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The Test Rig For Analysis Of The Fog Optical Properties

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Abstract
This paper raises the problem of the traffic safety in the foggy conditions. The main optical properties are considered. The literature review related to determination of the fog optical properties was performed which speaks of the absence of obvious effect of the fog on the optical emission. The design of the laboratory plant allowing measuring the optical characteristics of the fog for different lengths of waves within the visible range is described. The detailed description of the laboratory plant design and the principle of its action allow reproducing it easily. The main attention by design of the laboratory plant is paid to creation of conditions that allow maintaining unchanged the fog characteristics for performance of the long-term experiments. The presence of a Web-cam located within the space under investigation allows to visually control the fog state during performance of the experiments. The measuring technique with the use of light emitting diodes is presented that is divided into a few stages: calibration, preparation and measurement. For investigation of the fog properties the 8 LEDs were used: 6 of which emitted the red, orange, yellow, green, blue and violet colors and the two LEDs emitted the warm and cool white light. The results of the measurements are presented as well as their relevance by design of the special light sources for fog head lamps is specified.

Keywords: fog, fog generator, optical properties of the medium, light emitting diodes, emission band, transmission coefficient.

1. INTRODUCTION

At the moment of appearance of the first vehicles little attention was paid to the safety. Now in the century of the high technologies when equipment plays an important role in the life of people safety comes first. The modern systems installed at vehicles significantly simplify the process of control, reduce the human factor to the minimum and in many cases allow preventing accidents [10], however, neither of the systems is able to withstand the unfavorable weather conditions one of which the fog is.

Fog has always constituted great threat to all kinds of vehicles [5]. Today there are different methods facilitating the vehicle control process in the foggy conditions, for example, installation of the fog head lamps [6, 8], however, they don't solve this problem completely which requires the more detailed investigation of the fog optical properties.

2. DISCUSSIONS

Fog is the finest particles of moisture suspended in the air [12]. The main problem of the fog is the finest water drops acting as reflective elements of reflectors reflect most of the incident rays towards the light source (Figure 1) [4].

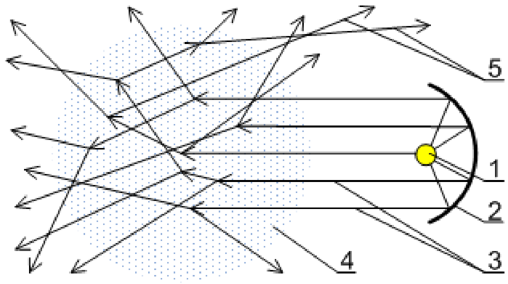

Figure 1 – Simplified scheme of the light diffusion in the fog: 1 – light source, 2 – reflector, 3 – parallel light beam, 4 – fog cloud, 5 – light beams diffused by fog

Thus, for features two main optical characteristics: the transmission coefficient and the diffusion coefficient. The transmission coefficient shows which part of light will pass from the source to the receiver through the fog cloud. The diffusion coefficient shows which portion of light will be diffused by the fog cloud and reflected to the source. The nature of the light interaction with for to a great extent depends on the size of the fog particles and the length of the light waves used [3, 13].

According to the experiments performed by researchers of the New Jersey Technological Institute the intensity of the light attenuation in the fog they produced with the use of the fog generator FSS60C increases with the increase in the distance between the light source and receiver and features a non-linear nature [2].

It is known that the light with different wave lengths interacts with the fog in a different manner and, therefore, the transmission and diffusion coefficients for the light with different wavelengths are different. The researchers from the Kaunas University of Technology that used in their experiments the fog generator ANTARI Z300 and the carbonic ice state that the light with a longer wavelength is more diffused in the fog then the light with the short wave-length [1].

All of this significantly complicates the process of analysis of the fog optical properties and further use of the results obtained by design of the lighting devices designed for the use in the foggy conditions. The problem related to the effect of the intensity of the landing lights of airplanes and signaling lights on the visibility in the foggy conditions is described in the text book for the specialized secondary schools of the civil aviation ‘Lighting engineering and light measurements’ [9].

3. DESIGN OF THE UNIT

For investigation of the fog optical properties the laboratory unit for fog production was assembled in which the fog generator Exo Terra Fogger (PT-2080) [7] presented in the Figure 2 was used. 2 spectral radiometers Specbos 1211 were used for measurements.

