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Evaluation on the Effects of Deicing Chemicals on Soil and Water Environment

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Abstract

Deicing chemicals are widely used to clear the pavement snow in the cold areas of China and many other countries in winter, because of their simple operation and excellent snow-melting effect, which leads to more convenience for traffic and low probability of traffic accident in the city, especially in metropolis. However, with the ever-growing application of deicing chemicals, their negative effects on environment such as soil and water system increased dramatically. Based on the related researches in China and abroad, this paper summarized the two categories of deicing chemicals and their working principles, and then provided the unique characteristics of deicing chemicals' effects on soil and water environment in large cities, which may need considerable quantity of the chemicals to relieve traffic congestion. What's more, main aspects of impacts by deicing chemicals on regional soil and water environment and the fundamental factors related to the aspects above respectively were generalized, in order to propose a conceptual model to evaluate the harmful effects. Moreover, this paper put forward some suggestions for the further research in this field to fulfill the model, and provided a scientific basis for the pollution prevention of deicing chemicals on urban environment.

Keywords: deicing chemicals; regional evaluation of soil and water environment; conceptual model

1. Introduction

Snow in winter brings a lot of difficulties for our living. Especially when the temperature keeps low continuously, the snow on the road could be very hard to melt and even freeze to ice. Thereby, the snow

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and ice may lead to traffic block, closure of high way and airport. On the other hand, many traffic accidents occurred during the winter were due to the snow as well. Nowadays, in the context of rapid economic development and globalization, clearing the snow on the street as soon as possible to provide a smooth flow of traffic is an increasingly important problem. However, it is a world-class problem which is very hard to solve by now. Some of the developed countries have been trying many methods since 1950s. Among the various ways, applying deicing chemicals on the roads and bridges before and after the snow is the most common one. In China, we use deicing chemicals first in Beijing city in 1970s [1], to relieve traffic accident under the terrible road conditions after snow.

In recent decades, deicing chemicals are widely used all around the world in winter to remove the snow on the road [2-4]. Although deicing chemicals significantly reduce the clearing cost by machine and people, and to some extent, can melt the snow in a relative short period, they bring negative effects on the environment. For most of the deicing chemicals are made by chloride, melted snow water may pollute pavement, roadbed, overpass and even the metal pipe network underground, as well as the original water and soil around trees and grass roadside [2, 5-12]. Therefore, using deicing chemicals may lead huge financial losses. However, there is a lack of researches on assessment of deicing chemicals' effects on soil and water environment system by now, so it is very necessary and important to study the characteristics of the deicing chemicals and build a model to evaluate their impacts.

2. Types of deicing chemicals and their working principles

2.1 Types of deicing chemicals

There are two major kinds of deicing chemicals. One is organic chemical with potassium acetate as the mainly consist. It is effectual and almost non-corrosive, but the cost is too high to apply broadly. Hence it is usually used in the airport. The other kind is chlorate which contains NaCl, $CaCl_2$, $MgCl_2$, KCl and so on. Because of the chemical component, it is generally called "deicing salts". The advantages of this kind of deicing chemical is the low cost which is nearly one-tenth of the former kind, but on the other hand, the breakage by it is quite serious.

2.2 Working principle

Besides heat absorption, lower freezing point is also the reason why salty water is not easy to ice up. Deicing chemicals reduce the melting point of snow and ice. When the point is under air temperature, ice and snow can turn to solid phase from liquid.

Recently, a new type of deicing chemicals appears. Although it is called "new type", in fact, its main component is $CaCl_2$ other than totally different chemicals from the previous ones. Consequently, it could be harmful to the environment as well. In this study, the deicing chemicals refer particular to chloride.

3. Effects on soil and water environment by deicing chemicals

Ice and snow can melt faster by using deicing chemicals and the busy traffic will be ameliorated. However, melting water from ice and snow can destroy the road, infrastructure and environment through the following ways [2]. First, the melting water with chemicals can enter surface water and pollute the environment. Second, it can stay in the soil by surface water or underground water for a short or long

period. Third, it can go in the gutters by the pipes. Fourth, it can be absorbed by plants and affect plant growth. At last, it can be adsorbed by particles in the air and transported far away.

