TRAFFIC IMPACT ON THE ICE MELTING

Michel M. Eram
Danish Road Directorate, Department of Traffic Management, Denmark
me5@vd.dk

ABSTRACT

Most of road agencies have always known that traffic has an accelerating effect on ice melting on a road surface. A physical reaction between a car tire and the road surface creates heat, which may be exploited to reduce salt consumption, or at best cases avoid some salting. Despite, it has not been possible to obtain knowledge that demonstrates the effectiveness.

Ice-carousel is built by a large steel plate, which is divided into three annular lanes, each has synthetic material coating as a replacement for regular pavement. At the centre of the assembly, there is a variable electric motor, which by means of a control device, can be controlled for different speeds. A wide cross-beam made of steel is mounted on the engine, which is intended to reach out to all the lanes, that are clamped six wheels mounted to the cross bar with a profile iron. Each lane is covered by one road sensor in order to measure the parameters in the experiment. Furthermore, all three sensors together with an air and moisture meter are controlled with a complete measuring station.

The results would be incorporate in application rate for de-icing agents thus traffic intensity will work as a function for winter service management.

1.0 BACKGROUND

The Danish Road Directorate, is continually seeking to improve winter service by utilizing existing knowledge to develop new knowledge that can facilitate to improve the use of de-icers and to achieve an optimization of resources, both with human resources and economic advantage.

De-icers group part of the winter committee an association of Road Authorities in Denmark, together with its members has created a device that may solve the riddle. The device is dubbed the "Ice carousel".

The aim of Ice carousel is:

- Determine the friction energy created by the rolling resistance between tires and road surface.
- Determine traffic accelerating effect and time to melting ice at different temperatures.

This paper provides an introduction and information about applications of ice carousel and also to explain the possibilities of using knowledge gained in the experiments to develop new applications rates where traffic impacts is considered.

2.0 STRUCTURE OF ICE CAROUSEL

Ice carousel is built by a large steel plate, which is divided by three annular lanes, each having received synthetic material coating as a replacement for regular pavement. Traditional asphalt could not be used because the asphalt properties together with steel would not yield good results when the temperature drops to minus degrees.

In the middle of the assembly there is a variable electric motor, which by means of a control unit can be controlled at different speeds. A wide cross-beam made of steel is mounted on the engine, which is intended to reach out to all the lanes, that are clamped with six wheels mounted to the cross bar by profile steel.

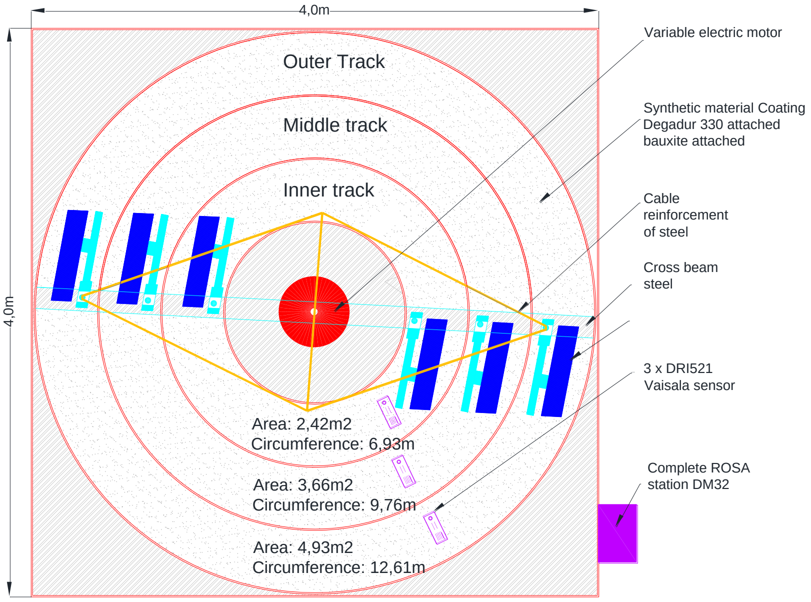

Figure 1 Plan view of ice carousel

Parameters to be measured in the experiment are done with particular Vaisala's DRI 521 sensors. On each track there is a sensor to ensure that parameters such as road temperature, water layer thickness and road condition, etc. measured for each test. All three sensors are controlled together with an air-and moisture meter with a complete Vaisala measurement station of type ROSA DM32.

