A Refined Procedure for Evaluating the Airport Runway De-icing Products Performance

Claire Charpentier[1], Jean-Denis Brassard[1], Marc-Mario Tremblay[1], Gelareh Momen[1]

[1] *Anti-icing Materials International Laboratory / Université du Québec à Chicoutimi Canada*

Claire.Charpentier1@uqac.ca, Jean-Denis1_Brassard@uqac.ca, Marc-Mario_Tremblay@uqac.ca Gelareh_Momen@uqac.ca

Abstract—**The clear runways concept is of paramount importance for airports: to increase passengers and employees' safety; to improve cost and environmental impact; and to increase knowledge of de-icing and anti-icing performance of runway de-icing products in order to optimize winter operations. As for now, there are three aerospace standards currently used to evaluate the de-icingperformance of runway de-icing products (RDP) as performance indicators. Those test methods, comparative in nature, provide with relative efficiency values of RDP under controlled conditions. The main goal of this research is to present how those methods could be refined to better characterize the RDP performance. To do that, those three test methods have been applied, including few modifications to the original protocols, to generic RDP: potassium acetate (KAC), potassium formate (KFO) and hybrid. Those products are commonly used by the industry. The ice melting capacity test method (AS6170) provides with the mass of ice that theproduct will melt per minute. The result represents the speed at which a product could melt ice. A thermal analysis was performed to give the minimum temperature reached as a function of time using an infrared camera (Optris PI400). This information was used to analyze the results by adding them to the phase diagram curves. In addition, the results obtained are processed in the form of melt rates. The ice penetration test method (AS6211) givesthe depth, in mm, that the RDP penetrates ice per minute. The result shows how well a product would penetrate the ice by melting it. In addition, the results obtained are processed in the form of penetration rates. The ice undercutting test method (AS6172) givesthe area that the RDP can clear from a substrate per minute. Since this method does not use an asphalt block, this method is then suitable for any type of study. Taking photos increases the precision on the measurement (instantaneous in this way) of the test duration and cavity diameter by the analysis made to the hundredth of pixel. All these test methodsrequire measurements at 5, 10 and 30 minutes test time durations. The aim here is to refine them by adding measurements taken at 1, 2, 3 and 4 minutes. Thus, the peak of efficiency is reached at this period. The product showing the best results is potassium acetate (KAC) for most of the tests. The additional test time durations allowed to determine with more precision Tmin which corresponds to the product's peak of effectiveness. KAC reaches a minimum temperature of -21.6°C, in ice melting at -10°C at approximately 3 minutes. All those results help to establish a comprehensive methodology to classifyRDP. Potentially, all those additions to the protocols could be proposed and integrated to the actual aerospace standards to improveaccuracy.**

Keywords— ***de-icing, anti-icing, ice melting, ice penetration, ice undercutting, runway de-icing product***

I. INTRODUCTION

In northern countries, such as Canada, large amounts of de-icing chemical products are applied on airport runways to ensure safe aircraft take-offs and landings in often adverse winter weather conditions. Most of these adverse conditions consist of what is known as atmospheric icing, which includes: freezing rain, wet or dry snow and freezing drizzle. Most of these meteorological events lead to unsafe runway conditions that unnecessarily increase the risk to users [1] [2]. Although these winter conditions are recurrent and, in some cases get worse year after year. Until now very little attention has been paid to evaluating the performance and determining the optimal quantities of de-icing and anti-icing products to apply to the runways. Each product supplier provides recommended application rates and duration of effectiveness based on their own knowledge. However, in some situations, a simple change in weather conditions can jeopardize safety on the runway.

In February. 8, 2019, an aircraft ran off the runway at Bagotville Airport (YBG) after a landing [3]. A total of 42 passengers and 3 crew members were on board, but fortunately, no injuries resulted from the incident. According to the airline, the nose gear left the paved surface, which was caused by the ice on the ground.

In North America, large amounts of de-icing chemical products are applied to airport runways to ensure safe aircraft take-offs and landings in often adverse winter weather conditions.

Water, ice, or snow on runways was a factor in more than 100 aircraft accidents between 1958 and 1993. Most of these accidents were fatal [4]. The risks of an icy runway in Canada are high. Indeed, the northern conditions can induce accidents, and therefore impact the airports by delays and non-functional aircraft [3].

The environmental impact of these products is also not negligible. Indeed, the products used are potassium formate, potassium acetate and hybrid compounds; and these products can have a negative effect on aquatic life [5].

