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NEW PRINCIPLES OF CULTIVATION OF AGRICULTURAL CROPS ON THE BASIS OF MODULAR ROTARY CONVEYOR HYDROPONIC SYSTEMS *

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NEW PRINCIPLES OF CULTIVATION OF AGRICULTURAL CROPS ON THE BASIS OF MODULAR ROTARY CONVEYOR HYDROPONIC SYSTEMS

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The reproduction of different kinds of biomass which are the principal sources of food and raw material necessary for the life of people is actually one of the most important problems of global character. This reproduction is developing mainly on the surface of the earth and close to it, in a very thin layer which was defined by the Russian famous scientist V.I. Vernadsky as "pellicle of life". This "pellicle of life" means the soil, vegetation, animals of the land and the plankton surface layer of the ocean.

The reproduction of the vegetable biomass is the result of the natural process-photosynthesis on the basis of radiation energy absorption and carbon-oxygen-hydrogen exchange.

This nautral process has been already used by the man during many millenia since the times when he began to change his nomadic way of life for the settled one with the aim to obtain maximum quantities of the vegetable biomass-agricultural crops.

The historical facts show that people since the ancient times have been studying and developing the agricultural science in an effort to improve the yields.

Some very interesting information and separate facts on agronomy have come to us from the works of the ancient authors like Varron, Vergilius, Cato, Columella, Mago, Plinius.

In the Middle Ages same scientists tried already to systematize the agricultural agronomic knowledge.

The French scientist B.Pamisy (1510-1589) in his study "Scientific treatise on different soils (salts) in agriculture" for the first time defines a concept of the soil/water combination as a source of feeding of the plants with mineral elements.

The English chemist D.Priestly (1733-1804) and Dutch botanist J.Ingengus (1739-1799) discovered that the plants exposed to the light decompose the carbonic acid gas (CO_2) absorb the carbon and release the oxygen. The Swiss J.Cenebier (1742-1809) and T.Sossure (1767-1845) proved experimentally and gave a full description of the process of the plants feeding.

The discoveries made by the German scientist Liebich (1803-1873) and French Boussengot (1802-1887) laid the foundations of the modern agrochemical science about the feeding of the plants.

They have discovered that for the vital functions of the plants such elements as nitrogen, phosphorus, potassium, magnesium, ferrum, oxygen, arsenicum and others are needed; they have also studied the processes of assimilation of these elements by the plants.

The vegetable biomass production on artificial substrates (without soil) has become possible only as a result of important achievements in the domain of soil-science, plants physiology and agrochemistry because for this purpose it is necessary to know the whole delicate vegetation process, to be able to reproduce artificial optimum conditions for plants growth.

The German scientists Knopp and J.Sax (1832-1897), first, in 1859-1861 succeeded in growing plants from seed to seed on water salt solutions.

An important contribution in the biotechnology of plants growing on artificial substrates was made by the Russian scientsts D.Mendeleev, K.Timiriazev, D.Prianishnikov, V.Dokuchaev and others.

In the 30ties of XX century as a result of numerous laboratory experiments by Ellis, Sowpay, Turner, Henry, Lory, W.Gericke, V.Archikhovsky, V.Chesnokov, N.Rodnikov an idea has appeared of using the nutrient salt water solutions for plants growing on industrial basis. At the same time W.Gericke defined this biotechnology by the term "hydroponics" (translated literally it means "work with water").

During his experiments Gericke collected up to 60 kg/m^2 of tomatoes for one year, thus demonstrating that the hydroponics may fully compete with the conventional method of growing plants in the soil. However, during the following decades the investigations on hydroponics were carried out by separate and small groups of enthusiastic scientists without necessary analysis and conclusions on the efficiency of the new biotechnology. Only in the 60-s an international working group on the soilless growing of plants has been organized which nowadays coordinates the efforts of the scientists of more than 40 countries.

In the course of development of the soilless plants growing different methods of this technology have appeared. In fig. 1 a classification of these principal methods is given and on the fig. 2-6 different methods of nutrient solutions supply are shown.

During the investigations on the hydroponics technologies it has become evident that besides a simple supply of nutrient solution to the root system the environmental factors play an important role for the plant vegetation.

A constant and accurate control and regulation especially are necessary to:

- meter and mix precisely the nutrient solution components, by means of maintaining of pH and conductivity EC parameters within given limits;
- maintain optimal temperature of the nutrient solution supplied to the plants;
- oxygenate the nutrient solution;
- homogenize (prevent sedimentation) the nutrient solution;
- supply the nutrient solution to the root system of the plants with regulated intervals during the light phase;
- maintain optimal and uniform temperature of both the root system and leaf surface of the plants;
- maintain the humidity parameters within the cultivation house;
- maintain the gas composition (concentration of CO_2) of the plant environmental atmosphere etc.

