Development of an Integrated Unit for Chemical and Electron Beam Treatment of Agricultural Plants.

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Abstract. This article presents the design and testing results of an Integrated Unit for chemical and electron beam treatment of agricultural plants. Chemical treatment is performed using a fan sprayer. Electron beam treatment is carried out using two ultraviolet irradiation (UVI) lamps mounted on the front of the tractor. Before cotton defoliation, bench tests were conducted to determine the liquid flow rate. It was discovered that the total liquid flow rate per minute at a pressure of 5 to 10 bar ranged from 21 to 32 l/min. Specifications of the sprayer and the electron beam system, as well as its operating technology, are presented. Cotton cultivation conditions in Central Asia are described. A description of the integrated unit, as well as the design of a new sprayer and ultraviolet irradiation system, is provided. The integrated unit can be supplied to agricultural producers upon request in the following configurations: with a spraying unit, with an electron beam unit, and as a complete unit with both a spraying unit and an electron beam unit. The results of field trials of the machine for cotton defoliation are displayed. It was discovered that integrated chemical and electron beam treatment of cotton increased the boll-opening rate by 25%. Leaf abscission also has been increased. In practice, the combined unit can be used separately for chemical or electron beam treatment of plants.

Keywords: Cotton, defoliation, integrated unit, ultraviolet irradiation (UVR), tractor, sprayer

1 Introduction

Chemical treatment of agricultural plants to protect them from pests, diseases, and weeds is the basis for obtaining high crop yields. A disadvantage of this method is the harmful impact of chemicals on the environment. Crop cultivation conditions in Central Asia and southern Kazakhstan are specified by the highest annual sunshine hours, amounting to 2,500-3,000 hours [1]. This creates favorable conditions for cultivating heat-loving crops, including cotton. Almost all cultivated crops suffer annually from numerous pests and diseases [2, 3]. Increasing agricultural production is possible primarily through the implementation of intensive development methods, the introduction

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of the latest advances in science, technology, best practices, and the efficient use of production potential [4].

In developed countries with intensive agriculture, considerable attention is paid to advances in biotechnology and genetic engineering [5]. Defoliation and desiccation are among the main operations for managing the agricultural background of cotton fields and preparing them for machine harvesting [6, 7]. Boom and fan sprayers are used for chemical treatment of plants [8, 9]. Each type of sprayer has its own advantages and disadvantages. The advantage of a boom sprayer is its economical use of liquid chemicals. Its nozzles are located close to the plants being treated, reducing the amount of liquid droplets blown away by the wind and evaporation loss. However, boom sprayers require a larger headland, are less maneuverable, and are unable to apply the liquid evenly across the height of the plant. The undersides of leaves, where pests heat up, are particularly difficult to treat. Fan sprayers are more maneuverable, do not require a larger headland, and can apply the spray evenly across the height of the plant by stirring the plants with air pressure. The disadvantages of fan sprayers include wind drift, increased droplet evaporation, and uneven field coverage across the spray width. The diversity of soil and climatic conditions for agricultural crop cultivation, as well as the availability of a wide variety of pests, diseases, and weeds in certain regions, necessitate the development of several types of plant protection machines [10]. Plant protection machine designs are described in the literature [11, 12, 13, 14, 15, 16, 17].

Agrixim Joint Venture has developed a dual-nozzle fan sprayer [18], Tashkent Institute of Irrigation and Mechanization Engineers and "BMKB-Agromash" JSC, under the supervision of Professor A.M. Mukhammadiev, have conducted a comprehensive study on electron beam and electrical treatment of cottonseeds as well as cotton chopping, defoliation, and post-harvest sterilization [19]. The current state of knowledge on plant electrophysiology is presented by Medvedev [20]. Previous studies have not yet revealed the mechanisms of electron beam effects on seeds and plants, but they have outlined new approaches for studying and developing new technologies for protecting seeds and plants from infectious diseases. Currently used agricultural practices, as outlined in technological maps, do not produce a significant effect on the early ripening of cotton bolls, a significant increase in yield, improved cotton fiber quality, or the production of high-quality seed material resistant to various diseases.

