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Guardrail Hydrodynamic Washing Machine

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Abstract*: Road guardrails are intended for provision of vehicle traffic with minimum risk of collisions and slipping, for prevention of crossing median strip, for prevention of pedestrian falling, as well as for arrangement of pedestrian circulation and prevention of animals' penetration into roads. In order to improve visibility of guardrails, they are equipped with special reflecting markings, cat's eyes, which indicate boundaries of roadway under conditions of poor visibility. Under poor weather conditions, which occur quite often in Central Russia, surfaces of guardrails and reflecting markings become dirty, which can lead to road collisions with severe consequences. In addition, in wintertime roads are treated with sand and salt mixture, these particles promote early failure of guardrails due to corrosion. In order to prevent the aforementioned situations, guardrails from time to time should be cleaned from pollutions. Guardrails are generally cleaned from pollutions by machinery equipped with brushes, such as municipal cleaning vehicles (mechanical cleaning). However, their application leads to destruction of guardrail surface and damages of reflecting elements. Therefore, this work is aimed at improvement of cleaning procedure of guardrails by development and production of device for contactless washing. A device for contactless washing of guardrails is proposed which would improve quality of their cleaning and efficiency of cleaning machinery. Mathematical equation is presented for hydrodynamic pressure of jet on elements of guardrails.

***Keywords* : guardrails, contactless washing, guardrail cleaning machine, hydrodynamic pressure, sprayer.**

I. INTRODUCTION

Road guardrails are intended for provision of vehicle traffic with minimum risk of collisions and slipping, for prevention of crossing median strip, for prevention of pedestrian falling, as well as for arrangement of pedestrian circulation and prevention of animals' penetration into roads. [1]-[3]. Under poor weather conditions, which occur quite often in Central Russia, surfaces of guardrails and reflecting markings become dirty which can lead to road collisions with severe consequences. In addition, in winter time roads are treated with sand and salt mixture, these particles promote early failure of guardrails due to corrosion. In order to prevent the aforementioned situations, guardrails from time to time should be cleaned from pollutions [4]-[6]. In Russia guardrails are generally cleaned from pollutions by machinery equipped with brushes, such as municipal cleaning vehicles (mechanical cleaning).

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Such procedure, despite its advantages, is characterized by significant disadvantages: damages and wear of guardrails and destruction of reflecting elements.

Another procedure is hydrodynamic guardrail washing. It is based on application of high-pressure washing machines which can be installed on any vehicle. Several sprayers are installed in front part of vehicle directed at guardrails along the vehicle motion.

Hydrodynamic washing would allow to save expenses on restoration of guardrails. However, this procedure allows to clean only one surface of guardrail, and in order to clean inverse surface (for instance, in the case of four-lane roads equipped with double guardrails), it is required to move to opposite lane and repeat this procedure which decreases its efficiency and increases operation time.

This work is aimed at efficiency improvement of guardrail washing by development and production of contactless washing machine.

II. METHODS

A. Block Diagram

A device is proposed for contactless washing of double barrier guardrails of multilane highways per one run of the machine (Figs. 1, 2).

The proposed machine is based on the wheel type tractor 5 and is equipped with tanks for washing fluid installed on tractor lateral sides. Sprayers are assembled on the manipulator 2 installed on the rear tractor attachment 4, which makes it possible to locate them beyond the vehicle sizes and to vary their position with regard to the guardrails 6. Two bars 7 with spraying nozzles 1 rigidly fixed on frame are installed on the manipulator.

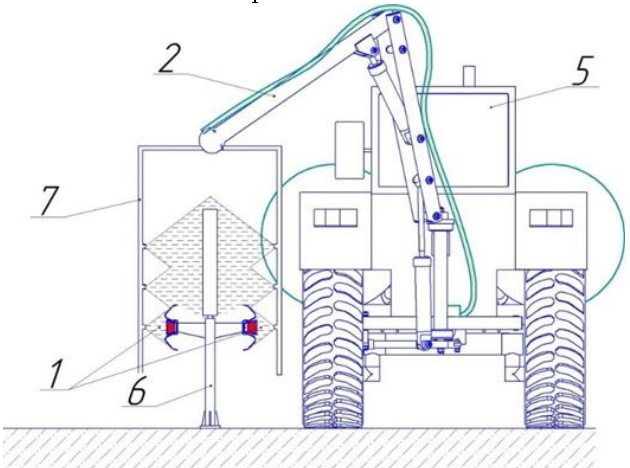

Fig. 1. Schematic view of contactless guardrail washing machine (rear view).