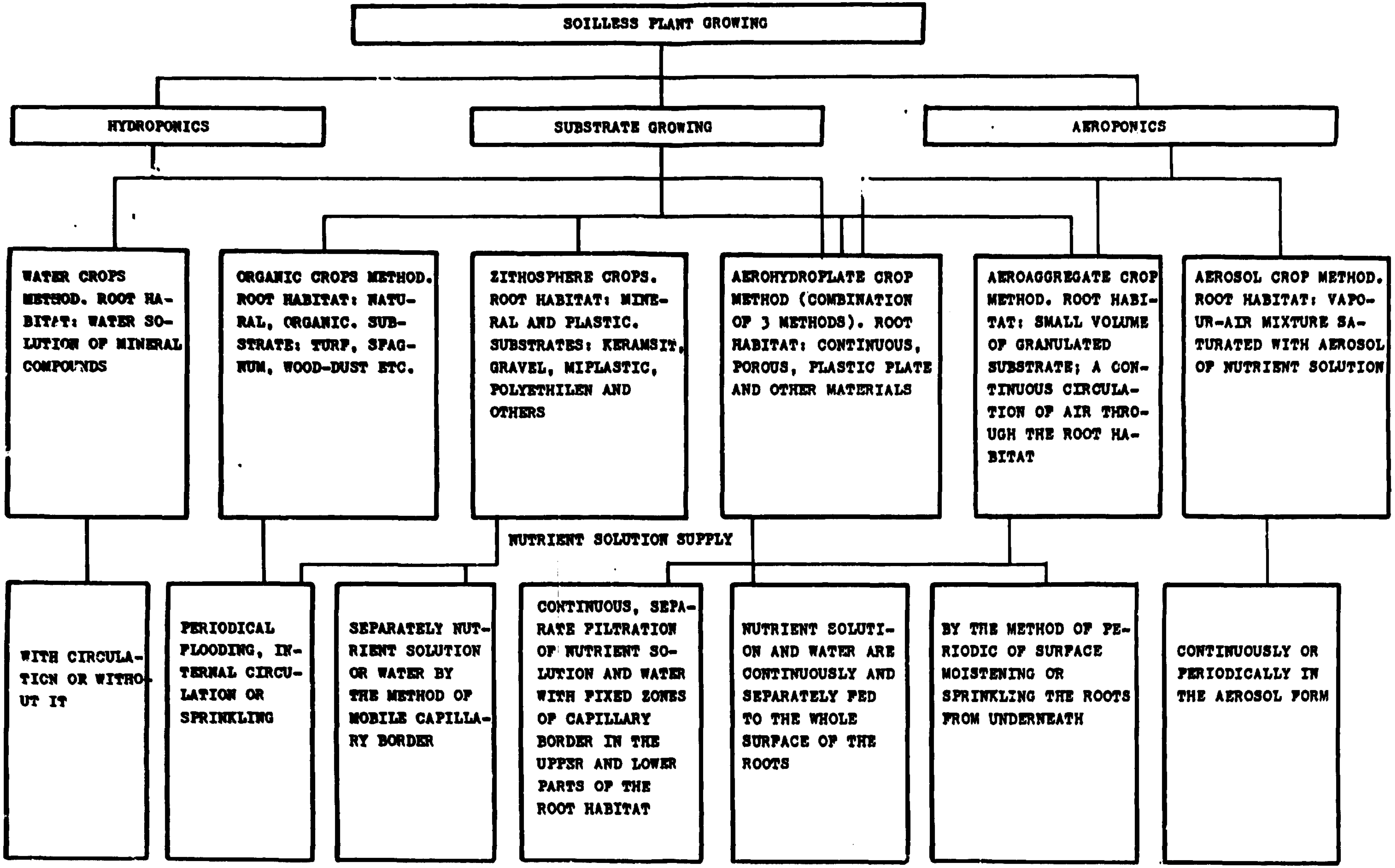


FIG. 1. CLASSIFICATION OF THE METHODS OF SOILLESS PLANT GROWING

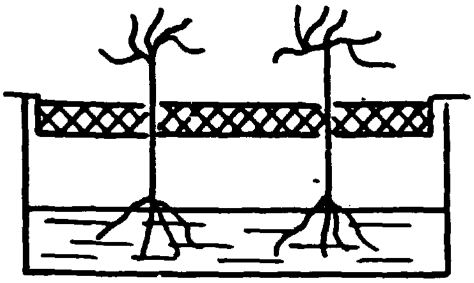


Fig. 2. Water crop method

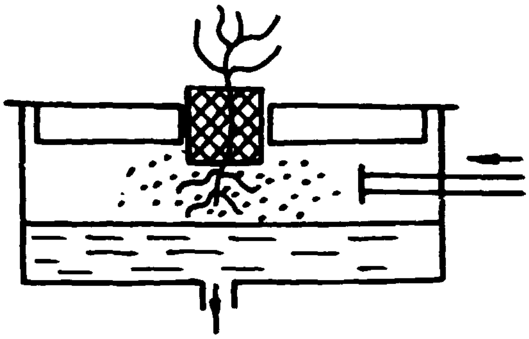


Fig. 3. Air crop method

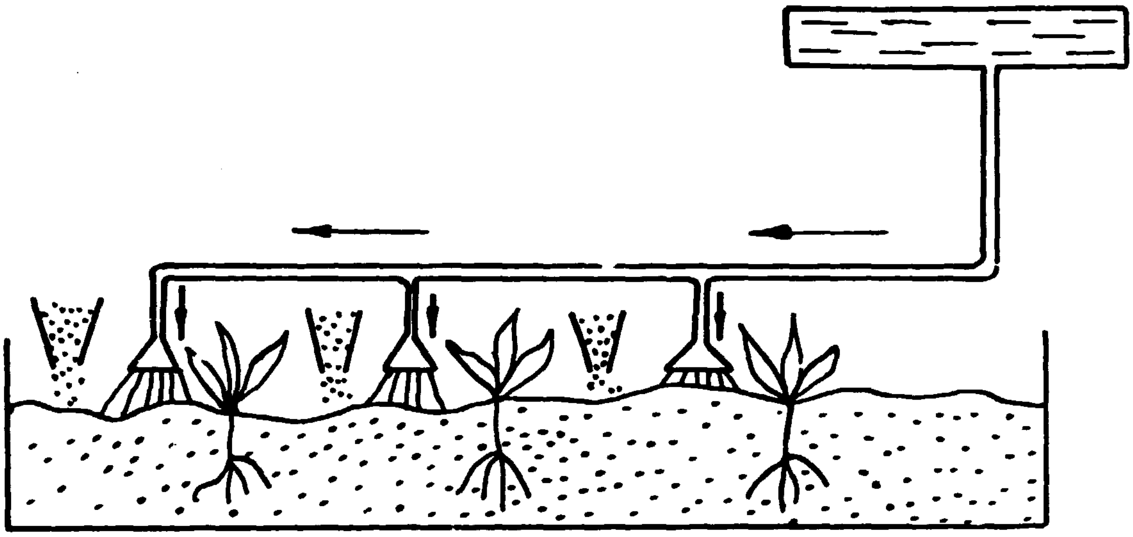


Fig. 4. Sprinkler (bengalese) method

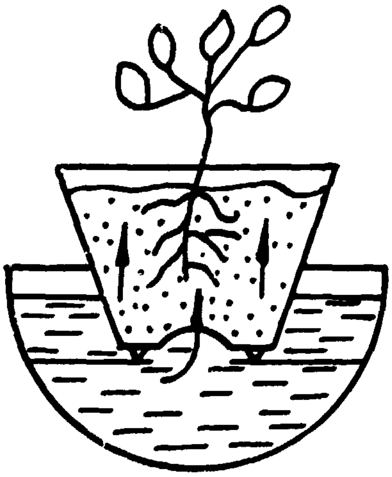


Fig. 5. Capillar method

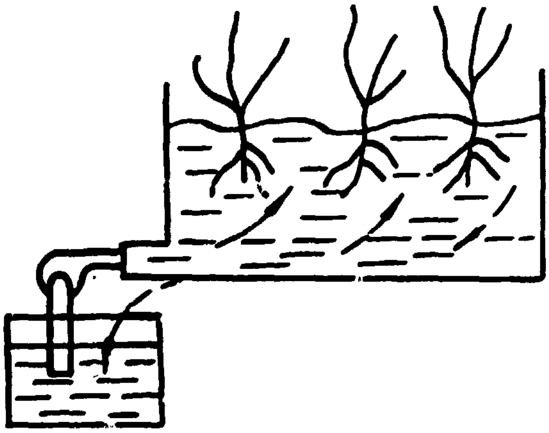


Fig. 6. Subirrigation method

The maintenance of these factors, within optimal limits especially in artificial condifions, is a complicated technical problem solved by engineering thought.

At present, there exist not only laboratories but experimental industrial plants as well, in which all the vital factors for the plants growth are created and regulated by the man and these factors allow to produce any vegetables in necessary (programmed) quantities.

For a long fime it was beleived that when growing plants in artificial conditions the major limiting factor is light. But as modern artificial light sources were created this problem ceased to be a stumbling block. Numerous experiments show, that in the conditions of artificial lighting, controlled by an operator, it is possible to collect fabulous crop of vegetable production, according to M.S. Moshkov data, more than 1 mln. kgs from 1 ha.

In the process of centuries of accomulation of agricultural experience the man was creating necessary implements, constanly improving and developing them, transforming them into mechanized, then automated and, at last, robotized means of production. At the same time, in the course of improvement of agricultural techniques the man has come to the idea of protecting the plants from the unwanted influence of the environmental media, and, in the long run, to the idea of building the protected ground cultivation houses. Even in the ancient Rome the cucumbers were grown in the bulk soil on the carts which were then sheltered into the caves for nighttime. Later the primitive types of protected ground appeared, such as different fences, field-protecting forest-plantations, beds with biological heating, covered with mats.

With the appearance of the translucent materials (mica, glass) a so-called "greenhouse effect" was discovered and used to grow the plants in the simplest cultivating green houses.