Over the past 50 years, the real possibility of using electricity in agricultural production by targeting seeds and vegetative organs of plants has been proven. It has become possible to control physiological and technological processes during the development of cotton and other cotton crops. The creation of environmentally friendly technologies with the introduction of new methods, including electrical stimulation, is becoming a vital necessity. The development of electrical technologies should solve the problem of reducing, and ideally eliminating, the use of pesticides in pre-sowing seed treatment. The aim of this study is to improve the effectiveness of chemical plant protection while reducing the applied doses of pesticides and their negative impact on the environment. A prototype of an integrated unit has been developed, manufactured, and tested.

2 Materials and methods

Fig. 1 and 2 show the installation diagram of the sprayer with an irradiator, viewed from the side and in the direction of arrow B. Fig. 3 shows the irradiator with adjustment mechanism of lamp position, and Fig. 4 schematically depicts the drive for the adjustment mechanism of lamp position. The lamp connection diagram and a general view of the irradiator control panel are displayed in Fig. 5 and 6, respectively.

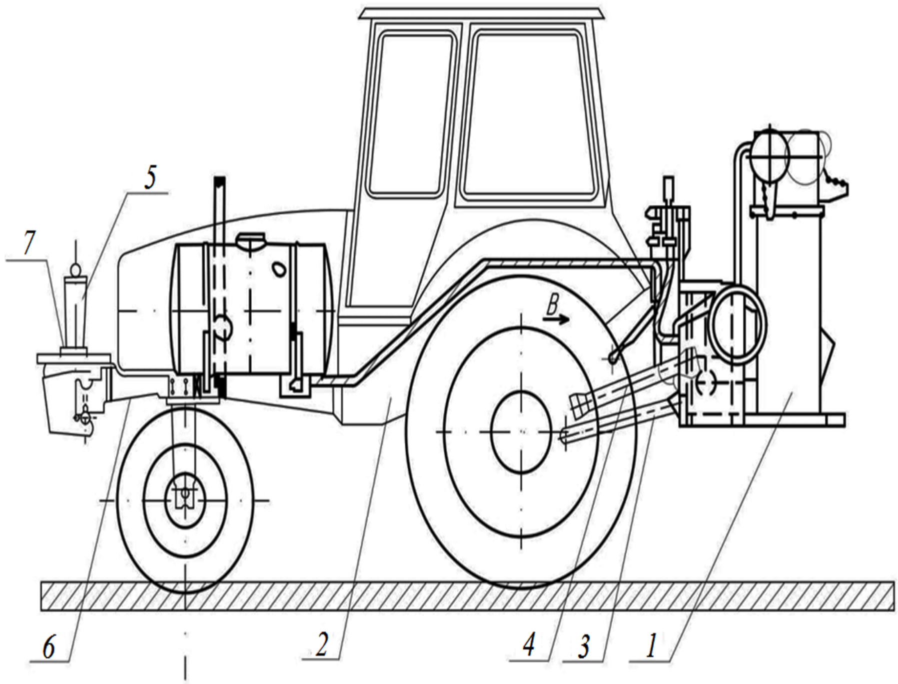

Fig. 1. Sprayer installation diagram, side view

Sprayer 1 (Fig. 1) is mounted to power vehicle (tractor) 2 via hitch system 3. PTO shaft 4 is also displayed. Electric irradiator 5 is mounted to the front of tractor 2 on its frame 6 via base platform 7. In Fig. 2, arrow B shows the sprayer in its stationary position, lowered onto mounting stands.

