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EXPERIMENTAL STUDIES ON DEVELOPMENT OF SUSTAINABLE AGRICULTURAL-BASED ROAD TRANSPORT DEICING APPLICATIONS

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Abstract: Snow and ice removal on highways and public streets is critical for safe operation of the road transportation infrastructure. The issues to be addressed in selecting suitable deicing and anti-icing materials include cost, effectiveness, and damage to the pavement, vehicles and the environment. Considerable research has been carried out in recent years to develop alternative deicers with better performance and cost effectiveness. Among the developed deicer materials are agricultural based deicers that are considered to be sustainable and environmentally-beneficial materials. Iowa is one of the States that is rich in agricultural renewable resources, some of which are being processed for applications such as fuel. Any industrial process, including that of converting corn to ethanol or soy to bio-diesel, is likely to have a number of by-products generated. Rather than face disposal issues for these by-products, it would be desirable to find those that, with a minimum of additional processing, can be used as a deicing compound, either alone, or in combination with products currently in use. Currently, a number of agricultural based deicer materials have been developed or are still under development. However, little information is known about the actual manufacturing/refining process since most of the developed materials are all proprietary products (patented or commercial). Furthermore, no standard test specifying agricultural-based deicer is available. The study described in this paper focuses on the development of an improved agricultural based deicing product. The objective of this study was to evaluate deicer materials including traditional and alternative deicer materials on road skid resistance which is critical for safe operation of the road transportation infrastructure.

Keywords: corn, soy, ethanol, glycerol, sodium chloride, calcium chloride, pavement, skid resistance.

1. Introduction

Snow and ice removal on public streets is a critical part of the work of departments of transportation in northern U.S. states, including Iowa. Traditionally, sand has been used to provide traction, while cheap salts such as sodium and calcium chloride have been used to melt ice.

The traditional method of pavement deicing consists of plowing to remove the bulk of the snow cover followed by the application of sand and/or deicing

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chemicals. Sand improves traction and acts through mechanical action to break down ice. Deicing chemicals act to melt the remaining ice and packed snow and to prevent subsequent snow from accumulating on the pavement surface (Taggart et al., 2002). For example, chloride salts react with snow to form a layer of salty water (i.e., brine) that has a freezing point below 32°F (0°C). The brine helps to break the bond between the ice and the road surface, which allows the resulting mixture to be plowed from the road (TAC, 1999). A more recent approach has been the application of salts before the snow event, either as solids or as a slurry. These compounds prevent a bond from forming between the pavement and the ice layer, making plowing much simpler and more effective (Pacific Northwest Snowfighters, 2002). A variety of salts are used in this application, including magnesium chloride and potassium acetate.

The field of snow and ice removal is well summarized by the The Snowfighters Handbook (Salt Institute, 2007) and is the sphere of expertise of consortia such as the Pacific Northwest Snowfighters (PNS) Association. Considerable work has also been published on the relative benefits of different compounds (Levelton Consultants, 2007) and how they can be assessed (Chappelow and Darwin, 1992).

A negative side effect of deicing pavement surfaces is that the crystallization of salts is expansive and can cause damage to the pavement, particularly if the pavement is concrete. In addition, it has been shown that some of the deicing compounds recently promoted can chemically attack the concrete itself (Sutter, 2007). Use of small entrained air bubbles is the standard means of providing protection from the freezing effects, but work is continuing on finding reliable methods to protect concrete from chemical attack. Materials such as magnesium chloride and potassium acetate are the topics of extensive research and debate as the mechanisms behind their affects are investigated (Rangaraju and Olek, 2011; Sutter, 2008).

Asphalt surfaces are generally less affected by traditional deicing salts, but compounds containing acetates and formates have been shown to cause distress (Alatyppo and Valtonen, 2007). Ethylene glycol has also been implicated in airfield distress (Advanced Asphalt Technologies, 2009).

Organic materials generally have acceptable ice melting performance, but tend to be viscous, potentially leading to problems with placing them uniformly on the pavement, and with reduced skid resistance. This challenge is compounded by the reportedly relatively high costs of these materials on the market. Traditional road salt (NaCl) is reported to cost about $40/ton while calcium magnesium acetate (CMA) costs about $800/ton. Therefore, on balance, there is no ideal deicing material or combination of materials in use at present.

