terms of gauging how much liquid is being dispersed: 4
Reliability in performing during winter weather events: 4
Q14 Have you done any formal testing of this equipment to evaluate its performance?
No, have relied on field experience and personnel feedback
Q15 Have you tried any other systems?
Selected Choice: No

Survey 2
Agency: WYDOT
State/Province: Wyoming

Q2 Do you use brine or any liquid ice melters in your snow and ice program (including pre-wetting liquid treatments applied directly to the road and/or liquid additives applied to solid salt)?
Yes
Q3 How are solid and liquid ice melters distributed?
Selected Choice: Solid and liquid together in one truck
Q4 What is your agency's typical liquid application rate?
Other comments: -10 gal/ton at the spinner
Q5 What type of hydraulic systems do you use in trucks used for snow and ice removal? –
Selected Choice: FORCE America, please specify model
Text: left blank
Q7 Is your liquid pump or pump system integrated into the hydraulic system or is it a stand-alone system that feeds into the hydraulic system data?
Selected Choice: Pump is separate from hydraulic system
Q9 Please tell us about the pump(s) you use in your fleet, how many you have, and how long you have used them. If you have multiple, use a new row for each one.
Left blank
Q8 Are the pump outputs collected by the truck's hydraulic system?
Selected Choice: Don't know
Q12 Does your system automatically modify the pump speed to adapt to changes in truck operating speed?
Selected Choice: Comments
Text: I believe it does
Q13 Please rate the following attributes of the pump/pump system you use. (5 is best)
Overall satisfaction: left blank
Accuracy in terms of gauging how much liquid is being dispersed: left blank
Reliability in performing during winter weather events: left blank
Q14 Have you done any formal testing of this equipment to evaluate its performance?
No, have relied on field experience and personnel feedback
Q15 Have you tried any other systems?
Selected Choice: Yes; if so, please specify type of system and reasons for not using it anymore.
Text: left blank

Survey 3
Agency: WVDOH
State/Province: West Virginia

Q2 Do you use brine or any liquid ice melters in your snow and ice program (including pre-wetting liquid treatments applied directly to the road and/or liquid additives applied to solid salt)?

Yes

Q3 How are solid and liquid ice melters distributed?

Selected Choice: Solid and liquid together in one truck, Liquid-only truck

Q4_1 What is your agency's typical liquid application rate?

For direct liquid application (Prefer answer in gallons/mile): left blank

For anti-icing (Prefer answer in gallons/mile): 60

For pre-wetting (Prefer answer in gallons/ton): 10

Q5 What type of hydraulic systems do you use in trucks used for snow and ice removal?

Selected Choice: Other, please specify model

Text: Certified Power Solutions, XDS

Q7 Is your liquid pump or pump system integrated into the hydraulic system or is it a stand-alone system that feeds into the hydraulic system data?

Selected Choice: Pump and hydraulic system integrated

Q9 Please tell us about the pump(s) you use in your fleet, how many you have, and how long you have used them. If you have multiple, use a new row for each one.

Make/model of Pump 1: Danfoss, Series 45 J frame 75 cc, PTO mounted running at 116%

How many of these pumps are in your fleet?: left blank

How many seasons have you used it?: 13

Q8 Are the pump outputs collected by the truck's hydraulic system?

Selected Choice: No

Q12 Does your system automatically modify the pump speed to adapt to changes in truck operating speed?

Selected Choice: Yes

Q13 Please rate the following attributes of the pump/pump system you use. (5 is best)

Overall satisfaction: 5

Accuracy in terms of gauging how much liquid is being dispersed: 5

Reliability in performing during winter weather events: 5

Q14 Have you done any formal testing of this equipment to evaluate its performance?

No, have relied on field experience and personnel feedback

Q15 Have you tried any other systems?

