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Influence of Headlight Contamination on the Stopping Distance and Maximum Allowable Speed on Roads Covered with Chemical Anti-Icing Materials

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***Abstract* — The article aims to identify the influence of headlight contamination on the stopping distance and allowable speed on roads covered with chemical anti-icing materials at night. Headlight contamination effects were analyzed for determining the maximum allowable vehicle speed on winter roads covered with chemical anti-icing materials in dark conditions. The maximum allowable speed and stopping distance of the vehicle with contaminated headlights were calculated accounting for road visibility in dark conditions. New data on the influence of car headlight contamination, length of its stopping distance and maximum allowable speed on roads covered with chemical anti-icing materials were obtained.**

Keywords – ***chemical anti-icing materials, "road sandwich", headlight contamination, dark conditions, stopping distance, maximum allowable driving speed.***

I. Introduction

In Russia, due to an increase in the number of cars, one of the main tasks is to improve traffic safety.

Traffic accidents (TA) are one of the most dangerous threats to the human health and life. Most accidents occur in winter due to the road slipperiness caused by snow-ice deposits (SID). The Guidelines for preventing winter road slipperiness [1] provide for measures aimed at eliminating all types of SID within the established time. In Irkutsk region, to eliminate SID, the chemical anti-icing materials (CAIM) are used.

The authors published results of the study aimed at solving the problem of negative application of the CAIM on winter roads. In particular, it was found that when driving vehicles on winter roads covered with CAIM, the headlights become contaminated [2].

New data on the influence of headlight contamination with anti-icing materials on the illuminating power of headlights were obtained. The experiment results were presented in graphs that allow for analysis of headlight contamination effects on the illuminating power in winter conditions [3].

The effects of intensity of headlights contaminated with chemical anti-icing materials on road visibility in dark conditions were identified.

It was experimentally proved that the CAIM change the contaminated headlight intensity and reduce road visibility in dark conditions. The results were presented in graphs.

II. Methods and results

Most of the works dealing with vehicle safety on roads covered with CAIM identify CAIM effects on vehicle performance and tire grip characteristics [5–8].

Results of the experimental studies obtained by the authors will make it possible to determine the maximum allowable vehicle speed on roads covered with CAIM taking into account road visibility.

It is advisable to calculate the stopping distance of the car in order to determine the maximum allowable vehicle speed accounting for visibility conditions in dark conditions.

The car tire grip coefficient influences the vehicle safety. Its low high value causes numerous road accidents. About 70% of the total number of road accidents occur during unfavorable seasons. In order to enhance road safety, the car tire grip coefficient should be at least 0.4.

On dry hard roads, the car tire grip coefficient is high. On roads covered with chemical anti-icing materials, the coefficient significantly decreases (1.5–2 times).

These materials often form a "road sandwich", i.e. a superimposed layer of CAIM, SID and road sediment particles; a liquid layer of salt CAIM and SID solution and a solid layer of snow and icy sediments on the road pavement (Fig. 1).

Experimental studies aimed at identifying the influence of headlight contamination on the stopping distance and maximum allowable speed on dark roads covered with a road sandwich were conducted on Toyota FunCargo and Nissan Qashqai.

For the Toyota FunCargo, the relationships between the pedestrian visibility (S_{vis}) and the headlight contamination value *(Yef)* in the low and high beam modes were identified (Table 1).

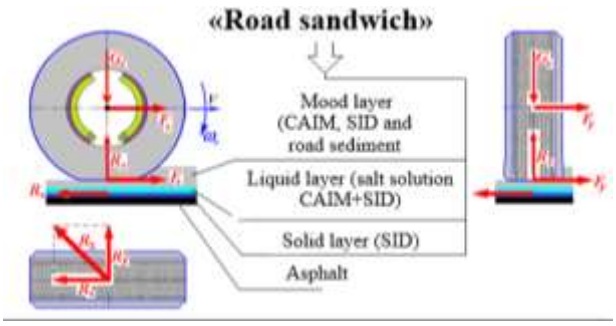

Fig. 1. Tire movement on the road covered with a road sandwich

TABLE I. PEDESTRIAN VISIBILITY DISTANCE IN THE DARK CONDITIONS DEPENDING ON THE LEVEL OF TOYOTA FUNCARGO HEADLIGHT CONTAMINATION