Figure 2 – Appearance of the ultra-sonic fog generator

The design of the test unit is presented in the Figure 3. The case 1 represents a leak-proof box with a cover (not shown in the Figure) with the dimensions 702×310×390 mm.

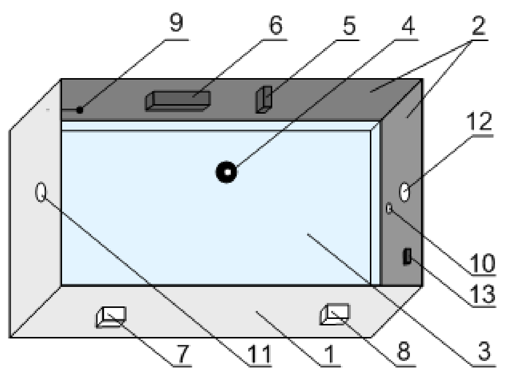

Figure 3 – The unit for investigation of the fog optical properties (top view): 1 – camera case, 2 – black fabric, 3 – water, 4 – ultra-sonic fog generator, 5 – blower for air recirculation in the chamber, 6 – infrared fog density sensor, 7 – blower for chamber blowing, 8 – fog-discharge hole, 9 – thermocouple, 10 – hole for installation of the light source, 11 and 12 – holes for installation of the spectral radiometers *a* and *b*, respectively, 13 – Web-camera.

The inner case surface is covered with a polyethylene film in such a manner that leak-proof water-proof vessel is formed which in its turn is covered with the black light-absorbing fabric 2. The box is filled with water 3 by the level of 6-7 cm in which the ultra-sonic fog generator 4 is placed [7]. In the upper part of the case the ventilator 5 is placed that is designed for the air recirculation within the chamber and the infra-red fog density control sensor 6. For the chamber blowing the blower 7 is used that is fixed at the external case wall and is located in such a manner that the light from the environment does not enter the chamber. The hole for discharge of the excessive fog is discovered from the external side of the case by the black light-absorbing casing 8. For control of the temperature inside of the chamber the thermocouple 9 is used. In the end walls of the case there are holes 10, 11 and 12 designed for installation of the light source and spectral radiometers a and b, respectively. Inside of the case there is the Web-cam 13 designed for the visual monitoring of the test plate (7 in the Figure 4).

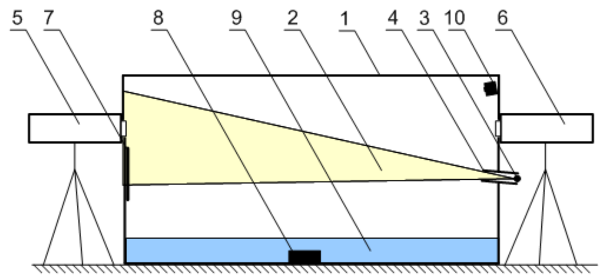

Figure 4 – The unit for investigation of the fog optical properties (lateral view): 1 – chamber case, 2 – light beam, 3 – light source, 4 – tube for light input, 5 – spectral radiometer *a* for measurement of the light passed through the fog, 6 – spectral radiometer *b* for measurement of the light diffused by the fog, 7 – test plate, 8 – ultra-sonic fog generator, 9 – water, 10 – Web-camera.

In order to avoid the reflection of the light from the camera case 1 and the water surface and to improve the integrity of the test it is necessary to form a directed light beam 2 (Figure 4). This is why the light source 3 is placed in the tube 4 with non-reflective inner surface absorbing all non-axial light beams. The tube length and angle is selected so that the light spot formed at the opposite wall of the camera does not go beyond its boundaries and completely overlaps the hole where the spectral radiometer *a* is located. The light component that passed through the fog is measured by the spectral radiometer *a* 5, and the portion reflected from the fog in the opposite direction – by the spectral radiometer *b* 6 located at the same wall as the light source.

For visual estimation of visibility inside of the camera there is the test plate 7 located at the wall directly under the hole where the spectral radiometer a is placed and partially falling within the light domain spot formed by the light source. This is a black matt rectangular plate with the dimensions of 150×100 mm and white stripes of different width (Figure 5).

