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STUDY OF THE OPERATION OF A LIQUID DOSING DEVICE WITH AN AIR-HYDRAULIC VALVE

ДОСЛІДЖЕННЯ РОБОТИ ДОЗУЮЧОГО ПРИСТРОЮ РІДИНИ З ПОВІТРЯНОГІДРАВЛІЧНИМ КЛАПАНОМ

Artiomov M.P / Артьомов М.П.
d.t.s., prof. / д.т.н., проф
ORCID: 0000-0002-2947-2664
Kaluzhnij O.D. / Калюжний О.Д.
c.t.s., as.prof. / к.т.н., доц.
ORCID: 0000-0002-4943-4235
State Biotechnological University, Kharkiv, Alchevskykh,44, 61002;
Державний біотехнологічний університет, Харків, Алчевських,44, 61002

Abstract. *The aim of the study is to carry out an experimental evaluation of the volume and accuracy of liquid dispensing, from:*

- height of the location of the doser relative to the atomiser;

- the cross-sectional area of the diameter of the delivery tubes;

- the influence of air-hydraulic valve to compensate for the reduction in the volume of supply from the change in the height of the water column in the dosing tank at the flow rate of working fluid. To compare the values of liquid supply performance obtained experimentally with the results of theoretical calculations. The full-scale experimental studies of the mock-up model of the pesticide solution dispenser were carried out. To improve the accuracy of dosing solutions of pesticides on the splashing disc, a doser consisting of a container for solutions of pesticides, a dosing tank moving in the vertical plane relative to the splashing disc, a air-hydraulic valve, a set of connecting tubes with different diameters of the cross-section is proposed. As a result of researches of the mock-up sample of the doser its satisfactory operability was obtained. It allows adjusting the dosage of pesticide solutions to the spraying disc within the required limits. Changing the diameter of the throughput cross-section of the feeding tube within 0,004...0,007 m. and the height of the dosing tank location from 0.2 to 1.0 m. to the spraying disc changes the liquid supply from 12 to 160 l·hour^{-1}. Air-hydraulic valve compensates for the effect of changing the height of the water column (h) in the dosing tank as it flows, on the performance of the volume of liquid supply. The height of the water column difference is set from the upper cut-off of the air-hydraulic valve to the upper plane of the sprinkler disc. Unevenness of distribution of liquid volume delivery is within the range of 1-4 %. Theoretical studies to determine the fluid delivery capacity allow calculations with sufficient accuracy within 2-10%.

Keywords: *liquid, dosing tank, connecting tubes, diameter of flowing section, air-hydraulic valve, atomiser, water column height.*

Introduction

Spraying of agricultural plants with chemical and microbiological preparations serves as measures to protect plants from weeds, pests and diseases. In order to minimise the negative impact of chemical plant protection products on the ecological situation, low-volume spraying is used, which involves the application of pesticides with a minimum amount of working solution without reducing the biological efficiency

[1; 2]. The greatest effect in the application of such preparations is achieved by the quality of spraying of the working liquid. One of the components of 'quality' is uniformity of distribution of pesticides over the field surface and density of coverage of the treated surface by droplets [3 - 5].

Technology and equipment of fine-drop atomisation allows to get the maximum effect from the sprayed preparations with the lowest costs and minimum damage to the environment. The operation of the equipment used is based on the principle of rotary atomiser. The most widespread are rotary atomisers in the form of mesh and perforated drums or discs of different configurations, which grind the incoming liquid (under low pressure) into small homogeneous droplets [6]. That allows to form the necessary droplet sizes according to the technology of low-volume spraying and to spray liquid within the limits of 10-50 litres$\cdot$ha^{-1}. The drive of atomisers is carried out by electric motors from the tractor's electric network with a power consumption of no more than 500 W.

Studying the designs of existing atomisers and analysing their operation allowed to identify the disadvantage in these devices. To such a shortcoming can be attributed to the node to adjust the supply of the required volume of working solution to the atomisers [7]. This node is installed in the fluid supply system of each atomiser. This unit in its design has a shut-off valve. Operation of the adjustment unit occurs at the working pressure of the liquid (according to technical requirements) in the supply system of the atomiser in the range of 0.7 - 0.9 kg$\cdot$cm^{-2}.