Iowa is a state rich in agricultural resources, some of which are processed for applications such as fuel. Any industrial process, including that of converting corn to ethanol or soy to bio-diesel, is likely to generate a number of by-products. Rather than face disposal issues for these by-products, it would be desirable to find those that, with a minimum of additional processing, can be used as a deicing compound, either alone or in combination with products currently in use.

Several commercial deicing products have been reviewed by the Iowa Department of Transportation (Iowa DOT), with limited success. Additionally, it is common for these products to be proprietary and therefore often of unknown composition. This paper reports the results of preliminary investigations carried out in search of agricultural-based products that will be suitable for use as deicing materials and that are suitably cost-effective, environmentally acceptable, and technically functional.

2. Review of Existing Deicing Agents from Agricultural Products

A comprehensive literature search was conducted to look for patents or reports of laboratory or field data about agricultural products used as deicing agents, either by themselves or mixed with currently used deicing chemicals. This review also included seeking commercially available products already on the market. Information regarding previous testing conducted on these materials was collected and evaluated.

Based on previous studies (Yehia and Tuan 1999; Fischel, 2001), the currently used deicing agents can be divided into the following four groups:

1. sanding materials,
2. chloride-based deicers,
3. acetate-based deicers, and
4. other chemicals deicers.

The chloride-based deicers include magnesium chloride, calcium chloride, and sodium chloride (Zenewitz, 1977). The acetate-based deicers include calcium magnesium acetate, potassium acetate, sodium acetate, etc. Other chemical deicers include urea, formamide, and tetrapotassium pyrophosphate (TKPP). Detailed information regarding each of these deicers as well as sand is provided by Yehia and Tuan (1999) and Fischel (2001).

The National Cooperative Highway Research Program (NCHRP) 577 report (Levelton Consultants, 2007) provides detailed guidelines for the selection of snow and ice control materials through an evaluation of their cost, performance, and impacts on the environment and infrastructure. The NCHRP 577 report classified the deicing materials into chloride salts, organic products, nitrogen products and abrasives, as shown in Fig. 1 (Levelton Consultants, 2007). In this classification, the deicer materials derived from agricultural by-products are included as organic products. Some hybrid deicer material mixtures combining chloride salts and agriculturally derived organic product are also available to reduce corrosion (Levelton Consultants, 2007). The general properties of chloride salts and organic products including agricultural by-products were also summarized in the NCHRP 577 report (Levelton Consultants, 2007).

The deicer materials used in Iowa include sodium chloride, calcium chloride, and abrasives. Potassium acetate usage is very limited and magnesium chloride is not used. The reported prices of deicer materials in Iowa are listed in Table 1.

Considerable research has been carried out in recent years on the topic of developing deicers from agricultural by-products. Most of the developed deicer materials are refined from various agricultural feedstock, including corn, wheat, and rice. Currently, little information is known about the actual manufacturing/refining process because most of the developed materials are all proprietary products (patented or commercial) (Levelton Consultants, 2007). Little information is available in the technical literature, but information about products was found in the patent literature.

Table 1
Unit Costs of Deicer Materials Used in Iowa (as of 2009)

Deicer materials	Prices
Sodium chloride	$50 per ton
Calcium chloride	Dry bags - $390 per ton ($7.8 per 50-lb bag) Liquid - $0.65 per gallon
Abrasives	$ 7 per ton
Potassium acetate	$ 2.85 per gallon

Table 2 lists the exiting deicing agents from agricultural products reviewed in this study. Some of these materials are commercial products available in the market.

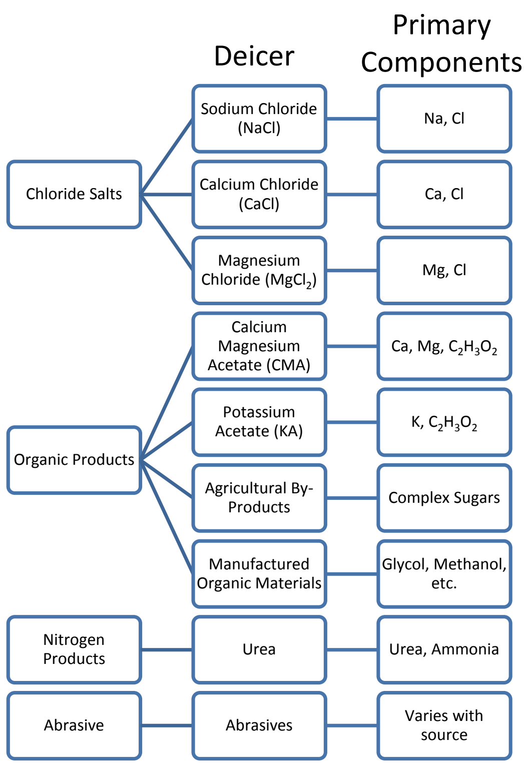

Fig. 1.
Deicing Materials and their Components
Source: Levelton Consultants (2007)