In this way as a result of centuries of development the modern cultivating facilities and agricultural techniques for the protected ground cultivation have been created which allow to put this agricultural sector, and the hydroponics in particular, on industrial basis.

The existing cultivating houses are of very different nomenclature and are provided with complicated engineering facilities. The technologies which allow to cultivate in these hothouses practically all the plants growing in open ground are also very different.

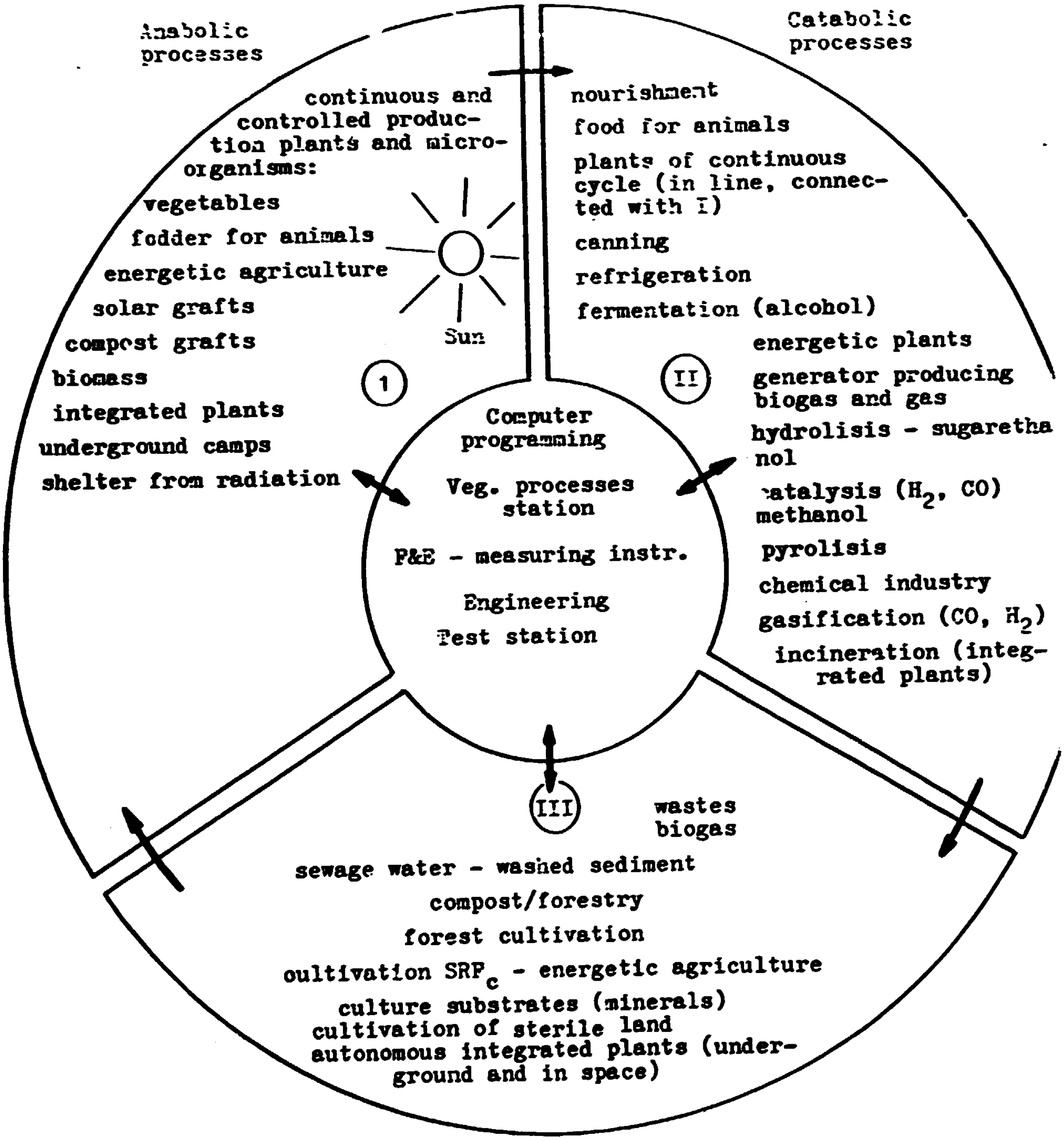
In order to mechanize all the principal labour-consuming operations in the technological processes special systems (complexes) of machines have been created marking the beginning of industrialization of the plant growing in protected soil.

The second stage of industrialization has begun from the moment of design and introduction of automated means into the conventional glasshouses. The further introduction of the manipulators and robots in the technological processes might be a top of industrialization of the protected soil but the strict geometry of the traditional glasshouses put limits to the possibilities of mechanization, automation and intensification of the technological processes. Besides, a rapid rate of increase of population and urbanization in the world lead to a steady reduction of agricultural cultivating areas and worsten the ecological situation. In this connection, the problem of creation of new, ecologically pure (isolated, wasteless) principles of reproduction of necessary vegetable biomass, in particular agricultural production, is becoming of vital importance.

One of the principles of integrated biotechnology, called phytotechnology, is shown in fig. 7, 8 and 9.

Within the framework of this phytotechnology which uses all the achievements of modern science and technics it is possible to ensure a continuous, autonomous, almost independent from the outside world process of growing of the vegetable production in any quantities per unit of time. The phytotechnology covers three major spheres.

1. Anabolic synthesis, which means the transformation of non-organic substances with the aid of plants and light from different energy sources into the organic, with high



P&Z - research and development

SRF_c - dwarf forest plantations (controlled)

Re-circulation (turnover) (energy and raw material)