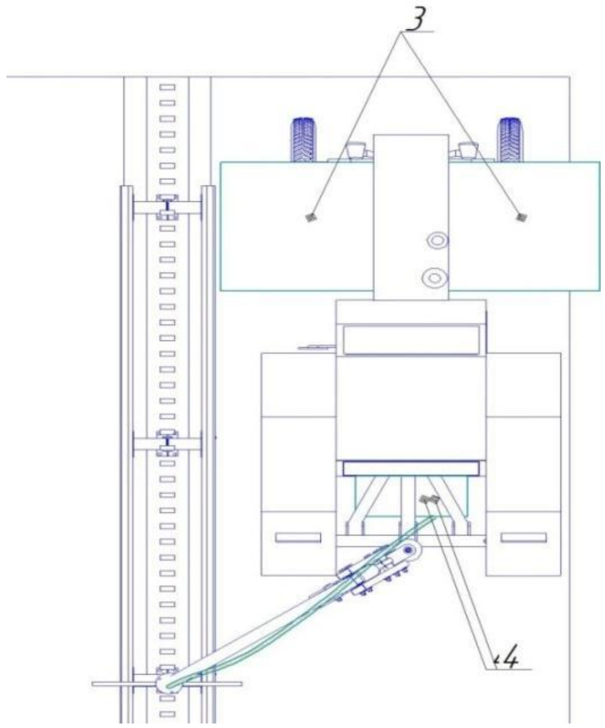

Fig. 2. Schematic View Of Contactless Guardrail Washing Machine (Top View).

The device operates as follows. Washing fluid is taken from the tank via filter by means of pump installed on the tractor power take-off shaft, then it is supplied under pressure to control panel and via pressure line directly to the bars with spraying nozzles.

The sprayers generate washing jets which are supplied under pressure to lateral elements of guardrails for washing. This machine can wash guardrails from both sides per one path which is especially important for multilane highways.

B. Algorithm

Theoretical studies were based on the methods of analytical geometry, hydrodynamics, and mathematical analysis.

Hydrodynamic pressure of washing fluid jet is determined as follows, N/m^2 [4]:

$$P = \rho_l \vartheta^2 \sin\beta \quad (1)$$

where ϑ is the speed of flow upon impingement with barrier, m/s; ρ_l is the average fluid density at the distance l to the sprayer; β is the angle of impact of jet on cleaned surface, °.

Average fluid density at the distance l to the sprayer is determined using aeration coefficient [7]:

$$\rho_l = \frac{\rho_{sp}}{k} \quad (2)$$

where ρ_{sp} is the washing fluid density at sprayer output, kg/m^3; k is the aeration coefficient.

$$k = \frac{S_{sect}}{S_0} \quad (3)$$

where S_{sect} is the surface area of jet cross section at the distance l to the sprayer, m^2; S_0 is the surface area of cross section of the sprayer slot, m^2.

The spray pattern and contact spot during operation of flat jet high pressure sprayer are illustrated in Fig. 3 [8].

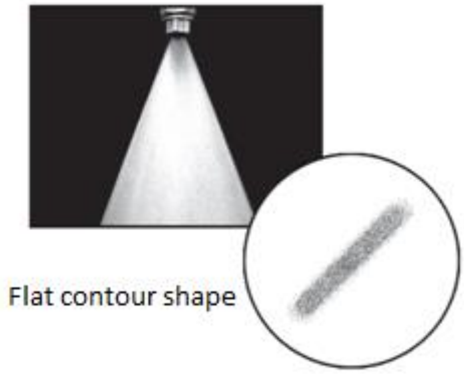

Fig. 3. Flat jet sprayer.

