Всеукраїнський науково-технічний журнал
Ukrainian Scientific & Technical Journal
ISSN 2306-8744
DOI: 10.37128/2306-8744-2024-1

Вібрації в техніці та технологіях

№1(112)
2024

Всеукраїнський науково-технічний журнал

Ukrainian Scientific & Technical Journal

Вібрації в техніці та технологіях

№ 1 (112)

Вінниця 2024

№ 1 (112) 2024 **Вібрації в техніці та технологіях**

ВІБРАЦІЇ В ТЕХНІЦІ ТА ТЕХНОЛОГІЯХ

Журнал науково-виробничого та навчального спрямування Видавець: Вінницький національний аграрний університет

Заснований у 1994 році під назвою “Вібрації в техніці та технологіях”

Свідоцтво про державну реєстрацію засобів масової інформації

КВ № 16643-5115 ПР від 30.04.2010 р.

Всеукраїнський науково-технічний журнал “Вібрації в техніці та технологіях” / Редколегія: Калетнік Г.М. (головний редактор) та інші. – Вінниця, 2023. – 1 (112) – 89 с.

Друкується за рішенням Вченої ради Вінницького національного аграрного університету (протокол № 10 від 22.04.2024 р.)

Періодичне видання включено до Переліку наукових фахових видань України з технічних наук (Категорія «Б» Наказ Міністерства освіти і науки України від 02.07.2020 р. № 886)

Технічний редактор ***Замрій М.А.***

Адреса редакції: 21008, Вінниця, вул. Сонячна 3, Вінницький національний аграрний університет, тел. 46 – 00– 03

Сайт журналу: http://vibrojournal.vsau.org/ Електронна адреса: vibration.vin@ukr.net

З М І С Т

Fedirko P.
Candidate of Technical Sciences, Associate Professor

Higher educational institution «Podillia State University»

Kubai M.
Teacher

Vinnytsia National Agrarian University

Федірко П.П.
к.т.н., доцент

Заклад вищої освіти «Подільський державний університет»

Кубай М.Г.
викладач

Вінницький національний аграрний університет

UDK 621.643.2:004.942.5
DOI: 10.37128/2306-8744-2024-1-6

JUSTIFICATION OF NOZZLE PARAMETERS OF JET-TYPE WASHING MACHINES FOR CLEANING AGRICULTURAL MACHINES AND UNITS

Agricultural machinery and equipment are exposed to significant contamination by various types of pollutants, some of which can be easily removed, while others require the use of special cleaning agents and machines. To remove these contaminants, a pressurized water jet is used, the biggest disadvantage of such devices is the significant water consumption, so the issue of intensifying the cleaning process of agricultural machinery using a limited amount of water is an important scientific task.

Cleaning of agricultural machinery and units from contaminants is a complex technological operation, therefore, there is a need to develop and justify the parameters and operating modes of a high-tech washing device that would ensure high-quality removal of all types of contaminants with high efficiency, minimal water consumption and minimal labor costs.

The analysis of cleaning technologies showed that water jet cleaning is the most promising for removing dirt from the surface of agricultural machines and units, the technology allows to increase the level of mechanical impact by using additional energy, which can be the energy of a rotating jet.

The study examines the efficiency of cleaning washing plants from various contaminants. The main focus is on studying the impact of nozzle design on the quality and productivity of the washing process. Nozzles determine the shape of water jets and their velocity, determining the cleaning efficiency. The dagger and fan nozzles, their advantages and disadvantages are considered.

Nozzle parameters such as orifice diameter, spray angle, and number of fan jets are investigated. It is shown that properly selected nozzle parameters play an important role in achieving the optimal cleaning effect and water saving. Factors such as flow coefficient, drag coefficient, and velocity coefficient that affect the performance and energy of the jet are outlined.

Keywords: *agricultural machines, high-pressure washers, water jet, external contamination, agricultural units, maintenance.*

Problem statement. Agricultural machines are exposed to intense pollution during their operation, forming various deposits such as road and soil residues, plant residues, oily mud, technical contaminants, etc. on the surfaces of their components. Over time, these contaminants can form a dense coating, which in turn can adversely affect the operation of the machines. The heat balance of the engine is disturbed, moving parts wear out, corrosion and other problems develop intensively. [1, 2].

Taking into account the above, effective external cleaning of agricultural machinery becomes a key stage of maintenance, helping to increase its efficiency in conditions of difficult use in the agricultural sector.

Decontamination and washing are critical operations in the process of servicing agricultural machinery, including combines, tractors and cars.

Statistics show that over the past 5 years in Ukraine, the number of agricultural machines has increased, which requires the improvement of technologies and equipment for the effective removal of various types of pollution.

However, there is a challenge in solving these tasks due to the variety of machines and equipment used in the agricultural sector. A detailed study and development of cleaning technologies should be carried out, taking into account the specifics of the pollution encountered.

In most regions of Ukraine, the problem of insufficient provision of modern service enterprises and repair shops with repair and maintenance equipment, lack of modern washing stations and washing equipment, as well as imperfect technologies is relevant [1, 2].

At the same time, the analysis shows that global and European leaders are not standing still, but are constantly developing their research towards the creation of advanced washing technologies, equipment and materials. They are always ready to respond to the most non-standard customer requirements, creating high-quality and unique products quickly and accurately.

Equipment for washing and removing contaminants can be classified according to various criteria:

- By function in the technological process: external washing of the machine, cleaning of units and parts.
- By type of washing machine: jet, monitor, submersible, combined, special.
- According to the degree of impact on agricultural machinery: equipment with contact impact, equipment with non-contact impact, equipment for steam cleaning.
- Depending on the type of production, it can be used as a repair facility, service station, or car wash.

Cleaning and washing machines play an important role in the system of maintenance operations, as their careful execution allows you to quickly identify breakdowns, leaks of process fluids, oils, and paint damage [1, 2]. These operations must be performed at the beginning of each stage of maintenance.

Carrying out washing and cleaning operations is associated with certain difficulties caused, on the one hand, by the variety of types of pollution that require the use of various cleaning methods, detergents and equipment, and, on the other hand, by the variety of cleaning objects (machine, unit, node, part), which differ in mass, material, construction, shape, etc. [1]. According to O.I. Sidashenko [1, 2], there are the following types of external pollution:

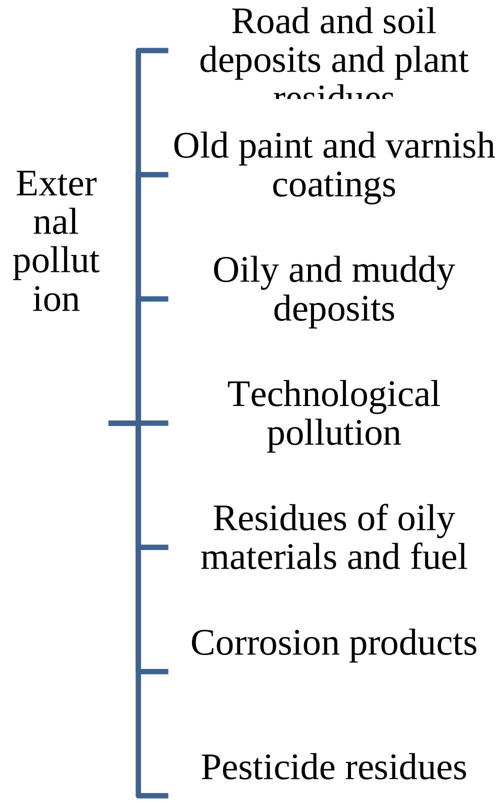


Fig 1. Classification of types of pollution.