When the solution pressure drops to 0.5 kg$\cdot$cm^{-2}, the valve automatically cuts off the atomiser from the working fluid flow, thus stopping its operation. This construction provides for the operation of atomisers with pressure fluctuations in the fluid supply system in the range of 0.2 - 0.4 kg$\cdot$cm^{-2}. This results in an uneven delivery of the working fluid volume to the atomiser from 20 to 40 %. Even the technically stipulated requirement for the working pressure (0,7 - 0,9 kg$\cdot$cm^{-2}) can change the unevenness of the working fluid supply in the range of up to 20 %. This is not permissible for low-volume spraying.

Experimental evaluation of quantitative and qualitative indicators of the doser operation, comparison of the obtained practical results with the theoretical results of the solution volume supply from the design parameters of the doser.

Materials and methods

Assessment of quantitative and qualitative indicators of liquid dosing by the pipette was carried out using a laboratory installation (figure 1). 'Pliability' of pneumatic actuators, resulting from the action of variable loads, imposes some limitations on the applicability as a drive of its working bodies. This can be avoided by using a pneumatic element as the driving element and hydraulic devices as the damping and regulating elements [8].

The design of the doser consists of: tank 3, air-hydraulic valve 4 with shut-off valves, feeding flexible tubes 5, telescopic stand 2 with which changes the height (H) location of the tank relative to the atomiser 6.

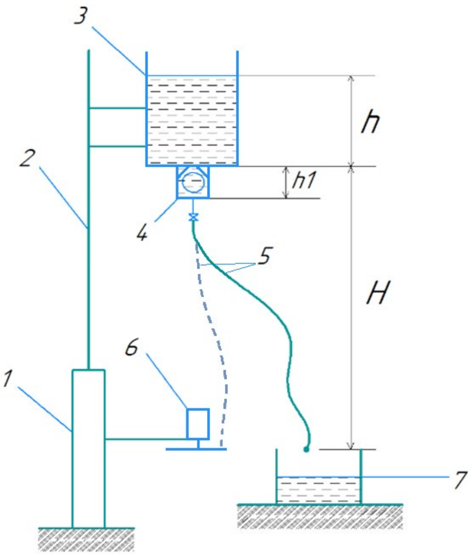

Figure 1: Laboratory installation of the doser : 1 - stand; 2 - telescopic stand; 3 - dosing tank; 4 - air-hydraulic valve; 5 - connecting flexible tube; 6 - atomiser. *Author's development*

The air-hydraulic valve (figure 2.) is designed to compensate for the change in the height of the water column (h) as the liquid flows out of the dosing tank 3.

The valve works as follows. Liquid from the tank 3 (figure 2.) flows into the body 1 of the air-hydraulic valve (figure 2.). That leads to the formation of 'air plug' between the body 1 and the cylindrical valve body 3, in which there is a shut-off ball 5 of the valve (the valve ball has a specific gravity less than water). The pressure of compressed air (air lock), when blocking the access of liquid from the dosing tank by the valve body corresponds to the height of the water column (H) (figure 1). This leads to the ejection of liquid from the valve body due to the expansion of air, which thereby compensates for the change in liquid equilibrium (h) in the dosing tank 3 as it flows. As a result of this process of operation of the air-hydraulic valve 4 (figure 1), in the fluid supply system to the atomiser 6, maintains a constant pressure equal to the height of the water column (H). As the valve 5 is lowered, the fluid supply from the dosing tank 3 resumes and continues until it is blocked by the valve ball.