2.1. Existing Analytical Methods Used in Characterizing Deicing Agents

Many jurisdictions have developed internal specifications and test procedures for traditional deicer materials. However, these have often adapted existing standards. The following specifications or reports are recognized as providing standard test methods developed directly for testing deicer materials (Kuemmel, 1994; Levelton Consultants, 2007):

- Pacific Northwest Snowfighters Snow and Ice Control Chemical Products Specifications and Test Protocols (PNS, 2002);
- SHRP H-332, Handbook of Test Methods for Evaluating Chemical Deicers (Chappelow and Darwin, 1992);
- American Society for Testing and Materials (ASTM);
- American Association of State Highway and Transportation Officials (AASHTO).

Table 2
Summary of Existing Deicing Agents from Agricultural Products

Product Name	Reference	US Patent No.
Desugared molasses	Bloomer, 2002	6416684
Monoalkyl esters	Chauhan et al., 2006	7048871
Starch	Gambino et al., 1998	5849356
Processed agricultural by-product	Hartley and Wood, 2007	7208101
Corn wet-milling by-products	Janke and Johnson, 1999a	5965058
Cheese brewing by-products	Janke and Johnson, 1999b	5919394
Beer brewing by-products	Johnson and Lawrence, 1999	5922240
Urea	Kerti et al., 2001	6319422
Particulate plant material	Koefod, 2000	6156227
Monohydric and polyhydric alcohols	Lockyer et al., 1998	5772912
Alkalinically reduced sugars	Montgomery and Yang, 2003	6605232
Succinate salts	Berglund et al., 2001	6287480
Alkali metal acetate	Dietl and Stankowiak, 2005	6955770
Calcium chloride and urea	Ossian and Steinhauser, 1997	5683619
Non-chloride based liquid deicer	Seo, 2007	7276179
GEOMELT®	Road Solutions, Inc., 2007	-
Magic Minus Zero™ and Magic Salt™	MagicSalt.info, 2007	-
Icenator Liquid Deicer	eHealth Solutions, 2005	-
Bare Ground Solution	Bare Ground Systems, 2003	-
Caliber M1000	Glacial Technologies, 2008	-

The general areas of deicer material testing in these specifications and reports have primarily focused on the following properties (Levelton Consultants, 2007):

- Physical – specific gravity, freezing point, eutectic temperature, gradation, and settling ability,
- Chemical and environmental – chemical species and toxicity,
- Corrosion – atmospheric, concrete, and concrete reinforcing.

Detailed information regarding each of these tests is provided in the NCHRP 577 report (Levelton Consultants, 2007). The desirable properties of deicing materials include cost-effectiveness; ease of application to the road or other surfaces; low freezing temperature; prevention of ice formation and reduction of the bonding of snow to the surface of the road; low corrosivity to vehicles and pavement reinforcing; biodegradable properties and a small impact on the environment; an ability to penetrate ice and snow on roads; rapid dissolution after application of the solid mixture; persistence on the surface after application; stable composition in storage; and low or no conductivity on surfaces, such that electrical systems are not shorted out (Yang and Montgomery, 2003).

The Iowa DOT has developed internal requirements for deicing chemical testing and evaluation, which involves a multi-step evaluation process: pre-qualification, laboratory testing, operational testing, and evaluation and recommendation. The manufacturer, distributor, or supplier should provide characteristic information and samples of any deicing chemical, mixture of deicing chemicals, or additives. An independent lab should be asked to test the deicer materials provided. Laboratory tests include chemical composition, environmental impact, friction test, drying time test, and other proposed performance tests (currently being developed by the University of Iowa). In order to fully assess the efficiency and usability of any deicing chemical or deicing chemical additive, an operational test would be performed by one or more Iowa DOT maintenance garages to determine how the product will perform in a real-world setting in Iowa's environment.

A Transportation Pooled Fund called Clear Roads (Clear Roads, 2009) has also been working on development of standardized test procedures for evaluating the effectiveness of agricultural-based deicer materials.