According to the degree of difficulty of removal, external contaminants can be classified into three groups: weakly bound, moderately bound, and strongly bound [1-4]. The nature of the contamination is important when choosing a cleaning method, so it is important to consider a scheme that allows you to separate contaminants by their sources, physical and chemical parameters, and their impact on the choice of removal method during cleaning (Pic. 2).

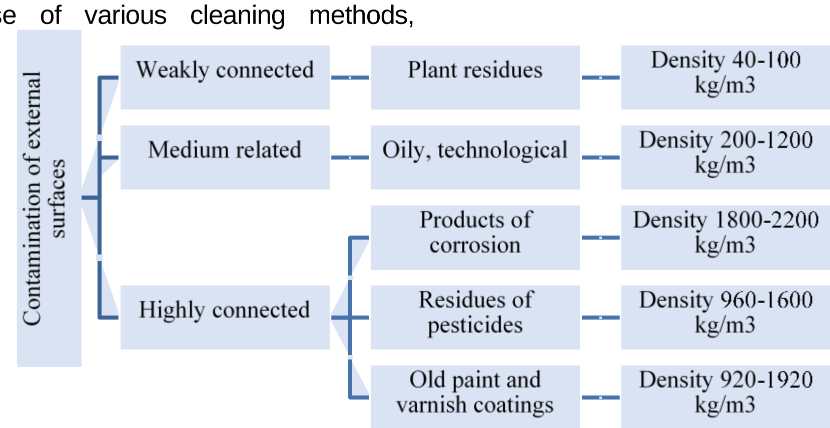


Fig 2. Classification of pollution depending on the difficulty of their removal and their density.

The results of the conducted research (Pic. 3 and 4) [1, 2, 4-6] indicate that of the entire area of contaminated surfaces, strongly bound pollution makes up only a small percentage. However, it is important to note that the effort required to remove them is several times higher than the effort required to clean up other types of contaminants.

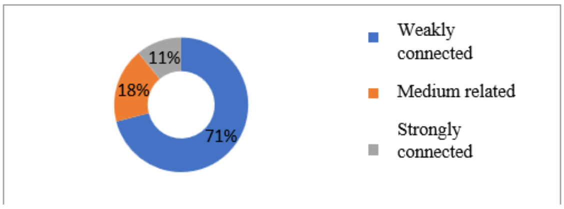


Fig. 3. Diagram of occupied areas of pollution.

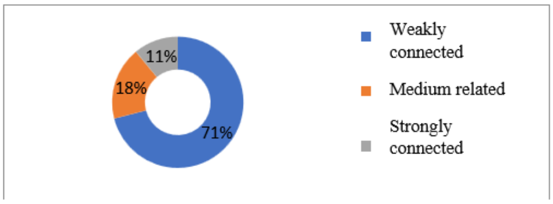


Fig. 4. Diagram of the labor intensity of pollution removal.

Purpose and objectives of the study. The goal is to solve the problem of improving the quality and energy efficiency of the process of washing agricultural machinery and equipment.

To achieve this goal, we need to solve the following tasks:

1. Determine the relevance of methods of cleaning agricultural machinery and equipment.
2. Analyze existing technologies for cleaning agricultural machinery.
3. To justify the parameters of washing machines for cleaning agricultural machines and equipment.

Analysis of the latest research. The study of tractor maintenance operations indicates that the most significant share is occupied by washing and cleaning (25-45%) and control and adjustment (26-43%) work [1, 2, 4-8]. To remove contaminants from tractor surfaces, a variety of tools are used, such as scrapers, brushes, wipers, and washing systems with the appropriate solution composition. It should be noted that high-quality cleaning and washing are important to ensure a proper culture of maintenance and repair of equipment, as well as to prevent environmental pollution. The disposal of oil products and the neutralization of chemicals are important tasks, which can be solved by introducing return water supply and using electrical and chemical methods of cleaning used cleaning solutions.

For the effective implementation of these tasks, the most rational is the organization of centralized outdoor washing, which provides better opportunities for the use of recycled water supply [1, 2]. As a rule, such sinks are equipped with stationary and mobile high-pressure washing units with a manual monitor. Two types of jet washers are used: monitor and jet washers. The most popular are high-pressure units, which provide a jet of water under high pressure (up to 12 MPa) using plunger pumps.

Among the available cleaning devices, high-pressure washers are the most popular. They provide high-quality cleaning of soiled surfaces with high-pressure water jets. The use of high-pressure washers allows you to effectively remove dirt from agricultural machinery using detergents, hot water and various cleaning nozzles. However, an important drawback is the high water consumption, which is becoming a problem, especially in the southern regions of Ukraine, where water is a valuable resource.

The technological conditions that determine the presence of residual dirt on the cleaned surface depend on the purpose of the sink and the conditions of its use. Cleanliness is defined as the state of a surface on which contaminants remain within acceptable limits [1-4].

Contamination typical of agricultural machinery and aggregates has a complex structure and may include liquid and solid phases with different adhesion. This affects the strength of adhesion of pollution particles to the surface to be cleaned [1-4].

It is noted that all types of contaminants are divided into three groups depending on the complexity of their removal and density:

1. Weakly connected (57%)
2. Medium-bound (33%) contaminants that are easily removed have low adhesion to the surface.
3. Strongly bound (10%) pollution, which is often located in hard-to-reach places, requires significant labor costs for cleaning [1-4].

Cleaning agricultural machinery from pollution is a technologically important operation, therefore there is a need to develop and justify the parameters and operating modes of high-tech washing equipment, which ensures high-quality removal of all types of pollution with high efficiency, minimal water and labor costs.

According to the method of removing pollution (Picture 5), washing and cleaning technologies are divided into mechanical (removal with a jet of water under high pressure or manual method using metal brushes or scrapers) and physical and chemical, which remove pollution by the method of chemical decomposition and washing in the process of chemical reactions [1, 2, 4].