In addition, the application rates of anti-icing and de-icing products are not precise. There is very little information on the operations to be followed during an airport runway anti/de-icing process.

In order to optimize winter operations, the concept of clear runways is therefore essential for airports: to increase passengers and employees' safety; to improve cost and environmental impact; and to increase knowledge of the de-icing and anti-icing performance of runway de-icing products.

As for now, there are three aerospace standards currently used to evaluate the de-icing performance of runway de-icing products (RDP) as performance indicators. Those test methods, comparative in nature, provide with relative efficiency values of RDP under controlled conditions. The main goal of this research is to present how those methods could be refined to better characterize the RDP performance.

It is important to define the term performance first. It has been put forward that a product can have two performances, either the speed of efficiency and/or the endurance time. There are different criteria that can be considered when determining the performance of a product, namely the melting rate, the minimum operating temperature, the penetration rate and the undercutting rate.

II. METHODOLOGY

The methodology will present the RDP used and then detail the three test methods as described in the current standard followed with the improvements proposed to refine the procedures.

All the tests were performed at -2°C and -10°C in a controlled temperature cold chamber

A. *Materials*

Three generic liquid RDPs were used in this study. AllRDPs were laboratory made using deionized water and from commercial solid salts. The first RDP consisted of 50% w/w (weight by weight) Potassium Formate (KFO: HCOOK). At this dilution, itsfreezing point is nearly -60 °C. The second RDP consisted of 50% w/w Potassium Acetate (KAC: CH_3COOK). At this dilution, its freezing point is also near -60 °C. The third product consisted of a hybrid RDP. Its components consisted of 25% w/w of liquid Propylene Glycol (PG: $C_3H_8O_2$) and 25% w/w KAC. The initial freezing point of this RDP is approximately -48 °C.

KAC, KFO and hybrid are presented in this study because they are the most common liquids used in the industry [6]. KAC is used as an example in this study because the three generic liquids show similar trends in results and most commercial de-icing liquids used in North America are based on this molecule [7].

B. *Ice Melting capacity*

The ice melting capacity test method is used to estimate the mass of ice that the product will melt per minute. The higher the mass of ice melted, the more effective the product will be considered. This process is performed according to the AS6170 standard [8]. The result represents the speed at which a product could melt ice.

This test gives the ice melting capacity of the RDP (Runway Deicer Product) in terms of grams per minute. The general test procedure is shown in Fig. 1. First, a Petri dish is filled with 60 ml of ASTM D1193 Type IV water and placed in a cold room at -10°C. After a minimum of 8 h, the Petri dish and the formed ice are weighed using a calibrated 2-digit scale. After that, 5 g of RDP is poured evenly over the ice sample. After 5 minutes, the brine, a mixture of RDP and melted ice, is removed by tilting and using compressed air. The Petri dish is then reweighed with the remaining ice. The amount of melted ice is calculated by subtracting the final mass from the initial mass. This procedure is repeated three times for 5, 10 and 30 minutes.

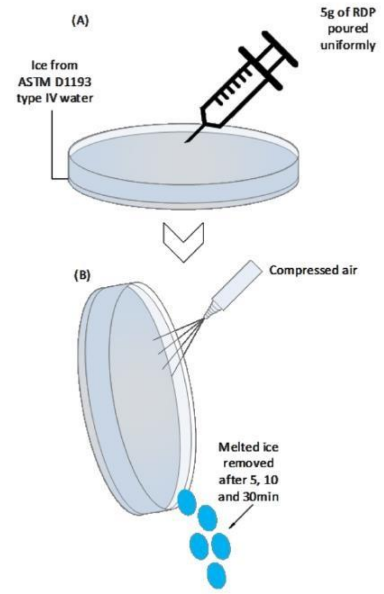


Fig. 1 : Ice melting test method as presented in AS6170. (A) Ice sample where 5 g of liquid RDP is poured. (B) Removal of the melted ice with compressed air. [8]

The procedure was refined by adding testing of RDP at 1, 2, 3 and 4 minutes. Furthermore, in addition tothe test method, a thermal camera (PI400) was placed over a petridish to record temperature during the test. This addition allowed, after using the PI Connect software, to extract the minimum temperature in the Petri dish throughout the test.

C. *Ice Penetration*

The ice penetration test method is performed according to AS6211 [9]. It gives the depth, in mm, that the RDP penetrates ice per minute. The result shows how a product, under ideal conditions, would penetrate the ice by melting it.

