Всеукраїнський науково-технічний журнал

Ukrainian Scientific & Technical Journal

ISSN 2306-8744

DOI: 10.37128/2306-8744-2021-1

Вібрації в техніці та технологіях

№1(100)

2021

№ 1 (100) 2021 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, 2021. – 1 (100) – 162 с.

Друкується за рішенням Вченої ради Вінницького національного аграрного університету (протокол №9 від 23.03.2021 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

1. ТЕОРІЯ ПРОЦЕСІВ ТА МАШИН

2. МАШИНОБУДУВАННЯ ТА МАТЕРІАЛООБРОБКА

Sevostianov I.
Dr. Sc. of Eng., Professor

Melnyk O.
Postgraduate Student

Vinnytsia National Agrarian University

Севостьянов І. В.
д.т.н., професор

Мельник О. С.
аспірант

Вінницький національний аграрний університет

УДК 631.589.2
DOI: 10.37128/2306-8744-2021-1-7

ELABORATION OF IMPROVED HYDROPONIC INSTALLATIONS

Hydroponics is a perspective direction of development of modern agriculture that provides perennial growing of main species of vegetables and greenery on small areas and with minimal expenses of water and fertilizers. This technology allows to get large enough harvests of fresh vegetables in big cities including office and living premises.

Last time entrepreneurs and inventors pay a lot of attention for elaboration of more effective methods of hydroponics and equipment for their realization in direction of decrease of using areas, economy of water, nutrients and increase of air supply and plants capacity.

There are several known methods of hydroponics: static solution culture, continuous-flow solution culture (NFT), deep water culture, passive sub-irrigation, flood and drain sub-irrigation, run-to-waste system, top-fed deep water culture, rotary system, aeroponics, fogponics. Commercial and industrial use got the first three from above mentioned methods. Herewith the method of static solution culture does not provide of necessary saturation of plant's roots with air. Under realization of the method of continuous-flow solution culture are possible little buffering against interruptions in the flow (power outages), water logging in some channels, besides there are limitations for maximal length of channels (12 – 15 m). The method of deep water culture in industrial scales is used mainly for growing of lettuce. The other mentioned methods are not enough effective from point of view of commercial utilization.

The improved hydroponic installations, presented in the article, were elaborated with consideration of such demands: versatility of use (a possibility of growing of various species of plants); harmonies optimal provision of crops with water, nutrients, light and air; maximal use of premise's space; a possibility of re-space during of the growth period, increase of area for each plant and support of its stalk and sprouts. Also, the formulas for definition of main parameters of the elaborated installations are presented in the article.

Keywords: *hydroponics, industrial installation, versatility, optimal provision, efficient use of area.*

Problem formulation. The first theoretical researches and practical experiments in sphere of hydroponics relate to 17th century but its more intensive use and improvement began after 1850. Industrial introduction of given technology on commercial base was realized in 21th century [1 – 6]. For wider and more effective using of hydroponics there is need to decrease the dimensions of installations for its realization, expenses of water and nutrients, to provide quite intensive feeding of air, versatility of installations for growing of different species of plants.

Analysis of last researches. There are several main methods of hydroponic technology: static solution culture, continuous-flow solution culture (NFT), deep water culture, passive sub-irrigation, flood and drain sub-irrigation, run-to-waste system, top-fed deep water culture, rotary system, aeroponics, fogponics [7 – 15].

The method of static solution culture (fig. 1) is simplest in realization: plants grow in solution of water and nutrients that can be gently aerated or unaerated at all and it is changed with some periodicity. Optimal level of solution is supported with help of sensors. The method is universal enough, but its shortcomings are: not effective use of areas of a premise, water and nutrients, labour-intensiveness of replanting during of the growth period, insufficient supply of plant's roots with oxygen.

Fig. 1 A variant of the static solution culture system

The method of continuous-flow solution culture (nutrient film technique - NFT) is most widespread [16, 17] since it is relatively simple, versatile and economically effective in realization (fig. 2). Thanks to constant circulation of water in NFT-installation it is more saturated with oxygen, than under using of the previous method, but such enrichment is less efficient than under impact of a compressor. This method also demands of large areas for the installation, significant expenses of time for replanting. There is possible little buffering against interruptions in the flow (power outages), water logging in some channels. Besides, under use of the NFT-technology there are limitations for maximal length of channels of the installations (12 – 15 m).

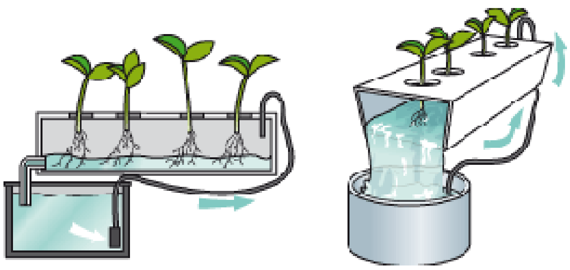


Fig. 2 A scheme of realization of the nutrient film technique (NFT)

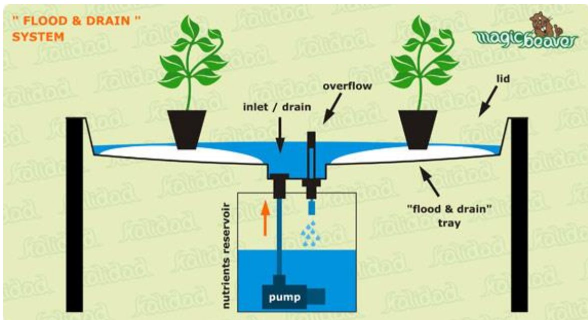
The next hydroponic method of deep water culture is also quite widespread (fig. 3) [14], but mainly for growing of lettuce because of absence of possibility of supporting for high stalks of the plants. Under realization of the method a compressor provides effective saturation of water and nutrients with air. This promotes to accelerated growth of plants. There are improved conditions for replanting, harvest and bedding of new portion of plants (these stages can be realized uninterruptedly). The main drawbacks of the method: insufficient versatility and inefficient use of area of premises where it is realized.