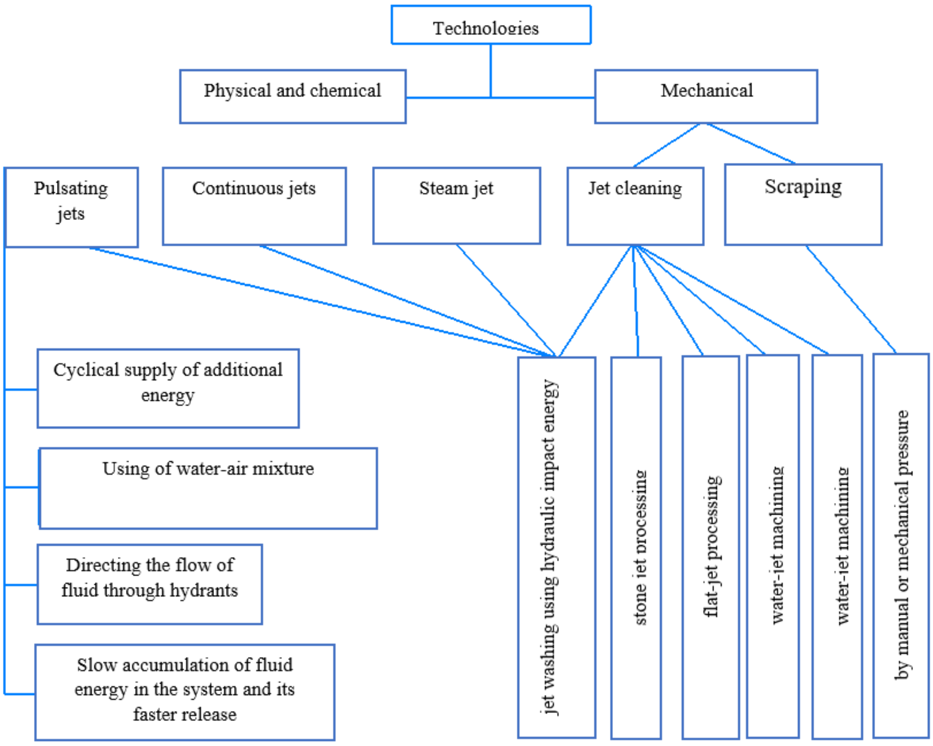


Fig.5. Technologies for removing contaminants from the machine surface.

Cleaning using physical and chemical energy includes such processes as emulsification, molecular transformations, dissolution, dispersion, chemical etching of the surface to be cleaned, and others. This type of cleaning uses detergents divided into organic, emulsifying solvents, acidic and synthetic detergents. Among them, synthetic detergents are the most effective, as they contain substances that reduce surface energy (surface tension) and actively destroy foci of contamination on the surface, subjecting it to cleaning [1,2].

Despite its effectiveness, physical and chemical cleaning has its drawbacks, including a significant negative impact on the environment, and can also pose risks to the operator of the cleaning device.

Mechanical cleaning of contaminants can be carried out using a variety of methods, such as manual application of brushes, scrapers or abrasive paper, or the use of jets of abrasive or waterjet material under air or water pressure. The last method, jet cleaning, is widely used because it allows you to remove even the most difficult types of dirt. As part of the maintenance and repair of machines, sandblasting and pressure water jet cleaning are often used [1, 2].

Scraping using hand tools is a less productive cleaning method that can involve both mechanical and electrical tools. This method is used in cases where other, more productive cleaning methods cannot be used. Scraping methods also include filleting and vibratory abrasive cleaning, which are used to clean individual parts. However, since these methods are characterized by the use of specialized equipment and their use is not relevant to the topic of this paper, they will not be discussed in detail.

The disadvantages of scraping technologies are low productivity, high labor intensity, and the need for specialized tools.

Dry and water jet cleaning technologies are widely used in small-scale agricultural production. The classification of these technologies is presented on picture 6 [1-4]. One of such technologies is stone cleaning, which is based on the use of finely ground stone fraction. Under a pressure of 3-5 MPa, this fraction is supplied with compressed air to the cleaning object.

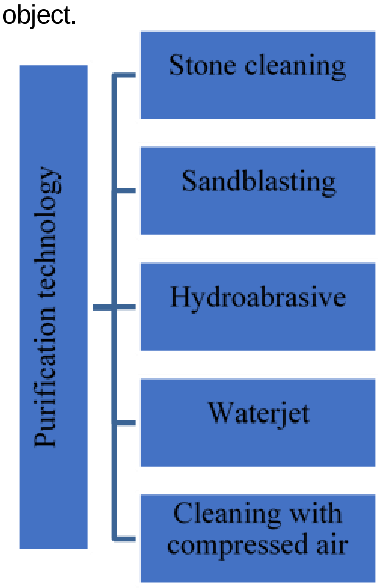


Fig. 6. Jet cleaning technologies

This method is characterized by high cleaning efficiency at minimal cost and does not adversely affect the external surfaces of the parts to be cleaned. It can also be successfully used to clean aluminum alloys[1-3]. Among the disadvantages is the high level of dust in the working area, which significantly complicates the operator's working conditions and requires the use of personal protective equipment or forced-air ventilation systems. An important disadvantage of this technology is the complexity of the equipment used, as well as high costs when using installations with manual control of jet nozzles.

Sandblasting is appropriate for removing medium to strongly bonded contaminants such as old paint and corrosion products. This technology is based on abrasive cleaning using sand as an abrasive material transported by compressed air [2]. It provides a high level of cleaning and creates a uniform surface roughness, which facilitates the application of paintwork or other corrosion protection.

The disadvantages of this technology are similar to stone cleaning, in particular, high dust output and a negative impact on the operator's health. However, the modern industry offers special cleaning boxes for sandblasting. However, they are expensive and require special skills and abilities from the operator. This type of technology also includes shot blasting, which is even more expensive than sandblasting. The main disadvantage is the occurrence of an electrochemical corrosion process during the cleaning of non-ferrous metals [2,3].

Waterjet technology uses quartz sand, silicon carbide, or aluminum oxide to clean machines. The principle of operation is a sharp ejection of the waterjet mixture onto the surface to be cleaned. The cleaning efficiency depends on the abrasive content, but an increase in this indicator can lead to difficulties in transporting the water-abrasive emulsion to the cleaning object. On the other hand, reducing the abrasive content can lead to a deterioration in the quality of contaminant removal.

In waterjet cleaning technology, the energy of the hydraulic impact is used as a mechanical factor. The principle of hydraulic jet action on the contaminated surface is shown in Picture 7.

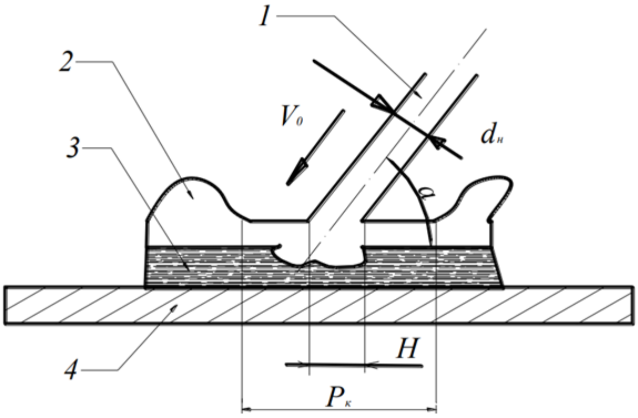


Fig. 7. Diagram of the effect of the jet on the surface to be cleaned: 1 - fluid flow; 2- hydraulic flow jump; 3 – pollution; 4 - cleaned surface; V_0- jet speed; α - angle of inclination (attack) of the jet; P - the force of the jet on the contaminated surface; N i T- normal and tangential components of the impact force of the jet on the contaminated surface; d_H- jet diameter.