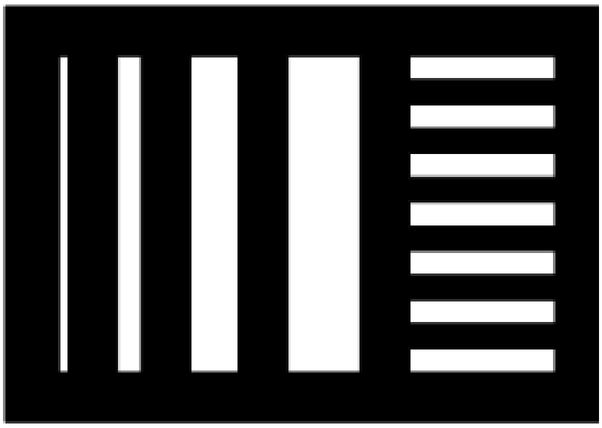

Figure 5 – Test plate

4. THE PRINCIPLE OF THE UNIT ACTION

The fog formed by the fog generator features relatively high density and is deposited at the camera bottom. In order to ensure the uniform fog distribution within the camera the blower located inside of the camera and operating at the low speed is used. In order to ensure that possibility of regulation of the air circulation rate within the camera the blower is connected to the variable power source which allows varying the blower engine speed within a certain range.

The ultra-sonic fog generator is rated at the power supply voltage of 24V. By reduction of the power supply voltage of the fog generator from 24 V to 20 V the intensity of the fog formation decreases. By drop in the power supply voltage below 20 V the operation of the fog generator becomes unstable [7]. The narrow range of the power supply voltage allows regulating the fog-formation process only a little which complicates the process of running the experiment since even at the power supply voltage of 20 V the fog density does not remain the same and increases gradually, therefore, it becomes impossible to perform long-term measurements under the same conditions. Besides, the intensity of fog-formation to a large extent depends on the water layer about the fog generator that is reduced during the experiment due to the transformation of water into fog. In order to solve the above-mentioned problem the unit was equipped with the auxiliary blower for chamber blowing and the infra-red fog density sensor as well as an additional hole covered with a light-absorbing casing designed for discharge of the excessive fog. The blower designed for the chamber blowing is located in a separate light-absorbing casing located at the external wall of the chamber frame. The internal casing volume is connected with the blower and the chamber through an access hole. The blower is controlled by the infrared fog density sensor, therefore, the blower rotation rate and air velocity directly depend on the density of fog inside of the chamber. During the performance of the experiment the level of water in the chamber is reduced as the result of which the intensity of the fog formation increases. Along with increase in the fog-formation intensity the density of fog inside of the chamber increases which results in enhancement of the blower rotation rate and therefore more intensive displacement of the excessive fog from the chamber. Thus, the blower prevents the increase of fog density in the chamber and allows maintaining the permanent density.

5. THE EXPERIMENT PROCEDURE

The experiment is divided into a few stages: calibration, preparation and measurements. During the process of calibration the required reference light flux is chosen and the supply currents are fixed at which the specified light flux is provided for each of the light-emitting diodes (LEDs).

With the use of the spectral radiometers the spectrum of the transmitted and reflected light is recorded as well as the image of the test plate is taken.

During the process of preparation for main measurements the specified fog density is selected, the power is supplied to the fog generator and the chamber is filled up with fog. One should wait about 15 minutes before starting measurements as this time suffices for the fog density inside of the chamber to stabilize and become uniform.

During the process of measurements the light sources are alternated, the preset supply current is fed, the recording of readings of both spectral radiometers is performed, the images of the test plate are taken. In order to obtain the accurate and reliable results the measurements shall be performed a few times, light sources shall be measured in the same sequence and then the results obtained shall be averaged.

6. PERFORMANCE OF MEASUREMENTS AND PROCESSING OF RESULTS

Eight light emitting diodes have been chosen as the light sources, the specifications of which are presented in the Table 1.

All LEDs were placed side-by-side at an aluminum heat sink and connected to the common stabilized controlled power source through a switch and limiting resistance. The heat sink with LEDs was attached to the chamber case with the use of splined attachment allowing sliding it along the tube designed for the light input into the chamber. By sliding the heat sink along the splines the required LED may be approximated to the tube hole, for the more accurate LED placement marks have been put on the heat sink.