In addition, each wheel is loaded with 250 kg weight equivalent to a car's weight of 1000 kg on four wheels.

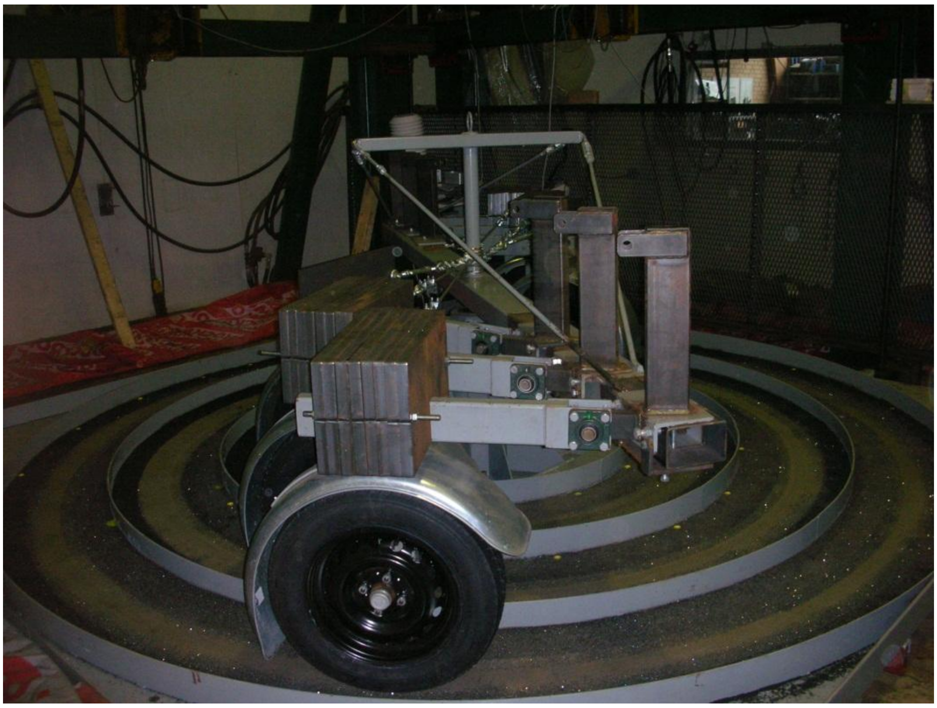

Figure 2 View of ice carousel inside cold chamber

Control of speed and number of rotations are ensured with a developed tachometer.
Tachometer allows controlling the speed of each lane, at the same time also register the number of rotations and lapping time.
Tachometer is reset after each experiment, but by then the values are recorded in an external database before the next experiment is started.

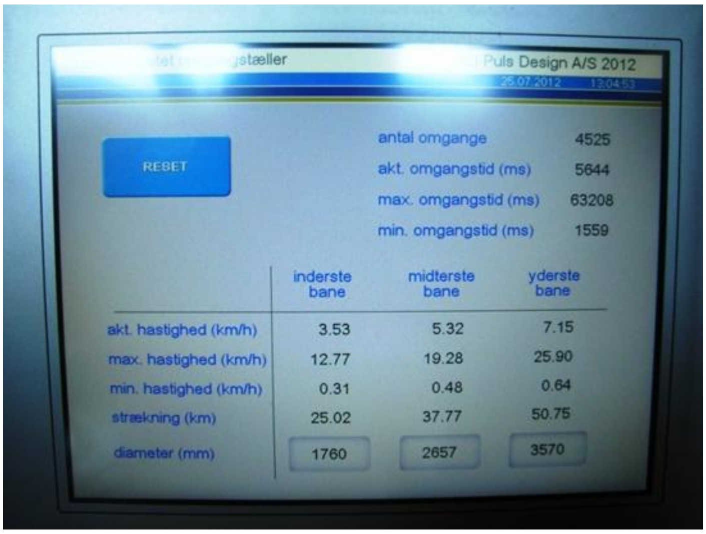

Figure 3 Tachometer

For storage of data, an Access database has been developed so that the results of each test can be updated, before the tachometer is reset.