The use of a hydraulic jet to remove loosely and medium-bound contaminants allows for a high level of cleaning. The use of a hydraulic jet to remove weakly bound and medium-bound dirt allows to achieve a high level of cleaning.

$$P = m_0 v_0 (1 - cos\alpha) = \rho \omega_0 v_0^2 (1 - cos\alpha), \qquad (1)$$

P – jet impact force, N;

m_0 – second mass of liquid, kg/s;

ρ – liquid density, kg/m3;

v_0 – is the rate of liquid outflow from the nozzle, m/s;

ω_0 – jet cross-section, m2;

α – angle of reflection from the point of meeting with an obstacle, rad;

The efficiency and quality of the water-jet cleaning process are determined by the speed of liquid exit from the nozzle, which is calculated using the formula:

$$v_0 = \varphi\sqrt{2gH}, \qquad (2)$$

H – water pressure, m;

g – acceleration of gravity m/s2;

φ – the speed coefficient depends on the shape of the hole and the type of nozzle.

The speed v_0 – determines the flow of water Q through the nozzles:

$$Q = \frac{\pi d^2 v_0}{4000} \qquad (3)$$

d - nozzle diameter.

By reducing the diameter of the nozzle *d* and increasing the pressure, we achieve a high rate of fluid flow, which leads to an increase in mechanical force (impact) at the same volume flow rate.

However, the use of waterjet technologies for removing medium and strongly binding contaminants is limited, as this leads to a significant increase in the pressure of the cleaning solution and, accordingly, an increase in electricity consumption [2].

To eliminate this drawback, a hydrodynamic cavitation cleaning method was developed [2]. This method is based on the erosive effect of cavitation bubbles generated in a special nozzle, which increase the destructive effect of the water jet on the object being cleaned. This technology allows to increase the mechanical impact due to additional energy and ensure high-quality cleaning at minimal cost [3].

However, this method is characterized by low productivity and complexity of cavitation process control, which limits its widespread use. For this method to be effective, the design parameters must be determined accurately, ensuring that cavitation bubbles are formed correctly directly on the contaminated surface.

During the analysis of various cleaning technologies, it was found that water jet cleaning is the most promising for removing contaminants from the surface of agricultural machines and aggregates. This technology allows you to increase the mechanical effect due to the additional energy that can be provided by the energy of the rotating jet. Therefore, to improve the quality of washing contaminated surfaces of agricultural machinery, it is necessary to develop a device design that allows the formation of a rotating jet and its impact on the surface to be treated.

Taking into account the stable growth of the technical level of agricultural enterprises and the increase in their need for modern and effective means for washing and cleaning, there is a need for further research and development in this field.

In the modern period in Ukraine, there is a low level of equipment of agricultural, farm and repair workshops with modern equipment for washing, as well as limited availability of consumables. In comparison, international experience shows that this area of maintenance is actively developing [3, 4]. Major global manufacturers are constantly improving cleaning technologies, equipment, and materials to meet the needs of the market, particularly in agricultural production.

The Ukrainian market regularly receives a significant number of universal outdoor washing devices, including models from well-known global manufacturers such as German, Italian, English and Spanish companies. The products of the well-known German company Karcher occupy a certain dominant position in the market of washing equipment. In addition, the market also includes devices from other recognized global manufacturers, such as Weidner, Wesumat, Kranzle, California Kleindiest Trommelberg (Germany), Istobal (Spain), Carebridge (UK), Ceccato, Comet, Oma, MAGIDO, FLEXBIMEC, RAV (Italy), Butler (Poland-Italy), SEONGJIN ENGINEERING (South Korea), STEAMRATOR OY (Finland), Profitech (Ukraine) and others.

For effective external cleaning and washing of agricultural machinery, three types of cleaning devices are widely used: high-pressure washers (HPW), portal washers, and tunnel washers [3-5]. In farms, high-pressure machines are the most common, available in mobile and stationary versions, powered by an internal combustion engine or the power grid. The variety of these devices includes the presence of water heating systems, pump type, and various nozzles that increase productivity and quality of cleaning.

Modern washing equipment with effective detergents simplifies and speeds up the removal of various contaminants in agricultural production. The use of gantry washers, which can be equipped with different brushes, drying fans and program control, or brushless gantry washers, where the cleaning process is carried out under high water pressure, is used in various industries.

Tunnel car washes use a different principle, where the car moves along rigidly fixed devices with different functions, and the movement is carried out using a conveyor [3-5]. The productivity of tunnel car washes depends on the characteristics of the equipment and the selected washing program, reaching from 35 to 120 cars per hour.

Although agricultural machinery can be washed manually, the efficiency and quality of this process is improved with the help of modern washing devices and detergents, which saves time and effort during the washing process.

Among the range of washing equipment, it is worth noting high-pressure devices from the German company KARCHER. The washing process can be carried out with the help of special brushes or by a non-contact method using active foam, which is then washed off with water under high pressure [3-6]. KARCHER offers a variety of unheated high-pressure devices such as HC10, HD 5/11 C, HD5/14C, K2.90M plus, HD 13/12-4 ST, HD 1050 B, HD 10/25-4 S, HD 801 B.

We would like to mention the AVT HC10 model, which can be operated from the mains or from a built-in battery, making it an ideal choice for washing on the road. KARCHER also offers gasoline-powered high-pressure pressure washers without water heating, such as the HD 1050 B, HD 801 B, HD 10/35 P B and others. These machines are characterized by professional equipment that is reliably protected for work in difficult conditions and effective in agriculture and forestry. The AVT model is equipped with Honda gasoline engines, a manual reverse starter and an Easy Press gun with a soft setting. The technical characteristics of the KARCHER vehicle are shown in Table 2. The HD 10/35 P B is equipped with a frame for component protection, a crane suspension and four wheels with pneumatic tires, and is characterized by high productivity thanks to the belt drive of the crankshaft [3,4].

We can also distinguish the 88 series of the Dukon industrial group's model range as efficient gasoline-powered automatic car washers without water heating. In particular, the 850 model has impressive technical characteristics: capacity - 906 l/h, pressure - 240 bar/24 MPa, power - 13 Nm at 1750 rpm, weight - 52 kg.

For employees of service and repair enterprises in agriculture and forestry, high-pressure washers with heated water are of particular interest, which can be either stationary or mobile. These machines guarantee high performance and are characterized by a variety of equipment.

Professional mobile pressure washers generally do not have built-in water heating, with the exception of stationary pressure washers [4,5]. The technical parameters of high-pressure water heaters from KARCHER and the Dukon Industrial Group are shown in Table 3. The series of sinks of the industrial group "Dukon" includes models: 15, 25, 22, 35, 45, 55, 66, 78, 88. The capacity of the Model 15 (1550) is 370 l/h, the pressure is 110 bar/11 MPa, the power is 1.8 kW, and the weight is 44 kg. The most productive among the machines is the 88 (8860) model with a capacity of 1260 l/h, a pressure of 200 bar/20 MPa, a power of 9.3 kW, and a weight of 135 kg.