Headlight screen contamination value, (Y_{ef}), (%)	Pedestrian visibility by the road side, (S_{vis}),(m)	
	Low beam	*High beam*
2,55	39,90	68,57
10	38,95	66,85
15	38,32	65,69
20	37,69	64,54
25	37,05	63,38
30	36,42	62,23
35	35,78	61,08
40	35,15	59,92
45	34,51	58,77
50	33,88	57,61
55	33,24	56,46
60	32,61	55,30
65	31,97	54,15
70	31,34	52,99
75	30,70	51,84
80	30,07	50,68
83,55	29,62	49,86

TABLE 2. PEDESTRIAN VISIBILITY DISTANCE IN THE DARK CONDITIONS DEPENDING ON THE LEVEL OF NISSAN QASHQAI HEADLIGHT CONTAMINATION

Headlight screen contamination value, (Y_{ef}), (%)	Pedestrian visibility by the road side, (S_{vis}),(m)	
	Low beam	*High beam*
1,7	50,42	93,31
10	48,68	89,07
15	47,63	86,51
20	46,58	83,96
25	45,53	81,40
30	44,48	78,84
35	43,44	76,29
40	42,39	73,73
45	41,34	71,17
50	40,29	68,62
55	39,24	66,06
60	38,19	63,51
65	37,15	60,95
67,65	36,59	59,59

Similar dependencies were identified for the Nissan Qashqai (Table 2).

The graphs of dependences of the distance of pedestrian visibility in the dark conditions on the level of headlight screen contamination in the low and high beam modes (Fig. 2) were plotted.

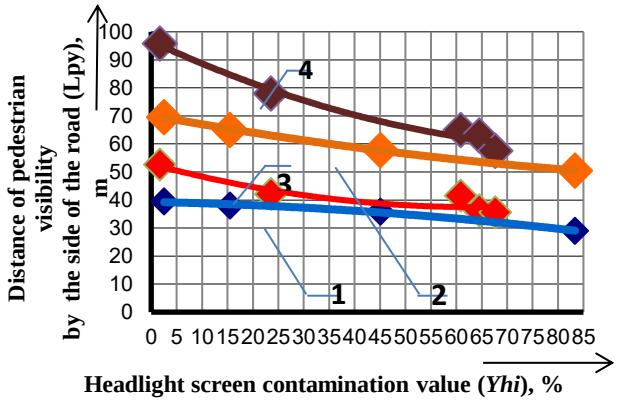

Fig. 2. Graphs of the dependence of the distance of pedestrian visibility *(L_{pv})* by the road side in dark conditions on the headlight contamination value (Y_{hi}) for *Toyota FunCargo*: 1 – low beam; 2 – high beam; ♦ and ♦ – experiment; —— – calculation; for *Nissan Qashqai*: 3 – low beam; 4 –high beam; ♦ and ♦ – experiment; —— – calculation

The functional dependence of the distance of pedestrian visibility on the headlight contamination level for *the Toyota Fun Cargo in the low beam mode* was identified:

$$L_{py} = -0{,}00103 \cdot Y_{hi}^2 - 0{,}03759 \cdot Y_{hi} + 39{,}31726 \quad (1)$$

where L_{pv} is the distance of pedestrian visibility;

The coefficient of approximation accuracy was R^2=0,993

The functional dependence of the distance of pedestrian visibility on the headlight contamination level *in the high beam mode* was identified:

$$L_{py} = 0{,}0011 \cdot Y_{hi}^2 - 0{,}32739 \cdot Yhi + 70{,}13623 \quad (2)$$

The coefficient of approximation accuracy was R^2=0,999.

The functional dependence of the distance of pedestrian visibility on the headlight contamination level for *the Nissan Qashqai in the low beam mode* was identified:

$$Lpy = 0{,}0038 \cdot Y_{hi}^2 - 0{,}4851 \cdot Y_{hi} + 52{,}817 \quad (3)$$

The coefficient of approximation accuracy was R^2=0,87

The functional dependence of the distance of pedestrian visibility on the headlight contamination level *in the high beam mode* was identified:

$$L_{py} = 0{,}0046 \cdot Y_{hi}^2 - 0{,}8422 \cdot Y_{hi} + 96{,}63 \quad (4)$$

The coefficient of approximation accuracy was R^2=0,98.