2.2. Impacts of Existing Agricultural-Based Deicing Agents on Infrastructure, Vehicles, and Environment

Chloride salts as traditional deicer chemicals are well known to affect concrete structures (Mehta, 1986; Neville, 1996), either through deterioration of the concrete or corrosion of the reinforcing steel (Nadezhdin et al., 1988; Adkins and Christiansen, 1989; Rosenberg et al., 1989; Raupach, 1996; Kosmatka et al., 2002; Mindess et al., 2002; Levelton Consultants, 2007; Sutter et al., 2008). While the effects of agricultural-based deicers on deterioration of the concrete and asphalt pavements are not well identified, these deicers tend to result in significantly lower corrosion rates than chloride-based salts (TRB, 1991; McCrum, 1989). The effectiveness of organic inhibitors is related to the extent to which they reabsorb and cover the metal surface. Absorption of the organic inhibitor depends on the structure of the inhibitor, on the surface charge of the metal, and on the type of electrolyte (Levelton Consultants, 2007). Because of this advantage, agricultural-based deicers have been used in conjunction with chloride-based chemicals as corrosion inhibitors.

Wang et al. (2006) evaluated five deicing chemicals (sodium chloride, calcium chloride with and without a corrosion inhibitor, potassium acetate, and an agricultural product). The properties of the paste and concrete subjected to these deicing chemicals included mass loss, scaling, compressive strength, chemical penetration, and micro-structure under freezing–thawing and wetting–drying exposure conditions. Results indicated that the various deicing chemicals penetrated at different rates into a given paste and concrete, resulting in different degrees of damage. Among the deicing chemicals tested, two calcium chloride solutions caused the most damage, and the agricultural deicing product resulted in the least chemical penetration and scaling damage of paste and concrete.

Shi et al. (2009) surveyed a total of 24 winter maintenance professionals, with one from Finland, one from New Zealand, and the rest from the United States representing agencies in 15 different states, to gain insight into the deicer products currently available and used by road maintenance agencies. In this survey, users were asked to rank the advantages of specific deicers with respect to low cost per lane-mile, low effective temperature, high ice melting capacity, ease of application, and overall safety benefits for winter roads based on field experience or research from the respondent's agency, and to provide any further comments on the topic. The rankings were on a scale of 1 to 5, with 1 being the least advantageous and 5 being the most advantageous. Based on the results of these surveys, Shi et al. (2009) concluded that agricultural deicer products were perceived by users to be the most advantageous, with abrasives being the least. No significant difference was reported between chlorides and acetates/formates.

All existing deicer materials can affect the natural environment. The NCHRP report 577 (Levelton Consultants, 2007) presents a simplified conceptual diagram showing primary transport mechanisms and pathways of deicer materials, as well as areas of effect of deicer materials. The primary component of currently available agricultural deicer materials is organic matter such as complex sugars, and the secondary attributes of these materials include phosphorus (P), nitrogen (N), and organic matter quantified by biochemical oxygen demand (BOD) (Levelton Consultants, 2007).

The organic matter and nutrients of agricultural deicer materials can cause oxygen depletion or eutrophication in water streams, which is critical to aquatic biology. Relatively small amounts of phosphorus can also change aquatic ecosystems drastically. There is limited information detailing the effects of agricultural deicer products on soil properties, but, based on organic constitution, the NCHRP report 577 (Levelton Consultants, 2007) suggested that they would be subject to degradation by soil micro-organisms. Degradation could lead to anaerobic conditions in the soil, which can decrease soil pH and increase the solubility of adsorbed metals. However, Klecka et al. (1993) reported that high levels of the deicing materials containing glycol are unlikely to be inhibitory to soil microorganisms. The biodegradation rates were very similar regardless of the type of glycol in deicer materials.

Few studies reported the effects of agricultural deicer materials on vegetation, animal, and human health. This might be a result of the number and variability of available proprietary products. Many of these products are biodegradable, and it is generally assumed that they pose minimal concern for vegetation and animal and human health when compared to other types of deicers products (Levelton Consultants, 2007). Small concentrations of phosphorus and ammonia in organic deicer materials can provide nutrients for plant growth.