The working element of electric irradiator 5 is two bactericidal ultraviolet lamps 8 and 9. The lamps are attached to mounting boxes 10 and 11 (Fig. 3). The position of the lamps is adjusted by a mechanism comprising a hydraulic cylinder 12, one end of which is connected to a support bracket 13 and the other to a slider 14. The slider can move in a guide sleeve 15, which is rigidly fixed to a base platform 7. The support bracket 13 is rigidly connected to the base platform 7. A hydraulic cylinder 12 is pivotally fixed to the free end of the support bracket, the other end of which is pivotally connected to the slider 14. Adjusting rods 16 and 17 are pivotally connected to mounting boxes 10 and 11 and to the slider 14. The lamp connection diagram contains a special two-channel ignition and power supply system 18 for lamps 8 and 9 (Fig. 5) for ultraviolet irradiation. The lamps are powered by a tractor generator or DC batteries (12V). Power source

19, terminals 20 and socket 21 are also displayed in Fig. 5. The ignition and power supply system is installed in the tractor cab, to the right of the driver. The control panel contains a housing 22, a socket 21, a toggle switch 23, a fuse 24, and terminals 20 (Fig. 6).

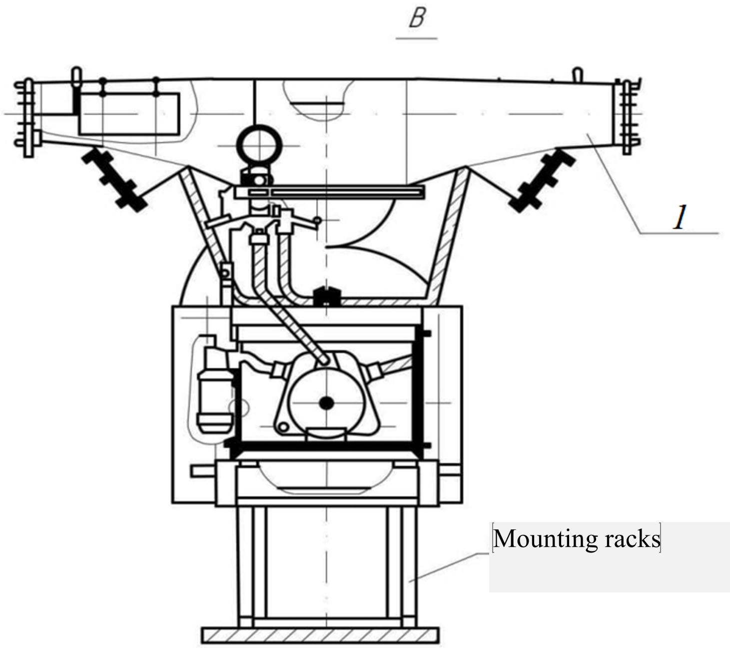

Fig. 2. Sprayer wiring diagram (arrow B)