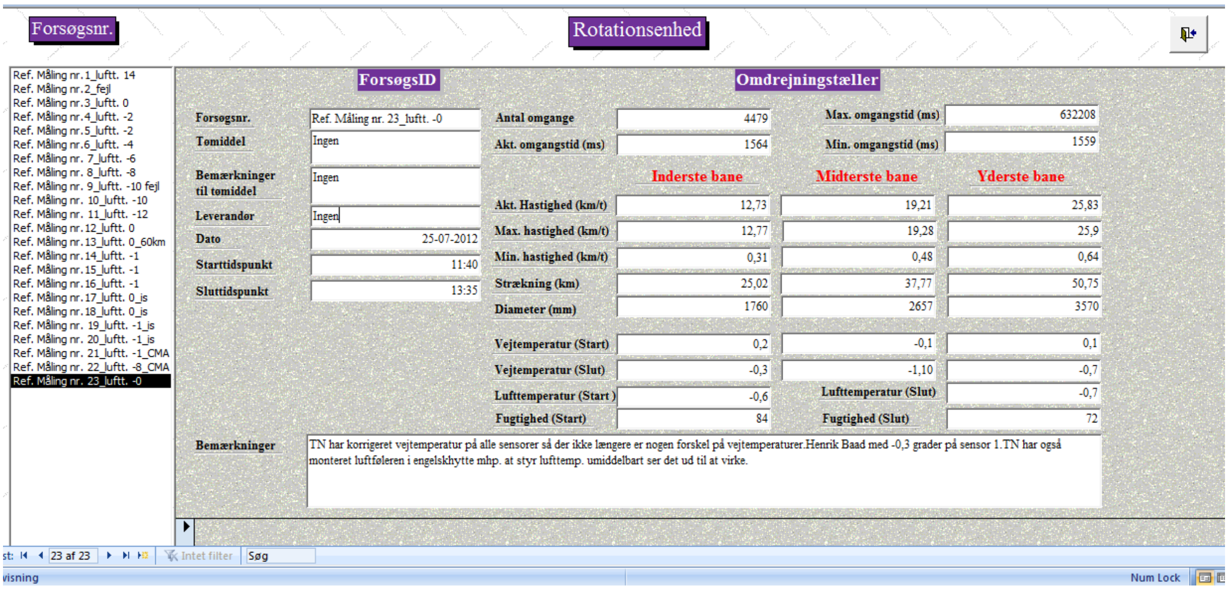

Figure 4 Screenshot of the Access database

3.0 METHOD DESCRIPTION

Method description indicates applications of ice carousel and planned experiments of de-icers.

3.1 Test of de-icers

- Determine the friction energy by rolling resistance between tires and road surface. The measurement is also used as a reference measurement. Reference measurement is carried out for temperatures between 0 - (-20 ^{0}C) with 2 degree temperature intervals. For the reason of reproducibility, two runs have been carried out for each temperature and traffic intensity (see section 3.2). The degree of similarity is assessed between the results of repeated measurements of the same measure carried out under maintain measurement conditions. Reference measurements are performed <u>without</u> the use of de-icers.

- Determine traffic accelerating effect on melting of ice. In this test, various de-icing agents and rates are applied for temperatures between 0 - (-20 ^{0}C) with 2 degree temperature intervals. The types of de-icers used to conduct the tests are approved by De-icers group. The salt rates are determined on the basis of an on-going project which is about finding Physical/Chemical Properties of de-icing agents in the marked.
    - The following de-icers are preliminary approved by the De-icers group:
        - Road salt
        - Magnesium chloride
        - Calcium chloride
        - Safecote
        - 30% CMA (Calcium Magnesium Acetate)
        - Potassium formate