3. Experimental Study

An experimental study was undertaken to investigate by-products from agricultural processes that may be suitable for use as deicing applications. Based on the information collected in the literature survey and discussions with researchers, several compounds or mixtures were selected for the development of alternative deicers based on agricultural products. The selection of these materials was based on the following considerations:

- Likely efficiency as a deicing or anti-icing compound,
- Usability,
- Likely effects on skid resistance,
- Likely cost and availability,
- Likely damage to the pavement,
- Likely damage to vehicles,
- Likely effects on the environment.

3.1. Deicer Materials and Combinations

Chloride-based deicers (NaCl and $MgCl_2$), considered to be traditional deicers, were used as control materials against which the performance of the others could be compared.

The commercial agricultural-based deicers selected for testing in this study were Geomelt® and Ice B Gone®. Geomelt® (referred to as GM) is derived from a renewable sugar beet source (Road Solutions, Inc, 2007) and Ice B Gone® (referred to as IBG) is manufactured from a molasses, high-fructose corn syrup, or other carbohydrate base (Sears Ecological Applications Company, 2009). Combining one of these materials with salt (NaCl) can allow for lower salt application rates on roads with equal or superior performance to that of only traditional deicer.

Two types of commercial agricultural by-products from biofuel production were also selected for laboratory testing. The commercial brand names of these materials are BioOil and E310, which have not been used and studied before as deicers. The BioOil was obtained from a commercial biomass conversion facility located in Canada (Dynamotive Energy Systems Corporation, 2007).

The BioOil is a dark brown, free-flowing liquid fuel with a smoky odor reminiscent of the plant from which it is derived. It is formed in a process called fast pyrolysis, wherein plant material (biomass), such as forest residues (bark, sawdust, shavings, etc.) and agricultural residues (sugar cane, cornhusks, bagasse, wheat straw, etc.), are exposed to 400-500°C in an oxygen-free environment (Dynamotive Energy Systems Corporation, 2007). BioOil has been used as a boiler fuel.

The E310 was obtained from a full-scale, wet-mill, corn-based ethanol plant of Grain Processing Corporation (GPC) in Muscatine, Iowa (Grain Processing Corporation, 2009). Alkaline-washed corn hull is obtained in the process of converting the corn into ethanol, and co-product B is a powdered version of this. The E310 has been used in animal feed applications.

Another type of agriculturally derived organic product used in this study was glycerol (also known as glycerine or glycerin). It is a colorless, odorless, and viscous liquid, and its very low toxicity allows its wide use in pharmaceutical, personal care, and food formulations. Glycerol, $HOCH_2CH(OH)CH_2(OH)$, has three hydrophilic hydroxyl groups that are responsible for its solubility in water and its hygroscopic nature. The glycerol substructure, $OCH_2CH(O)CH_2(O)$, is a central component of many fats and lipids. For example, it links together the three fatty acid portions of triglycerides that bind to the oxygens by replacing the hydrogens.

Glycerol is easily obtained as a by-product during the saponification of animal fats by treatment with sodium or potassium hydroxide in soap manufacture. Glycerol is also an easily obtained by-product in the production of biodiesel via treatment of animal fats and a wide variety of plant oils with methanol in the presence of catalytic amounts of sodium methylate or basic organic compounds in a process known as transesterification (Venkat et al., 2007).

Because of the vigorous activity in the development of the biodiesel market, the market for glycerol is depressed. Approximately 950,000 tons of biodiesel per year are currently produced in the U.S. and Europe, which translates to the co-production of about 99,000 tons of glycerin per year. Biodiesel manufacture will increase as European Union directive 2003/30/EC is implemented. This directive requires the replacement of 5.75% of petroleum fuels with biofuel in all member states by 2010 (Biodiesel, 2009).

Like ethylene glycol and propylene glycol, glycerol is very soluble in water. Its minimum freezing point is at about -36°F (-37.8°C), which is reached by a solution of 60%–70% glycerol in water.

Samples of the selected materials were obtained from appropriate sources, either commercial facilities, laboratories, or processing facilities at ISU.

3.2. Laboratory Testing

Laboratory tests were conducted on the selected materials that can either be combined with existing deicing chemicals ($NaCl$ or $MgCl_2$) or used alone. These tests were designed to investigate whether the agricultural-based deicers have the potential to meet the requirements of maximum effectiveness and minimum side effects. Based on the guidance provided in the SHRP H-332 report (Chappelow and Darwin, 1992), Handbook of Test Methods for Evaluating Chemical Deicers, the tests included determination of the following:

- Freezing points with eutectic temperature (ASTM D1177-88, 1988; SHRP H-332, Clause 3.1.5),
- Ice melting ability (SHRP H-205.1 and 2),
- Skid resistance (ASTM E 303, 2007),
- Viscosity.