In order to simplify prediction of geometrical parameters of washing fluid jet, let us assume that the spray pattern will be as illustrated in Fig. 4. The surface areas of cross section of theoretical and actual spray pattern will be close to each other with minor error.

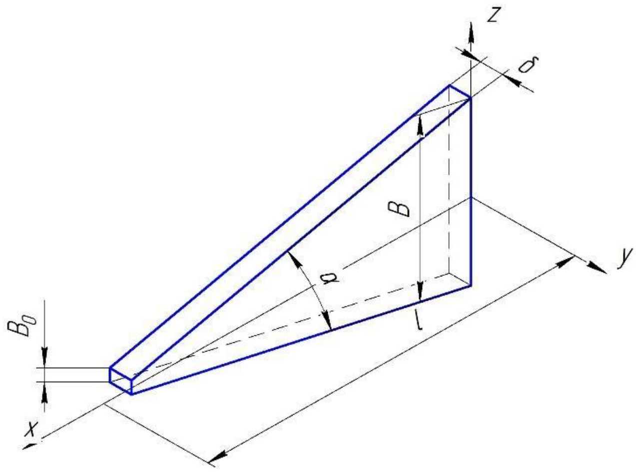

Fig. 4. Geometrical parameters of spray pattern of slot sprayer: α – spray angle, rad; l – distance from sprayer nozzle to barrier, m; B – theoretical jet width, m; δ – theoretical jet thickness (sprayer nozzle width), m, B0 – sprayer slot width, m.

The jet width is determined according to the flowchart below (Fig. 5).

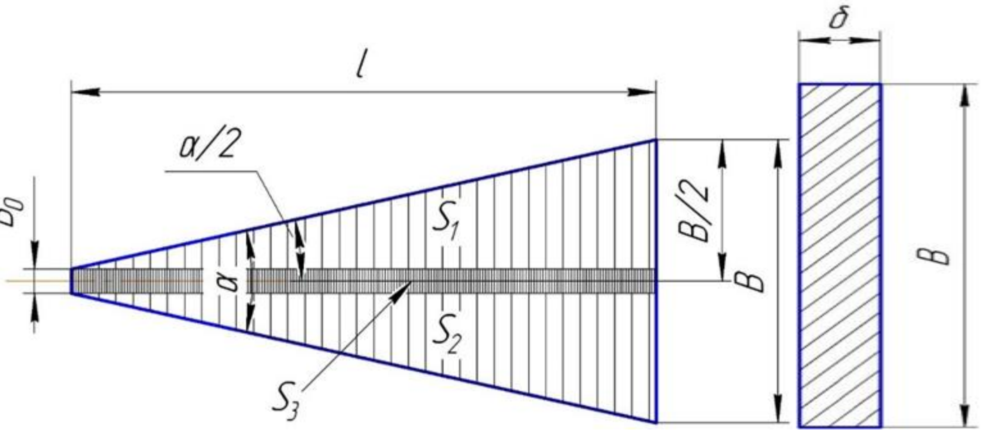

Fig. 5. Determination of jet width B.

$$\frac{\frac{B}{2}-\frac{B_0}{2}}{l} = tg\frac{\alpha}{2} \qquad (4)$$

From which:

$$B = B_0 + 2ltg\frac{\alpha}{2} \qquad (5)$$

Let us determine the surface area of transversal cross section of sprayed jet:

$$S_0 = \delta \cdot B_0 \qquad (6)$$

Then, the surface area of transversal cross section of jet at the distance *l* to the sprayer with consideration for Eq. (5) is as follows:

$$S_{sect} = \left(B_0 + 2ltg\frac{\alpha}{2}\right) \cdot \delta = B_0\delta + 2l\delta tg\frac{\alpha}{2} \qquad (7)$$

Taking into consideration Eqs. (6) and (7):

$$k = \frac{S_{sect}}{S_0} = \frac{B_0\delta + 2l\delta tg\frac{\alpha}{2}}{B_0\delta} \qquad (8)$$

