On impact of vehicle headlights contamination with products of road chemical deicing agents upon pedestrian visibility on unlit roads

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Abstract. The goal is to determine consistent patterns that characterize the impact of vehicle headlights contamination caused by products of chemical deicing agents treatment (PCDAT) used on the roads on the driver’s ability to see pedestrians on unlit roads. The analysis of theoretical works devoted to the impact of vehicle headlights contamination with PCDAT upon their lighting the road was carried out. The authors conducted experimental studies of the process of contaminating vehicle headlights with PCDAT used on roads in winter under the real traffic conditions as well as measurements of luminous intensity of the contaminated headlights. Experimental studies of a pedestrian’s visibility on the side of a dark unlit road under the conditions of headlights contaminated with PCDAT were carried out. The authors developed the procedure of experimental studies to measure the distance of pedestrian visibility on a dark road with passing and driving beam headlights. The patterns that characterize the impact of vehicle headlights contamination caused by PCDAT upon the driver’s ability to see pedestrians on unlit roads were determined. The results of the experiments are presented as tables, graphs and equations reflecting the new data. They relate to the consistent patterns of the impact of vehicle headlights contamination caused by PCDAT on the driver’s ability to see pedestrians on an unlit road side in winter. The graphs allow analyzing the influence of vehicle headlights contamination with PCDAT upon the driver’s ability to see pedestrians on the side of unlit roads in winter.

1. Introduction
The issue of improving safety of motor vehicles transport (MVT) on winter roads is still relevant. According to the official statistics of the State Traffic Safety Inspectorate of the Russian Federation, every third road traffic accident (RTA) occurs at night [1].

The climatic peculiarity of many regions in Russia is the winter slippery conditions on roads. The duration of the winter slippery surface condition in Russia is 5-6 months. During this period, the roads
are covered with snow, packed snow, and ice. According to the Road Industrial Methodical Document Guidelines for Disposing of Winter Slippery Conditions on Motorways [2], all types of snow and ice deposits (SID) must be disposed of within statutory time. One of the ways to dispose of SID is using chemical deicing agents (CDA) by road services [3].

Dealing with winter slippery conditions, road services spread CDA on the snow-covered base of the road. The result of it is formation of a “sandwich” – a multilayer structure composed of ice and snow mixed with deicing agents and salt brine [4-8]. Under the conditions of heavy traffic of MVTs salt brine and snow mixed with deicing agents are raised by the wheels and contaminate the lighting devices of oncoming and rear-going cars. Consequently, at night, such important characteristics as illumination of the road with headlights, as well as drivers’ ability to see road users, road infrastructure and pedestrians on unlit sections of roads and roadways significantly decrease. This reduces the traffic safety to a great extent.

The problem is compounded by the fact that the reduced driver’s ability to see the traffic situation during the winter season is accompanied by a low index of tire adhesion with the road covered with CDA, which increases the braking path of a MVT [4, 7-9]. As a result, a driver on a slippery road under the conditions of insufficient visibility is not always able to stop his/her MVT in front of a pedestrian or an obstacle. Moreover, in modern cars there are no devices showing drivers if the headlight contamination value changes.

2. Procedures of experiments and their results

The analysis of scientific works devoted to the study of the impact of using CDA on the traffic safety of MVTs and their service properties shows that the given works do not take into account the impact of using CDA on the contamination of the external lighting devices of the car, on their illuminating the road at night, on the driver’s ability to see the road infrastructure, and, consequently, on the traffic safety of MVTs on winter roads [10].

The basic scientific research is aimed at studying the impact of CDA on the condition of the road surface and assessing the adhesion of a car tire with the road covered with deicing agents [4-6, 8]. When conducting experiments, tire simulators are used; they allow determining the coefficient of sliding friction of rubber along the road surface covered with CDA [4, 5]. This scientific study presents the results of experiments conducted under the real road conditions on the roads covered with CDA in Irkutsk.