The dispense cycle repeats exactly at regular intervals

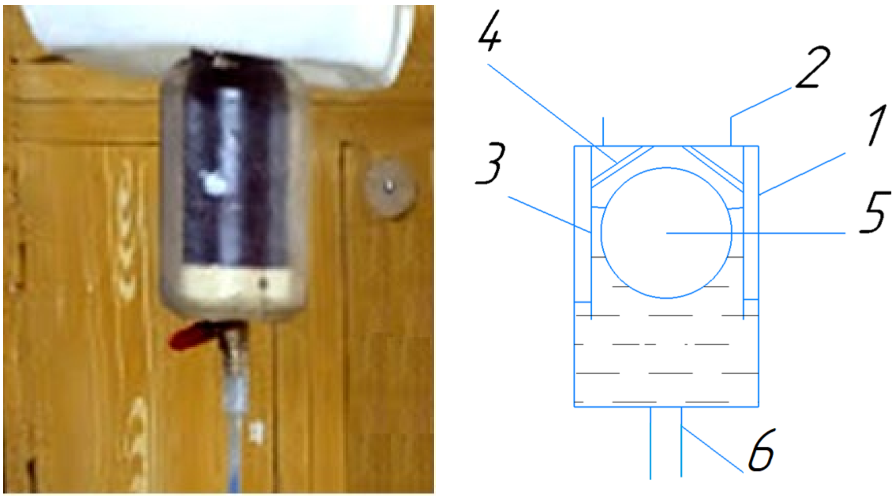

Figure 2 Air-hydraulic valve: 1 - body; 2 - inlet pipe; 3 - cylinder internal; 4 - valve seat; 5 - floating ball valve; 6 - outlet pipe. *Author's development*

The level of height difference (H) was set in increments of 0.20 m, which corresponded to the values: H = 1.0 m; H = 0.80 m; H = 0.60 m; H = 0.40 m; H = 0.20 m. The initial column of liquid in tank 3 was set with constant height and had the value h = 0.23 m, which corresponded to the volume of liquid 10 litres. Each subsequent experiment began with fixing the level of the column of liquid remaining in the tank after the previous experiment and so until the full flow of liquid from the tank. If the liquid was insufficient for fivefold repetition of experiments, it was refilled up to the initial value (h = 0.23 m.) and the experiments continued from the interrupted value and up to full completion.

The height of the valve body 1 (figure 2.) had a constant value of h = 0.013 m. The experiments were carried out with replacement of the supply flexible tube 5. Each tube had a constant length of two metres. The diameter of the passing section of the tubes (d) varied and had values of 0.003 m, 0.004 m, 0.005 m, 0.006 m and 0.007 m.

The experiments were carried out with fivefold repetition. Dimensional and weight values were determined using instruments:

- height of the dosing tank installation was measured with a tape measure of MT-0303 brand;
- the weight of the collected liquid in the tank was weighed on a QZ-157A scale.

The obtained numerical results were processed by the method of mathematical statistics [9] and are presented in Table 1.

Table 1. Results of statistical processing of the obtained values of productivity from the diameter (*d*) of the throughput cross-section of the tubes and the level of height difference (H).

Diameter flexible tube $d \cdot 10^{-3}$m.	Level of height difference. (H), m.	Average liquid volume (Q_{av}), $l \cdot hour^{-1}$	Standard deviation of liquid volume (Q_{av}.), litres.	Unevenness of fluid volume distribution (coefficient of variation) (υ)	Arithmetic average error (λ)	Relative error of the arithmetic mean (p)
1	2	3	4	5	6	7
7	1,00	164,52	1,02	0,006	0,456	0,002
	0,80	135,96	1,74	0,012	0,778	0,005
	0,60	128,16	2,94	0,022	1,314	0,010
	0,40	106,8	0,6	0,005	0,268	0,002
	0,20	71,64	0,66	0,009	0,295	0,004
6	1,00	110,64	0,54	0,004	0,241	0,002
	0,80	95,52	0,12	0,001	0,053	0,0005
	0,60	84,96	0,54	0,006	0,241	0,002
	0,40	65,4	0,3	0,004	0,134	0,002
	0,20	41,4	0,3	0,007	0,134	0,003
5	1,00	78,12	0,12	0,001	0,053	0,0006
	0,80	67,8	0,9	0,013	0,402	0,005
	0,60	54,72	0,12	0,002	0,053	0,0009
	0,40	40,08	0,18	0,004	0,080	0,002
	0,20	27,96	0,24	0,008	0,107	0,003

4	1,00	35,16	0,06	0,001	0,026	0,0007
	0,80	28,56	0,24	0,008	0,107	0,003
	0,60	22,92	0,18	0,007	0,080	0,003
	0,40	18,24	0,3	0,016	0,134	0,007
	0,20	12,12	0,42	0,034	0,187	0,015
3	1.00	33,24	0,24	0,007	0,107	0,003
	0,80	27,6	0,3	0,010	0,134	0,004
	0,60	21,84	0,24	0,010	0,107	0,004
	0,40	16,56	0,25	0,015	0,111	0,006
	0,20	12	0,3	0,025	0,134	0,011

Author's development

Results and discussion

From the tabulated values it is obvious that for tubes with diameter 0,003m. and 0,004m. the liquid flow rate and the obtained statistical results of the values have practically the same values. Therefore, the use of a tube with a throughput diameter d = 0,003m. is not reasonable. On this basis it was excluded from further studies.