Fig. 7. Integrated biotechnology (phytotechnology) by Ruthner

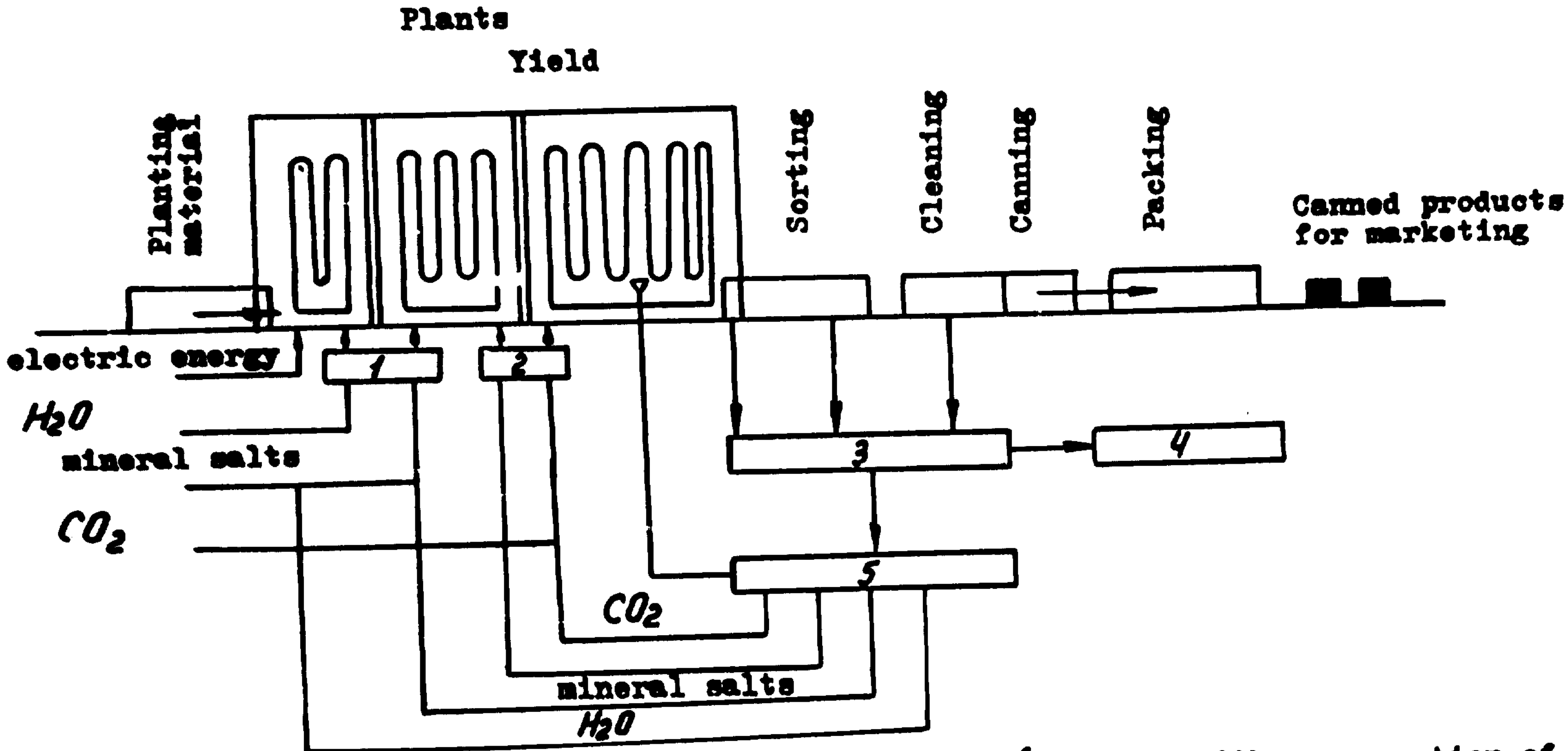


Fig. 8. Continuous production of foodstuff by Ruthner's method with recuperation of vegetable residues functioning along the circuit: planting material - plants - fruits - canned food;

1 - nutrient solution; 2 - climate; 3 - recirculation; 4 - fermentation (protein); 5 - incineration

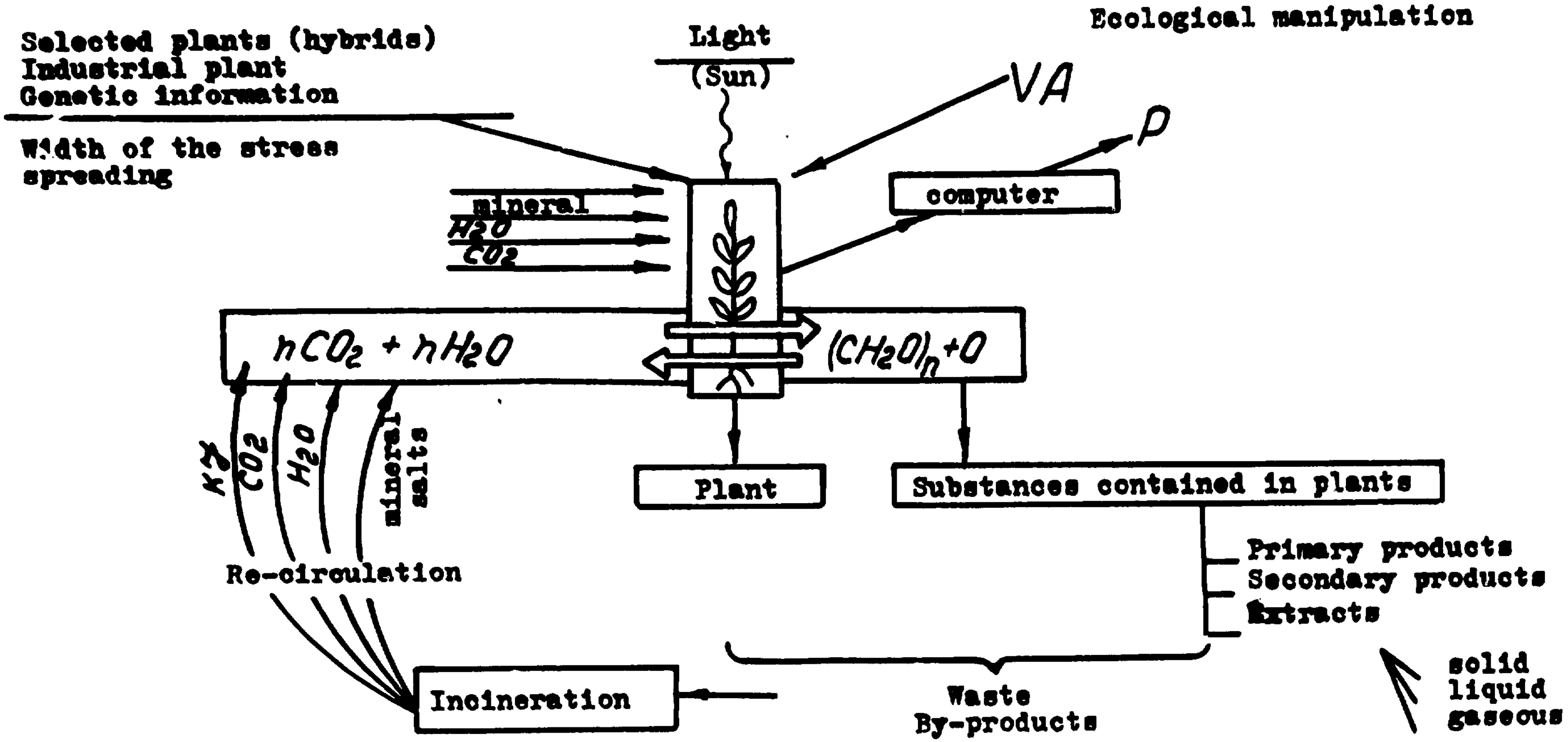


Fig. 9. Phytotechnology principle (industrial plant growing)

energetic potential. At the same time the output organic substances will be created which will be used for further purposes, in such a way that:

II. Catabolic processes will join directly to them. This will solve the problem of future food for men and animals as well as of storage of raw material and energy on big scale.

III. Turnover engulfes all the wastes from the I and II in any aggregate form (gas, liquid and solid) and leads to the secondary use of the raw material of organic and non-organic origin formed as a result of anabolic and catabolic processes.

The industrial plant growing operates on a continuous principle and, to a large degree, independently of its location and environmental media (fig. 8).

The plants are grown in a completely light - and gas-proof, isolated from outside world system. After the initial phase the continuously forming products may be transformed and the wastes produced therefrom, may be re-circulated and used once more for cultivation.

Unlike the traditional agricultural production where the plants are fixed invariably in the soil which allow them during the whole year not to pay attention to the location and season of the year of the corresponding natural climate in the industrial plant growing the optimal climate is created for different cultivation rooms and due to this factor the plants are forced to move continuously.

In this way, the industrial plant growing requires a universal mentality and therefore may be characterized as more "continuous" and, consequently, more general than simply "phytotechnology" (according to Ruthner).