The general test procedure is shown in Fig. 2. Ice is obtained by pouring 0.5 ml of ASTM D1193 type IV water into a glass tube. A first measurement, M1, is performed. Then 25 µl of dyed RDP is poured into the tube. Using rhodamine B as a dying agent does not alter neither improve the performance of the RDP nor helps to accurately determine penetration. After an interval of 5 min, 10 min and 30 min, a second measurement, M2, is taken. Ice penetration, in mm, is calculated by subtracting M1 from M2. The test is repeated 4 times for each product [10].

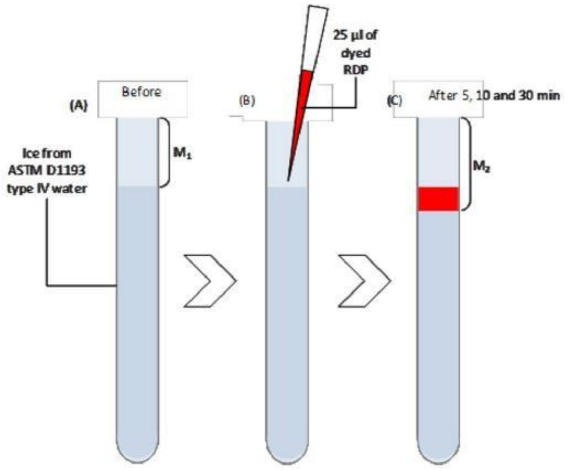


Fig. 2 : Ice penetration test method. (A) Initial ice samples in microcentrifuge tubes, (B) Deposition of dyed RDP on the ice sample, and (C) RDP penetration of the ice according to AS6211 [9]

The procedure was refined by adding testing of RDP at 1, 2, 3 and 4 minutes. In addition, a camera was placed in front of the test tubes to check the penetration pattern.

D. *Ice Undercutting*

The ice undercutting method is performed according to AS6172 [11]. It gives the area that the RDP can clear, in mm^2, from a substrate per minute. Since this method does not use an asphalt block, it is suitable for any type of study. The result obtained represents how a product, when it reaches the underside of the ice, will promote debonding.

The general testing procedure is shown in Fig. 3. First, a Petri dish, lined with silicon carbide abrasive paper, grain 120, is filled with 60 ml of ASTM D1193 type IV water and placed in a cold room at -10 ° C. After a minimum of 8 h, a 70 ° C aluminum rod is used to obtain 3 mm cavities. The melted ice is removed with a syringe. After 2h, 25 µl of dyed RDP is deposited in the cavities. After 5, 10 and 30 minutes, two measurements are made, M1 and M2. The undercut area is obtained by subtracting the initial area from the total undercut area, obtained with the average of M1 and M2 [10].

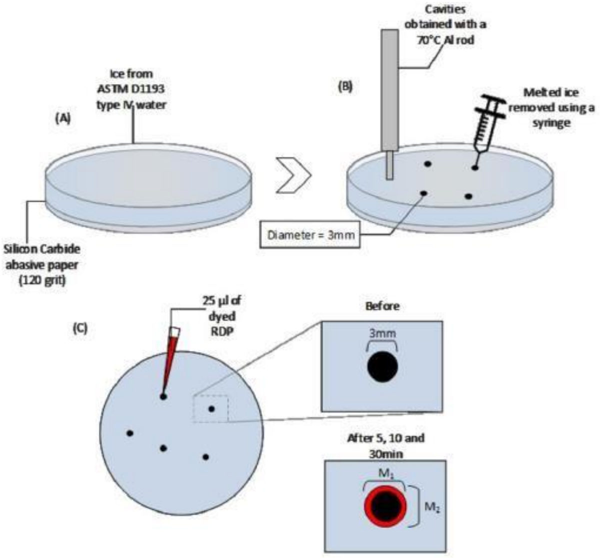


Fig. 3 : Ice undercutting test method. (A) initial ice sample in Petri dish, (B) cavity formation, and (C) dyed RDP deposition on ice sample with undercutting measurement [11]

However, the measurement method has been modified. Indeed, the measurements are made by taking a photograph of the Petri dish and the measurement is then done by computer with the ImageJ software. This allows a greater accuracy both in terms of time of measurement (instantaneous with a camera) and in terms of measurement itself (to the hundredth of a pixel). Furthermore, the procedure was refined by adding testing of RDP at 1, 2, 3 and 4 minutes.