Selected Choice: No

Survey 4
Agency: RM Balgowan Forensics
State/Province: New Jersey

Q2 Do you use brine or any liquid ice melters in your snow and ice program (including pre-wetting liquid treatments applied directly to the road and/or liquid additives applied to solid salt)?
Yes
Q3 How are solid and liquid ice melters distributed?
Selected Choice: Solid and liquid together in one truck, Liquid-only truck
Q4 What is your agency's typical liquid application rate?
For direct liquid application (Prefer answer in gallons/mile): left blank
For anti-icing (Prefer answer in gallons/mile): 40 gallons per lane mile
For pre-wetting (Prefer answer in gallons/ton): 8 gallons per ton
Q5 What type of hydraulic systems do you use in trucks used for snow and ice removal?
Selected Choice: FORCE America, please specify model
Text: left blank
Selected Choice: Other, please specify model
Text: left blank
Q7 Is your liquid pump or pump system integrated into the hydraulic system or is it a stand-alone system that feeds into the hydraulic system data?
Selected Choice: Pump and hydraulic system integrated
Q9 Please tell us about the pump(s) you use in your fleet, how many you have, and how long you have used them. If you have multiple, use a new row for each one.
Left blank
Q8 Are the pump outputs collected by the truck's hydraulic system?
Selected Choice: Don't know
Q12 Does your system automatically modify the pump speed to adapt to changes in truck operating speed?
Selected Choice: Don't know
Q13_1 Please rate the following attributes of the pump/pump system you use. (5 is best)
Overall satisfaction: 5
Accuracy in terms of gauging how much liquid is being dispersed: 5
Reliability in performing during winter weather events: 5
Q14 Have you done any formal testing of this equipment to evaluate its performance?
No, have relied on field experience and personnel feedback
Q15 Have you tried any other systems?
Selected Choice: Yes; if so, please specify type of system and reasons for not using it anymore.
Text: left blank

Survey 5
Agency: Iowa DOT
State/Province: Iowa

Q2 Do you use brine or any liquid ice melters in your snow and ice program (including pre-wetting liquid treatments applied directly to the road and/or liquid additives applied to solid salt)?

Yes

Q3 How are solid and liquid ice melters distributed?

Selected Choice: Other, please explain

Text: We utilize both. All snowplow trucks are set up to handle both liquids and solids plus we have a number of semi-tractors with trailers that apply liquid only.

Q4 What is your agency's typical liquid application rate?

For direct liquid application (Prefer answer in gallons/mile): 5-50 gallons per lane mile

For anti-icing (Prefer answer in gallons/mile): 5-50 gallons per lane mile

For pre-wetting (Prefer answer in gallons/ton): 5-50 gallons per lane mile

Q5 What type of hydraulic systems do you use in trucks used for snow and ice removal?

Selected Choice: Other, please specify model

Text: Danfoss

Q7 Is your liquid pump or pump system integrated into the hydraulic system or is it a stand-alone system that feeds into the hydraulic system data?

Selected Choice: Pump and hydraulic system integrated

Q9 Please tell us about the pump(s) you use in your fleet, how many you have, and how long you have used them. If you have multiple, use a new row for each one.

Make/model of Pump 1: Danfoss

How many of these pumps are in your fleet?: 900+

How many seasons have you used it?: 10-12

Q8 Are the pump outputs collected by the truck's hydraulic system?

Selected Choice: Yes, Comments

Text: The materials information is collected through our Cirus Spreader Controller

Q12 Does your system automatically modify the pump speed to adapt to changes in truck operating speed?

Selected Choice: Yes

Q13 Please rate the following attributes of the pump/pump system you use. (5 is best)

Overall satisfaction: 5

Accuracy in terms of gauging how much liquid is being dispersed: 4

Reliability in performing during winter weather events: 5

Q14 Have you done any formal testing of this equipment to evaluate its performance?:

Yes, some sort of formal research or organized evaluation was performed

Q15 Have you tried any other systems?

