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. 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.
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.

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.

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 shelves 27 with steps 22, installed at the pole 21. There is anticipated that operating personal will raise by steps at the shelves and laying at them will fulfill necessary care operations. At that each turning shell 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]

$$N_{el} = \frac{Q_p \rho_p}{\eta_p \eta_{el} \eta_{m1}},$$  \hspace{1cm} (1)

where $Q_p$ – feeding of the pump 13; $\rho_p$ – pressure in the force hydraulic line of the pump 13; $\eta_p$, $\eta_{el}$, $\eta_{m1}$ – 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 $q_m$ [m$^3$/s] 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]

$$Q_p = \frac{4 \cdot 1.3 \cdot q_m n_{pd} n_d}{24 \cdot 60 \cdot 60} = \frac{q_m n_{pd} n_d}{16615}. \hspace{1cm} (2)$$

Pressure $\rho_p$ 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

$$\rho_p = \lambda_p \rho_m \frac{l_v v_m^2}{d_i^2} + \left[2 \cdot \zeta_1 + \zeta_0 (n_d - 1)\right] \rho_m \frac{v_m^2}{2} + 4 \cdot n_d \lambda_b \rho_m \frac{l_b v_b^2}{d_b^2} + 4 \cdot n_d n_h \lambda_h \rho_m \frac{v_m^2}{2} + \rho_{ma} g \cdot H_i =$$

$$= \rho_m \frac{v_m^2}{2} + 4 \cdot n_d n_h \lambda_h \rho_m \frac{l_h v_h^2}{d_h^2} + 4 \cdot n_d n_h \lambda_h \rho_m \frac{l_h v_h^2}{d_h^2}, \hspace{1cm} (3)$$

where $\lambda_p$, $\lambda_b$, $\lambda_h$ – coefficients of hydraulic friction in hydraulic lines 4, 2 and in the hose 3 [21]; $\rho_{ma}$ – density of the mixture 3; $L_i$, $l_b$, $l_h$ – lengths of the lines 4, 2 and the hose 3; $d_i$, $d_h$, $d_b$ – 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; $\zeta_0$, $\zeta_1$, $\zeta_2$ – 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 atmostphere; $H_i$ – 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

$$N_{el} = \frac{Q_c \rho_c}{\eta_c \eta_{el} \eta_{m2}}, \hspace{1cm} (4)$$

where $Q_c$ – feeding of the compressor 12; $\rho_c$ – pressure in the pump line of the compressor 12; $\eta_c$, $\eta_{el}$, $\eta_{m2}$ – 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:

$$Q_c = k_a Q_p. \hspace{1cm} (5)$$

Pressure $\rho_p$ can be found by the formula
Fig. 8 The scheme of the improved industrial hydroponic installation

growing. 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; \( \eta_p \), \( \eta_{t1} \), \( \eta_{t1} \) – efficiency of pump 33, electric engine 15 and coupling 21.

\[
Q_p = \rho_p \eta_p \eta_t \eta_m \eta_{t2} \rho_0 \cdot \rho_{m,\text{g}} \cdot H_c ,
\]

where \( \rho_0 \) – 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

\[
N_{e2} = M_0 \omega_0 \eta_0 \eta_{t3} \eta_m \eta_{t4} \rho_0 ,
\]

where \( M_0 \) – moment of resistance at the shaft 19; \( \omega_0 \) – angular velocity of rotation of the shaft 19; \( \eta_0 \), \( \eta_{t3} \), \( \eta_m \), \( \eta_{t4} \), \( \eta_0 \) – efficiency of electric engine 15, coupling 40, reducer 17, open gears 16, 18 and thrust bearings 20.

Moment \( M_0 \) can calculate as

\[
M_0 = \frac{J_0 \omega_0^2}{2} ,
\]

where \( J_0 \) – moment of inertia of the shaft 19

\[
J_0 = \frac{m_d r_s^2}{2} + n_d \frac{m_f r_f^2}{2} ,
\]

where \( m_d \), \( m_f \) – 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 1 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 \( n_k \) of the cowlings at the chain 26 by the formula, [m³ / s]

\[
Q_p = \frac{l_3 \cdot q \cdot n_k \cdot n_p}{4 \cdot 0.6 \cdot 0.6} = \frac{q \cdot n_k \cdot n_p}{66462} .
\]

The pressure \( p_p \) can be found with help of the formula

\[
p_p = \frac{l_t \rho_{m,\text{g}} v_t^2}{4} + (z_1 + z_2) \rho_{m,\text{g}} \frac{v_s^2}{2} + \rho_{m,\text{g}} \cdot H_c + \rho_{m,\text{g}} .
\]

where \( l_t \) – 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; \( \rho_{m,\text{g}} \) –
middle speed of flowing of nutrient mixture in the hydraulic system of the installation; \( z_b \) – coefficients of local hydraulic resistance at the turn of the hydraulic line 4 and at the exit from the hydraulic line 4; \( H_c \) – general maximal height of raise of nutrient mixture to the upper cross-section of the hydraulic line 4; \( \rho_0 \) – 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 \( Q_0 \) – feeding of the compressor 34; \( \rho_0 \) – pressure in a force pump line of the compressor 34; \( \eta_{c0}, \eta_{e0}, \eta_{m2} \) – efficiency of compressor 34, electric engine 18 and coupling 20; \( \rho_0 \) – 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 \( M \) of friction forces in bearings of the brackets 24, 28

\[
N_{ef} = M_e \omega_{cw} \eta_{e0} \eta_{m2} \eta_{at} \eta_{b0},
\]

where \( \omega_{cw} \) – angular velocity of the chain-wheels 23, 27; \( \eta_{e0}, \eta_{m2}, \eta_{at}, \eta_{b0} \) – efficiency of electric engine 16, coupling 17, reducer 17, worm-and-worm gear 29, 22 and bearings of the brackets 24, 28.

The moment \( M \) can be determine as [23]

\[
M_e = F_l \frac{d_s}{2},
\]

where \( F_l \) – loading from gravity of the cowlings 12 and connected with them elements, which creates moment \( M \); \( \eta_{b0} \) – 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

\[
F_l = (m_{t2} + m_c n_c) g,
\]

where \( m_{t2} \) – 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.

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РОЗРОБКА ВДОСКОНАЛЕННИХ 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 свіхих овоців 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 врожайність.

Існує кілька відомих методів гідропоніки: культивування в статичному розчині, культивування в безперервному потоці (NFT), глибоководне культивування, пасивне додаткове зрошення підживлення, 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 розчин можлив невелика буферізація внаслідок перебоїв потоку (при відключені 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 ефективних з точки зору комерційного використання.

Представлена в статті вдосконалені гідропонні установи 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 площи приміщення, можливість пересадки в період зростання, збільшення площі
Під кожну рослину та створення опори для її стебла та побігів. Також в статті наведені формулі 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 круглогодичное 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: культурирование в статичном растворе, культурирование в непрерывном потоке (NFT), глубоководное культурирование, пассивное дополнительное орошение, полив с затоплением и дренажем, система безвозвратных стоков, глубоководная культура с подпитьей, повторная система, аэропоника, туманопоника. Коммерческое и промышленное использование получили первые три из вышеуперечисленных методов. При этом метод культурирования в статичном растворе не обеспечивает необходимого насыщения корней растений воздухом. При реализации метода проточного культурирования 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 культурирования 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, універсальність, оптимальное обеспечение, ефективне использование пространства.

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