Road temperature	Melting Effect (g NaCl pr 0.1 mm ice/m^2)	Melting time (min. pr g NaCl/0.1 mm ice/m^2)	Chemical properties	Value
˚C	gram	minutes		
0	0.23	8,000	Eutectic solution (Weight %)	23.9
-2	3.66	350		
-4	7.07	260	Eutectic temp. (^{0}C)	-21.3
-6	10.44	210		
-8	13.73	160	Density at 0^0 (kg/litre)	1.18
-10	16.91	270		
-12	19.95	160	Viscosity at 0^0 (µPa×s)	2,800
-14	22.81	560		
-16	25.45	680	Solubility at 0^0 (kg/litre)	0.355
-18	27.84	280		
-20	29.93	2,400		

Table 1 Chemical properties of NaCl Source: On-going project conducted by Danish Winter committee

3.2 Equivalence of traffic intensity

Both the rotating speed and rotational frequency has a major impact on the traffic intensity represented for such roads. In road regulations for Traffic Engineering, capacity and service levels in section 3.3.2 Ideal Capacity is listed:
"Ideal capacity of such roads is the starting point for capacity calculation of a line. Table 2 gives the ideal capacity for three typical types of roads. The stated ideal capabilities of the table are specified with a view to traffic load sustained for at least 15 minutes. "

Road type	Ideal Capacity, N_{ideal}
2-lane road	1700 hour/direction
2+1 road	1900 hour/direction
Road with 4 lane or more	2300 hour/direction

Table 2 Ideal capacity for road types - source: road regulations on Traffic Engineering, capacity and service

De-icers group subsequently recommended two traffic intensities which are the basis of traffic flow respectively on municipal roads and state roads. The following tests are conducted in accordance with De-icers group's recommendation.

Road type	Capacity	AADT
Municipal roads	300 hour/direction	≅ 7200 daily traffic/direction
State roads	1000 hour/direction	≅ 24000 daily traffic/direction

Table 3 Table 1 Capacity for road types - source: De-icers group

Taken the above-mentioned recommendation into consideration, the traffic intensity for each lane is determined on the basis of either rotation frequency or speed with the following spreadsheet:

Selection of speed

Track	diameter mm	Speed km/t	lap time msec	traffic intensity cars/hour
Inner	1682	0.53	12000	300
Middle	2592	0.82	12000	300
Outer	3498	1.10	12000	300

Selection of rotation frequency

Track	diameter mm	Speed km/t	lap time Msec	traffic intensity cars/hour
Inner	1682	5.28	3600	1000
Middle	2592	8.14	3600	1000
Outer	3498	10.99	3600	1000

Table 4 conversion of the rotation frequency or speed of traffic intensity. Preconditions: There are two wheels on the experimental setup and the traffic is assumed consisting of two-axle vehicles

3.3 Implementation of tests

For each de-icer agent, two different traffic intensities have been carried out, according to section 3.2, table 3.
Rates of each de-icer is as mentioned determined based on table 1. Cold chamber is set to the chosen temperature and in order to be able to detect the heat generated by friction energy, it is important the pavement has roughly same temperature as the air temperature. However, with the limitation of the cold chambers control function, we have allowed that the temperature can vary by ± 1 ^{0}C.

De-icing agent				
Application rate [g/m2] or [ml/m2]	**Traffic intensity [cars/hour]**	**Air temperature* [^{0}C]**	**Road temperature* [^{0}C]**	**RH [%]**
X	300	0	0	85-90
X	1000	0	0	85-90

Table 5 Number of tests carried out for each de-icer and at the set of temperature. *The temperature can vary by ± 1 ^{0}C

The relative humidity should be measured to be between 85-90% in order to achieve a humidity which corresponds to reality. Danish Meteorological Institute has made a statistic, with the lowest and highest measured humidity in temperatures below 0 ^{0}C, and the result is illustrated in table 6. The result gives an average of approx. 87%, which also aim to achieve in the cooling room.

Road temperature ^{0}C	Min. humidity %	Average humidity %	Max. humidity %	Number of measurements
0	16	88	100	734542
-1	17	88	100	694751
-2	16	87	100	525393
-3	16	87	100	398141
-4	16	86	100	286821
-5	16	87	100	213983
-6	16	87	100	137135
-7	21	87	100	92110
-8	17	87	100	63487
-9	25	88	100	40243
-10	24	88	100	23733
-11	25	88	100	13098
-12	42	88	100	7408
-13	51	87	100	4307
-14	44	87	100	1866
-15	57	86	100	967
-16	64	86	100	353
-17	56	86	100	136
-18	68	88	100	59
-19	57	85	98	42
-20	43	85	100	31

Table 6 Air Humidity data measured from 1999-2011 - Source: Danish Meteorological Institute

Before test with de-icer agents, reference measurements are carried out. Reference measurements will in addition to the issue of friction energy generated by the rolling resistance between tires and road surface, also clarify traffic accelerating effect on the melting of ice without de-icers.