Selected Choice: No

Survey 6
Agency: McHenry County DOT
State/Province: Illinois

Q2 Do you use brine or any liquid ice melters in your snow and ice program (including pre-wetting liquid treatments applied directly to the road and/or liquid additives applied to solid salt)?
Yes
Q3 How are solid and liquid ice melters distributed?
Selected Choice: Solid and liquid together in one truck, Liquid-only truck, Other, please explain
Text: We have four liquid-only routes.
Q4 What is your agency's typical liquid application rate?
For direct liquid application (Prefer answer in gallons/mile): 40-80
For anti-icing (Prefer answer in gallons/mile): 40
For pre-wetting (Prefer answer in gallons/ton): 8-22
Q5 What type of hydraulic systems do you use in trucks used for snow and ice removal?
Selected Choice: FORCE America, please specify model
Text: 6100
Q7 Is your liquid pump or pump system integrated into the hydraulic system or is it a stand-alone system that feeds into the hydraulic system data?
Selected Choice: Pump and hydraulic system integrated
Q9 Please tell us about the pump(s) you use in your fleet, how many you have, and how long you have used them. If you have multiple, use a new row for each one.
Make/model of Pump 1: Varitech
How many of these pumps are in your fleet?: 25
How many seasons have you used it?: 8
Q8 Are the pump outputs collected by the truck's hydraulic system?
Selected Choice: Yes
Q12 Does your system automatically modify the pump speed to adapt to changes in truck operating speed?
Selected Choice: Yes
Q13 Please rate the following attributes of the pump/pump system you use. (5 is best)
Overall satisfaction: 4
Accuracy in terms of gauging how much liquid is being dispersed: 4
Reliability in performing during winter weather events: 4
Q14 Have you done any formal testing of this equipment to evaluate its performance?
No, have relied on field experience and personnel feedback
Q15 Have you tried any other systems?
Selected Choice: Yes; if so, please specify type of system and reasons for not using it anymore.
Text: Spread Smart and Raven
Additional comments: We test our equipment by calibrating the spreader systems multiple times a year so even though we have not completed formal research, we perform our own in-house testing.

Survey 7
Agency: Alaska DOT
State/Province: Alaska

Q2 Do you use brine or any liquid ice melters in your snow and ice program (including pre-wetting liquid treatments applied directly to the road and/or liquid additives applied to solid salt)?:
Yes
Q3 How are solid and liquid ice melters distributed?
Selected Choice: Solid and liquid together in one truck, Liquid-only truck
Q4 What is your agency's typical liquid application rate?
For direct liquid application (Prefer answer in gallons/mile): 60 gallons/ lane mile
For anti-icing (Prefer answer in gallons/mile): left blank
For pre-wetting (Prefer answer in gallons/ton): left blank
Other comments: Very wx dependent
Q5 What type of hydraulic systems do you use in trucks used for snow and ice removal?
Selected Choice: FORCE America, please specify model
Q5_1_TEXT What type of hydraulic systems do you use in trucks used for snow and ice removal?
FORCE America, please specify model
Q7 Is your liquid pump or pump system integrated into the hydraulic system or is it a stand-alone system that feeds into the hydraulic system data?
Selected Choice: Pump and hydraulic system integrated
Q9_1_TEXT Please tell us about the pump(s) you use in your fleet, how many you have, and how long you have used them. If you have multiple, use a new row for each one.
Make/model of the Pump 1: Varitech
How many of these pumps are in your fleet?: 10
How many seasons have you used it?: 10
Q8 Are the pump outputs collected by the truck's hydraulic system?
Selected Choice: Yes
Q12 Does your system automatically modify the pump speed to adapt to changes in truck operating speed?
Selected Choice: Yes, Comments
Text: We operate mostly in manual mode
Q13_1 Please rate the following attributes of the pump/pump system you use. (5 is best)
Overall satisfaction: 3
Accuracy in terms of gauging how much liquid is being dispersed: 2
Reliability in performing during winter weather events: 2
Q14 Have you done any formal testing of this equipment to evaluate its performance?:
No, have relied on field experience and personnel feedback
Q15 Have you tried any other systems?
Selected Choice: Yes; if so, please specify type of system and reasons for not using it anymore.
Text: Gravity feed tanker