In any case we may not consider the phytotechnology as a competitive technique with the traditional agriculture but, on the contrary, we should see it as an extension of traditional agricultural methods especially in the arid zones, deserts and other areas where the conventional methods are impossible to apply. Besides, we should not overlook a fact that big cities, in the first place the cities-millionaires" are like a special kind of "deserts" in which due to the costly infrastructure, for example, the transport, storage and distribution systems etc. the nature is the most vulnerable media suffering severely from the urbanization impacts.

The phytotechnology is based on the principle that carbonic acid, water, mineral substances and electromagnetic radiation energy (light) by means of photosynthesis are transformed into the carbohydrates and oxygen (fig. 9).

In order to achieve a desirable optimal result of production the growth process should be submitted to one manipulation within the width limits of the stress expansion using the program of environmental media factors. The environmental media factors will be optimized with the aid of computer system in accordance with the growth process, production target and coordinated in time. By means of plants selection and due to their natural genetic information a wide scope for possible manipulations may be achieved.

The carbohydrates derived thereof serve as raw material for the primary and secondary products of diosynthesis (for example, the substances contained in the plants, biomass etc.). All the wastes and by-products may be re-circulated and transformed, for example, by simple incineration, into heat energy, CO_2, water and mineral salts and then used once more in the production process.

At present about 400000 of different plants and about 12000 of cultivating plants are known and only one thousand from them is intensively used and may become an object for industrial cultivation. Although the existing plants in the process of their growth will be subjected to some ecological manipulations through an optimized controlled program of the environmental factors, it is more advisable, in future, to grow special "plants for industrial cultivation" for planting them in phytotechnological systems; a methodical investigations and research of the growth process of such plant would allow to create their different kinds and varieties which might be successfully used in the continuous plant growing.

The industrial development practice shows that further increase of the social labour pruductivity and qualitative transformation of the productive forms in agriculture may be achieved only by means of transition from the machines and implements making one or several operations to a completely automated production - automated lines on the basis of the qualitatively new technology.

In this connection, in our opinion, today we are already facing a task to transfer the agricultural production onto the industrial basis with the use of phytotechnologies which ensure:

- line production, i.e. when the operations are fulfilled in the determined, strictly fixed and specially equipped working places arranged in the order of fulfilling the technological operations, which reduces considerably waste of time for the operators to shift from one place to another;
- maximum possible automation of all technologic operations for maintenance, control. regulation etc.;
- adaptivity of the automated technological means to the plant physiology which contributes to the improvement of their productivity.

A wide use in the agricultural production of the rotary conveyor systems opens big possibilities of solution of this grandious task. The rotary conveyor systems are such systems where the technological process is going on continuously or with stops at regular intervals and the object submitted to treatment, packing, growing etc. is moving in an infinitely closed trajectory.

In the USSR, in the 30's,early attempts were made to create a mschine with the infinitely closed chain (caterpillar) with different working tools mounted on it for soil tillage, plants and food products treatment etc.

In the years 60s in the USSR as well as in other countries a wide introduction of rotary conveyor systems has begun in different sectors of economy: metal stamping and casting, plastics industry, powder metallurgy, packing. The wirld's industrial practice has shown a great economic efficiency and rationality of such systems in comparison with others.

The rotory conveyor lines give the possibilities of the full automation of the processes:

- remote control of the conveyors with the aid of automatic devices, including the sequential automated switch on and off of the conveyor systems, of lighting and feeding of plants, microclimate conditioning systems inside the greenhouses;
- automatic control of each system separately and in functional combination, switch off of one or another system (of the whole complex) in case of an abnormal operation which is signalled automatically to the control board;
- automatic maintenance of the optimal working regime of the systems by regulating the parameters within programmed limits;
- control of the whole complex (separate systems) according to a program;
- use of computer to establish the optimal working regimes of separate systems in one technological process;
- control of the drive conditions and other principal elements which ensure a high reliability of the complex functioning.

The introduction of the rotary conveyor lines allows to exclude from the technological equipment idle elements and reduce by 15-20 times the production areas and equipment costs.

The rotary conveyor lines are easily maintained and repaired systems since after a failure its wirking capacity may be restored at minimum expense.

The successful use of the rotary conveyor systems in industry, analysis of the choice conditions and principal factors of biotechnological systems have given an impulse to a creation of the rotary conveyor systems for continuous production of vegetables and other crops in enclosed houses with artificial climate and lighting.

The most important conditions which determine the choice of one or another biotechnological system must ensure that a system:

- corresponds to given agrotechnical requirements;
- is reliable in given conditions;
- allows high degree of mechanization and automation with minimum maintenance personnel;
- ensures the most favourable labour conditions;
- gives a high economic efficiency.

The concrete parameters of a biotechnological system to be designed will depend on the following factors:

- characteristcs of the crops to be cultivated in the future system;
- principal parameters of the cultivation technologies (feeding regimes of root systems with mineral salts and O_2, CO_2 concentration);
- required productivity of the system;
- configuration (geometry), linear dimensions, cinematics, dynamics of the system;
- methods of technological maintenance of the system (biological and technical);
- climatic conditions of the enviromental media (temperature and humidity regimes);
- optimal spectral composition of the light energy;
- total power consumption;
- economic indexes (investments and operational costs, production cost per unit, number and productivity of service personnel, terms of return of investments).

Every alive being on our planet and, first of all, the plants have appeared and exist due to the Sun radiation. The use of the sun radiation as a technological factor for plant growing is not related with mechanical action but is to the penetrating capacity of the radiation and its specific effect on the plants at the cellular and molecular levels.

On the Earth only the plants are capable to transform the radiation energy into the chemical energy of organic substances. The process of formation of the organic substances by the plants from the mineral salts under the influence of radiation is known as photosynthesis.

The radiation produces a double effect on the plants: photosynthetic and thermic, i.e. one part of the energy is used for the photosynthesis (spectrum of 300-750 Nm - light radiation) and another part is consumed for heating and evaporation of water (transpiration). The thermic effect is proper not only to the light part of radiation but also to the ultraviolet (UV less than 295 Nm) and infrared (IK more than 750 Nm) ranges of radiation.

Under the naturol conditions from all the photosynthetically active radiation (PAR) released by the Sun the plants absorb 80-90% and only 2% is used for the photosynthesis and the rest is transformed into the heat in the plants.

According to the law of conservation of energy the process of transformation of the PAR in the plants is described by the following equation:

$$W_{\varphi} = \alpha \int_{t_1}^{t_2} \varphi(t)dt = W_{\text{э}} + W_{\text{п}} ,$$

where W_{φ} - is the energy of PAR received by the plants during a certain space of time dt , J;

α - coefficient of radiation absorption by the plants;

$\varphi(t)$ - radiation flow received by the plants in function of time, W;

$W_{\text{э}}$ - effective energy, J;

$W_{\text{п}}$ - energy losses, J.

The Russian scientist K.A. Timiriazev has discovered that the green pigment of the leaves (chlorophil) absorbs photosynthetically active radiation (PAR) and the carbonic acid gas (CO_2) and water (H_2O) are transformed into the organic substances rich in energy (carbohydrates, albumen, fats etc.).

Different plants have different spectral intensity of photosynthesis. The spectral untensity of photosynthesis of one and the same plant depends, to a large degree, on the phase of its development and on other factors of growth such as CO_2 concentration, environmental temperature and air humidity. For example, the cucumbers require an illumination intensity of 8-10 thou. lux, tomatoes - 10-12 thou. lux and the duration of radiation of 12-14 and 14-16 hours respectively.