Then, the hydrodynamic pressure of jet on barrier is as follows:

$$P = \frac{\rho_{sp}\vartheta^2 B_0\delta}{B_0\delta + 2l\delta tg\frac{\alpha}{2}} sin\beta \qquad (9)$$

Average speed of jet flow at the distance *l* can be approximately considered equal to initial flow speed ϑ_0, m/s [7]:

$$\vartheta = \vartheta_0 = \varphi\sqrt{2gH}$$

Figures 7, 8 illustrate hydrodynamic pressure as a function of distance to cleaned surface. Water was selected as washing fluid ($\rho_{sp} = 1000\ kg/m^3$). Lechler high pressure sprayers were applied with the flow rates of 7.1, 8.9, and 10.6 l/min at the pressure of 60 atm and spray pattern angles of 15°, 25°, and 40° [9].

Spray angle	Type of	1 / min	
		60 atm	100 atm
0°	00-04	7,1	9,2
	00-05	8,9	11,5
	00-06	10,6	13,6
15°	15-04	7,1	9,2
	15-05	8,9	11,5
	15-06	10,6	13,6
25°	25-04	7,1	9,2
	25-05	8,9	11,5
	25-06	10,6	13,6
40°	40-04	7,1	9,2
	40-05	8,9	11,5
	40-06	10,6	13,6