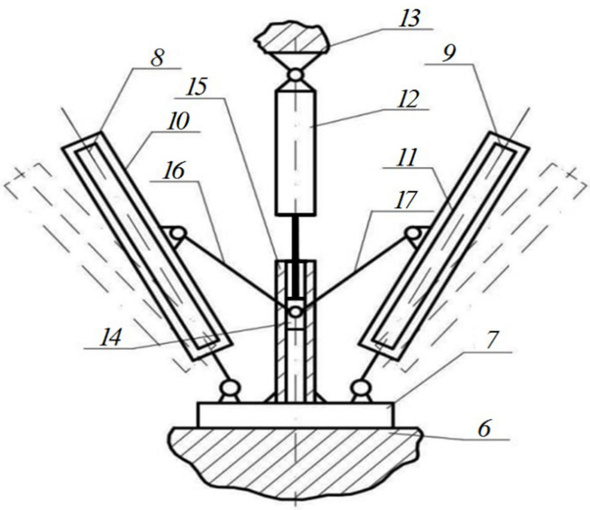

Fig. 3. Irradiator with adjustment mechanism for lamp angle

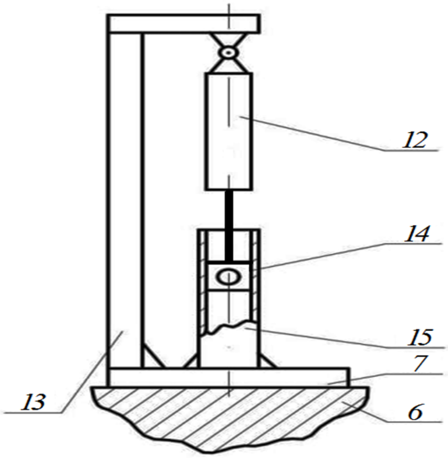

Fig. 4. Adjustment mechanism drive for lamp angle

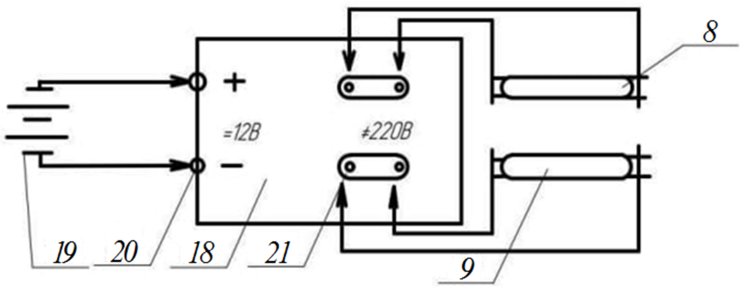

Fig. 5. Lamp connection diagram

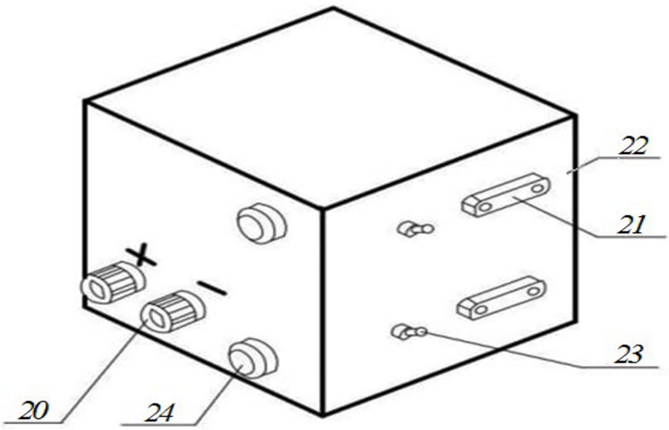

Fig. 6. Control panel

The irradiator operates as follows: Before entering the field, with the tractor running, the driver uses the toggle switch (in the cab) to turn on power source 19, activating bactericidal ultraviolet lamps 8 and 9. The tractor begins moving, and the sprayer is activated, chemically and electrically treating the plants. If the irradiation coverage width needs to be changed, the driver adjusts the position of the bactericidal lamps relative to the horizon from 0 to 45° using hydraulic cylinder 12 (Fig. 3) and rods 16 and 17. The unit was tested on cotton defoliation at the TCET (Testing Center for Equipment and Technology) test site using two background conditions:
I-background – without the use of ultraviolet irradiation;
II-background – with the use of ultraviolet irradiation.
Prior to the tests, the VP-1IB sprayer and the electric irradiator (UV irradiation) were assembled and mounted on a TTZ-811 cotton-growing tractor. The soil at the test site was typical gray soil with a flat topography. The cotton row spacing was 90 cm, with an average furrow depth of 17.0 cm. The topsoil moisture content in the 0-10 cm horizon was 9.32% (no more than 19.0% according to the ATT) with a hardness of 1.06 MPa. Spraying was carried out at an air temperature of +30°C at a height of 2.0 m. At the time of treatment, the average plant height was 103 cm (up to 130 cm according to the ATT) with a width of 45 cm. Each plant had 13 fruiting branches. The plants had a dense foliage cover with 36 branches per plant. Liquid magnesium chlorate was used as a defoliant at a rate of 10 kg/ha.
Mechanism and machine part theory methods were used in the design of the integrated unit. Field trials of the unit were conducted in accordance with the standard O'z DSt 3203:2017 "Testing of agricultural machinery. Sprayers and dusters. Test methods" [21].