III. Results and discussion

The results and discussion will be presented in three separate sections where they will be highlighted by describing and viewing the photographs and videos for each method.

A. *Ice melting results*

The thermal images provide an insight into the behavior of the fluid in the Petri dish during the test. Fig. 4 shows the thermal photographs during the generic KAC test at -10°C using the ice melt capacity method.

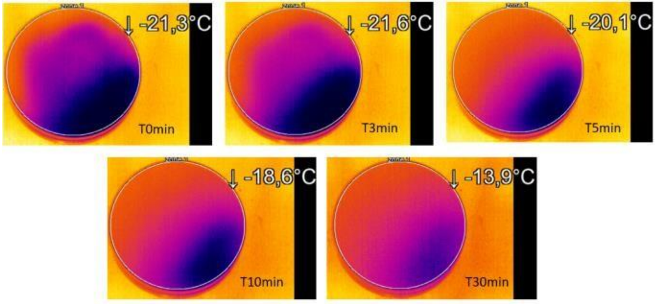


Fig. 4 : Thermal photographs of generic KAC at -10°C with the Ice melting method

In Fig. 4, the main observation is the instantaneous temperature drop observed from the beginning of the test represented on the T0min image. The minimum temperature of -21.6°C, which corresponds to the product’s peak of effectiveness, is then reached at 3 minutes, and then increases until 30 minutes.

The three generic products behave in the same way for each method. Fig. 5 shows melting rates for generic products at -10°C. The presentation of the results in the form of rates makes it possible to compare the results of the different methods with each other, which is useful for a correlational analysis.

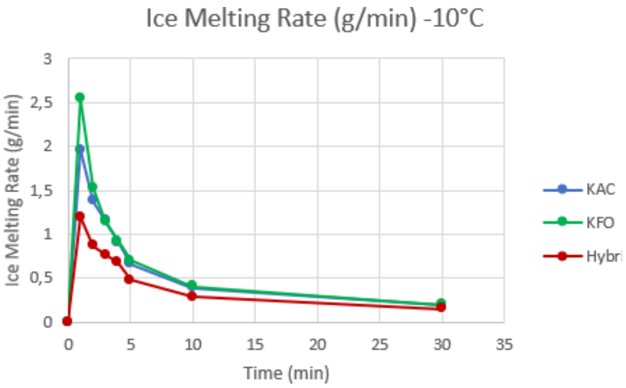


Fig. 5 : Ice melting rates for generic products at -10°C

For the ice melting capacity test method, the higher melting rate is reached at 1 minute and then gradually decreases to reach a minimum rate at 30 minutes. The product with the higher melting rate is the KFO with a maximum of around 2.6 g/min at 1 minute. The second one is the KAC with an average of 2 g/min. Finally, the hybrid has a melting rate of 1.25 g/min during the first minute. All the RDP show a similar decreasing trend to finish with a rate of 0.2 g/min at 30 minutes. The product with the best melting capacity is the KAC.

The ice melting capacity tests are performed at two different temperatures, -10°C and -2°C, according to the standards. Fig. 6 shows the melting rates of KAC at -2°C and -10°C and is presented as a comparative example. Generic KAC is taken as an example in this study because the three generic liquids show similar trends in results and most commercial de-icing liquids used in North America are based on this molecule [7].

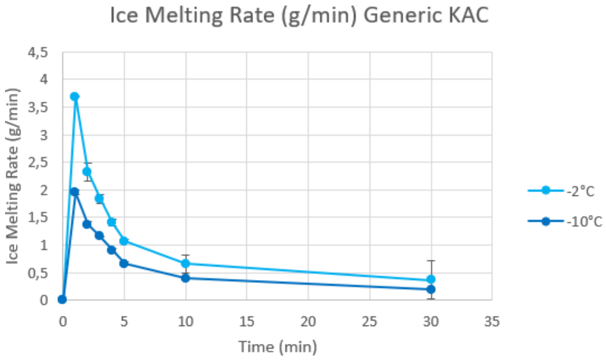


Fig. 6 : Melting rate of generic KAC at -2°C and -10°C

The results show that ice melting rate at -2 C is superior to those obtained at -10°C regardless of the product or the method used. It should be noted that the standard deviation is greater at -2°C than at -10°C. This is explained by the large values and therefore a more pronounced possibility of variations. For an example, the melting rate at 1 minute is ±0.006 at -10°c and ±0.002 at -2°C.