For values of average statistical liquid flow rate Q_{av}. (Table 1) the graph (figure 3) is constructed.

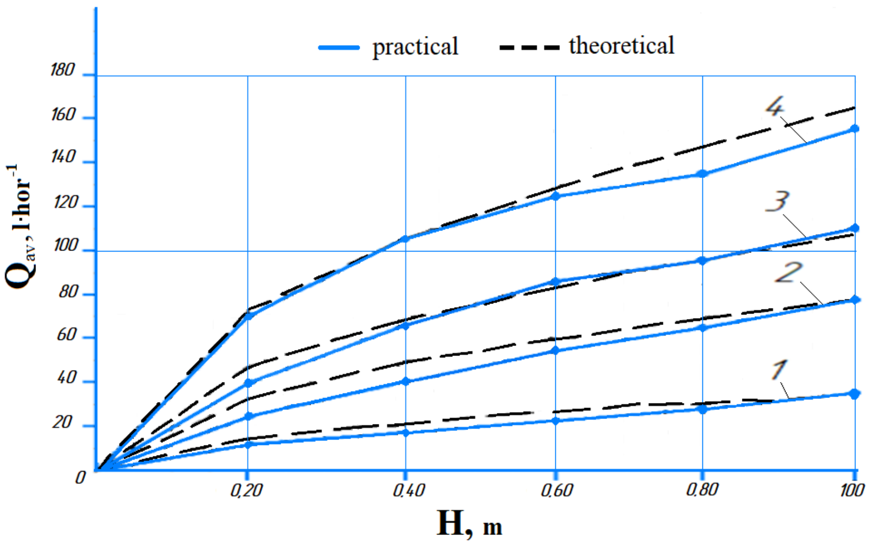

Figure 3. Liquid flow rate (Q_{av}, $l \cdot h^{-1}$.) from height difference (H, m.) and diameter (d, m.) of the flow section: 1 – d = 0,004 m; 2 – d = 0,005 m; 3 – d = 0,006 m; 4 – d = 0,007 m; (── practical liquid flow rate; ─ ─ ─ theoretical liquid flow rate). *Author's development*

From the graph shows that variation of diameters of the throughput section from 0.004 to 0.007 m. at setting the height of the dosing tank from 0.2 to 1.0 m. allows to regulate the liquid supply in the range from 12 to 160 litres·hour^{-1}.

As the results of statistical processing of the obtained values of productivity (Table 1) show the unevenness of distribution (coefficient of variation-- υ) is values from 0.001 to 0.022, which meets the requirements for unevenness of supply of pesticide and fertiliser solutions by the doser.

The analysis of the obtained coefficients of variation (Table 1) taking into account the developed methodology of experiments (repetition of the whole series of experiments was carried out regardless of the initial level of liquid in the dosing tank 3) allows us to assert that the air-hydraulic valve compensates the influence of changes in the height of the water column (h) (figure 1) as it flows out of the tank and maintains the productivity of liquid supply in the required values. Thus provides a given capacity from constant dimensional and geometric parameters of the metering unit.

The theoretical capacity of liquid supply was calculated by equation (1) [10].

$$Q = 3{,}6 \cdot 10^6 \mu S \sqrt{2gH}, \qquad l/h. \tag{1}$$

where: μ - coefficient of hydraulic resistance of the flexible tube;

S - cross-sectional area of the tube, m^2.

g - acceleration of free fall, m·s^{-2}.

H - height of the water column, m.

Comparing the results obtained theoretically and in the laboratory (figure 3), it can be stated that the performance discrepancy is within 2 % to 10 %. Such accuracy allows to use formula (1) for calculations of liquid volume delivery from the above mentioned dimensional and geometrical parameters.

The hydraulic resistance coefficient (μ) for the whole series of tested flexible tubes (figure 4) was determined experimentally.

$$\mu = \xi \cdot \frac{V^2}{2g} \tag{2}$$

where ξ - is the local resistance coefficient used to calculate energy losses in individual system components;;

V - s the average flow velocity;;

g - is the acceleration due to gravity.

The obtained calculated results are shown on the graph by a dotted line (figure 3).