3 Results

To achieve the desired effect with the combined chemical and electric beam effects on plants, it is possible to reduce the application rates of pesticides while increasing the treatment efficiency. A new sprayer has been developed for use in the combined unit. The technical solution is displayed in Fig. 7, 8, 9, 10, 11, 12, 13. The design of the fan sprayer with a double nozzle used in the integrated unit combines the positive elements of boom and fan sprayers [18]. Fig. 7 displays a side view of the fan sprayer; Fig. 8 displays a branch with inclined blower holes and nozzles on an enlarged scale; Fig. 9 – rear view; Fig. 10 displays an displays enlarged view of the inclined pipe with nozzles along arrow A. Fig. 11 the sprayer in a top view. The sprayer's hydraulic system and the working fluid distribution system are displayed in Fig. 12 and 13, respectively. Mounted on frame 1 are fan 2 with pipe 3; air ducts – left 4 and right 5, oppositely directed and carrying nozzles at their ends, respectively left 6 and right 7; drive 8, connected to the power take-off shaft of the power vehicle.
The oppositely directed air ducts are offset relative to each other in the horizontal plane along the direction of travel of the power vehicle and, at the junction, form a box 9, divided by diaphragm 10 into front 11 and rear 12 compartments. The rear section of

the box 9 is curved, with a swirl channel 13 at the top and a branch 14 at the bottom, to which the inclined rear nozzles 15 and blower tubes 16 are attached. Branch 14 has a segmental shape in the horizontal plane.