Fig. 3 An example of the deep water culture in lettuce production

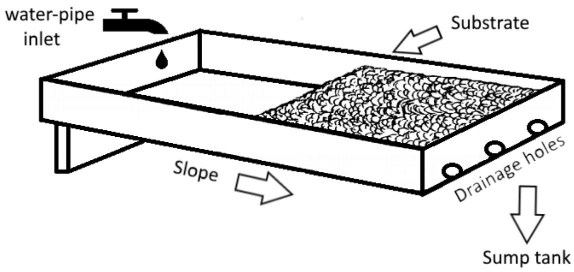
The method top-fed deep water culture has approximately the same advantages and shortcomings as the previous method, but top-fed DWC-technology is more complex and expensive in realization.

The method of passive sub-irrigation [12, 13] does not provide of intensive enough saturation of water and therefore it is used for growing of small parties of plants.

The method of flood and drain sub-irrigation (fig. 4, a) [18] and the method of run-to-waste system (fig. 4, b) [19] demand for accomplishment of a more complex equipment and do not provide of significant advantages in comparison with DWC-technology. Because of that the methods got mainly experimental using. For this moment there are absent the schemes of big industrial installation for realization of these methods.



a)



b)

Fig. 4 Schemes of a flood and drain sub-irrigation (a) and a run-to-waste system (b)

The method of a rotary system (fig. 5) [15] is used at experimental level mainly for demonstration of effect of dynamical impacts at plant's growth (periodical decrease of gravitation, increase of intensity of illumination and feeding of water and nutrients). In spite of receipt of positive results of such impacts, the method, from our point of view, has small prospects for mass industrial introduction because of complex and expensive construction of the installations.

Fig. 5 The scheme of a rotary hydroponic system

The methods of aeroponics (fig. 6) [7, 8, 9] and fogponics [10, 11] are most efficient from point of view of rational using of water and saturation of it with oxygen, but their application demands of using of ultrasonic electromagnetic vibro-exciters in construction of installations. That makes these installations quite expensive and limits their industrial using.

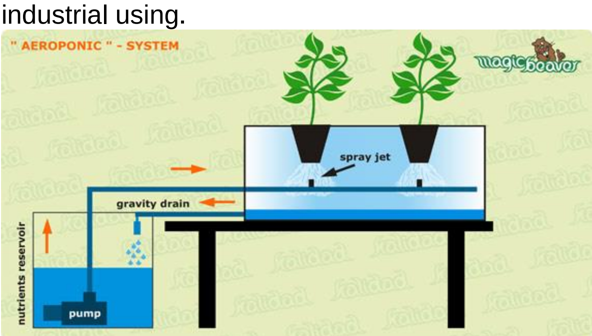


Fig. 6 The scheme of an aeroponic technique

Aim of researches. The aim of the research is elaboration of demands for high-efficient industrial hydroponic installations, working out of schemes of improved installations and formulas for definition of their main working parameters.

Main results of researches. With examination of experience of creation and operation of hydroponic installations of different types and also of results of analysis of their advantages and drawbacks there were formulated the demands for improved industrial hydroponic installations:

- maximal use of area of a premise for growing of plants;
- versatility for growing of different species of plants;
- intensive saturation of water for sprinkling and rootage of plants with oxygen;
- efficient use of water and nutrients, sufficient provision of plants with light;
- possibility of quick and convenient replanting, harvest and bedding of plants;
- possibility of support of stalks and sprouts of plants;
- simplicity, manufacturability and reliability of design of the installation, possibility of its wide industrial introduction;
- simplicity of maintenance of the installation, low operational expenses;
- stable automatic support of main working parameters of the installation.

With consideration of these demands was elaborated the scheme of the improved industrial hydroponic installation, presented at the fig. 7.

Roots 8 of plants 7 are situated in baskets 6 made from metallic net and filled with mineral nutrient solution (see also the element I at fig. 7). The baskets have cylindrical form and clamps. By the clamps the baskets are freely installed on the planks 9. The planks 9 can move in slot 5 of the drum 36. Also, the baskets 6 can move along of the planks 9 and there is possible to change this way the number of the baskets inside of the drum and distances between the nearest baskets, depending from sizes of the crops in different periods of their growth. For increase of rigidity of the drum to its upper edge are fastened the rods 24, which also connect the drum with the shaft 19. In lower part of the drum 36 are fastened the metallic nets 33, 37. At lower surface of the net 37 are installed the ventilators 10 and the lamps 34. The ventilators 10 provide intensive feeding of air to roots of the plants. There are also the lamps 35 at the ceiling. After increase of the distances between the nearest baskets empty spaces can be filled with nutrient, that is put at the net 33. The shaft 19 is installed in the thrust bearings 20, which are fastened at the celling and at the floor of the premise. There are several drums 36 at the shaft 19, depending from height of the plants and necessary conditions for care about them (see lower). The pump 13, that is drove from the electric engine 14 through the coupling 41