Fig. 6. Lechler flat jet sprayers

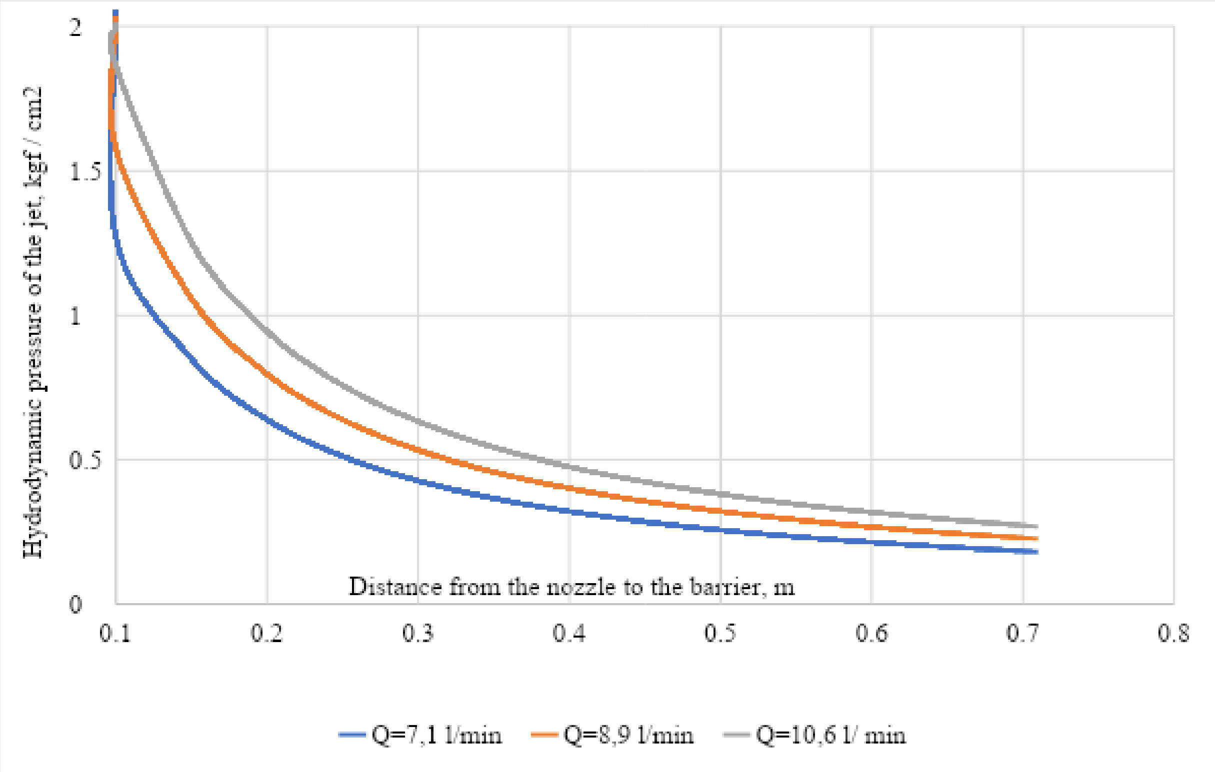

Fig. 7. Hydrodynamic pressure as a function of distance l at various flow rates Q0 and spray angle α = 40° (nozzle pressure 60 atm.).

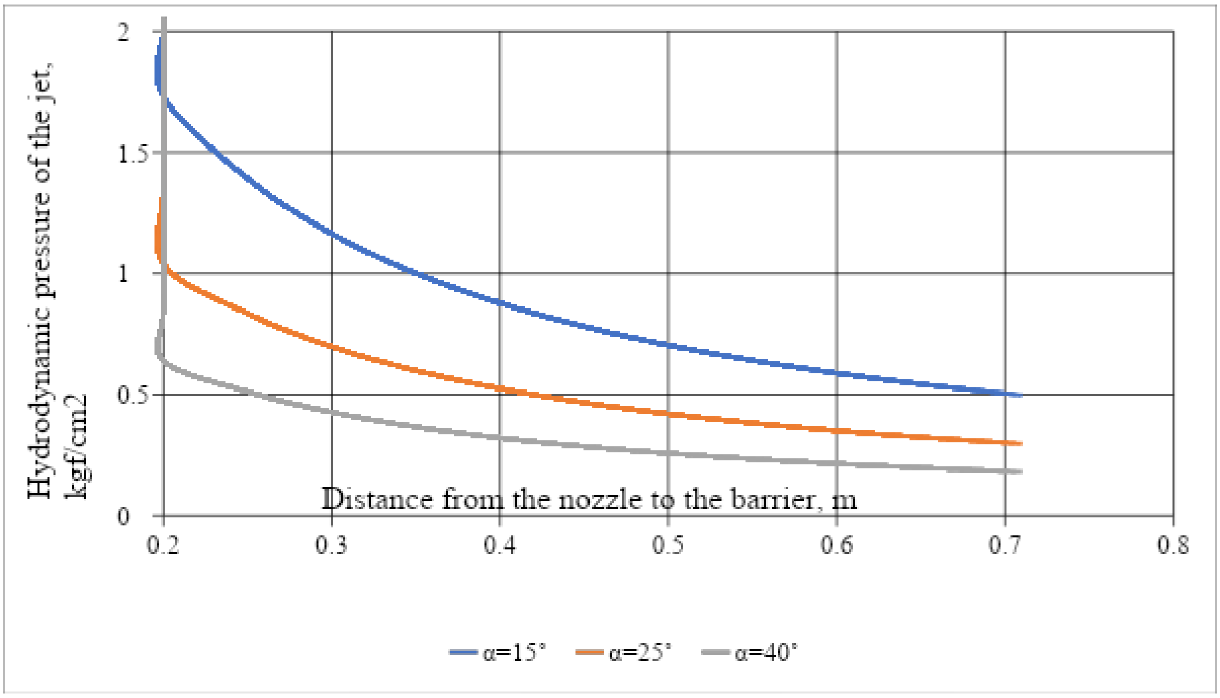

Fig. 8. Hydrodynamic pressure as a function of distance l at different angles of the spray cone (flow rate - 7.1 l/min; nozzle pressure 60 atm).

Three factors were highlighted during optimization of engineering operation parameters of guardrail washing machine by means of screening experiments, which exerted the maximum influence on washing quality. They were as follows: the distance from sprayer to barrier; washing fluid flow rate; and spray pattern angle. They were included into the design matrix of multifactor experiment (Table 1).

Hydrodynamic pressure on cleaned surface was selected as optimization criterion of multifactor experiment according to Box–Behnken design.