3.1 Effects on soil

Soil suffers harmful effects by deicing chemicals directly. Because the salt can stay in the soil for a long time and lead to soil physical, chemical and biological properties become worse. For example, Land degradation such as soil sealing and land salinization may emerge under the circumstances. Due to Cl^- takes negative charge, it can spread to water environment easily, rather than absorbing by soil colloid, while the positive part of Na^+ can accumulate in the soil until replacing exchangeable cations such as Ca^{2+}, Mg^{2+} [13-15]. Moreover, Soil *pM* increases and results in destabilization of aggregate and reduction of infiltration [16].

3.2 Effects on water

Slush with deicing chemicals enters surface water and underground water by pipes and infiltration. At present, researches about effects of deicing chemicals on water focus on surface water, instead of underground water.

3.2.1 Effects on surface water

The effects exist in the following processes. Changes of density gradient of water: Deicing chemicals can alter water density, consume large quantity of dissolved oxygen and then change the physical and ecological properties of lakes, suppress convective motion of water in spring [17]; Cl^- content increases: Maxe (2001) [18] found that within the distance of 100 m from public road, about 67 % of well water contained quite high amount of chlorine; Algae grows: Briggins and Walsh (1989) [19] pointed out that if concentration of Na^+ was larger than 40 mg/L, blue algae could grow excessively.

3.2.2 Effects on underground water

Deicing chemicals affect underground water mainly by polluting drinking water. Water polluted can be found with worse taste and higher salinity. Such kind of water can result in some diseases, e.g. hypertension (Serrano & Gaxiola, 1994) [20].

3.3 Effects on environment

Deicing chemicals can destroy plants and atmosphere as well. The element of chlorine could destroy ozone layer owing to chlorine radical and bromine radical which can be released into the atmosphere. Besides, the hazardous substance can influence plants by the following aspects [15, 21-25]. First, physiological drought: when slush with deicing chemicals was absorbed by plants, it would cause water stress for plants. Especially when relative humidity of atmosphere was low, salt injury could be more serious with increasing transpiration. Second, damage by certain ion: high content of certain ion could change permeability of plasmalemma and destroy the balance in the cells of plants. Third, disturb metabolism: too much salinity impacts photosynthesis and respiration by inhibiting synthesis of chlorophyll and kinds of enzymes, accordingly, suppress growth of plant.

In the winter of 2002, the snowfall in Beijing lasted very long and people had to spread large amount of deicing chemicals to melt snow in the street. However, 370 thousand of living green fences died in the next spring, as well as 10 thousand of arbors and bushes. Besides, 30 thousand square meters of grassland damaged. After testing the left snow near main roads and soil around the injured or dead plants, it was found that salt content in soil was 392 times higher than the normal value. While Cl^- content was even larger, it was more than 1000 times than the normal level. Specialists pointed out that slush with high content of deicing chemicals infiltrated and accumulated around plants' roots, leading to serious salt damage and finally, "kill" the plants nearby [26, 27].

4. Characteristics of deicing chemicals on regional soil and water environment

Compared with rural areas, busy cities have considerably larger demand of deicing chemicals in winter. Fully realization of effects by deicing chemicals on urban region should be done before proposing more reasonable model to evaluate the application of deicing chemicals. In general, characteristics of effects by deicing chemicals on regional soil and water environment have some unique aspects as follows.

4.1 Influenced much by human

Deicing chemicals are used in the most busy and important roads and places, so the application is totally influenced by people. In different roads and buildings, various quantity deicing chemicals spread according to the amount of snow. Some important main roads and positions with larger and concentrated passengers, such as cinema, theatre, supermarket, megastore and so on need much more concern in chemical usage.

4.2 Obviously periodic application

Deicing chemicals are usually used in winter when most plants in high latitude and altitude areas grow very slowly or even suspend growth. On the other hand, process which contains infiltration, combination with underground water and absorption by plants of slush with deicing chemicals need a period of time. Therefore, when spring comes, effects by deicing chemicals on plants could arise gradually. Accordingly, time factor should be considered into the evaluation model.