Survey 8
Agency: Idaho Transportation Department
State/Province: Idaho

Q2 Do you use brine or any liquid ice melters in your snow and ice program (including pre-wetting liquid treatments applied directly to the road and/or liquid additives applied to solid salt)?:
Yes
Q3 How are solid and liquid ice melters distributed?
Selected Choice: Solid and liquid together in one truck, Liquid-only truck
Q4 What is your agency's typical liquid application rate?
For direct liquid application (Prefer answer in gallons/mile): 35 to 60 gal/miles
For anti-icing (Prefer answer in gallons/mile): 35 to 60 gal/mile
For pre-wetting (Prefer answer in gallons/ton): 8 to 20 gal/ton
Q5 What type of hydraulic systems do you use in trucks used for snow and ice removal?
Selected Choice: Other, please specify model
Text: Certified Power Solutions SpreadSmart RX
Q7 Is your liquid pump or pump system integrated into the hydraulic system or is it a stand-alone system that feeds into the hydraulic system data?
Selected Choice: Pump and hydraulic system integrated
Q9 Please tell us about the pump(s) you use in your fleet, how many you have, and how long you have used them. If you have multiple, use a new row for each one.
Make/model of the Pump 1: Oberdorfer N4000515
How many of these pumps are in your fleet?: 330
How many seasons have you used it?: 10
Make/model of Pump 2: Hypro 9306S
How many of these pumps are in your fleet?: 100
How many seasons have you used it?: 10
Q8 Are the pump outputs collected by the truck's hydraulic system?
Selected Choice: Yes
Q12 Does your system automatically modify the pump speed to adapt to changes in truck operating speed?
Selected Choice: Yes
Q13 Please rate the following attributes of the pump/pump system you use. (5 is best)
Overall satisfaction: 4
Accuracy in terms of gauging how much liquid is being dispersed: 4
Reliability in performing during winter weather events: 3
Q14 Have you done any formal testing of this equipment to evaluate its performance?
No, have relied on field experience and personnel feedback
Q15 Have you tried any other systems?
Selected Choice: Yes; if so, please specify type of system and reasons for not using it anymore.
Text: Various tests of other pumps, but have not switched.
Additional comments: As far as pump output, the output is measured by a flow meter fed to the spreader controller, not the pump

Survey 9
Agency: Maryland DOT SHA
State/Province: Maryland

Q2 Do you use brine or any liquid ice melters in your snow and ice program (including pre-wetting liquid treatments applied directly to the road and/or liquid additives applied to solid salt)?:
Yes
Q3 How are solid and liquid ice melters distributed?
Selected Choice: Solid and liquid together in one truck, Liquid-only truck
Q4 What is your agency's typical liquid application rate?
For direct liquid application (Prefer answer in gallons/mile): 50/ 60 gal per mile
For anti-icing (Prefer answer in gallons/mile): 40/65 mile
For pre-wetting (Prefer answer in gallons/ton): 6-16/ ton
Q5 What type of hydraulic systems do you use in trucks used for snow and ice removal?
Selected Choice: FORCE America, please specify model
Text: 5100, 6100
Q7 Is your liquid pump or pump system integrated into the hydraulic system or is it a stand-alone system that feeds into the hydraulic system data?
Selected Choice: Pump and hydraulic system integrated
Q9 Please tell us about the pump(s) you use in your fleet, how many you have, and how long you have used them. If you have multiple, use a new row for each one.
Make/model of the Pump 1: Varitech
How many of these pumps are in your fleet?: 585
How many seasons have you used it?: 15
Make/model of pump 2 - Text: Henderson
How many of these pumps are in your fleet?: 38
How many seasons have you used it?: 5
Q8 Are the pump outputs collected by the truck's hydraulic system?
Selected Choice: Yes
Q12 Does your system automatically modify the pump speed to adapt to changes in truck operating speed?
Selected Choice: Yes
Q13 Please rate the following attributes of the pump/pump system you use. (5 is best)
Overall satisfaction: 5
Accuracy in terms of gauging how much liquid is being dispersed: 5
Reliability in performing during winter weather events: 5
Q14 Have you done any formal testing of this equipment to evaluate its performance?:
Yes, some sort of formal research or organized evaluation was performed
Q15 Have you tried any other systems?
Selected Choice: No