In the rotary conveyor biotechnological complexes the artificial sources of light have in their spectrum of radiation the wavelengths of 300-750 Nm, which are capable to provoke the photoperiodic reaction of the plants. With a sufficient amount of PAR the photosynthesis is developing faster than the respiration and as a result the plants accumulate the organic substances. If the amount of PAR decreases it may occur that the intensity of respiration and photosynthesis become equal and this balance is known as a compensation point. If the quantity of PAR is further diminishing then the respiration process prevails over the photosynthesis. As a result of this the plants do not accumulate the organic substances but, on the contrary, spend them and, in the long run, die.

When growing plants in the modular complexes it is very important to minimize the energy consumption in order to make this technology less costly.

The radiant energy sources used for the plant growing in artificial conditions should meet the following requirements:

- the spectrum composition of the radiant energy must ensure its maximum absorption and must not contain the radiation inhibiting the plants;
- the integral power of the radiation sources should be the most economic;
- the maximum possible uniformity of the radiation distribution on the surface of the plants for optimal conditions of the photosynthesis;
- the radiation sources must not overheat the plants and must maintain optimal temperature regime in the light phase of the day;
- the energy sources must not contain radiations harmful to the health of the personnel;

In the modular complexes the following sources of radiant energy are used:

- incandescent lamps; their principal advantages consist in their simple design and easy maintenance and relatively low cost; the disadvantages are a low coefficient of performance and excess of infrared radiation;

- luminiscent lamps have a large radiant surface which gives a sufficient uniformity of radiation without overheating the plants but this type of lamps have small power and therefore it is necessary to increase their number that leads to higher cost of equipment;

- gas discharge lamps of high pressure (up to 0.3 MPa) of type DRI, DNaT, DKcT, SON-H-500, Tungsram 500 and others. The small volume of these lamps ensures a considerable concentration of light and electric power; they work independently of the outside temperature but the power losses in start/regulation devices are about 10% and the radiation distribution is not uniform.

There are many classification methods of the soilless cultivation of plants. The most appropriate methods to use in the rotary conveyor biotechnological systems are the following:

a) film crops with the circulating nutrient solution;

b) cultivation of plants on mineral substrates of rock-wool type ("grodan").

The hydropinic biotechnology of the plants cultivation in the rotary conveyor systems, installed in an enclosed room with artificial climate and lighting gives a number of valuable advantages (besides of those mentioned for the rotor conveyor systems in general):

- independence from the weather conditions;

- continuous, programmable, all year-round production of vegetables and other production (continuous technological process);

- possibility of mounting the plant with similar systems in the shortest terms and locate them near the consumers;

- elimination of transport problems connected with the delivery of products to distant points and their intermediate storage;

- a small area occupied by the plants and their ecological purity;
- possibility of full or partial automation and robotization of most technological operations (feeding, treatment, collection of crops etc.);
- elimination of chemicals;
- high quality of the production practically without nitrates contents;
- comfortable labour conditions.

In figs 10 and 11 an example of technological schemes of two versions of the rotary conveyer bio-hydroponic systems are shown which give an idea of the principle of their functioning (more detailed information about the design and technologies are given in other reports).

In the course of investigations and use of the rotor-conveyer hydroponic biological systems in the NPO VISKHOM a qualitatively new idea about the increasing their productivity has appeared. This idea envisages that these systems should be modular complexes which could function in closed cycle and would allow to recuperate and use repeatedly the thermic energy.

In fig. 12 a block-scheme of such modular complex is shown.

As it appears from the fig. 12 the vegetation block 1 is the source of heat not only for the plants in which they are grown but for the block 2 as well. In case of the excess of heat it can be accumulated in the block 3.

Such modular complex allows to use the energy in the most efficient way and make this life-support system more reliable.

The principal complex index of reliability is a coefficient of readiness

$$K_r = T_0 \left(T_0 + T_в\right) ,$$

where T_0 - time of infallible work, h;

$T_в$ - mean time required for repair characterizing the capability of the complex to be repaired in a given period of time, h (K_r = 0,98-0,99).

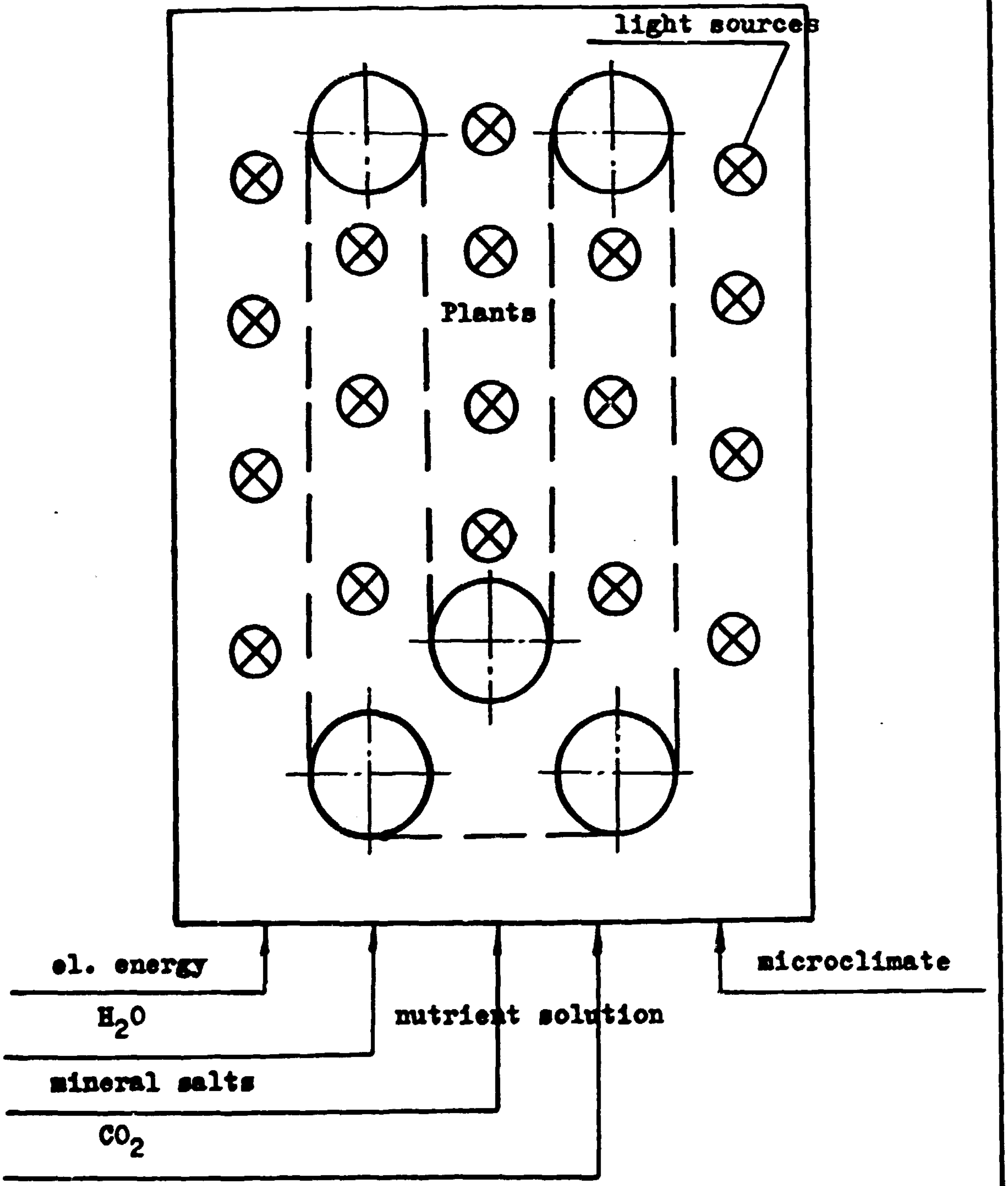


Fig. 10. Principle technological scheme of a vertical vegetational conveyor system