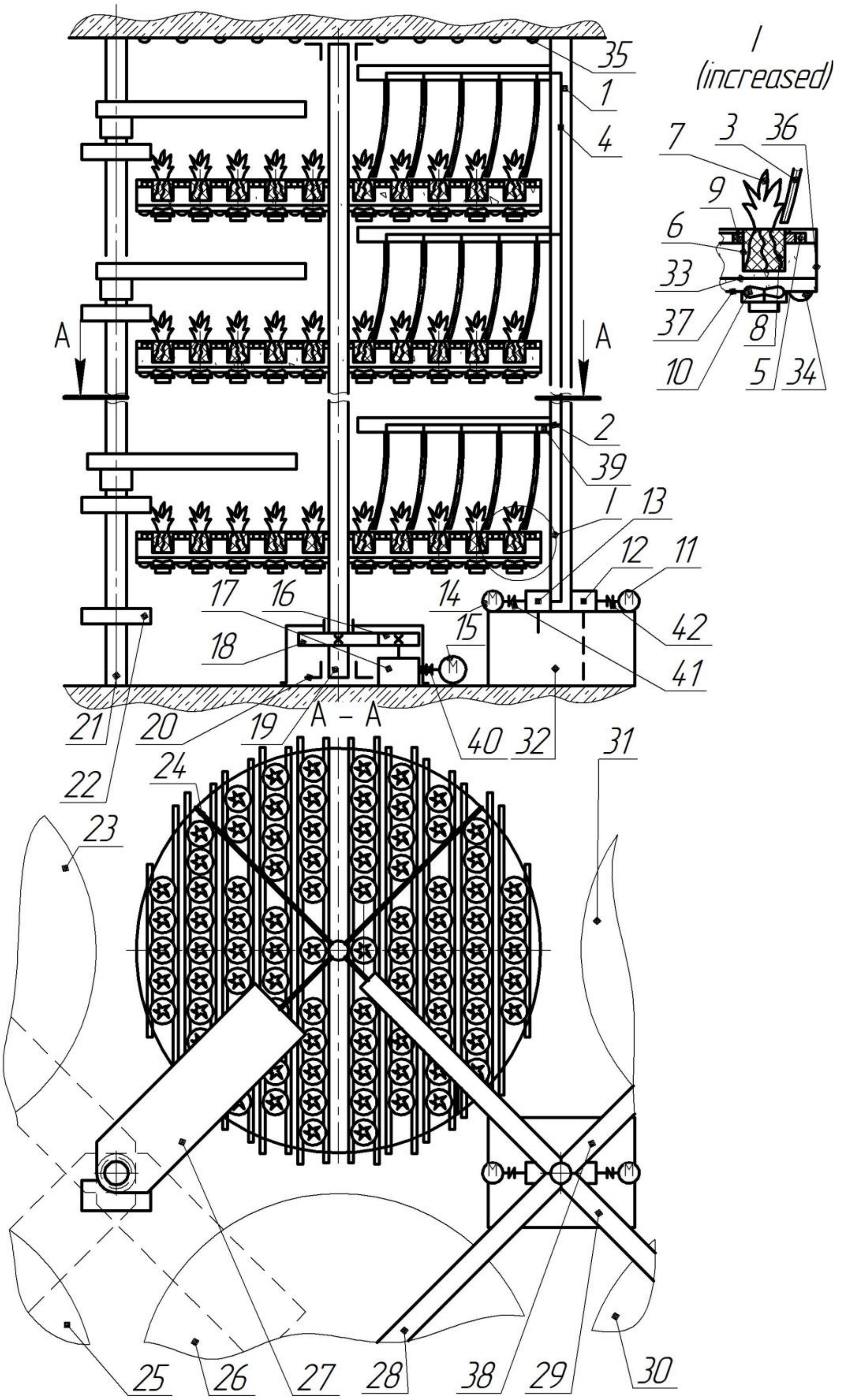


Fig. 7 The scheme of the improved industrial hydroponic installation

provides feeding of water with additions of nutrients from the tank 32. This mixture is enriched with oxygen that feeds the compressor 12 with drive from the electric engine 11 through the coupling 42. Enriched mixture goes over the hydraulic lines 4, 2 and through the flexible hoses 3 is fed to the plants 7. The hydraulic lines 4, 2 are adjusted inside of the tube 1 and the bar 39. As we can see at the cross-section A – A, the mixture from the tank 32 is fed simultaneously to four drums (36, 31, 30, 26) of the same level through the bars 28, 29, 38, 39. The hoses 3 can bend in correspondence with form and sizes of crops. For feeding of nutrient mixture to all plants of certain level the shaft 19 with drums 36 are brought into rotation from the electric engine 15, through the coupling 40, worm-and-wheel gear-box 17 and gears 16, 18. Control over periodical rotation of the shaft 19 and feeding of mixture from the tank 32 provides an automated system with help of sensors. Care for the plants of high levels (planting, change of location of baskets in course of plant's growing, harvest) is provided with help of turning shelfs 27 with steps 22, installed at the pole 21. There is anticipated that operating personal will rase by steps at the shelfs and laying at them will fulfil necessary care operations. At that each turning shelf of some level intended for care about plants of four drums (23, 25, 26, 36).

Necessary capacity of the electric engine 14 of the installation can be determined by the formula [20]

$$N_{e1} = \frac{Q_p p_p}{\eta_p \eta_{e1} \eta_{m1}}, \qquad (1)$$

where Q_p – feeding of the pump 13;

p_p – pressure in the force hydraulic line of the pump 13;

η_p, η_{e1}, η_{m1} – efficiency of the pump 13, the electric engine 14 and the coupling 41 [20].