The results of the experimental study obtained by the authors of the article made it possible to determine consistent patterns of the influence of vehicle headlight contamination with road chemical deicing agents on their luminous intensity change.

It is experimentally proved that during the winter period chemical deicing agents can significantly reduce the light intensity of the vehicle headlamps in both low beam mode (11-23 times) and high beam mode (15-29 times), which is particularly dangerous if the coefficients of adhesion of automobile tires with the road are low [11].

The given research allowed determining characteristics of the influence of dirty car headlights on the driver’s ability to see both pedestrians on the side of the road and the traffic situation at night on winter roads covered with deicing materials.

The goal of the experiment is to determine the distance $L_{pv}$ from a pedestrian walking along the side of the dark part of the road at night to a driver sitting in the driver’s cabin of a car with dirty headlights.

Before conducting the experimental measurements of the distance of pedestrian visibility on the side of the road in the dark under the conditions of contamination of external light devices of a car with products of road chemical deicing agents in the low and high beam modes a number of preliminary actions were taken:

1. the time and place of the experiment were determined;
2. a flat, horizontal, safe section of the road was selected;
3. the roadway coating complied with the requirements specified in the methodology;
4. the staff (2 people) received training required for the experiment;
5. the equipment for measuring the distance of visibility $L_{pv}$ was prepared.

The experimental studies were carried out in the dark, both with clean headlights and with headlights contaminated by the products of road deicing agents in the low and high beam modes.

The experiments were carried out under the following reference conditions:
- air temperature from $-20 \, ^\circ C$ to $+4 \, ^\circ C$ (since the slippery surface condition on the roads is observed at this temperature range);
- the road is covered with snow with chemical deicing agents.

The distance of visibility $L_{pv}$ is influenced by such external factors as:
- color of a pedestrian’s clothes;
- visual acuity of the driver;
- the reaction time of the driver;
- illumination of the road section.

The procedure of the experimental studies of the impact of car headlights contamination with the slush of snow, ice and deicing agents upon the driver’s ability to see both pedestrians on the side of the road and the traffic situation on the roadway in the dark included the following sequence of actions:
1. *Screens* were placed on the car headlights (Figure 1). Transparent screens being removable allow measuring the value of their light transmission after their contamination with CDA (which is very difficult to do with vehicle integral headlights).
2. The car with the screens placed on the headlights was on the unlit part of the road in the dark at the distance of 0.5 meters from the edge of the roadside (Figure 2).

![Figure 1. Transparent Screen on the Vehicle Headlamp.](image1)

3. The low beam mode was switched on.
4. The pedestrian was walking ahead from the standing car along the line of the headlights luminous flux on the unlit section of the road. The pedestrian in the dark clothes was moving along the edge of the roadway (Figure 3).

![Figure 2. Ready Section of the Road.](image2)

![Figure 3. A Pedestrian on the Roadside.](image3)
5. As soon as the driver could not detect the pedestrian, the latter was stopped with the help of the car horn.
6. The sighting device was put at the place where the pedestrian stopped.
7. The distance $L_{pv}$ reflecting the driver’s ability to see the pedestrian in the light of car headlights was measured with the use of a measuring tape.
8. The car headlights were put in the *high beam mode*, then the actions 4-7 of the given procedure were repeated.
9. The measurements results are presented in Table 1.

| Experimental Studies Cycle, No | Distance of Pedestrian Visibility ($L_{pv}$), m |
|-------------------------------|-----------------------------------------------|
|                               | in the low beam mode, m | in the high beam mode, m |
| 1                             | 39.5                         | 69.5                        |
| 2                             | 38.0                         | 65.0                        |
| 3                             | 35.8                         | 57.8                        |
| 4                             | 29.0                         | 50.5                        |

10. There were several cycles of the vehicle runs along the streets and roads covered with CDA in Irkutsk; the length of each run was 100 km.
11. *The light transmission of the headlights screen glass* ($T_{hl}$) and *the luminous intensity of the headlights* ($I_{hl}$) in the *low and high beam modes* were measured after each cycle of the vehicle run.
12. Then *the distance of the driver’s ability to see the pedestrian* $L_{pv}$ was measured (the actions 1-9 of the given procedure were performed). The number of the experimental measurements of the visibility distance $L_{pv}$ corresponded to the number of measurements of light transmission of the car headlights screens and their luminous intensity.