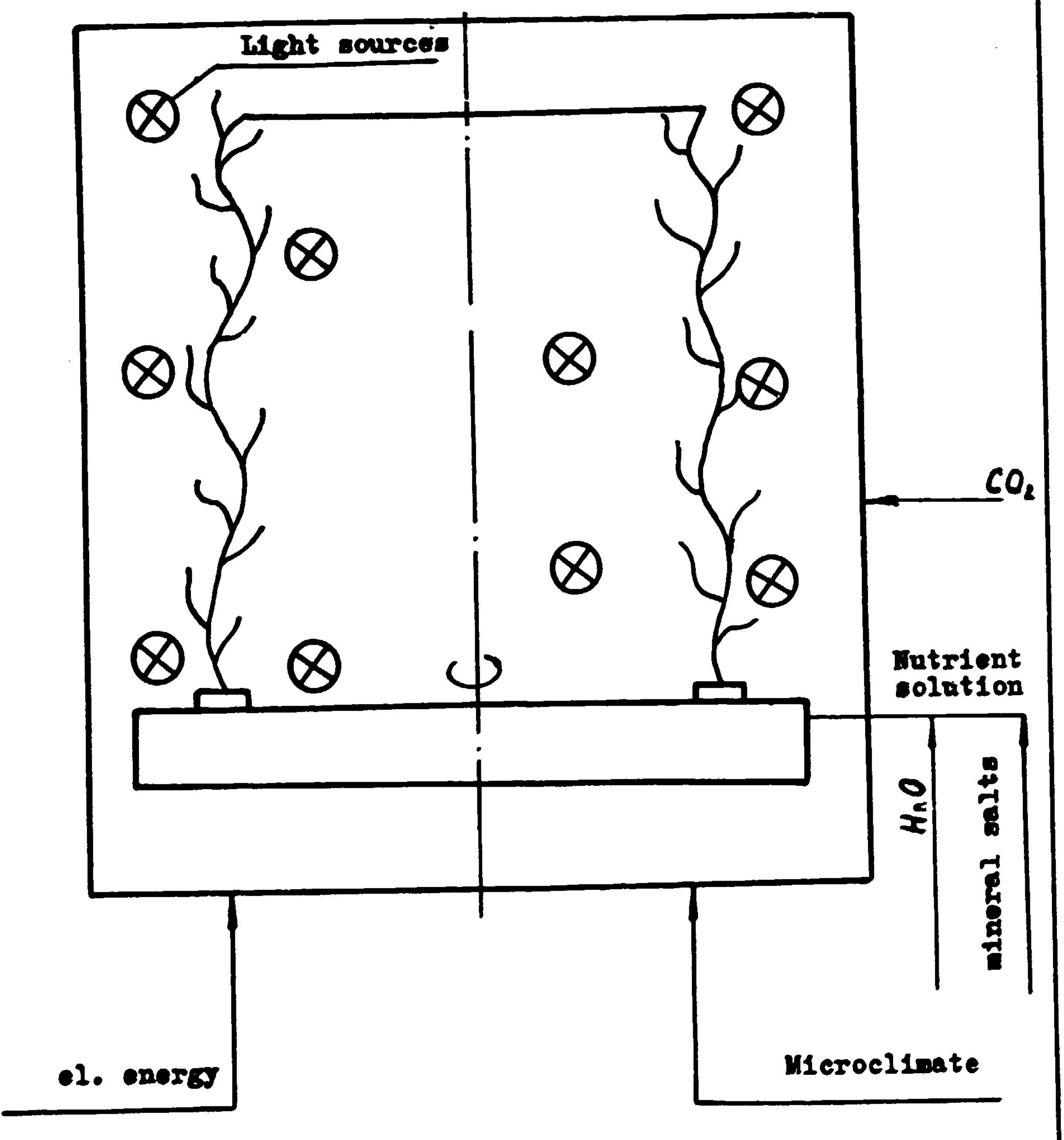


Fig. 11. Principle technological scheme of a horizontal rotary vegetational system