Freezing point, ice melting ability, and viscosity tests were conducted at the Chemistry Department Laboratory at ISU. Skid resistance tests were carried out at the Portland Cement Concrete (PCC) Laboratory at ISU. The deicer combinations selected for testing are summarized in Table 3.

Table 3
Deicer Material Combinations Selected for Laboratory Testing

I.D.	Combination
A	100% glycerol
B	90% glycerol + 10% MgCl2
C	80% glycerol + 20% NaCl
D	90% GM + 10% MgCl2
E	80% GM + 20% NaCl
F	90% IBG + 10% MgCl2
G	80% IBG + 20% NaCl
H	5% solution of NaCl in water
I	50% E310 + 50% glycerol
J	100% NaCl
K	40% E310 + 40% glycerol + 20% NaCl
L	50% glycerol + 50% MgCl2
M	50% Glycerol + 50% IBG
N	90% BioOil + 10% MgCl2
O	80% BioOil + 20% NaCl
P	Wet surface condition without deicer for skid resistance test
Q	Dry surface condition without deicer for skid resistance test

3.3. Results and Discussion

The freezing points of water solutions of the selected combinations were determined. Solutions of each combination were cooled slowly with stirring, while time and temperature were recorded. Each combination was evaluated over a range of concentrations in water: 25%, 50%, 75%, and 100% by solution weight. The freezing temperature was determined as the temperature at which the first ice crystals form. The phase diagram of each combination was constructed to determine eutectic temperature and concentration using the recorded freezing temperatures. Fig. 2 shows the phase diagram for combination A (100% glycerol) for illustration purposes. Eutectic temperature was determined as the lowest temperature in the phase diagram for a given combination. Eutectic concentration is the concentration corresponding to the eutectic temperature. As seen in Fig. 2, the eutectic temperature of combination A (100% glycerol) is -34°C, and the eutectic concentration is 70%.

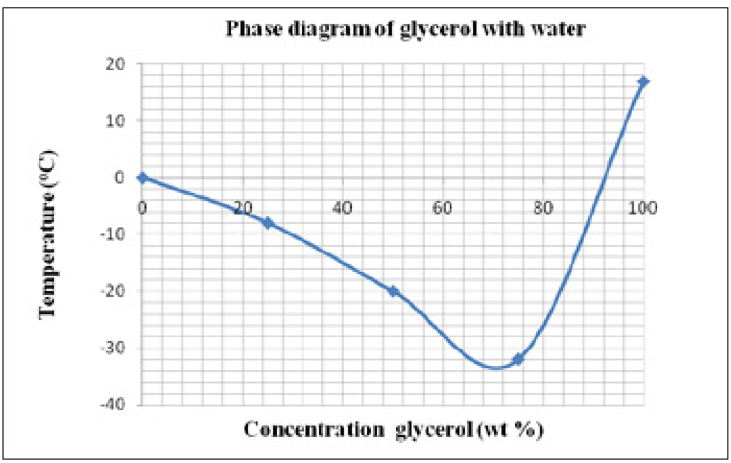

Fig. 2.
Phase Diagram of Combination A (100% Glycerol) in Water

The ice melting test provides information on the time-dependent quantities of ice melted by a deicer, which can be used to evaluate new or modified deicers in comparison to existing deicers (Chappelow and Darwin, 1992). This test has been considered a primary method for evaluating chemical deicers (Chappelow and Darwin, 1992). In this test, 25 mL water was placed in a flat-bottom dish and frozen in a constant temperature bath at -12°C to form a 1/8 inch solid layer. To this was added 25% of each combination group by solution weight. The volume of water that melted was recorded at regular intervals of time. Fig. 3 presents the rate of ice melting of combination A (100% glycerol) in water for the purposes of illustration.