4.3 Liner distribution in space

Due to the operation of spreading deicing chemicals is often applied along the road and runway, the harmful effects emerge and vary with a compliance of linear regions in space. Nevertheless, in metropolis, many roads assemble crisscross to network which leads to effects of the chemicals used on soil and water system c from single lines to areas in some way.

4.4 Significant differences among locations

Applications of deicing chemicals in different roads with various levels and busy degrees are always unlike, as well as distinct sections and positions of the same road. Roads with higher level and transport hubs usually may need more quantity of deicing chemicals, which could result in much more serious problems for the environment. What's more, because of the gravity, water always goes to the low-lying places, where may suffer more by the chemicals.

From the characteristics above, we can conclude that effects of deicing chemicals on soil and water environment are multi-component and extensive. It is one of the most primary reasons why evaluation of deicing chemicals on soil and water environment lacks by now.

5. Conceptual model of evaluation of using deicing chemicals on regional soil and water environment

Working principle and the subjects affected by deicing chemicals should be considered when build the model. The model would be applied by regional hydrological, vegetation, soil and meteorological data to quantify each factor (Figure 1).

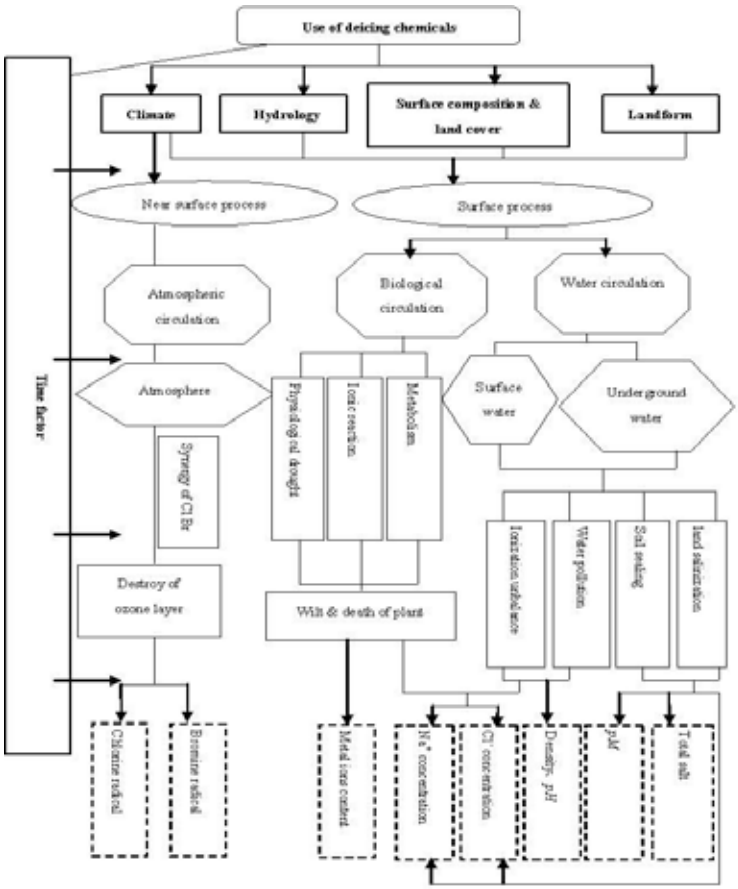

Fig. 1. The conceptual model for evaluating the effects of deicing chemicals on soil and water environment

Here we use the following formula as a conceptual model.

$$E=f(a, p, w, s, d) \quad (1)$$

where a is air factor, p is vegetation factor, w is water factor, s is soil factor and d is diffuse factor, respectively.

a factor means chlorine radical and bromine radical, which can be obtained by air condition monitoring data.

p factor means concentration of Na^+, Cl^- and other heavy metal cations in the plants. It could be gained from plant properties related to tests of phytobiology and phytophysiology.

w factor contains concentration of Na^+ and Cl^- in surface and underground water, *pH* value and water density. It can be calculated from data of water quality report.

s factor relates to concentration of Na^+ and Cl^-, *pM* and total salt which are all important aspects to represent soil alkalinity and soil hardening. This factor can be used in researches about changes of soil properties and extent of sustainable development of soil.