The obtained experimental data were processed using Statistica10 software.

Table 1: Design matrix and variability levels

No.	Factors			Optimization criterion
	Sprayer-to-barrier distance, m	Washing fluid flow rate, l/min	Spray pattern angle, °	Hydrodynamic pressure, kN/m^2
	x_1	x_2	x_3	y
(+) (0) (-)	0.75 0.5 0.25	10.6 8.9 7.1	40 25 15	
1	-	0	-	16.9
2	+	+	0	4.1
3	0	+	-	10.2
4	+	0	+	2.1
5	0	0	0	5.1
6	+	0	-	5.8
7	0	-	+	2.5
8	0	+	+	3.7
9	-	+	-	12.1
10	-	0	+	6.2
11	-	-	-	8.2
12	0	0	-	5.1
13	0	0	+	3.1
14	0	-	-	6.8
15	+	-	+	1.6

III. RESULTS AND DISCUSSION

The following equations were obtained after processing experimental data, they are illustrated in Figs. 9, 10, and 11, respectively:

$$P = 9.68 - 38.28l + 1.21Q + 30.52l^2 - 0.8lQ - 0.001Q^2$$

$$P = 38.63 - 54l - 0.99\alpha + 27.2l^2 + 0.4674l\alpha + 0.01\alpha^2$$

$$P = 1.78 + 2.4Q - 0.36\alpha - 0.085*Q^2 - 0.012Q\alpha + 0.0036\alpha^2$$

The experiment was carried out at the system pressure of 60 atm.

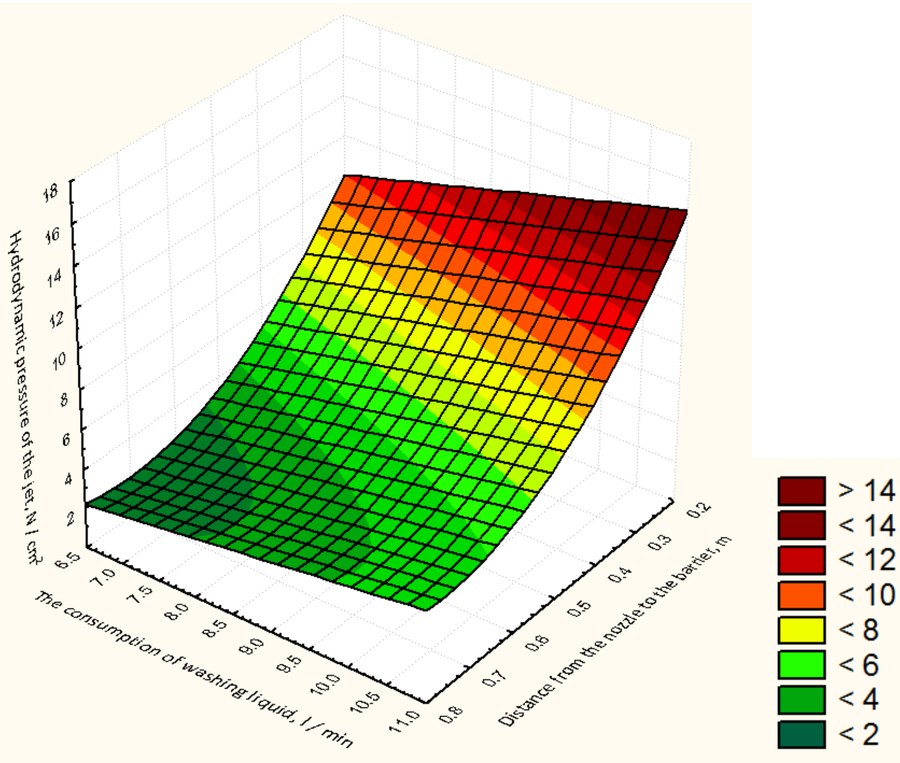

Fig. 9. Hydrodynamic pressure as a function of distance and washing fluid flow rate.