The HDS 9/14-4 ST Eco and HDS 12/14-4 can be used not only to wash appliances with warm or hot water at the required temperature, but also to remove heavy dirt with a steam and water mixture. This makes them ideal for use in repair shops. In particular, the HDS 12/14-4 stationary high-pressure apparatus is characterized by the operation of a liquefied gas boiler [4,5].

For effective cleaning of small and medium-sized components, parts, and tools, you can use the PC 60/115 T (German company KARCHER) and VE 800 M (Italian company RAV) with the ability to load parts weighing 115 and 120 kg, respectively. For cleaning larger parts and assemblies, you can use the following machines: PC 70/230 F (German company KARCHER), VE 1000M and VE1200M (Italian company RAV), L152 (Italian company MAGIDO) with the ability to load parts weighing from 200 to 350 kg.

Fig. 8. The PARTS CLEANER PC 60/115 T apparatus (made by KARCHER)

To improve the quality of washing and cleaning of parts, many washers are equipped with a variety of additional equipment. For example, the PC 60/115 T and PC 70/230 F have a three-level nozzle system and a basket for washing small parts [4,5]. Many of these machines also have oil separators to clean the used solution of oils and greases, which supports their long-term use without replacement. In particular, the VE 800 M has the following parameters: water pump power - 0.55 kW, heater power - 4.0 kW, tank volume - 100 liters, operating voltage - 380 (220) V, weight - 170 kg.

To eliminate various types of contaminants on parts and large assemblies, you can use automatic cleaning and heating equipment from the Italian company MAGIDO, such as the L190E and L210E models. The temperature range of the machines is 0-700°C. These machines can provide water heating using gas, diesel fuel, and electric heating elements [4,5].

One of the most advanced cleaning technologies today is the use of steam. It is used for high-quality cleaning and quick removal of various contaminants. Steam washing technology is aimed not only at preserving nature and the environment, but also significantly reduces water consumption, while maintaining the quality of the machine's coating, without the need for special polishing [5]. Steam cleaning can be used not only in the repair industry, but also for cleaning car and bus interiors and disinfecting rooms.

SEONGJIN ENGINEERING (South Korea) offers steam generators with an electric heater (models Optima EDS, Optima EST3, Optima EST1) and steam generators with a heat source due to fuel combustion (models Optima DM(F) and Optima DS). The 0.3 kW Optima DM(F) and Optima DS steam generators with a weight of 70 kg and a 17-liter boiler volume can produce steam at a temperature of 85...120°C at a pressure of 8 kg/cm². The Optima EDS and Optima EST3 steam generators with a power of 12.2 kW, a weight of 85 kg, and a boiler volume of 20 liters can produce steam at a temperature of 85...120°C at a pressure of 8 kg/cm². Steam generators can be used effectively for cleaning internal combustion engines.

It is also worth paying attention to mobile steam generators manufactured by STEAMRATOR OY (Finland), such as MN-700, MNT-700, MNS-700 (200 kW thermal power, 350-450 kg/h output, 220 W voltage), Steam 800 (530 kW thermal power, 800 kg/h output, 380 W voltage), Steam mate (40 kW thermal power, 80-100 kg/h output, 220 W voltage).

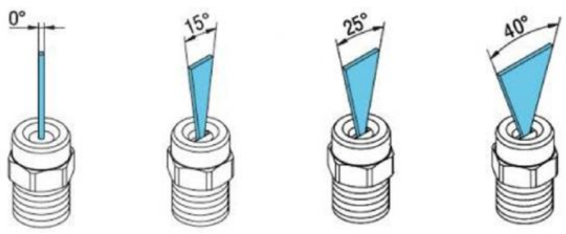
These universal machines can be used in agriculture and utilities, as well as during repair and maintenance [5]. High temperatures and a powerful steam stream are used to clean surfaces and remove stubborn dirt. Samples of steam generators from STEAMRATOR OY are shown in Figure 9.

Fig. 9. Steam generator by STEAMRATOR OY

When choosing equipment for cleaning machines, it is important to focus on companies that specialize in the development of technologies, production, supply, installation, and maintenance of automatic cleaning equipment.

The main results of the study. The cleaning efficiency is determined by the shape of the nozzle (nozzle) design and the water outflow rate from it. The nozzles are designed to create a powerful head, regulate the volume of liquid flow and form water jets with different configurations. They can be made of metal, ceramic, or plastic, and their various configurations allow for various forms of cleaning jets, such as scattering, fan-shaped, dagger, slit, and other (see Figure 10) [5-7]. The jets formed by the nozzles have a cylindrical shape.

Nozzles of other geometric shapes are used less frequently due to the high complexity of their manufacture, even though the performance characteristics of some designs can exceed cylindrical ones [9, 12-16]. It is important to keep in mind that the right nozzles play a key role in ensuring optimal cleaning effect and reducing water consumption during the cleaning process.



a b c d

Fig. 10. Nozzles of washing units: a - dagger jet, b, c, d - flat jet.

The dagger jet has a high cleaning capacity but low area performance, while the fan jet has a high area performance and lower cleaning capacity. The dagger jet retains up to 70% of the initial impact pressure at a distance of up to 20 cm, while the fan jet retains up to 5% [5-7].

The dagger nozzles form a sharp and focused jet that penetrates deep into dirt and pushes it away from the surface, allowing you to clean hard-to-reach areas.

Fan nozzles, which have a flat cross-section, form a wide and powerful jet with high impact force at low angles, and as the angle increases, the jet becomes wider but less powerful (Picture 11).

Indicators characterizing the efficiency of the nozzle include the flow coefficient μ, the resistance coefficient ε, and the velocity coefficient μ. The fluid flow rate at constant head is determined by the formula [5-7]:

$$Q = \mu \frac{\pi d^2}{4} \sqrt{\frac{2P}{\rho}} \quad (4)$$

d - hole diameter, m;
P - is the liquid pressure in the nozzle, Pa;
ρ - liquid density, kg/m3.

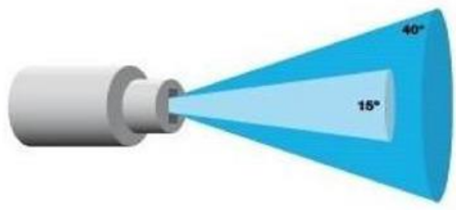


Fig. 11. The degree of saturation of the water jet depending on the angle of its spray.

The energy of the liquid flowing from the nozzle is determined by the formula:

$$W = \frac{mV^2}{2} \quad (5)$$

m is the mass of the flowing liquid; V is the flow rate of the liquid from the nozzle.

The outflow rate is calculated by the formula:

$$V = \varphi \frac{2P}{\rho} \quad (6)$$

φ is the speed coefficient.

$$\varphi = \frac{1}{\alpha + \varepsilon} \quad (7)$$

α is the coefficient of unevenness of the velocity distribution across the flow cross-section (usually α = 1); ε is the air resistance coefficient.