Q_p can calculate with consideration of necessary maximal daily discharge q_p, [m^3] of enriched mixture for one plant, maximal amount n_{pd} of plants inside of one drum 36 and amount n_d of the drums at the shaft 19 by the formula, [m^3 / s]

$$Q_p = \frac{4 \cdot 1{,}3 \cdot q_p n_{pd} n_d}{24 \cdot 60 \cdot 60} = \frac{q_p n_{pd} n_d}{16615}. \qquad (2)$$

Pressure p_p can be found with consideration of losses of pressure for hydraulic friction by length in the hydraulic lines 4, 2 and in the hoses 3 and also losses in local resistances (turnings of hydraulic lines, passing of branches, exits from hydraulic lines in atmosphere). At that we are using the formula

$$p_p = \lambda_t \rho_{m.o} \frac{l_t}{d_t} \frac{v_m^2}{2} + \left[2 \cdot \varsigma_t + \varsigma_b (n_d - 1)\right] \rho_{m.o} \frac{v_m^2}{2} +$$

$$+ 4 \cdot n_d \lambda_b \rho_{m.o} \frac{l_b}{d_b} \frac{v_m^2}{2} + 4 \cdot n_d \left[\varsigma_t + \varsigma_b (n_h - 1)\right] \rho_{m.o} \frac{v_m^2}{2} +$$

$$+ 4 \cdot n_d n_h \lambda_h \rho_{m.o} \frac{l_h}{d_h} \frac{v_m^2}{2} + 4 \cdot n_d n_h \varsigma_e \rho_{m.o} \frac{v_m^2}{2} + \rho_{m.o} g \cdot H_i =$$

$$= \rho_{m.o} \frac{v_m^2}{2} \left\{ \begin{array}{l} \lambda_t \frac{l_t}{d_t} + \left[2 \cdot \varsigma_t + \varsigma_b (n_d - 1)\right] + 4 \cdot n_d \lambda_b \frac{l_b}{d_b} + \\ + 4 \cdot n_d \left[\varsigma_t + \varsigma_b (n_h - 1)\right] + 4 \cdot n_d n_h \lambda_h \frac{l_h}{d_h} + \\ + 4 \cdot n_d n_h \varsigma_e + g \cdot H_i \frac{2}{v_m^2} \end{array} \right\}, \qquad (3)$$

where λ_t, λ_b, λ_h – coefficients of hydraulic friction in hydraulic lines 4, 2 and in the hose 3 [21]; $\rho_{m.o}$ – density of using in the installation nutrient mixture with consideration of content in it of dissolved air; l_t, l_b, l_h – lengths of the hydraulic lines 4, 2 and the hose 3; d_t, d_b, d_h – diameters of the hydraulic lines 4, 2 and the hose 3; v_m – middle speed of flowing of nutrient mixture in the hydraulic system of the installation; ς_t, ς_b, ς_e – coefficients of local hydraulic resistance at the turn of a hydraulic line, at the passing of a branch and at the exit from a hose in atmosphere; H_i – general maximal height of raise of nutrient mixture to the upper hydraulic line 2.

Necessary capacity of electric engine 11 of the installation can be determined by the formula

$$N_{e1} = \frac{Q_c p_c}{\eta_c \eta_{e2} \eta_{m2}}, \qquad (4)$$

where Q_c – feeding of the compressor 12; p_c – pressure in the force pump line of the compressor 12; η_c, η_{e2}, η_{m2} – efficiency of the compressor 12, the electric engine 11 and the coupling 42.

Q_c can calculate with consideration of maximal necessary content k_a of air in enriched mixture:

$$Q_c = k_a Q_p. \qquad (5)$$

Pressure p_p can be found by the formula growing.