The results obtained by the authors allowed constructing *graphs of the light transmission of the headlights screen* against the sequence number of the experimental studies cycle in Microsoft Excel (Figure 4). The graph clearly shows the degree of the headlamps screens light transmission reduction depending on the cycle of the experimental research.

![Figure 4](image-url)
Table 2. Results of recalculation.

| Experimental Studies Cycle, No | Light transmission ($T_{hl}$) of the screen glass, % | Value of the screen glass contamination ($Y_{hl}$), % |
|------------------------------|-------------------------------------------------|--------------------------------------------------|
|                              | left headlamp | right headlamp | average | left headlamp | right headlamp | average |
| 1                            | 96.6          | 98.3           | 97.4     | 3.4           | 1.7            | 2.55    |
| 2                            | 84.2          | 84.8           | 84.5     | 15.8          | 15.2           | 15.5    |
| 3                            | 55.0          | 54.8           | 54.9     | 45.0          | 45.2           | 45.1    |
| 4                            | 11.5          | 21.8           | 16.6     | 88.5          | 78.2           | 83.3    |

The graph of car headlights screen light transmission against the value of headlights screen contamination is presented in Figure 5.

Figure 5. Graph of Headlights Screen Light Transmission ($T_{hl}$) against the Value of Headlights Screen Contamination ($Y_{hl}$).

The experiments related to changes of the headlights luminous intensity (measured by IPF-01) in the low and high beam modes depending on the screen contamination with the products of road chemical deicing agents allowed constructing the graphs in Microsoft Excel; they are presented in Fig. 6.

Figure 6. Graphs of Headlights Luminous Intensity ($I_{hl}$) Against the Value of Their Screens Contamination ($Y_{hl}$) with CDA: 1 – in the low beam mode; 2 – in the high beam mode; ◆ and ▲ - result of the experiment; –– –– - result of approximation.
Approximating dependence of the graphs of headlights luminous intensity change on the value of their screens contamination with CDA in the low beam mode was calculated as follows:

\[ I_h = -0.3951 \cdot Y_{hl}^2 - 53.802 \cdot Y_{hl} + 7788.6 \]  

(2)

where \( I_h \) – helmet luminous intensity.

The coefficient of approximation certainty is \( R^2=0.9936 \).

Approximating dependence of the graphs of headlights luminous intensity change on the value of their screens contamination in the high beam mode was calculated as follows:

\[ I_h = 2.68529 \cdot Y_{hl}^2 - 464.225 \cdot Y_{hl} + 21336.05 \]  

(3)

The coefficient of approximation certainty is \( R^2=0.98670 \).

The experimental data presented in Table 1 were processed with the help of Microsoft Excel. The graphs of the distance of pedestrian visibility on the roadside in the dark against the value of headlights screens contamination were constructed and presented in Figure 7.

The functional relationship between the distance of pedestrian visibility on the roadside in the dark and the value of headlights screens contamination in the low beam mode was calculated as follows:

\[ L_{pv} = -0.00103 \cdot Y_{hl}^2 - 0.03759 \cdot Y_{hl} + 39.31726 \]  

(4)

where \( L_{pv} \) – distance of pedestrian visibility.

The coefficient of approximation certainty is \( R^2=0.993 \).

The functional relationship between the distance of pedestrian visibility on the roadside in the dark and the value of headlights screens contamination in the high beam mode was calculated as follows:

\[ L_{pv} = 0.0011 \cdot Y_{hl}^2 - 0.32739 \cdot Y_{hl} + 70.13623 \]  

(5)

The coefficient of approximation certainty is \( R^2=0.999 \).