The above factors are obtained by measurement. They can be compared and quantified with the threshold values in standards, and then calculated later.

d factor is a diffuse factor. It demonstrates an integral effect of time, meteorology, hydrology, composition of earth surface and land cover. It can be an exponent function for *d* factor. Due to time effect of ecological system, factors above may vary during the time. For instance, air motion can affect evapotranspiration, and then influence absorbing deicing chemicals in the ice and snow by plants. Interaction of surface water, ground water, soil water and runoff in hydrological circle may bring the harmful chemicals far from the original location where they were applied. Earth surface and land cover partly determine the flow direction and infiltration of the slush with deicing chemicals. For example, totally different results can be found between cement pavement and soil road. Melted water flows to the low-lying areas and finally to the underground pipelines. While on the soil road, water can infiltrate directly into the earth. Because of the differences among soil types and physical properties, infiltration ability varies a lot. In addition, topography is critical as well. Flows of slush are influenced by the lay of landscape either on the earth's surface or underground. Divergences of terrain's property cause uneven distribution of slush in space. This element could be expressed by elevation difference.

Main impacts of deicing chemicals on soil and water environment vary under either distinct regions and conditions or different sections of the same road. For divergent time period and topography, the factors above also change to some extent. Hence, for the same period and on one road, effect index of deicing chemicals on soil and water environment could be:

$$E=\sum E_i \qquad (2)$$

where E_i is the index of different topography. Figure 2 showed the evaluation process of assessment.

In order to obtain the result of regional impact of deicing chemicals, i.e., *E*, we should add all the roads together. However, road level, busy degree, quantity and scale of important positions should be considered.

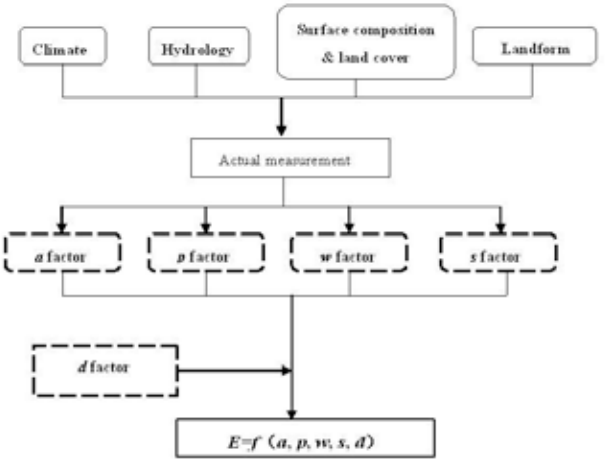

Fig. 2. Evaluation process

6. Conclusion and discussion

Deicing chemicals have very complicate influences on ecological processes and researches about them and related are badly needed. In recent decades, scholars all around the world have made numerous achievements, which focused on soil, water, plants, air and so on. Among these fields, studies on soil and water are more intensive while those changes of biological and ecological aspects of plants and aquatic animals are much less. At present, most researches on deicing chemicals are about developing real environment friendly chemicals, specific influence mechanisms on infrastructures, roads, bridges and environment. However, the influence of deicing chemicals on regional environment is a long period ecological process, but there are few researches on regional spatial and temporal environment differences, especially on soil and water systems in metropolis. Therefore, this paper summarized previous works about the deicing chemicals and tried to propose a conceptual model of its effects on local soil and water environment assessment. Further studies should be considered as the following topics: How to set the threshold values of the factors and quantify the index in the model; How to set the weight of each factor; How do the detrimental ingredients migrate in environment and whether enrichment exists. Which fields suffer most if there is enrichment effect; How to define the weight of road hierarchy; How to put special nodes effect, such as super markets, shopping malls, cinemas, theatres and so on, which are concentrated by passengers into the model.

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