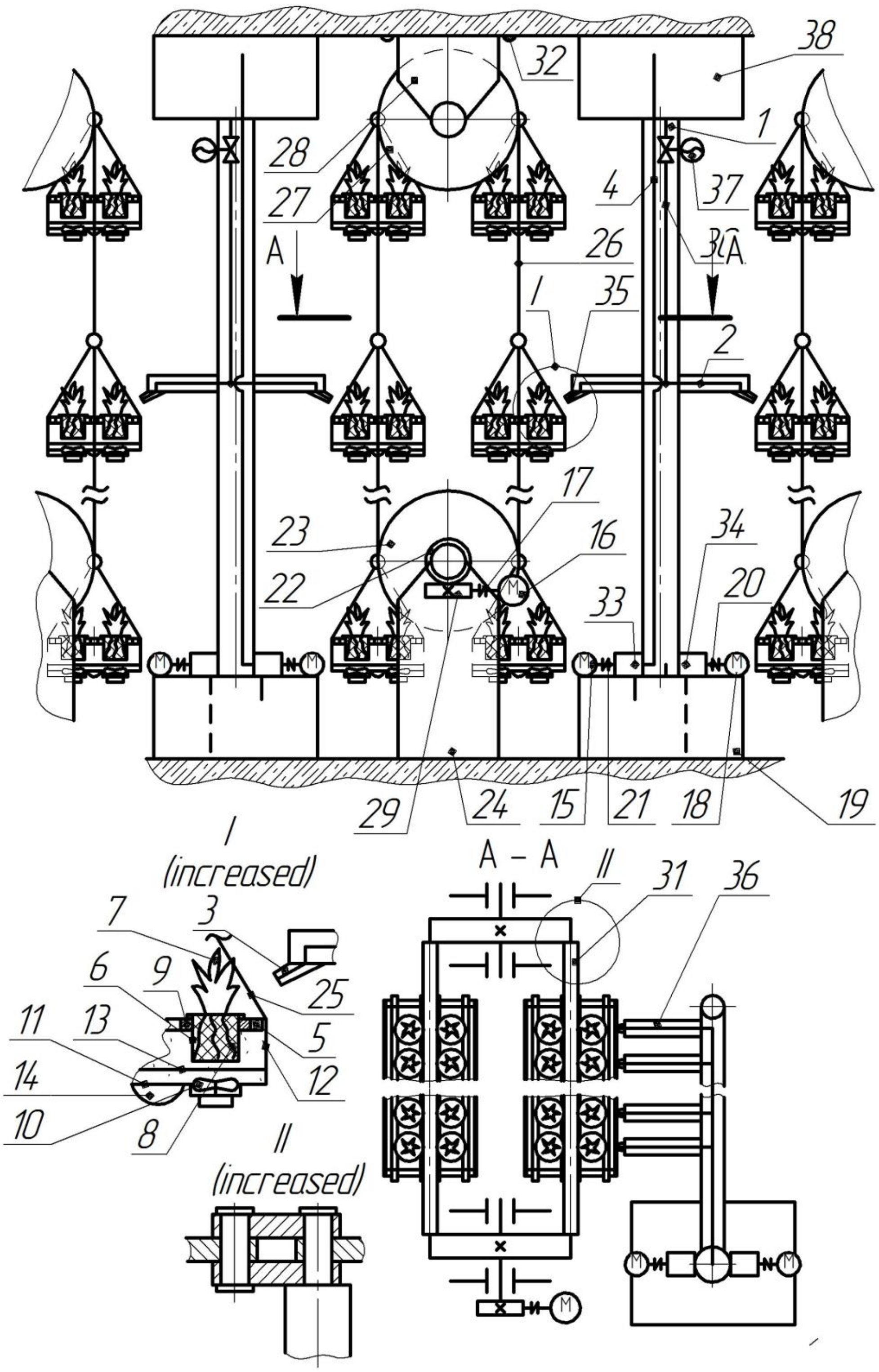


Fig. 8 The scheme of the improved industrial hydroponic installation

Chains movement provide the chain-wheels 23, 27, which are installed with help of the brackets 24, 28 at the floor and the ceiling of the premise. The chain-wheel 23 is drove from the electric engine 16 through the coupling 17 and the worm-and-worm gear 29, 22. Vertical distance between the nearest cowlings depends from dimensions of the crops, from demands of their growing and can be changed by rearrangement of the bars 31. The pump 33, that is drove from the electric engine 15 through the coupling 21 provides feeding of water with additions of nutrients from the tank 19. This mixture is enriched with oxygen that feeds the compressor 34 with a drive from the electric engine 18 through the coupling 20. With aim of increase of efficiency of the hydraulic system of the installation enriched mixture is fed from the tank 19 over the hydraulic line 4 into the collecting tank 38. After filling of the tank 38 the pump 33 is turned off. The sprinkling of plants 7 is realized from the tank 38 by command of an automated control system (it is not presented on the figure) through the tap 37 with electromagnetic control, the hydraulic lines 30, 2 and the nozzles 35. The hydraulic lines 4, 30, 2 are adjusted inside of the tubes 1, 36. As we can see at the cross-section A – A, the mixture from the tank 38 is fed simultaneously to the cowlings that fastened at two different parallel chains. So, depending from dimensions of the premise, for its most efficient using, we can place there a necessary number of the sections of the installation (corresponding to the length of the premise), with chains of optimal length (corresponding to the height of the premise) and with cowlings length that corresponds to the width of the premise. Regime of the cowlings movement and feeding of nutrient mixture is adjusted depending from specie of growing plants and controlled with help of sensors and an automated control system.

This scheme also corresponds to above formulated demands and in comparison with the previous scheme (see fig. 7) in case of its realization and using there will be provided more convenient care for the plants in the cowlings (planting, change of location of baskets in course of plant's growing, harvest).

Necessary capacity of the electric engine 15 of the installation can be determined by the formula (1), where Q_p – feeding of the pump 33; p_p – pressure in a force hydraulic line of the pump 33; η_p, η_{e1}, η_{m1} – efficiency of pump 33, electric engine 15 and coupling 21.

Q_p can calculate with consideration of maximal daily discharge q_p, [m^3] of enriched mixture for one plant, maximal amount n_{pc} of

$$p_c = p_0 + \rho_{m.o} g \cdot H_c, \qquad (6)$$

where p_0 – pressure at the surface of the mixture in the tank 32; H_c – depth of feeding of air in the tank 32.

Necessary capacity of the electric engine 15 of the installation can be determined by the formula

$$N_{e1} = M_s \omega_s \eta_{e3} \eta_{m3} \eta_r \eta_{o.t} \eta_b, \qquad (7)$$

where M_s – moment of resistance at the shaft 19; ω_p – angular velocity of rotation of the shaft 19; η_{e3}, η_{m3}, η_r, $\eta_{o.t}$, η_b – efficiency of electric engine 15, coupling 40, reducer 17, open gears 16, 18 and thrust bearings 20.