The jet energy can be determined:

$$W = \frac{mV^2}{2} = \frac{Q\rho V^2}{2} = \mu\varphi^2 \frac{\pi d^2 \rho}{8} \left(\frac{2P}{\rho}\right)^{\frac{3}{2}} = \mu \frac{\pi d^2 \rho}{8(\alpha+\varepsilon)^2} \left(\frac{2P}{\rho}\right)^{\frac{3}{2}} \quad (8)$$

From expression (8), it can be deduced that the jet force depends on the mass of the liquid and its flow rate [5,6]. According to the principles of hydraulics, as the head in the nozzle increases, the rate of fluid leakage increases, which leads to an increase in jet energy.

Based on the reviewed information, it was found that devices that use the energy of hydraulic fluid impact with a periodic direction of fluid flow through the channels, as well as use the phenomena of energy saturation of the jet as an element to increase the efficiency of the cleaning process, are promising [5,8].

Currently, existing nozzle designs are expensive, unstable and have low performance, which limits their widespread use. As a result, there is a need for scientific substantiation of the optimal parameters and operating modes of such nozzles for their use in universal washer designs to remove contaminants from agricultural machinery and equipment. Based on the regression equation, a graph was constructed showing the dependence of the degree of sample surface cleaning (VaR 5) on the nozzle rotation speed (VaR 4) and the number of fan jets (VaR 1) (see Figure 12) [6,7].

$$Var\ 5 = 0{,}6263 + 0{,}0369 \cdot x + 0{,}0188 \cdot y + 0{,}1857 \cdot x \cdot x + 0{,}0207 \cdot x \cdot y - 0{,}094 \cdot y \cdot y \quad (9)$$

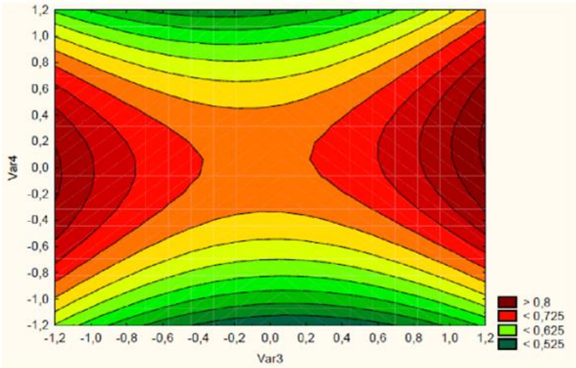


Fig. 12. The contour graph shows how the degree of cleaning of the sample surface changes depending on the pressure of the liquid in the pressure line and the nozzle rotation speed, expressed in revolutions per minute.

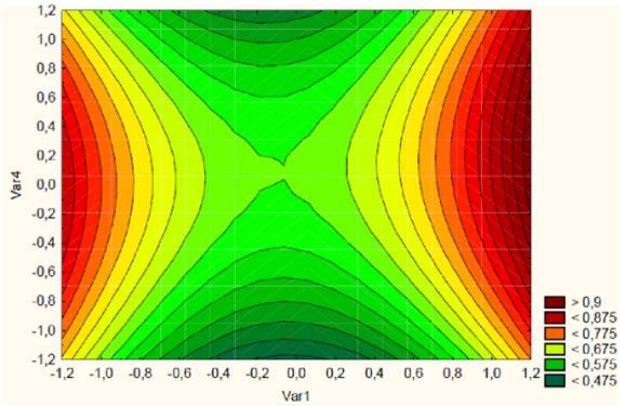


Fig. 13. The graph shows the relationship between the degree of cleaning of the sample surface and the nozzle rotation speed in revolutions per minute, as well as the number of fan jets expressed in units.

The use of the developed nozzle design with rational parameters leads to obtaining not only qualitative but also quantitative characteristics of the rotating jet, which guarantees a high level of surface cleaning [7-9]. The results of determining the optimal distance from the nozzle to the surface in Figure 14 show that this design allows you to achieve maximum surface cleaning values due to the effective effect of the rotating jet.

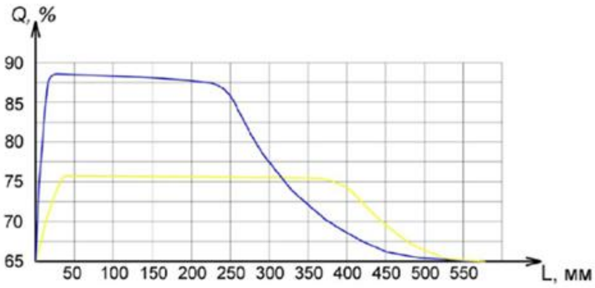


Fig. 14. Graph of the dependence of the degree of cleaning Q on the distance L: Yellow bar, jet without rotation; Blue bar, jet with rotation.

During the operation of the experimental nozzle, the structure of the liquid changes, in which the liquid droplet increases in size, and, accordingly, its mass increases. Smaller droplets lose their cleaning effectiveness due to air resistance, while larger droplets have an impact on the surface, providing more effective cleaning. This process is accompanied by a powerful shock pulse, the size of which is 87% at a distance of 220 mm from the nozzle. [7-9].

The unique design of the nozzle contributes to a steady increase in the fluid flow rate and the formation of a stable boundary layer, which contributes to the formation of a compact jet with high energy characteristics.

Figure 15 shows the results of experiments to determine the optimal rotation speed of the developed nozzle, at which the maximum quality cleaning performance is achieved [9-11]. According to the graph, the maximum degree of cleaning is achieved at a rotational speed of 132 rpm and amounts to 87%.

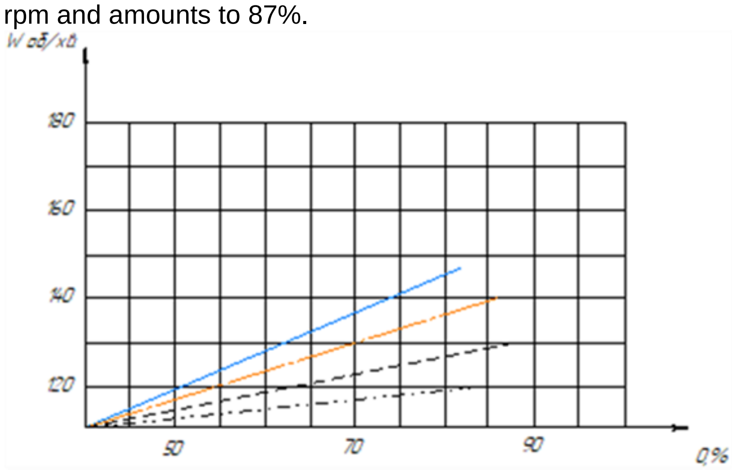


Fig. 15. Graph of the dependence of the degree of purification Q on the speed W.