Survey 10
Agency: Delaware DOT
State/Province: Delaware

Q2 Do you use brine or any liquid ice melters in your snow and ice program (including pre-wetting liquid treatments applied directly to the road and/or liquid additives applied to solid salt)?:
Yes
Q3 How are solid and liquid ice melters distributed?
Selected Choice: Solid and liquid together in one truck, Liquid-only truck
Q4 What is your agency's typical liquid application rate?
For direct liquid application (Prefer answer in gallons/mile): 80gal/lane mile
For anti-icing (Prefer answer in gallons/mile): 80gal/lane mile
For pre-wetting (Prefer answer in gallons/ton): 10-14gal/ton
Q5 What type of hydraulic systems do you use in trucks used for snow and ice removal?
Selected Choice: Other, please specify model
Text: certified cirus
Q7 Is your liquid pump or pump system integrated into the hydraulic system or is it a stand-alone system that feeds into the hydraulic system data?
Selected Choice: Pump and hydraulic system integrated
Q9 Please tell us about the pump(s) you use in your fleet, how many you have, and how long you have used them. If you have multiple, use a new row for each one.
Left blank
Q8 Are the pump outputs collected by the truck's hydraulic system?
Selected Choice: Yes
Q12 Does your system automatically modify the pump speed to adapt to changes in truck operating speed?
Selected Choice: Yes
Q13 Please rate the following attributes of the pump/pump system you use. (5 is best)
Overall satisfaction: 3
Accuracy in terms of gauging how much liquid is being dispersed: 4
Reliability in performing during winter weather events: 3
Q14 Have you done any formal testing of this equipment to evaluate its performance?:
No, have relied on field experience and personnel feedback
Q15 Have you tried any other systems?
Selected Choice: No

Survey 11
Agency: MDOT
State/Province: Michigan

Q2 Do you use brine or any liquid ice melters in your snow and ice program (including pre-wetting liquid treatments applied directly to the road and/or liquid additives applied to solid salt)?:
Yes
Q3 How are solid and liquid ice melters distributed?
Selected Choice: Solid and liquid together in one truck, Liquid-only truck
Q4 What is your agency's typical liquid application rate?
For direct liquid application (Prefer answer in gallons/mile): 50-70 gal/mi
For anti-icing (Prefer answer in gallons/mile): left blank
For pre-wetting (Prefer answer in gallons/ton): 7-10 gal/ton
Other comments: we are piloting DLA on three routes.
Q5 What type of hydraulic systems do you use in trucks used for snow and ice removal?
Selected Choice: Other, please specify model
Text: do not know
Q7 Is your liquid pump or pump system integrated into the hydraulic system or is it a stand-alone system that feeds into the hydraulic system data?
Selected Choice: Other, please explain
Text: do not know
Q8 Are the pump outputs collected by the truck's hydraulic system?
Left blank
Q12 Does your system automatically modify the pump speed to adapt to changes in truck operating speed?
Selected Choice: Don't know
Q13 Please rate the following attributes of the pump/pump system you use. (5 is best)
Overall satisfaction: left blank
Accuracy in terms of gauging how much liquid is being dispersed: left blank
Reliability in performing during winter weather events: left blank
Q14 Have you done any formal testing of this equipment to evaluate its performance?:
Left blank
Q15 Have you tried any other systems?
Left blank