Moment M_s can calculate as

$$M_s = \frac{J_s \omega_s^2}{2}, \qquad (8)$$

where J_s – moment of inertia of the shaft 19 and connected with it elements:

$$J_s = \frac{m_s r_s^2}{2} + n_d \frac{m_d r_d^2}{2}, \qquad (9)$$

where m_s, m_d – masses of the shaft 19 and the drum 36 with all connected elements (see fig. 7).

The scheme of one more improved industrial hydroponic installation, presented at the fig. 8. Roots 6 of plants 7 are situated in baskets 6, that filled with nutrient (see also element I at the fig. 8). Clamps of the baskets 6 rest upon planks 9. The planks 9 can move in slots 5 of rectangular cowlings 12. Also, the baskets 6 can move along of planks 9 and there is possible this way to change the number of the baskets inside of cowlings and distances between the nearest baskets, depending from the sizes of crops in different periods of their growth. In the lower part of the cowlings 12 are fastened metallic nets 11, 13. At lower surface of the net 11 are installed the ventilators 10 and the lamps 14. The ventilators 10 provide intensive feeding of air to roots of plants. There are also the lamps 32 at the ceiling. After increase of distances between the nearest baskets empty spaces can be filled with nutrient, that is put at the net 13. The cowlings are suspended with help of the metallic ropes 25 at the bars 31, that connected with the chains 26 (see also cross-section A-A and element II at the fig. 8). The chains 26 provide constant or periodic movement of the cowlings 12 with the plants for their more active interaction with air and intensification of

plants inside of one cowling 12 and amount n_c of the cowlings at the chain 26 by the formula, [m^3 / s]

$$Q_p = \frac{1{,}3 \cdot q_p n_{pc} n_c}{24 \cdot 60 \cdot 60} = \frac{q_p n_{pc} n_c}{66462}. \qquad (10)$$

The pressure p_p can be found with help of the formula

$$p_p = \lambda_t \rho_{m.o} \frac{l_t}{d_t} \frac{v_m^2}{2} + (\varsigma_t + \varsigma_e) \rho_{m.o} \frac{v_m^2}{2} + \rho_{m.o} g \cdot H_i + p_{0m}, \qquad (11)$$

where λ_t – coefficient of hydraulic friction in the hydraulic line 4 [21]; l_t – length of the hydraulic line 4; d_t – diameter of the hydraulic line 4; v_m –

middle speed of flowing of nutrient mixture in the hydraulic system of the installation; ς_t, ς_e – coefficients of local hydraulic resistance at the turn of the hydraulic line 4 and at the exit from the hydraulic line 4; H_i – general maximal height of raise of nutrient mixture to the upper cross-section of the hydraulic line 2; p_{0m} – overpressure in the middle of nutrient mixture at the exit from the hydraulic line 4.

Necessary capacity of electric engine 18 of the installation can be determined by the formulas (4 - 6), where Q_c – feeding of the compressor 34; p_c – pressure in a force pump line of the compressor 34; η_c, η_{e2}, η_{m2} – efficiency of compressor 34, electric engine 18 and coupling 20; p_0 – pressure at the surface of the mixture in the tank 19; H_c – depth of feeding of air in the tank 19.

Active moment, which created by gravity of the cowlings 12 and connected with them elements from one side of the chain-wheels 23, 27 is balanced by reactive moment created by gravity of the cowlings from other side of the chain-wheels. Therefore in calculation of necessary capacity of the electric engine 16 of the installation we are considering only moment M_f of friction forces in bearings of the brackets 24, 28

$$N_{e1} = M_f \omega_{cw} \eta_{e3} \eta_{m3} \eta_{wt} \eta_b, \qquad (12)$$

where ω_{cw} – angular velocity of the chain-wheels 23, 27; η_{e3}, η_{m3}, η_{wt}, η_b – efficiency of electric engine 16, coupling 17, reducer 17, worm-and-worm gear 29, 22 and bearings of the brackets 24, 28.

The moment M_f can determine as [23]

$$M_f = F_l f_f \frac{d_s}{2}, \qquad (13)$$

where F_l – loading from gravity of the cowlings 12 and connected with them elements, which creates moment M_f; f_l – coefficient of friction in the bearings [23]; d_s – diameter of a shaft of the chain-wheels 23, 27.

The loading F_l can be found with help of the formula

$$F_l = (m_{ct} + m_c n_c) g, \qquad (14)$$

where m_{ct} – mass of chain transmission, including masses of shafts, chain-wheels, chain, worm wheel 22; m_c – mass of the cowling with all connected elements (see fig. 8).

Conclusions. 1. Hydroponics is a perspective and effective enough direction of the modern agriculture which is intensively developed and improved for decrease of necessary areas, expenses of energy, water, nutrients, increase of specified productivity at the expense of more intensive supplying of plants with air and light, increase of versatility, reliability, extent of automation and convenience in operation of equipment for realization of the technology.

2. There are several known methods of hydroponics for the moment, but for commercial and industrial use are perspective the methods of static solution culture, continuous-flow solution culture (NFT) and deep water culture. All these methods demand of improvement.

3. Authors of the article formulated the demands to the improved hydroponic equipment and on the base of them elaborated the schemes of perspective industrial hydroponic installations.

4. The formulas for definition of main parameters of elaborated installations (power of the driving electric engines, feeding of nutrient mixture, pressure in hydraulic system of the installations) are also presented in the article. On basis of these formulas there can be developed methods of design calculation of the proposed hydroponic equipment.