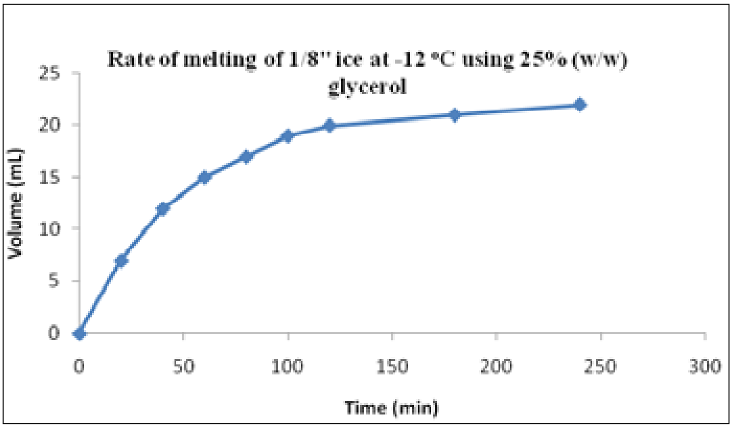

Fig. 3.
Rate of Ice Meting for 25% of Combination A (100% Glycerol) in Water

A portable skid resistance tester, British pendulum tester (BPT), was used to measure skid resistance on a concrete surface coated with various deicer combinations in accordance with ASTM E 303. Fig. 4 displays the portable skid resistance tester used in this study next to a coated surface. In this test, the pendulum of BPT is released from the horizontal position, and the rubber slider at the bottom of the pendulum contacts the coated surface for a fixed previously set length. The greater the friction between the slider and the coated surface, the more the swing is retarded. A drag pointer that moves with the pendulum during the forward part of its swing indicates a scale reading defined as British pendulum number (BPN). Higher BPN indicates greater skid resistance. The European standard EN 1436 specifies that BPN should be higher than 45 (Wallman and Astrom, 2001). Table 4 summarizes the results of skid resistance test for various deicer materials tested.

Table 4
Results of Skid Resistance Test for Various Deicer Materials

ID	Description	Average BPN
A	100% glycerol	37.7
B	90% glycerol + 10% MgCl2	36.7
C	80% glycerol + 20% NaCl	52.3
D	90% GM + 10% MgCl2	51.0
E	80% GM + 20% NaCl	39.0
F	90% IBG + 10% MgCl2	42.7
G	80% IBG + 20% NaCl	43.0
H	5% solution of NaCl in water	65.0
M	50% Glycerol + 50% IBG	34.3
N	90% BioOil + 10% MgCl2	45.0
O	80% BioOil + 20% NaCl	38.0
P	Wet surface condition without deicer	66.0
Q	Dry surface condition without deicer	85.3

Table 5 summarizes the results of the experimental tests conducted on the various deicer combinations. The freezing temperatures and ice melting volumes reported in this table are measurements corresponding to a 75% concentration of each combination in water and 240 minutes, respectively. The skid resistance percentage reported is the percentage of the BPN on each combination-coated surface relative to the BPN on the surface treated with plain water (100%).

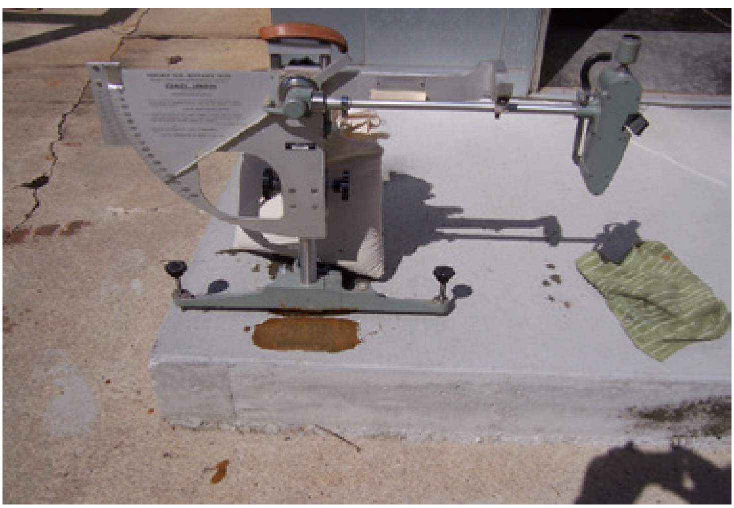

Fig. 4.
Portable Skid Resistance Tester near Deicer Coated Concrete Surface

The approach to assessing the overall performance of the different combinations was to highlight the best performing combinations for each test parameter. Based on the variety of parameters tested, the combination that shows the greatest promise is a combination of 80% glycerol + 20% NaCl (I.D.C).

When considering other parameters, such as corrosive effects to steel, the dilution of NaCl will help reduce these effects while the addition of glycerol will not increase the risk. Likewise, the effects of glycerol on plant life are reported to be minimal. The greatest concern about the use of this combination will be in handling the product and applying it to the pavement due to its viscosity.