Survey 12
Agency: Nebraska DOT
State/Province: Nebraska

Q2 Do you use brine or any liquid ice melters in your snow and ice program (including pre-wetting liquid treatments applied directly to the road and/or liquid additives applied to solid salt)?:
Yes
Q3 How are solid and liquid ice melters distributed?
Selected Choice: Solid and liquid together in one truck, Liquid-only truck
Q4 What is your agency's typical liquid application rate?
For direct liquid application (Prefer answer in gallons/mile): 35-80
For anti-icing (Prefer answer in gallons/mile): bridges only
For pre-wetting (Prefer answer in gallons/ton): 8-12
Q5 What type of hydraulic systems do you use in trucks used for snow and ice removal?
Selected Choice: FORCE America, please specify model
Text: 6100, 5100EX
Other, please specify model
Text: Certified Power Freedom ACS, Freedom 2, GL400
Q7 Is your liquid pump or pump system integrated into the hydraulic system or is it a stand-alone system that feeds into the hydraulic system data?
Selected Choice: Pump and hydraulic system integrated
Q9 Please tell us about the pump(s) you use in your fleet, how many you have, and how long you have used them. If you have multiple, use a new row for each one.
Left blank
Q8 Are the pump outputs collected by the truck's hydraulic system?
Selected Choice: Yes
Q12 Does your system automatically modify the pump speed to adapt to changes in truck operating speed?
Selected Choice: Yes
Q12_4_TEXT Does your system automatically modify the pump speed to adapt to changes in truck operating speed? - Comments - Text:
Q1 Please rate the following attributes of the pump/pump system you use. (5 is best)
Overall satisfaction: left blank
Accuracy in terms of gauging how much liquid is being dispersed: left blank
Reliability in performing during winter weather events: left blank
Q14 Have you done any formal testing of this equipment to evaluate its performance?:
No, have relied on field experience and personnel feedback
Q15 Have you tried any other systems?
Selected Choice: No
Additional comments: We use rock salt much more than liquids. I don't have information on the pumps at this time, but will email you if I can get the information reasonably soon.

Survey 13
Agency: NDDOT
State/Province: North Dakota

Q2 Do you use brine or any liquid ice melters in your snow and ice program (including pre-wetting liquid treatments applied directly to the road and/or liquid additives applied to solid salt)?:
Yes
Q3 How are solid and liquid ice melters distributed?
Selected Choice: Liquid-only truck
Q4 What is your agency's typical liquid application rate?
For direct liquid application (Prefer answer in gallons/mile): 20-150 gal per lane
For anti-icing (Prefer answer in gallons/mile): 20-80 gal per lane
For pre-wetting (Prefer answer in gallons/ton): 3 gal per lane mile
Q5 What type of hydraulic systems do you use in trucks used for snow and ice removal?
Selected Choice: FORCE America, please specify model
Q7 Is your liquid pump or pump system integrated into the hydraulic system or is it a stand-alone system that feeds into the hydraulic system data?
Selected Choice: Pump and hydraulic system integrated
Q9 Please tell us about the pump(s) you use in your fleet, how many you have, and how long you have used them. If you have multiple, use a new row for each one.
Make/model of the Pump 1: high pro 3 in inlet 2 in outlet
How many of these pumps are in your fleet?: 8
How many seasons have you used it?: 10
Q8 Are the pump outputs collected by the truck's hydraulic system?
Selected Choice: Yes
Q12 Does your system automatically modify the pump speed to adapt to changes in truck operating speed?
Selected Choice: Yes
Q13 Please rate the following attributes of the pump/pump system you use. (5 is best)
Overall satisfaction: 5
Accuracy in terms of gauging how much liquid is being dispersed: 5
Reliability in performing during winter weather events: 5
Q14 Have you done any formal testing of this equipment to evaluate its performance?:
Yes, some sort of formal research or organized evaluation was performed
Q15 Have you tried any other systems?
Selected Choice: No

Survey 14
Agency: Road Commission for Oakland County
State/Province: Michigan

Q2 Do you use brine or any liquid ice melters in your snow and ice program (including pre-wetting liquid treatments applied directly to the road and/or liquid additives applied to solid salt)?:
Yes
Q3 How are solid and liquid ice melters distributed?
Selected Choice: Solid and liquid together in one truck, Liquid-only truck
Q4 What is your agency's typical liquid application rate?
For direct liquid application (Prefer answer in gallons/mile): Approx. 100gal/mile
For anti-icing (Prefer answer in gallons/mile): Approx. 40gal/mile
For pre-wetting (Prefer answer in gallons/ton): Approx. 10gal/ton
Other comments: still experimenting with direct de-icing application rate
Q5 What type of hydraulic systems do you use in trucks used for snow and ice removal?
Selected Choice: FORCE America, please specify model
Text: 5100
Other, please specify model
Text: Rexroth CS550
Q7 Is your liquid pump or pump system integrated into the hydraulic system or is it a stand-alone system that feeds into the hydraulic system data?
Selected Choice: Other, please explain
Text: Some Epoke units
Q9 Please tell us about the pump(s) you use in your fleet, how many you have, and how long you have used them. If you have multiple, use a new row for each one.
Make/model of the Pump 1: Varitech
How many of these pumps are in your fleet?: 36
How many seasons have you used it?: left blank
Make/model of pump 2: Oberdorfer
How many of these pumps are in your fleet?: 104
How many seasons have you used it?: left blank
Make/model of pump 3: Hypro 9307
How many of these pumps are in your fleet?: 9
How many seasons have you used it?: left blank
Q8 Are the pump outputs collected by the truck's hydraulic system?
Selected Choice: Yes, Comments
Comments - Text: When in closed loop mode
Q12 Does your system automatically modify the pump speed to adapt to changes in truck operating speed?
Selected Choice: Yes
Q13 Please rate the following attributes of the pump/pump system you use. (5 is best)
Overall satisfaction: 2
Accuracy in terms of gauging how much liquid is being dispersed: 2
Reliability in performing during winter weather events: 2