References

1. Heiney, A. (2004). "Farming for the Future". www.nasa.gov. Retrieved Nov 21, 2018.

2. Adelman, Jacob (2008). "Urban growers go high-tech to feed city dwellers". Newsvine. The Associated Press. Archived from the original on 2009-05-03. Retrieved Nov 21, 2018.

3. "Eurofresh Farms Adds 53-acre Greenhouse" (2007) Eurofresh Farms Press Release. Archived from the original (PDF) on July 10, 2011 – via Wayback Machine.

4. "Nature Sweet switches varieties in old EuroFresh greenhouses" (2013). Archived from the original on April 7, 2018. Retrieved Apr 6, 2018.

5. Schaefer, Karen (2017). "Canadian greenhouse industry seeks methods to reduce pollution into Lake Erie". Marketplace.org. Marketplace.org. Retrieved 17 January 2017.

6. Wood, Laura (2017). "Global Hydroponics Market Report 2017-2023 - Research and Markets". Business Wire. Berkshire Hathaway. Retrieved Apr 1, 2018.

7. "Commercial Aeroponics: The Grow Anywhere Story" (2008). In Vitro Report. Research News. The Society for In Vitro Biology. 44 (2). Archived from the original on 2017-01-31. Retrieved 2018-11-22.

8. NASA (2006). "Progressive Plant Growing Has Business Blooming" (PDF). 2006 Spinoff. NASA Center for AeroSpace Information (CASI): 64–67.

9. Ritter, E.; Angulo, B.; Riga, P.; Herrán, C.; Relloso, J.; San Jose, M. (2001). "Comparison of hydroponic and aeroponic cultivation systems for the production of potato minitubers". Potato Research. 44 (2): 127–135.

10. Elliott, S. (2016). "Figuring Out Fogponics". Maximum Yield. Retrieved Mar 15, 2017.

11. "DIY Fogponics". Garden Culture Magazine (2016). Retrieved Mar 15, 2017.

12. "What is Hydroculture?" (2018). Greens Hydroponics. Archived from the original. Retrieved Nov 22, 2018.

13. Barbosa, G.; Gadelha, F.; Kublik, N.; Proctor, A.; Reichelm, L.; Weissinger, E.; Wohlleb, G.; Halden, R.; Barbosa, G. L. (2015). "Comparison of Land, Water, and Energy Requirements of Lettuce Grown Using Hydroponic vs. Conventional Agricultural Methods". Int. J. Environ. Res. Public Health. MDPI. 12 (6): 6879–6891.

14. "Deep Water Culture" (2010). GroWell Hydroponics & Plant Lighting. Archived from the original on April 13, 2010.

15. Sky Green (2016). "Commercial Vertical Farming Initiatives" (PDF). MVO Netherland. Archived from the original (PDF) on May 9, 2018. Retrieved Nov 22, 2018.

16. "Nutrient Film Technique" (2018). *www.flairform.com. Archived from* the original *on 2018-04-16*. Retrieved Nov 22, 2018*.*

17. "What are the fundamentals of setting up an NFT system?" (2014). *Practical Hydroponics & Greenhouses. Casper Publications (148). Oct 2014. Archived from* the original *on 2017-09-04*. Retrieved 2017-05-16 *– via* Wayback Machine*.*

18*.* "Flood and Drain or Ebb and Flow" (2013). *www.makehydroponics.com. Archived from* the original *on 2013-02-17*. Retrieved 2013-05-17*.*

19*.* "Frequently Asked Questions" (2011). *Newagehydro.com*. Retrieved 2011-09-20*.*

20. Sevostianov, I. (2021) Protsesy ta obladnannia dlia vibroudarnoho filtruvannia volohykh dyspersnykh seredovyshch : monohrafiia [Processes and equipment for vibro-blowing filtering of damp dispersive mediums: monograph]. Vinnytsia : VNAU, 2021. 184 p. ISBN 978-966-949-795-6 [in Ukrainian].

21. Sevostianov, I. (2020) Technologia ta obladnannia dlia vibroudarnoho znevodnennya volohykh dyspersnykh materialiv : monohrafiia [Technology and equipment for vibro-blowing dehydration of damp dispersive materials: monograph]. Vinnytsia : VNAU. ISBN 978-617-7789-16-0 [in Ukrainian].

22. Iskovych-Lototskyi, R. D., Obertiukh, R. R., Sevostianov, I. V. (2006) Protsesy ta mashyny vibratsiinykh i vibroudarnykh tekhnolohii. Monohrafiia [Processes and machines of vibration and vibro-blowing technologies: monograph]. Vinnytsia: UNIVERSUM. Vinnytsia [in Ukrainian].

23. Tsurkan, O.V., Polievoda, Yu. A, Sosnovska, L.V., Prysiazhniuk, D.V. (2018) Metodychni vkazivky dlia vykonannia laboratornykh robit z navchalnoi dystsypliny "Detali mashyny ta osnovy konstruiuvannia" dlia studentiv napriamu pidhotovky 6.100102 "Protsesy, mashyny ta obladnannia ahropromyslovoho vyrobnytstva" dennoi formy navchannia [Methodical instructions for laboratory work in the discipline "Machine parts and basics of design"]. Vinnytsia: VTs VNAU [in Ukrainian].

РОЗРОБКА ВДОСКОНАЛЕНИХ ГІДРОПОННИХ УСТАНОВОК

Гідропоніка - перспективний напрямок розвитку сучасного сільського господарства, що забезпечує цілорічне вирощування основних культур овочів та зелені на невеликих площах і з мінімальними витратами води та добрив. Ця технологія дозволяє отримувати чималі врожаї свіжих овочів у великих містах, включаючи офісні та житлові приміщення.