Fig. 7 shows the minimum temperatures reached in the generic KAC Petri dish during the -2°C and -10°C tests at each time a measurement is done.

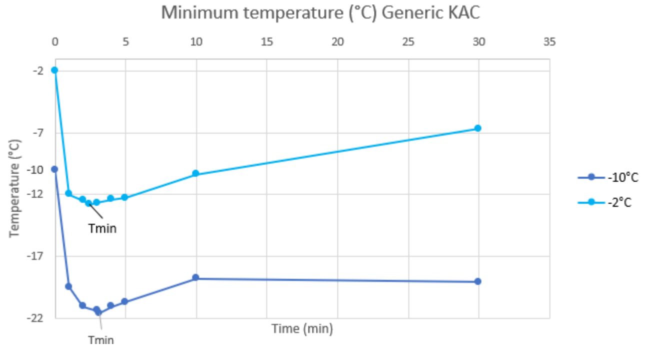
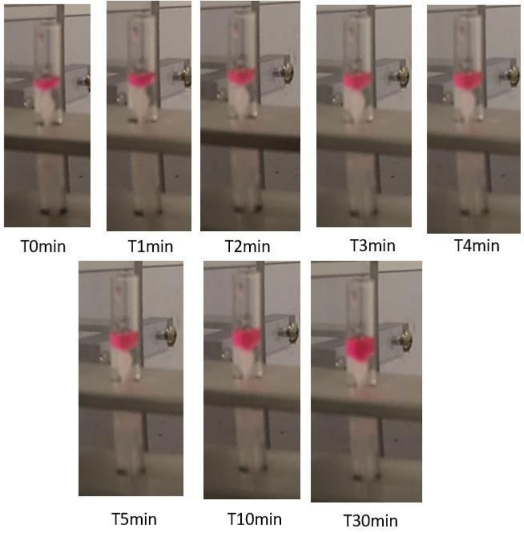


Fig. 7 : Minimum temperatures of generic KAC at -2°C and -10°C

The minimum temperature reached is lower at -10°C than at -2°C, which is understandable. Nevertheless, the difference between the initial temperature of the test and the minimum delta temperature reached is 10.8°C at -2°C and 11.6°C at -10°C. The product drops in temperature in the same way. The higher is the melting rate, the lower the temperature is. This was observed with the other products in the study.

B. *Ice penetration results*

The video during the ice penetration method allowed to highlight the general behavior of the product. Fig. 8 shows the screen captures of the video during the test of generic KAC at -10°C with the ice penetration method.


T0min T1min T2min T3min T4min

T5min T10min T30min

Fig. 8 : Screenshot of generic KAC at -10°C with the ice penetration method

In Fig. 8, the main observation is that the ice penetration is not visually significant for the first few minutes. It is therefore important to look at the measurements taken during the test to determine if the ice penetration is significant between 0 and 4 minutes.

The three generic products behave in the same way for each method. Fig. 9 shows penetration rates for generic products at -10°C.

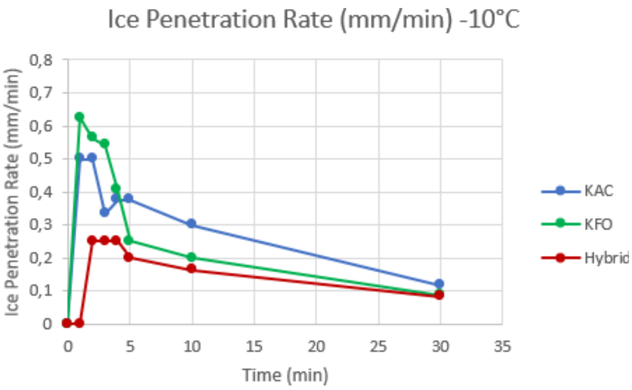


Fig. 9 : Ice Penetration rates for generic products at -10°C

The product with the higher penetration rate is the KFO with a rate of 0.62 mm/min during the first minutes. The penetration rate gently reduced after 2 and 3 minutes then drastically reduce at 5, 10 and 30 minutes. The second one is the KAC with a peak during the 2 first minutes and then with a reduction to the 30 minutes. The hybrid reacts less than the others. After 1 minutes, there is no penetration detected. It increased after that, during the 2, 3, and 4th minutes and then slightly reduce. The best ice penetration product is the KFO.

C. Ice undercutting results

The photographs taken during the ice undercutting test allowed to highlight the general behavior of the product. Fig. 10 shows the photographs during the generic KAC test at -10°C using the ice undercutting method.