Q14 Have you done any formal testing of this equipment to evaluate its performance?:

No, have relied on field experience and personnel feedback

Q15 Have you tried any other systems?

Selected Choice: Yes; if so, please specify type of system and reasons for not using it anymore.

Text: We've had a few pump versions over the years.

Additional comments: The small, low volume pre-wet pumps are prone to clog/malfunction. Difficult to get "closed loop" ground speed control to function properly. Frequently run in "manual" control mode.

Survey 15
Agency: Maine DOT
State/Province: Maine

Q2 Do you use brine or any liquid ice melters in your snow and ice program (including pre-wetting liquid treatments applied directly to the road and/or liquid additives applied to solid salt)?:
Yes
Q3 How are solid and liquid ice melters distributed?
Selected Choice: Solid and liquid together in one truck
Q4_1 What is your agency's typical liquid application rate?
For direct liquid application (Prefer answer in gallons/mile): left blank
For anti-icing (Prefer answer in gallons/mile): left blank
For pre-wetting (Prefer answer in gallons/ton): 6,8,10,12 gallons
Q5 What type of hydraulic systems do you use in trucks used for snow and ice removal?
Selected Choice: Other, please specify model
Text: Sauer Dan Foss, Cirus
Q7 Is your liquid pump or pump system integrated into the hydraulic system or is it a stand-alone system that feeds into the hydraulic system data?
Selected Choice: Pump is separate from hydraulic system
Q9 Please tell us about the pump(s) you use in your fleet, how many you have, and how long you have used them. If you have multiple, use a new row for each one.
Make/model of the Pump 1: flojet
How many of these pumps are in your fleet?: 400
How many seasons have you used it?: 8
Q8 Are the pump outputs collected by the truck's hydraulic system?
Selected Choice: No
Q12 Does your system automatically modify the pump speed to adapt to changes in truck operating speed?
Selected Choice: Yes
Q13 Please rate the following attributes of the pump/pump system you use. (5 is best)
Overall satisfaction: 4
Accuracy in terms of gauging how much liquid is being dispersed: 3
Reliability in performing during winter weather events: 5
Q14 Have you done any formal testing of this equipment to evaluate its performance?:
Yes, some sort of formal research or organized evaluation was performed
Q15 Have you tried any other systems?
Selected Choice: Yes; if so, please specify type of system and reasons for not using it anymore.
Text: Reed Contol Systems, still currently using