Останнім часом велика увага підприємців та винахідників приділяється розробці нових більш ефективних методів гідропоніки і обладнання для їх реалізації в напрямку зменшення використаних площ, економії води, поживних речовин та збільшення подачі повітря і врожайності.

Існує кілька відомих методів гідропоніки: культивування в статичному розчині, культивування в безперервному потоці (NFT), глибоководне культивування, пасивне додаткове зрошення полів, метод затоплення та дренажу, система безповоротних стоків, глибоководне культивування з підживленням, поворотна система, аеропоніка, туманопоніка. Комерційне та промислове використання отримали перші три з перерахованих вище методів. При цьому метод культивування в статичному розчині не забезпечує необхідного насичення коренів рослин повітрям. При реалізації методу проточного культивування розчину можливі невелика буферизація внаслідок перебоїв потоку (при відключенні електроенергії), замулювання деяких каналів, крім того, існують обмеження на максимальну довжину каналів (12 – 15 м). Метод глибоководного культивування в промислових масштабах використовується в основному для вирощування салату. Решта згаданих методів недостатньо ефективні з точки зору комерційного використання.

Представлені в статті вдосконалені гідропонні установки розроблені з урахуванням таких вимог: універсальність використання (можливість вирощування різних культур рослин), гармонійне оптимальне забезпечення сільськогосподарських культур водою, поживними речовинами, світлом та повітрям, максимальне використання площі приміщення, можливості пересадки в період зростання, збільшення площі

під кожну рослину та створення опори для її стебла та побігів. Також в статті наведені формули для визначення основних параметрів розроблених установок.

Ключові слова: *гідропоніка, промислова установка, універсальність, оптимальне забезпечення, ефективне використання простору.*

РАЗРАБОТКА УСОВЕРШЕНСТВОВАННЫХ ГИДРОПОННЫХ УСТАНОВОК

Гидропоника - перспективное направление развития современного сельского хозяйства, обеспечивающее круглодичное выращивание основных культур овощей и зелени на небольших площадях и с минимальными затратами воды и удобрений. Эта технология позволяет получать достаточно большие урожаи свежих овощей в крупных городах, включая офисные и жилые помещения. В последнее время большое внимание предприниматели и изобретатели уделяют разработке новых более эффективных методов гидропоники и оборудования для их реализации в направлении уменьшения использованных площадей, экономии воды, питательных веществ и увеличения притока воздуха и урожайности.

Существует несколько известных методов гидропоники: культивирование в статичном растворе, культивирование в непрерывном потоке (NFT), глубоководное культивирование, пассивное дополнительное орошение, полив с затоплением и дренажем, система безвозвратных стоков, глубоководная культура с подпиткой, поворотная система, аэропоника, туманопоника. Коммерческое и промышленное использование получили первые три из вышеперечисленных методов. При этом метод культивирования в статичном растворе не обеспечивает необходимого насыщения корней растений воздухом. При реализации метода проточного культивирования раствора возможны небольшая буферизация вследствие перебоев потока (при отключении электроэнергии), заболачивание некоторых каналов, кроме того, существуют ограничения на максимальную длину каналов (12-15 м). Метод глубоководного культивирования в промышленных масштабах используется в основном для выращивания салата. Остальные упомянутые методы недостаточно эффективны с точки зрения коммерческого использования.

Представленные в статье усовершенствованные гидропонные установки разработаны с учетом таких требований: универсальность использования (возможность выращивания различных видов растений), гармоничное оптимальное обеспечение сельскохозяйственных культур водой, питательными веществами, светом и воздухом, максимальное использование площади помещения, возможность пересадки в период роста, увеличения площади под каждое растение и создания опоры для его стебля и побегов. Также в статье представлены формулы для определения основных параметров разработанных установок.

Ключевые слова: *гидропоника, промышленная установка, универсальность, оптимальное обеспечение, эффективное использование пространства*.

Відомості про авторів

Sevostyanov Ivan – Doctor of Technical Sciences, Full Professor of the Department "Technological Processes and Equipment of Processing and Food Productions" of Vinnytsia National Agrarian University (Solniachna St., 3, Vinnytsia, 21008, Ukraine, e-mail: ivansev70@gmail.com).
Melnik Oleksandr – Post-Graduate Student of Vinnytsia National Agrarian University (Solniachna str., 3, Vinnytsia, Ukraine, 21008, e-mail: millermanel@gmail.com).

Севостьянов Іван Вячеславович – доктор технічних наук, завідувач кафедри «Технологічних процесів та обладнання переробних і харчових виробництв» Вінницького національного аграрного університету (вул. Сонячна, 3, м. Вінниця, 21008, Україна, e-mail: ivansev70@gmail.com).
Мельник Олександр Сергійович – аспірант Вінницького національного аграрного університету (вул. Сонячна, 3, м. Вінниця, Україна, 21008, e-mail: millermanel@gmail.com)

Севостьянов Иван Вячеславович – доктор технических наук, профессор кафедры «Технологических процессов и оборудования перерабатывающих и пищевых производств» Винницкого национального аграрного университета (ул. Солнечная, 3, г. Винница, 21008, Украина, e-mail: ivansev70@gmail.com).
Мельник Александр Сергеевич – аспирант Винницкого национального аграрного университета (ул. Солнечная, 3, г.. Винница, Украина, 21008, email: millermanel@gmail.com)