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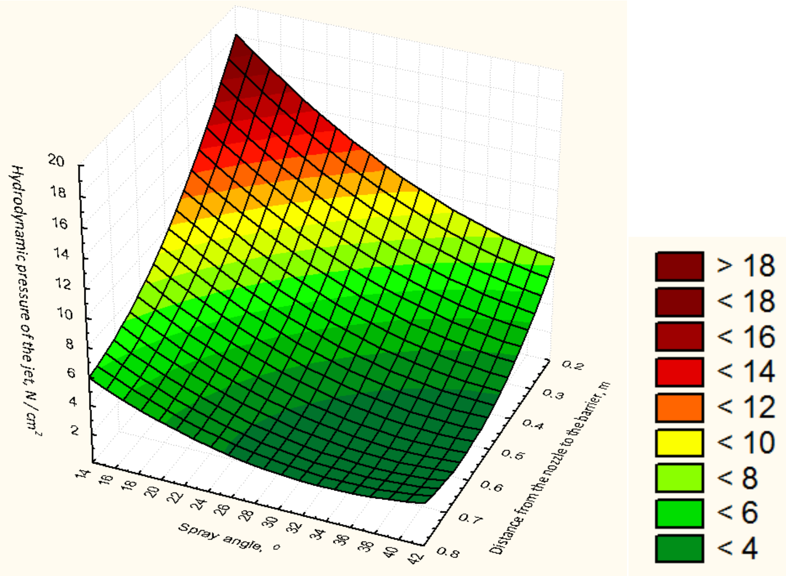

Fig. 10. Hydrodynamic pressure as a function of distance and spray pattern angle.

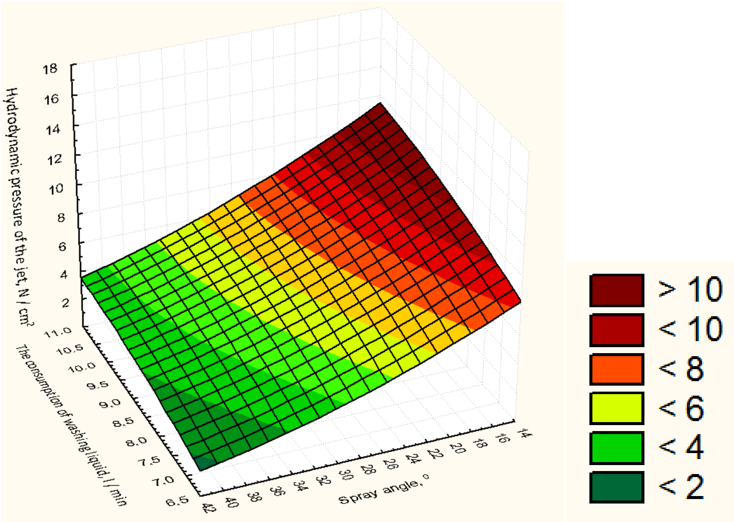

Fig. 11. Hydrodynamic pressure as a function of washing fluid flow rate and spray angle.

Figure 12 illustrates hydrodynamic pressure as a function of distance to barrier (guardrail) at various spray angles.