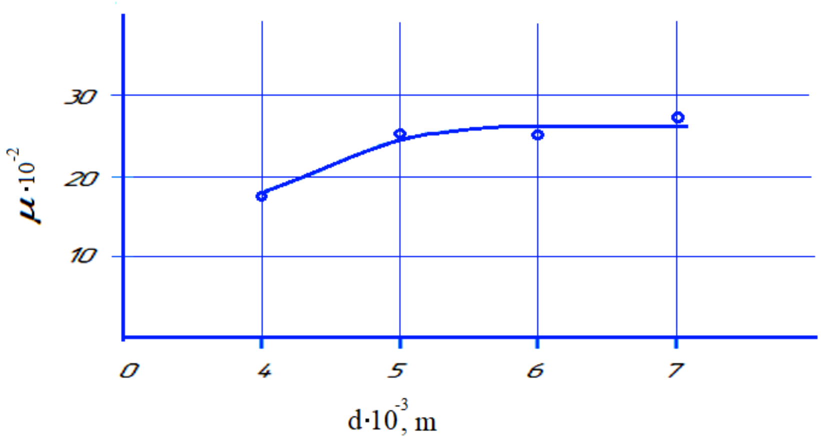

Figure 4: Graph of dependence of the coefficient of hydraulic resistance (μ) on the diameter (d) of polyvinylchloride flexible tubes *Author's development*

Analysis of the graph of the dependence of hydraulic resistance (figure 4) shows that when a certain diameter is reached, of the feeding tubes stabilise and the hydraulic resistance becomes, practically constant.

Conclusions

1. Changing the diameter of the flow section of the feed pipe (d) within 0.004...0.007 m and the height of the dosing tank location (H) from 0.2 to 1.0 m from the spreading disc changes the liquid feed from 12 to 160 $l \cdot hr^{-1}$.

2. Air-hydraulic valve compensates for the effect of changing the height of the water column (h) in the dosing tank as it flows, on the performance of the volume of liquid supply.

3. The water column differential height setting level should be set from the top of the air-hydraulic valve to the top plane of the spray disc.

4. The unevenness of the fluid volume delivery rate should be within the range of 1 - 4 %.

5. The theoretical justification for determining the fluid delivery capacity allows calculations to be carried out with sufficient accuracy within a range of 2 to10%.

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Анотація. *Метою дослідження є проведення експериментальної оцінки об'єму та точності дозування рідини, виходячи з:*

- висоти розташування дозатора відносно розпилювача;

- площі поперечного перерізу діаметра подавальних трубок;

- впливу повітряногідравлічного клапана на компенсацію зменшення об'єму подачі від зміни висоти стовпа води в дозуючому баку при швидкості потоку робочої рідини. Порівняти значення продуктивності подачі рідини, отримані експериментально, з результатами теоретичних розрахунків. Були проведені натурні експериментальні дослідження макетного зразка дозатора розчинів пестицидів. Для підвищення точності дозування розчинів пестицидів на розпилювальний диск запропоновано дозатор, що складається з ємності для розчинів пестицидів, дозуючого бака, що рухається у вертикальній площині відносно розпилювального диска, повітряногідравлічного клапана, комплекту з'єднувальних трубок з різними діаметрами поперечного перерізу. В результаті досліджень макетного зразка дозатора отримано його задовільну працездатність. Це дозволяє регулювати дозування розчинів пестицидів на розпилювальний диск у необхідних межах. Зміна діаметра пропускного перерізу живильної труби в межах 0,004...0,007 м та висоти розташування дозуючого бака від 0,2 до 1,0 м до розпилювального диска змінює подачу рідини від 12 до 160 л/год. Повітряногідравлічний клапан компенсує вплив зміни висоти водяного стовпа (h) у дозуючому баку під час його протікання на продуктивність об'єму подачі рідини. Різниця висоти водяного стовпа встановлюється від верхньої точки відсічення повітряногідравлічного клапана до верхньої площини розпилювального диска. Нерівномірність розподілу об'єму подачі рідини знаходиться в межах 1-4 %. Теоретичні дослідження для визначення продуктивності подачі рідини дозволяють проводити розрахунки з достатньою точністю в межах 2-10 %.

Ключові слова: *рідина, дозувальний бак, з'єднувальні трубки, діаметр проточної ділянки, повітряногідравлічний клапан, розпилювач, висота водяного стовпа.*

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