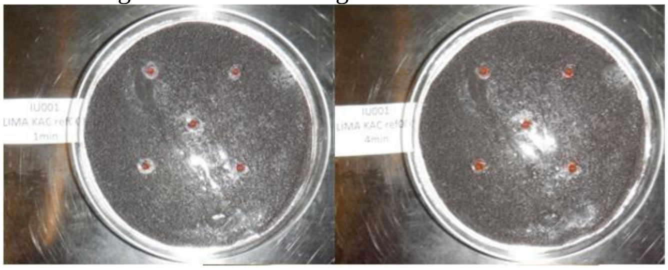


Fig. 10 : Photographs of generic KAC at -10°C with the ice undercutting method. The left picture is after 1 minute and the right one after 4 minutes.

The main observation is that the ice undercutting is not visually significant for the first few minutes. It is therefore important to look at the measurements taken during the test to determine if the ice undercutting is significant between 0 and 4 minutes.

The three generic products behave in the same way for each method. Fig. 11 shows undercutting rates for generic products at -10°C.

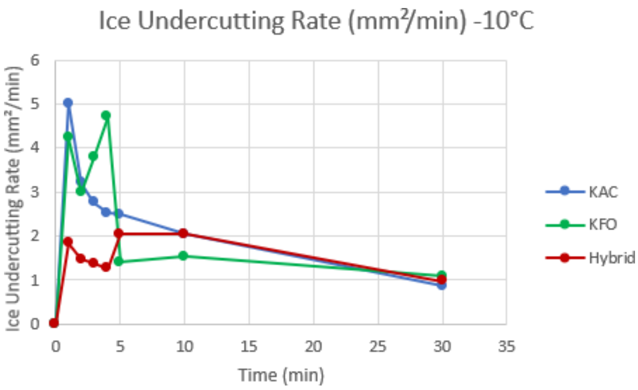


Fig. 11 : Ice undercutting rates for generic products at -10°C

For the undercutting method, the rate does not seem to follow a general trend for all the products. The best products are the KFO and KAC. KAC had an undercutting rate slightly higher than KFO. KFO decreases at the second minute and then increase again at 3 and 4 minutes. Again, the hybrid reacted less than the 2 others.

D. Comparison between the three test methods

By comparing the results of the three test methods, their similar trends are highlighted. Fig. 5, Fig. 9, Fig. 11 show the melting rate, penetration rate, and undercutting rate of generic liquids at -10°C, respectively.

The difference in maximum value reached at 1 minute for generic KFO and generic KAC is greater with melt rate than with penetration rate or undercutting rate.

Thus, it seems essential to do all three tests since they provide different information on the products and the classification of the products differs according to the test put forward. All the results seem to respect the general trend found in the literature [12].

The refinement proposed in the three methods, i.e. the measurement at 1, 2, 3, and 4 minutes, the photography, and the thermal imagery help to understand more how the products react under all the conditions. All these refinements will help to classify the products in terms of their performance as well as need of the airport's maintenance team, in order to maintain the runway surface safe and practicable.

IV. CONCLUSIONS

In North America, large amounts of de-icing chemical products are applied to airport runways to ensure safe aircraft take-offs and landings in often adverse winter weather conditions.

As for now, there are currently three aerospace standards in order to evaluate the de-icing performance of runway de-icing products (RDP) as performance indicators. Those test methods, comparative in nature, provide with relative efficiency values of RDP under controlled conditions. The main goal of this research is to present how those methods could be refined to better characterize the RDP performance.

The main observation for ice melting is the instantaneous temperature drop observed from the beginning of the test represented on the T0min image. The main observation for ice penetration and ice undercutting are that the phenomenon is notvisually significant for the first few minutes. It is therefore important to look at the measurements taken during the test to determine if the ice penetration or undercutting is significant between 0 and 4 minutes.

The comparison between the three methods reveals that it seems essential to do all three types of tests since they provide different information on the products. In addition, the classification ofthe products differs according to the test put forward.

The observation by adding data is that the melt rate is at its maximum at 1 minute, but it is possible for the deicer to have a maximum melt rate at first contact with the ice interface. Thereafter, the rate gradually decreases as the liquid mixes with the melted ice, forming a less and less effective brine.

All those results help to establish a comprehensive methodology to classify RDP. Potentially, all those additions to the protocols could be proposed and integrated to the existing standards to improve accuracy.

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