At the calibration stage the required LED was brought to the input tube hole, the supply voltage was supplied with the use of switch after which the required value of the supply current was set. The calibration procedure was performed alternatively in respect of each LED. The supply current for each of the LEDs was selected so that the illumination intensity at the chamber wall close to the test plate measured by the spectral radiometer *a* was equal to 16 lx, except for the violet LED (Table 1). The illumination intensity at the maximal supply current (700 мA) made 1,7 lx and was taken as the start value for the violet LED.

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Table 1 – LED specifications

Color	Wavelength, nm / T_{col}, K	LED capacity, W	Supply current, мA	Initial intensity, lx
red	643	3	713	16
orange	619	3	169	16
yellow	590	3	510	16
green	520	1	136	16
blue	465	3	545	16
violet	430	3	700	1,7
warm white	2982	3	116	16
cool white	6699	3	116	16

In order to obtain the reference data and perform control of calibration the first measurement was carried out without fog (Table 2). The LEDs were alternatively brought to the input tube hole and the supply currents preset during the calibration stage were set. Then readings from the spectral radiometers *a* and *b* were taken at that the value of the illumination intensity received from the spectral radiometer *a* had to be equal to 16 lx which confirmed the calibration accuracy. The photos of the test plate were taken with the use of the Web-camera.

All further measurements were performed in the presence of fog in the chamber. The chamber was completely filled up with homogenous fog 10-15 minutes after switching on the fog generator after which like during the first measurement each LED was brought to the input tube hole and the supply current preset during the calibration stage was set. Then readings from the spectral radiometers *a* and *b* were taken, the photo by the Web-camera was taken. In order to obtain the reliable results measurements were performed 5 times and the results obtained were averaged (Table 2).

Table 2 – Readings of spectral radiometers

presence of fog	spectral radiometer	№ of measurement	illumination intensity, lx							
			Red LED	Orange LED	Yellow LED	Green LED	Blue LED	Violet LED	warm white LED	cool white LED
no	*a*	1	16	16	16	16	16	1,7080	16	16
	b	1	0,1578	0,1273	0,1304	0,1116	0,1264	0,0612	0,1092	0,0899
yes	*a*	2	4,3370	4,2440	5,2810	4,9520	5,2470	0,6897	4,9420	4,8550
		3	4,2760	4,4610	4,6720	5,0210	4,5620	0,6907	4,8250	4,5090
		4	4,0420	4,0530	4,2560	5,1690	5,0200	0,5764	4,7770	4,7540
		5	4,7800	4,3980	4,5800	4,5390	5,1280	0,6185	4,4560	4,4820
		6	4,1750	4,0360	4,0090	4,5400	5,1610	0,6169	4,6340	4,7940
		ср.	4,3220	4,2384	4,5596	4,8442	5,0236	0,6384	4,7268	4,6788
		%	27,013	26,49	28,4975	30,2763	31,3975	37,3794	29,5425	29,2425
	b	2	0,6267	0,5822	0,5778	0,5439	0,5625	0,1116	0,5759	0,5936
		3	0,6432	0,5747	0,5979	0,5441	0,5806	0,1109	0,5734	0,5928
		4	0,6595	0,5928	0,6275	0,5411	0,5977	0,1217	0,6246	0,5699
		5	0,6606	0,5833	0,6145	0,5840	0,6208	0,0933	0,6472	0,5656
		6	0,6897	0,6250	0,6399	0,5615	0,6133	0,1097	0,6291	0,5742
		ср.	0,6559	0,5916	0,6115	0,5549	0,5950	0,1094	0,6100	0,5792
		%	3,1134	2,9019	3,0070	2,7708	2,9287	2,8244	3,1303	3,0584

The calculation of the fog transmission and reflection coefficient for different wavelengths was performed according to the formulas:

$$K_{\text{пр.}} = E_{\text{ср. пр. с тум.}} / E_{\text{ср. пр. без тум.}} \times 100\%, \quad (1)$$

$$K_{\text{отр.}} = E_{\text{ср. отр. с тум.}} / E_{\text{ср. отр. без тум.}} \times 100\%, \quad (2)$$