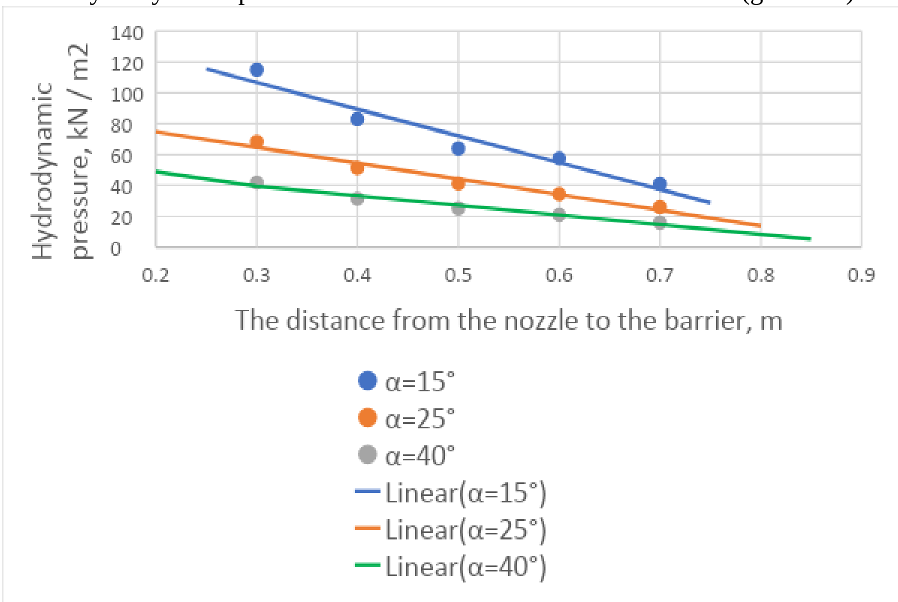

Fig. 12. Hydrodynamic pressure as a function of distance to barrier at washing fluid flow rate of 7.1 l/min.

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Hydrodynamic pressure as a function of washing fluid flow rate (at steady distance to guardrail barrier equaling to 0.5 m) at various spray angles is illustrated in Fig. 13.

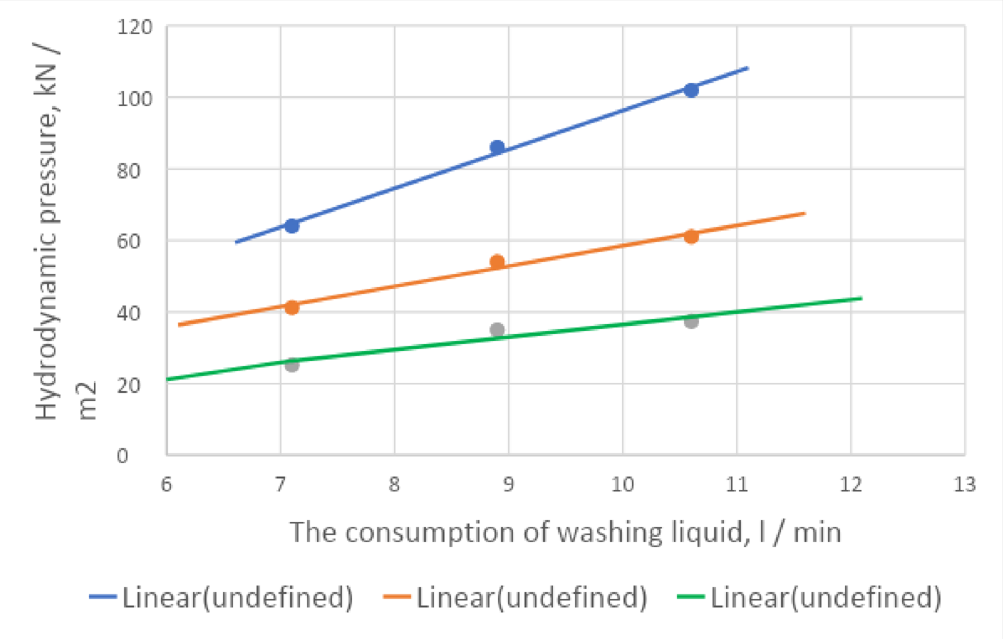

Fig. 13. Hydrodynamic pressure as a function of washing fluid flow rate at the distance of 0.5 m to barrier.

IV. CONCLUSION

The obtained data demonstrate that hydrodynamic pressure of washing fluid jet decreases with the increase in the distance from sprayer to cleaned surface. Herewith, the jet pressure on guardrail surface depends significantly on spray pattern angle α, and, to a lower extent, on fluid flow rate Q.

Depending on geometrical sizes of polluted surfaces, types of pollutions, and other parameters effecting on washing efficiency and quality, using Eq. (9) it is possible to describe certain engineering and operation parameters of hydrodynamic washing machine.

The mathematical regression models of hydrodynamic pressure based on the processed experimental data make it possible to estimate the influence of engineering and designing parameters of guardrail washing machine on operation quality.

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