Appendix E Evaluation Matrix

E.1 Evaluation Criteria and Testing Approaches

Criteria	Elements of criteria	Recommended evaluation protocols
Durability and reliability	How corrosion resistant are the metal components?	*Corrosion test in laboratory based on ASTM B117 salt spray test. Test durations of 96, 240, 480, and 1,000 hours should be considered to determine the most appropriate duration to simulate the harsh conditions and long-term exposure to saltwater that the pump might experience during its service life.*
	Can it operate under extreme temperatures?	*stress test components. Choose temperature range that is based on Ohio's minimum and average temperatures during the last 20 years. Recommended temperature range 34 °F (1 °C) to -22 °F (-30 °C)*
	Will rubber components be susceptible to deterioration?	*Select from a number of stress tests for rubber: ASTM D430 (dynamic fatigue), D1329 (low temperature), D1148 (UV/heat exposure). Alternately, perform a literature review based on material specifications.*
	How often would it have to be replaced?	*Manufacturer information combined with laboratory test results*
Accuracy	Does it work at high flow and low flow?	*Create a closed loop course. Test a range of flow rates, vehicle speeds, and materials; weigh truck before and after application and compare measurements to system's computer output. Alternatively, put down mats to catch material, collect it using squeegees, and weigh it; use Iowa's 2013 report "Measuring Salt Retention" as a guide.*
	Does it work at high speeds and low speeds?	
	Does it work with various materials and brine concentrations?	
	Can operators manipulate the application rate quickly and accurately?	
Ease of use	Can it be integrated into current hydraulic system?	*This may require different approaches depending on whether evaluation of add-ons to current system or novel systems.*
	Will operators be able to easily adopt the new system?	*Determining a new system will require feedback and buy-in from the operators; confirm that users are willing to adopt.*
	Can new system be standardized throughout the state?	*Confirm that variable weather conditions across state and varying route lengths are conducive with all potential systems.*
	Is it serviceable? Is vendor support available for training or help?	*Manufacturer information combined with feedback from other agency users*
	Can it be integrated with GPS AVL system?	*Manufacturer information combined with feedback from other agency users*
Cost	What is the system's full cost?	*Perform a cost-benefit analysis based on manufacturer information and results of testing. Include up-front costs, maintenance costs, expected lifespan and, if applicable, associated costs of specialized associated equipment.*
	Can individual parts be replaced without replacing the entire system?	*Manufacturer information combined with feedback from other agency users*
	Can it reduce material or fuel costs?	*If efficiency can be proven, calculate how that translates to less material usage, shortened routes, or other measures.*

Please use the following scoring matrix as an aid in evaluating each pump/pump system

Criteria	Weight	Score Points Value (0-10)
Durability and reliability	40%	
Accuracy	30%	
Ease of use	20%	
Cost	10%	
Total	100%	

E.2 Liquid Pump Types for Testing on ODOT Vehicles

ODOT trucks need a liquid pump that is dependable, serviceable, and capable of accurately delivering a wide range of flow rates (e.g. 2 to 30 gpm). Currently, several different pump types can perform the tasks needed by ODOT trucks, but each require slightly different plumbing configurations and flow-control hardware. Below are the general strengths and weaknesses that should be considered when selecting a specific pump from the various types:

Pump Type	Strengths	Weaknesses
Centrifugal	• Capable of generating high flow rates needed for anti-icing and DLA applications • Designed to operate at temperatures <32˚F • Relatively easy to service • Most components are replaceable • Does not require a pressure relief system	• Disruptions on suction line can cause priming and performance issues • Pump is easily damaged if run dry for prolonged periods • Is not self-priming
Gear	• Capable of generating high flow rates needed for anti-icing and DLA applications • Best suited for flow rates <15 gpm • Self priming • Produce a known volumetric output per pump revolution • Designed to operate at temperatures <32˚F	• Unable to provide high flow rates required for anti-icing and DLA • Gear tolerances can be eroded if pumping solution contains abrasive material • Requires a pressure relief system
Diaphragm	• Well suited for handling abrasive materials • Self priming • Can run dry without damage • Produce a known volumetric output per pump revolution • Most components are serviceable • 12V powered options for flow rates <5 gpm	• Limited production of low-pressure models • Better suited for high pressure applications • Restriction on the suction side of pump can cause a major pump failure • Significantly higher cost compared to other pump styles • Require a pressure relief valve
Piston	• Produce a known volumetric output per stroke • Single or double action pumping	• Generally used for high pressure applications

		• Capable of handling a wide range of fluid viscosities •		• Pump seal material must be compatible with salt brine • Solutions with high turbidity can accelerate pump wear • Require a properly sized pressure relief valve
Roller		• Produce a known volumetric output per pump revolution • Capable of a wide range of flow rates • Easy to service and repair • Relatively low cost		• Better suited for high pressure applications • Abrasive materials cause excessive pump wear • Should not pump fluids below 34°F • Running pump dry can damage bearings • Requires a pressure relief valve