The maximum allowable vehicle speed (*Va*) was calculated for the roads with a car tire grip coefficient of 0.3 [4] taking into account the headlight contamination with the

CAIM (%) and road visibility at night in the low and high beam modes (m) (5):

$$V_{max} = 3{,}6 \cdot g \cdot \varphi \cdot (t_1 + t_2 + 0{,}5 \cdot t_3) \cdot \left(\sqrt{\frac{2 \cdot S_{вид}}{g \cdot \varphi \cdot (t_1 + t_2 + 0{,}5 \cdot t_3)^2} + 1} - 1 \right) \quad (5)$$

where g- acceleration of gravity;

ϕ – car tire grip coefficient;

S_{vis} – pedestrian visibility;

t_1 – driver's response time, (s);

t_2 – lag time (s);

t_3 – slowdown rise time, (s).

The graphs of dependencies of the maximum allowable vehicle speeds at night on the level of headlight contamination with road sandwich particles were built (Fig. 3).

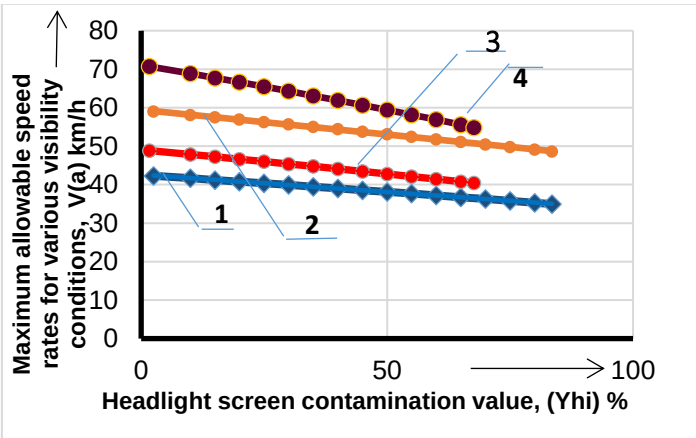

Fig. 3. Graphs of dependencies of the maximum allowable vehicle speeds at night at the level of *Toyota Fun Cargo* headlight contamination on the roads with a car tire grip coefficient ϕ = 0.3: 1 – in the low beam mode; 2 – in the high beam mode; on the level of *Nissan Qashqai* headlight contamination: 3 – in the low beam mode; 4 – in the high beam mode.

The approximate dependence of the graphs of dependencies of the maximum allowable speed at night on the level of *Toyota Fun Cargo* headlight contamination with CAIM (at the car tire grip coefficient ϕ = 0.3) in the low beam mode was identified:

$$V_{\max} = -0{,}0090664608\ 9 \cdot Y_{hi} + 42{,}6109512527 \quad (6)$$

The coefficient of approximation accuracy was R^2=0,9999.

The approximate dependence of the graphs of dependencies of the maximum allowable speed at night on the level of *Toyota Fun Cargo* headlight contamination with CAIM (at the car tire grip coefficient ϕ = 0.3) in the high beam mode was identified:

$$V_{\max} = -0{,}1284769578 \cdot Y_{hi} + 59{,}4531207076 \quad (7)$$

where V_{max} – maximum allowable speed;
$Y_{cф}$ – headlight contamination level;
The coefficient of approximation accuracy was R^2=0,999.

The approximate dependence of the graphs of dependencies of the maximum allowable speed at night on the level of *Nissan Qashqai* headlight contamination with CAIM (at thecar tire grip coefficient ϕ = 0.3) in the low beam mode was identified:

$$V_{\max} = -0{,}0002 \cdot Y_{hi}^2 - 0{,}124 \cdot Y_{hi} + 49{,}139 \quad (8)$$

The coefficient of approximation accuracy was R^2=1

The approximate dependence of the graphs of dependencies of the maximum allowable speed at night on the level of *Nissan Qashqai* headlight contamination with CAIM (at the car tire grip coefficient ϕ = 0.3) in the high beam mode was identified:

$$V_{\max} = -0{,}2528 \cdot Y_{hi} + 71{,}62 \quad (9)$$

where V_{max} – maximum allowable speed;
Y_{hi} – headlight contamination level;
The coefficient of approximation accuracy was R^2=0,999.