For this reason, the viscosity of the combination of 80% glycerol with 20% NaCl was measured at different concentrations in water. The results, presented in Fig. 5, indicate that the viscosity of this combination can be controlled by its concentration in water. In terms of practical application in the field, it seems feasible to use this combination with the Iowa DOT deicer spray truck at a reasonable concentration-to-flow ratio.

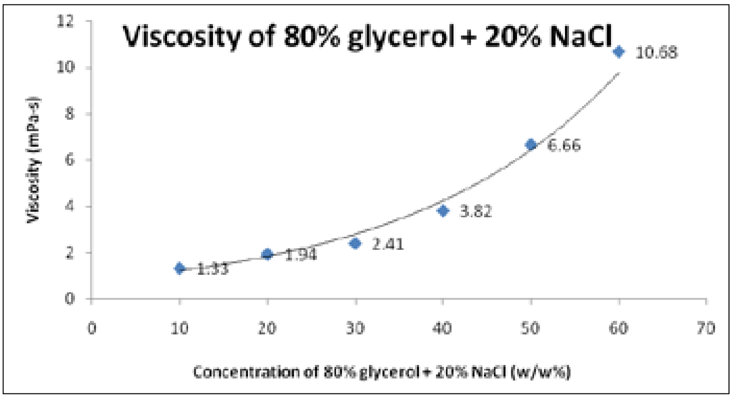

Fig. 5.
Viscosity of 80% Glycerol with the 20% NaCl Combination at Different Concentrations in Water

4. Summary and Conclusions

Snow and ice removal is critical for the safe operation of the road transportation infrastructure. Considerable research has been carried out in recent years to develop alternative deicers with better performance and cost effectiveness. Among the developed deicer materials are agricultural based deicers that are considered to be sustainable and environmentally-beneficial materials. Iowa is one of the States that is especially rich in agricultural renewable resources, some of which are being processed for applications such as fuel.

The focus of the experimental study described in this paper was to investigate by-products from agricultural processes that may be suitable for use as road transport deicing applications in Iowa. This topic has been investigated in the past by others, with many patented products described in the literature. An initial screening was carried out to assess the potential acceptability of selected commercial products, as well as a glycerol developed for this project.

Based on a comprehensive review of the literature and preliminary experimental investigations, it is concluded that a mixture of 20% NaCl with 80% glycerol diluted to a viscosity suitable for distribution equipment shows promise as a deicing chemical based on agricultural by-products. The biodegradability of glycerol, its high solubility in water, its odor-free character and its colorless appearance combine to make it a better choice when compared with commercially available deicers which are dark in color and tend to have a strong unpleasant odor.

The next stage of work necessary will be to investigate what resources are required to produce the product in large quantities. A pilot demonstration of production and use in Iowa DOT equipment during a winter storm is recommended.

Table 5

Summary of Experimental Study Test Results

I.D	Description	Freezing temperature, °F	Eutectic temperature, °F	Ice melting, ml	Skid resistance, %
A	100% glycerol	-32	-34	22	57
B	90% glycerol + 10% MgCl2	-44	-45	24	56
C	80% glycerol + 20% NaCl	-46	-48	25	79
D	90% GM + 10% MgCl2	-23	-23	9	77
E	80% GM + 20% NaCl	-37	-37	11	59
F	90% IBG + 10% MgCl2	-48	-48	25	65
G	80% IBG + 20% NaCl	-50	-50	25	65
H	5% solution of NaCl in water	-3	-3	17	98
I	50% E310 + 50% glycerol	-14	-15	13	-*
J	100% NaCl	-3	-3	25	-
K	40% E310 + 40% glycerol + 20% NaCl	-41	-42	20	-
L	50% glycerol + 50% MgCl2	-	-	25	-
M	50% Glycerol + 50% Ice B Gone®	N/A**	N/A	N/A	52
N	90% BioOil + 10% MgCl2	N/A	N/A	N/A	68
O	80% BioOil + 20% NaCl	N/A	N/A	N/A	58
P	Wet surface condition without deicer	-	-	-	100
Q	Dry surface condition without deicer	-	-	-	129

** Could not be tested due to difficulties associated with preparing the combination for testing.*
*** Test was not conducted after determining that the skid resistance value was poor for this combination.*

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