The measurements are then carried out with a layer of ice on the road of 0.1 mm ≈ 100 g, and is made for temperatures between 0 to -20 ^{0}C with 2 degree temperature intervals. This will apply to both traffic intensities see section 3.2 table 3.

While the temperature in the chamber is lowered to the desired temperature, a layer of water of about 0.1 mm on each track is created. At same point the sensors will detect the pavement condition to be with "ice". As soon as the pavement temperature is reached at about the same temperature as the air, while the humidity also achieved between 85-90%, the de-icing agent is evenly distributed on the whole area of each track and immediately after that the test will be initiated.

Using the control device for variable electric motor, the speed can be maintained at planned speed.

Hence, the test runs until road conditions change to either wet or moistly.

Each test takes about 5-10 minutes to carry out. The period of time depends on pavement temperature and ice thickness. However, during the short time as the test runs, all necessary parameters are registered and provide the basis for analysis.

After each test, all three tracks are completely clean with water and vacuumed in order to be sure that not a single de-icing agent is left that can affect the next test.

4.0 UNCERTAINTIES

There will be some factors which will create uncertainty about the outcome of the final results, which must be rectified by analysing the data. Among other things is parameter such as "wind". The impact of wind, which under normal circumstances would blow on a surface, will not be present in the chamber. Other parameters include the "irradiance and radiance" which can't be achieved because the whole set-up is in the chamber during experiments. The importance of the used synthetic pavement and traditional pavement is so far unknown. Last but not least, there is always some uncertainty subjected by using road sensors.

5.0 CONVERTING PHYSICAL REACTION FROM ICE CAROUSEL TO REACTIONS THAT OCCUR IN REALITY

Under normal conditions, the vehicles are subjected to various forces when they are in motion. The total force that acts on the vehicle is the sum of gravity and the pulling force, the pulling force may be assumed to consist of:
Rolling resistance, air resistance, side bolsters resistance and steering and brakes (gear resistance, including losses in the bearings). [Source: VTI Road Surface influence on rolling resistance]
In curves, cars are also exposed to a so-called frictional force which tries to keep the vehicle back into its position. A motorist who moves into a road curve, which has no slope, is dependent on the frictional force between tire and road. It means that if the car wants to avoid slipping, the frictional force have to provide the necessary centripetal force. It provides the following limit on how much the speed should be.
The tires on ice carousel when they first begin to move, are constantly exposed to the frictional force and the rolling resistance. Therefore, the forces are calculated for the carousel and are considered during data analysis.
Furthermore, the wheels on ice carousel are constantly driving on a same track, therefore probability calculation has been done in order to determine how often vehicles driving on the same track.

6.0 IMPLEMENTATION OF RESULTS

It is expected that the results from the study will contribute to new knowledge about the impacts generated by the rolling resistance between tires and road surface, which will lead us to the project's second objective of determining the traffic accelerating power and time of melting of ice.
If it turns out that the friction energy have enough effect on heating the road surface, the results will immediately be applied to a review of existing application rate, which is currently used by municipalities and the state. It is expected that the results may contribute to salt consumption during callout, can also be traffic dependent, i.e. in rush hours, salt consumption can be decreased, and at best, some salting actions can completely be avoided by creating sufficient heat.
We will in other words, have an understanding of the physical reactions that occurs when a tire rolls on the road surface, and the heat generated by both the rolling resistance and the de-icers chemical reaction with the surrounding nature, which helps to slow down the freezing process by lowering the freezing point temperature, thereby weakening the ice to be formed.

5.0 REFERENCES

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5. Danish road regulations for Traffic Engineering, capacity and service levels in section 3.3.2 "Ideal Capacity"