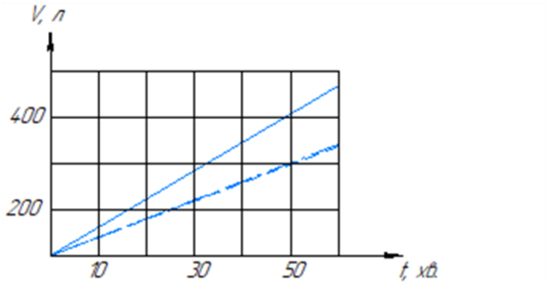


Fig. 16. Graph of water consumption during washing.

The time for washing the surfaces of agricultural machines is given in Table 1

Table 1: Time for washing the surfaces of agricultural machines.

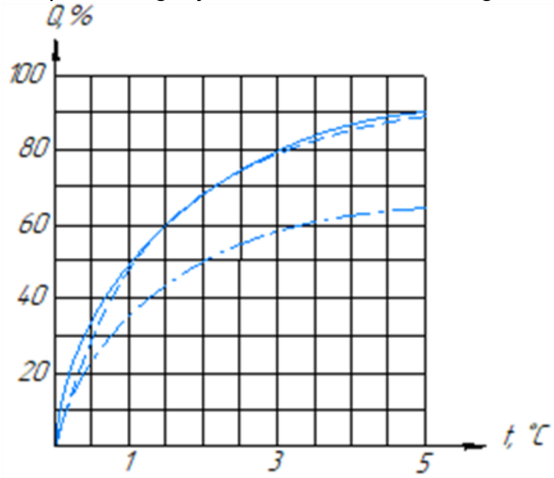
№	The content of the operation	Technical requirements	Number of performers	Operation time, min	Labor costs, man/hour
1	2	3	4	5	6
Preparatory operations					
1	Prepare and assemble the machine	According to the instructions	1	1	1
2	Locate the unit close to the place of work	Not closer than 0.4 m	1	0,1	0,1
3	Ground the machine	According to the instructions	1	0,3	0,3
4	Connect the machine to the network	220B	1	0,1	0,1
Additional Operations					
5	Work out washing methods		1		3
6	Rest and natural needs of the operator		1	3	3
Ancillary Operations					
7	Determine the surface area by the shape and type of contamination		1	1	1
8	Starting the machine into the work	According to the instructions	1	0,1	0,1
9	Stopping the machine: reducing the mains shut-off pressure	According to the instructions	1	1	1
Basic Operations					
10	Open the monitor valve and hold until a steady stream		1	0,5	0,5
11	Wash surfaces at a distance of 0.5-0.7 m		1	16,75	16,75
12	Move the monitor at a speed of 0.25-0.6 m/s		1	5,1	5,1
13	Turn off the monitor (gun)		1	0,1	0,1
Final operations					
14	Remove fluid from the machine and pump idle		1	1	1
15	Turn off the ground		1	0,3	0,3
16	Disconnect the nachine from the mains		1	0,1	0,1
17	Disassemble the machine		1	1	1

Table 2. Performance indicators of cleaning agricultural machinery from medium and weakly bound contaminants.

№	Name of the cleaning method	Installation Brand	Evaluation indicators				
			Power consumption	Washing liquid consumption	Working pressure, MPa	Cleaning time, min	Residual pollution, g/m2
1	Pressure washer	«Huter W105-GS»	0,6	128	6,8	25,4	0,85
2	Pressure washer	«KARCHER K7»	0,9	158	14,3	20,3	0,74
3	Washer with a rotating jet	Pilot plant	0,8	116	7,8	18,5	0,71

The highest degree of surface cleaning is achieved when using the KARCHER K7 cleaning unit compared to the pilot unit with a rotating jet. The amount of residual contamination on the surface is 7-9% lower than when using the Huter W105-GS high-pressure washer. Analysis of technical and operational indicators confirms that the rotary jet washer is the most economical, with a 15-20% lower consumption of electricity and working fluid compared to the KARCHER K7 high-pressure washer, while still providing high performance. Residual contamination is only 3-5% [10].

A graphical display of the results of the analysis of the quality of cleaning of reference samples using a jet nozzle is shown in Figure 17.



1. High pressure installation *"KARCHER K7"*
2. Experimental installation.
3. High pressure installation *"HUTER W105-GS"*

Fig. 17. Graph of the degree of purification versus time.

At the initial stage of the washing process, the highest level of cleaning is observed, but this indicator decreases over time. In order to ensure the high efficiency of the purification plants, it is necessary to limit the time of the purification process [10, 11]. The most effective in this regard are the KARCHER K7 and the experimental unit. It is known that it is possible to achieve a high quality of purification of a reference sample within 5 seconds.

It is important to note that the efficiency of cleaning depends not only on technical and operational parameters, but also on the use of optimal work organization technology. We conducted a study regarding the impact of cleaning technology on the labor intensity and quality of the work performed, and these results are presented in Figure 18.

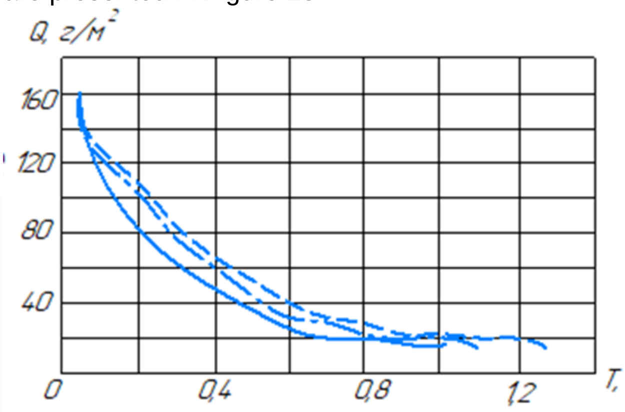


Fig. 18. Graph of influence of cleaning technology on labor intensity and quality of works.

The analysis of cleaning efficiency in terms of labor costs indicates that the highest labor costs for washing agricultural machinery are observed when using the Hunter W105-GS and KARCHER K7 units. The introduction of the experimental unit led to a significant increase in the efficiency of cleaning agricultural machinery from contaminants. To achieve the required quality of cleaning (residual contamination of 1 g/m2), the labor intensity of washing the experimental unit is 1.03 man-hours, in the case of KARCHER K7 - 1.11 man-hours, and in the case of Hunter W105-GS - 1.15 man-hours.

Conclusions. The provision of Ukrainian agricultural, farming and maintenance workshops with modern cleaning equipment is relevant. A study of global experience shows that the maintenance market is constantly evolving, offering new cleaning technologies, equipment and materials.

Washing equipment, such as high-pressure washers, gantry washers and tunnel washers, is proving to be an important tool for ensuring efficient and high-quality cleaning of agricultural machinery. Global manufacturers such as Karcher, Weidner, Wesumat, and others offer a wide range of equipment with different characteristics to solve different problems.

Using of newer technologies, such as steam cleaning, can be further effective in ensuring cleanliness and disinfection, particularly in agriculture and municipalities. The development of infrastructure for access to modern cleaning equipment will increase productivity and improve the quality of maintenance in the agricultural sector of Ukraine. It is noted that the efficiency of the cleaning process of washing installations is determined by the shape of the nozzle design and the rate of water outflow. The use of a variety of nozzles, such as dagger, fan, and slotted nozzles, expands the possibilities of forming water jets of various configurations, which contributes to the optimal cleaning of various surfaces.