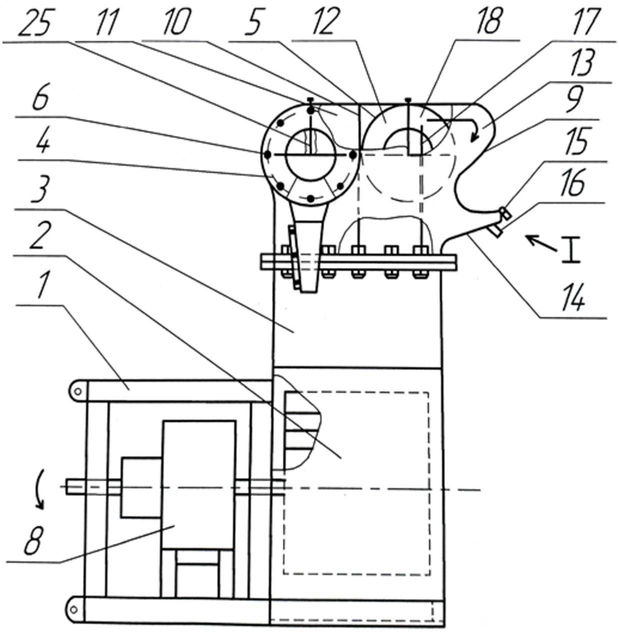

Fig. 7. Sprayer - side view

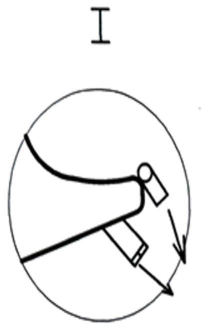

Fig. 8. Inclined branch

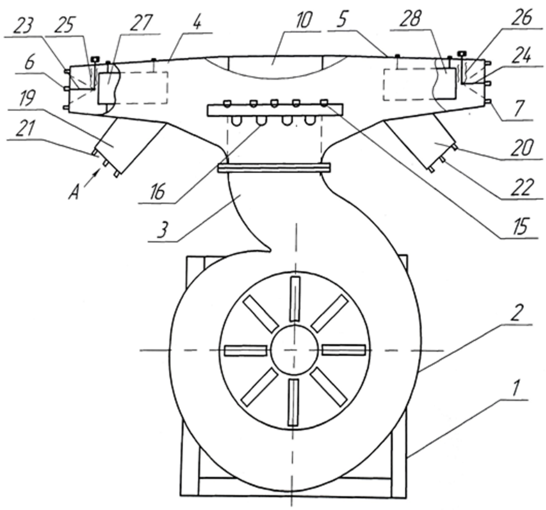

Fig. 9. Sprayer- back view

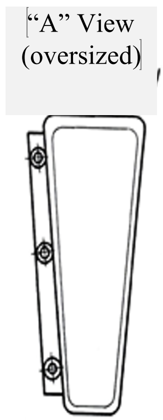

Fig. 10. Inclined nozzle

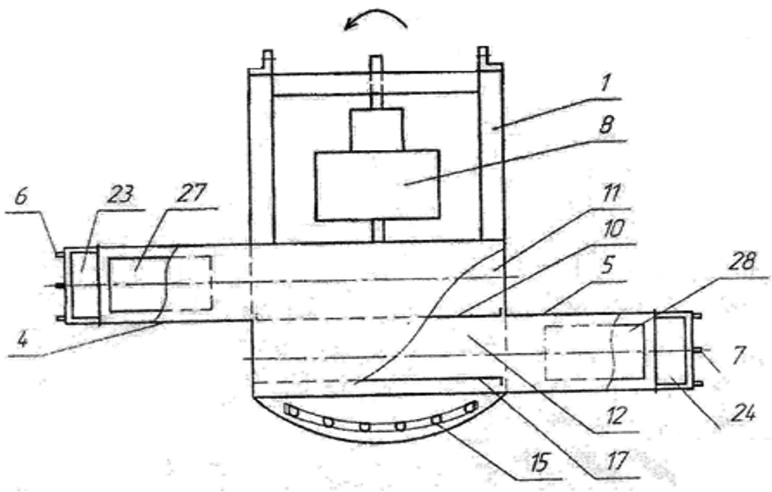

Fig. 11. Sprayer – top view

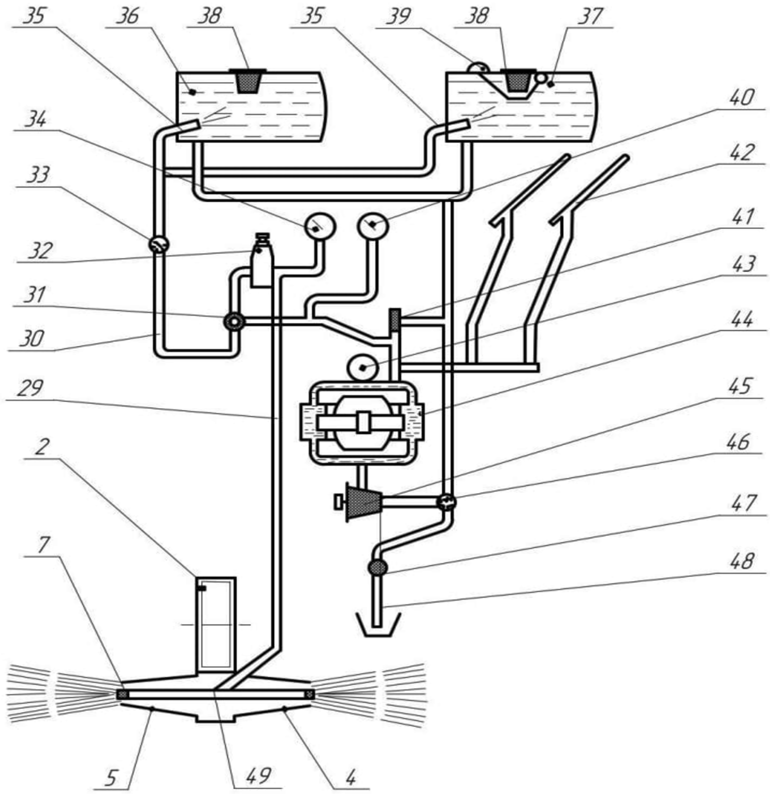

Fig. 12. Sprayer hydraulic system

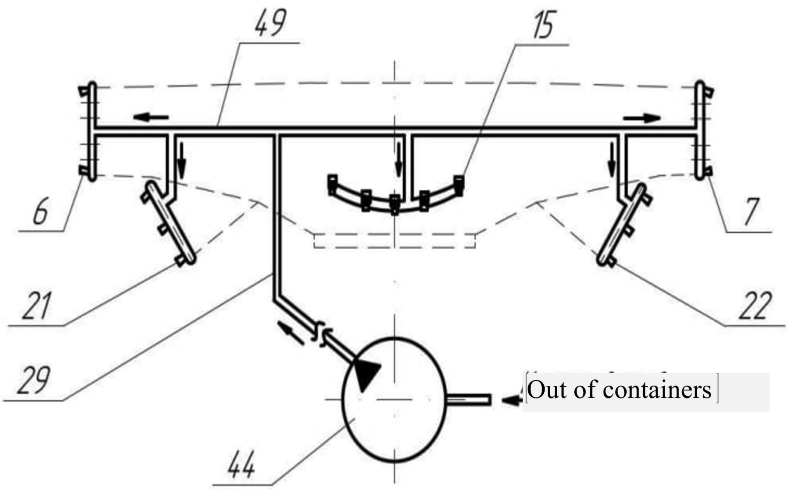

Fig. 13. Working fluid distribution system

In the rear compartment 12 is a truncated flap 17 located, which forms a window 18 at the top. At the bottom of the air ducts are left 19 and right 20 inclined blower nozzles, which are equipped with nozzles 21 and 22, respectively, and are positioned at an angle relative to the soil surface. At the ends of the air ducts are left 23 and right 24 airflow guides, the position of which is adjusted by screw mechanisms 25 and 26. Left 27 and right 28 hollow cylinders are mounted inside the working elements.

The sprayer has a hydraulic system and reservoirs for the working fluid.

The sprayer hydraulic system includes a pressure line 29, a discharge line 30, a distribution valve 31, a pressure regulator 32, a valve 33, a low-pressure gauge 34, hydraulic mixers 35, left 36 and right 37 tanks with filler necks 38, a level indicator 39, a high-pressure gauge 40, a safety valve 41, a fire hose 42, an air cap 43, a pump 44, a filter 45, a suction valve 46, a filling hose valve 47, a filling hose 48, and a working fluid distribution system 49.

The device operates as follows. Via the power take-off shaft of the power unit, drive 8 rotates fan impeller 2, creating an airflow that is fed through pipe 3 into box 9, where it is divided into two portions by diaphragm 10 and directed into left 4 and right 5 air ducts. At the same time, working fluid is supplied from reservoirs 36 and 37 to nozzles 6 and 7. The working fluid is sprayed by them, picked up by the air stream, and applied to the surface of plants (trees, vineyards) located to the left and right of the sprayer. The spray direction is adjusted by left 23 and right 24 air guides, which can be adjusted up and down by screw mechanisms 25 and 26. This sprayer is used for treating orchards and vineyards. For processing field crops, blowing nozzles 19 and 20, supporting nozzles 21 and 22, as well as nozzles 15 and blowing tubes 16 are additionally put into operation. The working fluid, sprayed by nozzles 21, 22 and 15, is picked up by the air flow created by nozzles 19, 20 and blower tubes 16, respectively, and is applied to plants (field crops) at an angle. Laminar airflow for nozzles 6 and 7 is provided to the required degree by hollow cylinders 27, left, and 28, right. The air pressure required for