Where $E_{\text{ср. пр. с тум.}}$ – the illumination intensity produced at the photocell of the spectral radiometer *a* by the light passed through the fog;

$E_{\text{ср. пр. без тум.}}$ – the illumination intensity produced at the photocell of the spectral radiometer *a* by the light source without fog;

$E_{\text{ср. отр. с тум.}}$ – the illumination intensity produced at the photocell of the spectral radiometer *b* by the light diffused by fog;

$E_{\text{ср. отр. без тум.}}$ the illumination intensity produced at the photocell of the spectral radiometer *b* by the light source without fog.

Based on the results of measurements the diagrams representing the dependence of the transmission and diffusion coefficient on the wavelength were construed (Figure 6).

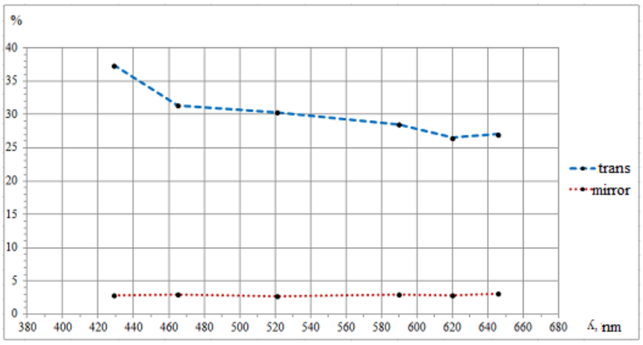

Figure 6 – The diagram of dependence of the fog transmission and diffusion coefficient on the wavelength

Based on the results obtained it follows that the light with the longer wavelength is more diffused by fog. Thus, visibility in the foggy conditions shall be better by illuminating the object with the light of the indigo emission than by red one.

The photos made by the Web-camera placed inside of the unit presented in the Fig, 7 confirm the above-described experimental data, however, due to the fact that a Web-camera as compared to a human eye features somewhat different specifications certain conclusions can hardly be drawn.

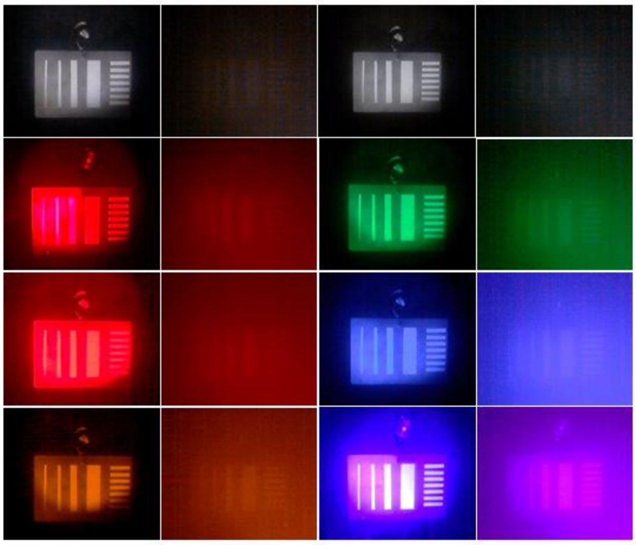

Figure 7 – Images of the test plate in the camera, with and without fog, illuminated with the light with different wavelengths taken by the Web-camera

7. SUMMARY

The driving in conditions of colored lighting causes visual discomfort since a human organ of vision is adapted to the white light. Besides, it is forbidden by the traffic rules to use the light of different colors in the fog head lamps [11]. In this regard the results of the experiments described in the paper do not bear particular sense to common drivers; however, they may be relevant by design of the special light sources for the fog head lamps, the white light in which is produced by the additive mixing of light with different wavelengths.

The design of the laboratory unit and the technique of performance of measurements described in the paper will allow detailed investigating the optical properties of fog during further experiments. This will allow selecting the optimum wavelengths of the visible band of emission producing the white light by additive superposition for which the fog transmission coefficient will be the maximal. The use of fog head lamps with such flight will in its turn allow improving visibility in the foggy conditions and increasing the traffic safety.

CONFLICT OF INTERESTS

The authors confirm that the data provided does not contain a conflict of interests.

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