An important aspect is the selection of the optimal nozzle parameters, such as the orifice diameter, spray angle and number of fan jets. The dagger nozzles under consideration are characterized by a high ability to clean, in particular hard-to-reach areas, but have limited area performance. Fan nozzles, on the other hand, deliver a wide and powerful jet with less cleaning effort.

Important parameters, such as flow coefficient, drag coefficient, and velocity coefficient, which affect the performance and energy of the jet, are highlighted. It was established that with an increase in pressure in the nozzle (nozzle), the energy of the jet increases, which can positively affect the efficiency of the cleaning process.

References

1. Sidashenko, O.I., et al. (2014). Remont mashyn ta obladnannia: pidruchnyk. Kyiv: Agroosvita. [in Ukrainian].
2. Shvets, L.V., Paladiichuk, Yu.B., Trukhanska, O.O. (2019). Tekhnichnyi servis v APK: navch. posib. T. 1. Vinnytsia: VNAU. [in Ukrainian].
3. Tekhnolohiia rozbyrannia silskohospodarskykh mashyn (chastyna tretia). (n.d.). URL: https://hydro-maximum.com.ua/ua/a343465-tehnologiya-razborki-selskohozyajstvennyh.html (data zvernenia: 06.03.2024). [in Ukrainian].
4. Obladnannia dlia ochyshchennia ta vydalennia zabrudnen detalei silhosptekhniky. (n.d.). URL: https://propozitsiya.com/ua/obladnannya-dlya-ochishchennya-ta-vidalennya-zabrudnen-detaley-silgosptehniki (data zvernenia: 06.03.2024). [in Ukrainian].
5. Reklamnyi prospekt myjky vysokoho tysku. (n.d.). URL: https://profitech.com.ua/ua/p980466408-professionalnaya-mojka-vysokogo.html (data zvernenia: 06.03.2024). [in Ukrainian].
6. Sidashenko, O.I., Tikhonov, O.V., Skoblo, T.S., et al. (2018). Praktykum z remontu mashyn. Tekhnolohiia remontu mashyn, obladnannia ta yikh skladovykh chastyn: navch. posib. T. 2. Kharkiv: TOV "Prom-Art." [in Ukrainian].
7. Paladiichuk, Yu.B., Teliatnyk, I.A. (2021). Pidvyshchennia efektyvnosti tekhnolohii ta tekhnichnykh zasobiv kontrolu yakosti vidnovlennia dvyhuniv malohabaritynoi tekhniki. Tekhnika, enerhetyka, transport APK. vol. 1 (112). pp. 137-151. [in English].
8. Paladiichuk, Yu. (2021). Substantiation of technology of conservation of agricultural equipment during storage. Colloquum-journal. vol. 9 (96). pp. 42-59. [in English].
9. Paladiichuk, Yu. (2021). Research quality control of Spare parts of mobile equipment. Colloquum-journal, vol. 5 (92). pp. 49-57. [in English].
10. Trukhanska, O.O. (2020). Perspektyvni napriamky tekhnolohii vidnovlennia detalei mashyn. Vibratsii v tekhnitsi ta tekhnolohiiakh. vol. 3 (98). pp. 104-110. [in Ukrainian].
11. Budiak, R.V., Posviatenko, E.K., Shvets, L.V., Zhuchenko, G.A. (2020). Konstruktsiini materialy i tekhnolohii: navch. posib. Vinnytsia: VNAU. [in Ukrainian].

ОБҐРУНТУВАННЯ ПАРАМЕТРІВ СОПЕЛ МИЙНИХ МАШИН СТРУЙНОГО ТИПУ ДЛЯ ОЧИЩЕННЯ СІЛЬСЬКОГОСПОДАРСЬКИХ МАШИН ТА АГРЕГАТІВ

Сільськогосподарські машини та агрегати піддаються значному забрудненню різними видами забруднювачів, одні можуть легко видалятись для видалення інших необхідно використовувати спеціальні миючі засоби та машини. Для видалення цих забруднень використовують струмінь води під тиском, найбільшим недоліком таких пристроїв є значна витрата води, тому важливим питання інтенсифікації процесу очистки сільськогосподарських машин є з використанням обмеженої кількості води є актуальним науковим завданням.

Очистка сільськогосподарської техніки та агрегатів від забруднень є складною технологічною операцією, тому, існує потреба в розробці та обґрунтування параметрів і режимів роботи *високотехнологічного пристрою миття, що забезпечував би якісне видалення всіх видів забруднень з високою ефективністю, мінімальними витратами води та мінімальними затратами праці.*

Аналіз технологій очищення показав, що найбільш перспективною для видалення забруднень з поверхні сільськогосподарських машин та агрегатів є водоструминне очищення, технологія дозволяє підвищити рівень механічного впливу шляхом застосування додаткової енергії, в якості якої може служити енергія обертається струменя.

У дослідженні розглянуто питання ефективності очищення мийних установок від різноманітних забруднень. Основний акцент приділено вивченню впливу конструкції сопла на якість та продуктивність процесу миття. Сопла визначають форму струменів води та їхню швидкість, обумовлюючи ефективність очищення. Розглянуті кинджальні та віялові сопла, їхні переваги та недоліки.

Досліджено параметри сопел, такі як діаметр отвору, кут розпилення та кількість віялових струменів. Показано, що правильно підібрані параметри сопел грають важливу роль у досягненні оптимального миючого ефекту та економії води. Окреслено фактори, такі як коефіцієнт витрати, коефіцієнт опору та швидкісний коефіцієнт, які впливають на продуктивність та енергію струменя.

Ключові слова: *сільськогосподарські машини, мийки високого тиску, струмінь води, зовнішні забруднення, сільськогосподарські агрегати, технічне обслуговування.*

Відомості про авторів

Fedirko Pavlo – Faculty of Engineering and Technology Higher educational institution «Podillia State University», Kamianets-Podilskyi, Ukraine, E-mail: pavlo.fedirko@pdatu.edu.ua, ORCID: 0000-0002-3724-8937
Kubai Marina – lecturer at the Department of Ukrainian and Foreign Languages, Faculty of Management and Law. of Vinnitsa National Agrarian University (3 Soniachna St., Vinnitsa, 21008, Ukraine, e-mail: marinakubaj@ukr.net, http://orchid.org/0009-0000-5703-295X).

Федірко Павло Петрович – кандидат технічних наук, доцент кафедри технічного сервісу і загальнотехнічних дисциплін Заклад вищої освіти «Подільський державний університет» Кам'янець-Подільський, Україна, E-mail: pavlo.fedirko@pdatu.edu.ua, ORCID: 0000-0002-3724-8937
Кубай Марина Григорівна – викладачка кафедри української та іноземних мов факультету менеджменту та права Вінницького національного аграрного університету (вул. Сонячна, 3, м. Вінниця, 21008, Україна, e-mail: marinakubaj@ukr.net, http://orchid.org/0009-0000-5703-295X).