The stopping distance was calculated for the maximum allowable speed accounting for visibility conditions for roads covered with rolled snow and treated with CAIM [4]. An example of the calculation by formula (4) is presented in Table 3:

$$S_{ост} = (t_1 + t_2 + 0{,}5 \cdot t_3) \cdot \frac{V_a}{3{,}6} + \frac{V_a^2}{26 \cdot g \cdot \varphi} \quad (10)$$

where t_1 – driver's response time, (s);

t_2 – lag time. (s);

t_3 – slowdown rise time, (s);

V_a – speed, (km/h);

g – acceleration of gravity;

φ – car tire grip coefficient.

Based on the above calculations, the graphs of dependences of the stopping distance (S_{st}) on the speed (*Va*) for roads covered with rolled snow and treated with CAIM at the car tire grip coefficient φ=0,3 were built (Fig. 4).

The dependence of the stopping distance on the speed at the car tire grip coefficient φ=0,3 was determined:

$$L_{st} = 0{,}013069 \cdot V_a^2 + 0{,}388889 \cdot V_a \quad (11)$$

where L_{st} – stopping distance; V_a – speed.

The coefficient of approximation accuracy was R^2= 1.

The dependence of the stopping distance on the speed at the car tire grip coefficient φ=0,4 was determined:

$$L_{st} = 0{,}0098016153 \cdot V_a^2 + 0{,}388889 \cdot V_a . \quad (12)$$

The coefficient of approximation accuracy was R^2= 1.

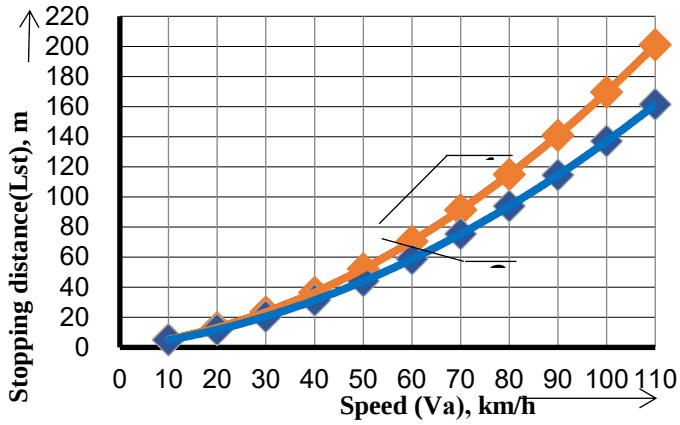

Fig. 4. The graphs of dependences of the stopping distance (S_{st}) on the speed (*Va*) for roads covered with rolled snow and treated with CAIM: 1 – at the car tire grip coefficient φ=0,3; at the car tire grip coefficient φ=0,4.

III. Conclusions

The following conclusions can be drawn:

- the change in the *Toyota Fun Cargo* headlight contamination level in the range from 2.6 to 83.6 % reduces pedestrian visibility on night winter roads from 40 m to 30 m in the low beam mode, and from 68 m to 50 m in the high beam mode;
- the change in the *Nissan Qashqai* headlight contamination level in the range from 1,7 to 67,6 % reduces pedestrian visibility on night winter roads from 50 до 36 m in the low beam mode, and from 93 to 60 m in the high beam mode;
- at low car tire grip coefficients, the maximum allowable speed for the Toyota Fun Cargo decreased from 42 to 35 km/h in the low beam mode, and from 59 to 48 km/h in the high beam mode. The maximum allowable speed for the Nissan Qashqai reduced from 49 to 40 km/h in the low beam mode, and from 70 to 54 km h – in the high beam mode;
- depending on the maximum allowable speed of the car with dirty headlights, the stopping distance of the *Toyota Fun Cargo* is 30–40 m in the low beam mode, and 49–68 m – in the high beam mode;
- depending on the maximum allowable speed of the car with dirty headlights, the stopping distance of the Nissan Qashqai is 36–50 m in the low beam mode, and 60–93 m – in the high beam mode.

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