nozzles 15 is provided by truncated valve 17, which forms a passageway 18 in the upper part of box 9, through which air is supplied to blower tubes 16.
The box of twin nozzles 4 and 5 has a swirl cavity 13 at the rear, where the concentrated air flow is diverted (in the direction of the arrow) and delivered to blower tubes 16, where it picks up the working fluid sprayed by nozzles 15 and applies it to the plants.
The sprayer frame is attached to the tractor's hitch. To fill tanks 36 and 37 with solution or clean water, filling hose 48 with filter is lowered into a body of water or container, suction valve 46 and distribution valve 31 are set to the "fill" position, and pump 44 is turned on. For the pump to operate, 30-40 liters of water must be added to the tanks through filler neck 38 with filter. Pump 44 then feeds the liquid under pressure through filling hose 48 with filter, valve 47, suction valve 46, filter 45, distribution valve 31, and valve 33 into hydraulic mixers 35, filling the tanks. Here, the water mixes with the pesticide, forming solutions, suspensions, or emulsions. The liquid level in the tanks is monitored by float-type indicator 39. Water from a pond and concentrated liquid pesticide from a special container can be simultaneously drawn in.
When the pressure in the discharge line 29 increases above the set value, the safety valve 41 is activated and part of the liquid is drained into the suction line. The pressure in pressure line 29 is monitored by high-pressure gauge 40.
To spray plants, suction valve 46 and distribution valve 31 are moved to the operating position, and fluid from the tanks flows to pump 44. The pump forces the working fluid through valve 31, where part of the fluid is diverted through discharge line 30 to hydraulic mixers 35, while the rest flows through discharge line 29 and pressure regulator 32 into distribution system 49 and then to nozzles 6, 7, 15, 21, and 22. If necessary, the fluid supply to the hydraulic mixers can be shut off with valve 33.
The fluid flow through the nozzles is set by pressure regulator 32, which is monitored by pressure gauge 34. Air valve 43 maintains a stable pressure in the system. Valve 33 has two positions. One is for filling tanks 36 and 37 with water, and the other is for transporting the working fluid. For selective treatment of plants or roadsides, fire hose 42 is used. Activating all of the aforementioned nozzles 6, 7, 21, 22, and 15 allows for a consistent, high-quality application of chemicals to the contaminated surface of field crops grown on level ground or in beds. The integrated unit, prepared for testing, is displayed in Fig. 14.

Fig. 14. Integrated Unit

Table 1. The unit's performance indicators

Indicators	according to ATT	Indicator value	
		according to test data	
		I- background	II- background
Date		07.09.2020	
Test location		Test site of the Central Institute of Toxic Technologies	
Unit name		VP-1IB+UFO	
Row spacing, cm	0,9	90,0	
Working speed, km/h	up to 7	3,9	
Name of the pesticide		magnesium chlorate	
Actual capture width, m	12	20	
Technical efficiency in cotton defoliation, %:			
- on the 6th day after treatment		84,09	75,95
- on the 12th day after treatment		92,6	93,1
Percentage of open cotton opening before defoliation, %:		20-28	
- on the 6th day after treatment		40	57
- on the 12th day after treatment		50	71

The unit's performance indicators are displayed in the Table 1. The unit, operating at a speed of 3.9 km/h, treated cotton plants with a working width of 20 m (at least 12 m according to the ATT). The technical efficiency of cotton defoliation on the sixth day of treatment was 84.09% under the first treatment conditions, 75.95% under the second treatment conditions with UV irradiation, and 92.6% and 93.1% on the 12th day, respectively. The boll opening percentage was 40.0% on the sixth day, and 50% on the 12th day without UV irradiation; with UV irradiation, it was 57% and 71%, respectively. Field trials showed that the developed unit performs the chemical treatment of cotton plants with simultaneous electro-beam exposure reliably and reliably. Chemical treatment and electrical irradiation have increased the effectiveness of defoliation by 1.4 times, increasing leaf fall and boll opening. This allows for earlier start of machine cotton harvesting and reduced chemical application rates. A dedicated research cycle is required to establish numerical values for the combination of chemical application rates and electrical irradiation levels.

4 Conclusion

An analysis of the technological and design parameters of known developments in chemical and electron beam treatment of agricultural plants allowed us to determine the rational design of a combined unit for the combined chemical and electron beam treatment of agricultural crops.

Field trials of the combined unit revealed that it fully meets established requirements for cotton defoliation [21-31].

The effectiveness of integrated chemical and electron beam treatment on cotton was 57% for open bolls on the sixth day and 71% on the 12th day. Without electron beam treatment, these figures were 40% and 50%, respectively.

Accelerating cotton boll opening allows for earlier machine harvesting and faster harvesting.

The combined unit can be supplied to agricultural producers upon request in the following configurations:

- with a spraying unit;
- with an electron beam unit;
- completely equipped with both a spraying unit and an electron beam unit.

Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article.

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