The experimental data presented in Table 1 and in Fig. 6 were processed with the help of Microsoft Excel. The graphs of dependence of pedestrian visibility distance on the roadside in the dark on the headlights luminous intensity in the low/high beam modes were constructed (Figure 8).
The experimental studies allowed calculating the functional relationship between the distance of pedestrian visibility on the roadside in the dark and the headlights luminous intensity in the low beam mode:

$$L_{pv} = 0.00145 \cdot I_h + 28.46240 \, \text{.}$$  \hspace{1cm} (6)

The coefficient of approximation certainty is $R^2=0.994$.

The functional relationship between the distance of pedestrian visibility on the roadside in the dark and the headlights luminous intensity in the high beam mode was calculated as follows:

$$L_{pv} = 0.001 \cdot I_h + 50.62119 \, \text{.}$$  \hspace{1cm} (7)

The coefficient of approximation certainty is $R^2=0.97$.

3. Conclusion

The results obtained during the experimental studies allowed determining that the use of chemical deicing agents on the roads in winter can reduce the distance of the driver’s ability to see pedestrians and road infrastructure in the dark 1.5 times. Besides, the low coefficient of tire adhesion with the road can significantly increase the vehicle braking path in comparison with pedestrian visibility distance in the dark.

Further research of the issue can involve the analysis of the vehicle braking path on the roads covered with CDA with the low adhesion coefficient taking into account the distance of pedestrian visibility on the unlit roadside which is limited due to dim light of the dirty vehicle headlights.

References
[1] Road safety data [Electronic resource], available at: http://stat.gibdd.ru/
[2] IRGM Road winter slipperiness guidance. Ministry of transport of the RF 2003 [Electronic resource], available at: http://infosait.ru/norma_doc/41/41133/index.htm
[3] IRGM Deicing materials requirements. 2003 (Moscow, Infromavtdor) 72 p.
[4] Fedotov A, Gergenov S and Darkhanov Z 2017A tire tester for experimental studies of automobile tire properties when moving on roads covered with deicing chemicals. Proc. of the 99th Int. Sci. and Technical Conf. of INRTU; pp. 150–159
[5] Gergenov S, Korchagin V and Darkhanov Z 2015 Studies on grip tire properties Polzunov Yearbook 2 91–95
Vetrova V 2006 *The influence of deicing agents on road conditions and road safety.* Dissertation, Moscow

Kustarev G, Morozov R and Gorshkov A 2013 *MARI. Moscow. Science Perspective* **10(49)** 18–21

Fedotov A and Gergenov S 2015 On the influence of deicing materials on wheeled vehicles operation and performance *J. of automobile engineers*. 4 38–41

Balakin V *Expertise of road accidents: manual, 2nd edition.* (Omsk: SibADI) 136 p.

Gromalova V, Fedotov A, Zedgenizov S and Gergenov S 2018 On the Impact of the External Light Devices Contamination with Chemical Deicing Agents on Traffic Safety of Vehicles *The Bulletin of the SIBADI* **15(1)** 55–60

Fedotov A, Gromalova V, Kornyakov M and Gergenov S 2018 Influence Of Deicing Chemicals Contaminating Automobile Headlamps On Light Intensity *Proc. of the Int. Conf. "Aviamechanical Eng. and Transport" (AVENT)* pp. 141–146

Saraykin A 2017 *Automobile under the lack of visual information*, PhD Thesis, Orenburg

Kim P 2014 *Improvement of pedestrian safety of zebra crosswalks*, PhD Thesis, Irkutsk

Syutova E and Alykov N 2012 Comparative tests of new deicing agents ASU. *Ecology and industry of Russia* 47–51

Federal Law No 131-FZ “On general principles of local government management in Russia of October 6, 2003.

Technical Regulations of the Customs Union CU TR018/2011 on wheeled vehicles safety. Moscow, 2011.