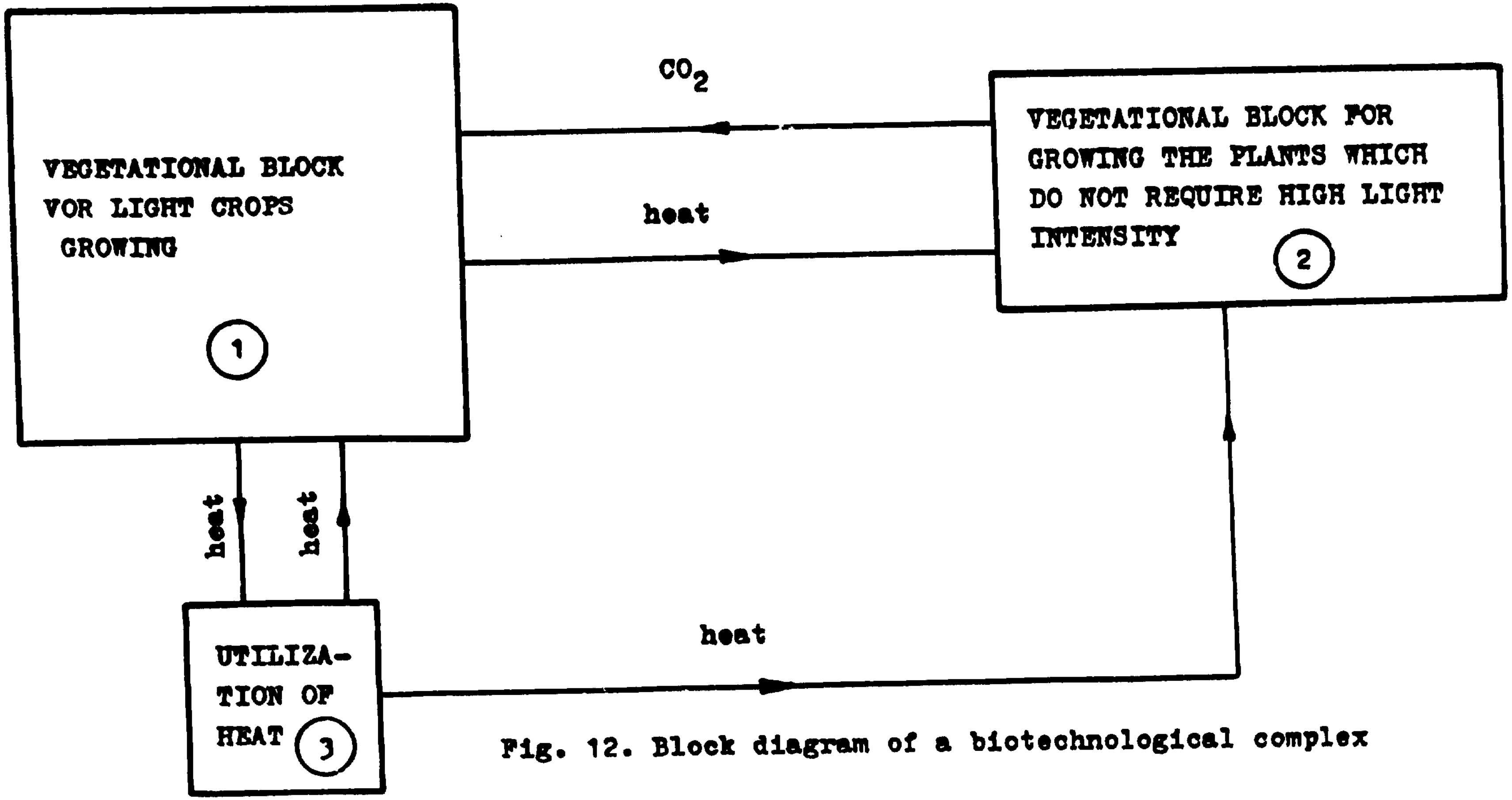


Fig. 12. Block diagram of a biotechnological complex

Large values of the coefficient of readiness are obtained by means of raising the technical level of design or increasing labour consumption for the maintenance and repair. To ensure a high reliability and efficiency of the complex systems all the major reliability indexes should be optimal. The probability of infallible work of the comples P_K, composed of n systems is determined as

$$P_K = \prod_{i=1}^{n} P_i ,$$

where P_i - probability of infallible work of each separate system.

The general coefficient of readiness of the modular complex is:

$$K_{rK} = \prod_{i=1}^{n} K_{ri} ,$$

where K_{ri} - is the coefficient of readiness of one of the systems of the complex.

It is very important in the process of vegetation of the plants in artificial conditions to receive continuous information on the levels (values) of the technological parameters of the process and be able to asymptotically approximate them to the production aim.

In its turn

$$N_{np} = K N_K ,$$

where N_K - overall quantity of trays on the conveyer;

K - proportionality coefficient, $K \leq 1$.

The most complicated is the ratio:

$$m_e = m(\tau_{np}) ,$$

since the accretion of the production mass according to the curve of growth is a variable value, which has not only $\frac{dm}{d\tau} \neq const$, but also $\frac{d^2m}{d\tau^2} \neq const$. In this connection it is very important to know the optimal value τ in order to obtain $m_e = max$.

The plants on the conveyer are in different stages of their physiological development and productivity. Let us suppose, that the trays, containing the plants of the same age, make a group. The number of groups on the conveyer q_K, and each of them is composed of n trays. Two neighbouring groups j and $j+1$ have a difference of age equal to an interval of time T-period of removal of a group of trays from the conveyer and mounting of a new one. Time of staying of the plants on the conveyer (conveyer time)

$$\tau_K = t_в - t_p ,$$

where $t_в$ and t_p - duration of vegetation and of staying of the plants in seedling stock section (before putting them on the conveyer).

$$\tau_{пр} = t_в - t_0 ,$$

where $\tau_{пр}$ - duration of collection of production from one vegetation group;

t_0 - time from the beginning of the vegetation up to the beginning of the production collection.

$$N_{пр} = \frac{t_в - t_0}{t_в - t_p} \cdot N_K ;$$

$$N_{нпр} = \frac{t_0 - t_p}{t_в - t_p} \cdot N_K ;$$

where $N_{нпр.}$ - number of fruitless trays on the conveyer.

The total number of groups and trays passed thro the conveyer during the whole period of vegetation

$$q = \frac{t_в}{\tau_K} \cdot \frac{N_K}{n}$$

$$N = \frac{t_в}{\tau_K} \cdot N_K .$$

The delay for the conveyer to get into the stationary regime of work

$$t_{ст} \geq t_0 + (K-1)T ,$$

where $K = \frac{t_в - t_0}{T}$.

The amount of production, received for i-stage of growth for a group of trays

$$m_{ji} = \varphi_{max} \int_{\tau_0+(i-1)T}^{\tau_0+iT} \varphi_0 \, d\tau = \varphi_{max} \cdot C_{ij} = \varphi_{max} \cdot C_i ,$$

where $\varphi_0(t)$ - relative intensity of the productive (collection of the product), which is divided in K stages, determined by a discrete time shift with a period T of the growth phase of the plants for each group of trays,

$$\varphi_0(t)=\frac{1}{\varphi_{max}}\varphi(t)$$

(there $\varphi_t=\frac{dM}{dt}$ - intensity of accumulation of the production mass which is collected).

The general collection of the crop during the vegetation

$$M=\sum_{j=1}^{\ell} m_j=N_K\frac{t_{\text{в}}}{\tau_K}\,\frac{\varphi_{max}}{n}\int_{\tau_0}^{\tau_K}\varphi_0\,d\tau=N_K\frac{t_{\text{в}}}{\tau_K}\int_{\tau_0}^{\tau_K}\varphi_0\,d\tau\ ;$$

$$M=N\cdot m_\ell\ .$$

The condition $t_{\text{опт}}$ corresponds to the optimal time of vegetation

$$\frac{dM}{dt_{\text{в}}}=\frac{M}{\tau_K}\ ,$$

which means, that there is only one point on the curve of growth $M(\tau)$ with the coordinate $M_{\text{опт}}$, for which the mean value of intensity of the production process within a space of time $t_{\text{опт}}-t_p$ is equal to its instantaneous value - to the maximum yield. In order to find this point and consequently $t_{\text{опт}}$ it is necessary to draw a tangent line to the curve t_p from the point $M(\tau)$ on the axis of abcissae.

The conveyor systems of the complex have a certain space-time structure, dependent on the design and geometry of the equipment and on the technology of cultivation of different crops.

In particular, for such trellis crop, like cucumber, tomatos etc. the optimal relation between the technological and design parameters is possible only with a variable pitch of the conveyor.

The functional relation between the conveyer parameters, which allow to have a maximum number of fruit bearing trays on the conveyer, all other things being equal, is expressed:

$$L_p = \frac{\Delta N \cdot t_{в} \cdot \ell_p \ell_n - L_n \ell_p}{2\ell_n},$$

where L_p - length of a portion of the conveyer with reduced pitch (for seedlings);

L_n - length of a portion of the conveyer with the trays for the fruit bearing plants;

ℓ_p - pitch of positioning of the trays with seedlings;

ℓ_n - pitch of positioning of the trays with the fruit bearing plants;

ΔN - number of the trays periodically mounted (removed) from the conveyer;

$t_{в}$ - general time of vegetation of the crop on the conveyer.

In fig. 13 a classification of the equipment for hydroponics is shown. This classification includes the facilities of three principal types: a single and multistoreyed systems and conveyers as well as the equipment for the preparation, supply and control of the nutrient solution composition.

The supply of the nutrient solutions ot the root system of the plants is one of the most important moments in their life-supporting media with any method of growing and any type of equipment.

The delay of filling the vegetation capactites (growers) with nutrient solution is determined by the following expression:

$$T_H = \frac{2S \cdot m}{\mu w \sqrt{2g}} \left(-\sqrt{H_a} + \frac{Q_n}{\mu \sqrt{2g}} \ln \frac{Q_n}{Q_n - \mu w \sqrt{2g H_a}} \right),$$

where m - porosity of substrate;

S - area of grower;

μ - coefficient of consumption;

w - section of the outlet hole;

g - gravity acceleration;

H_a - level of solution in the grower, required by technology;

Q_n - consumption of the solution fed to the grower.

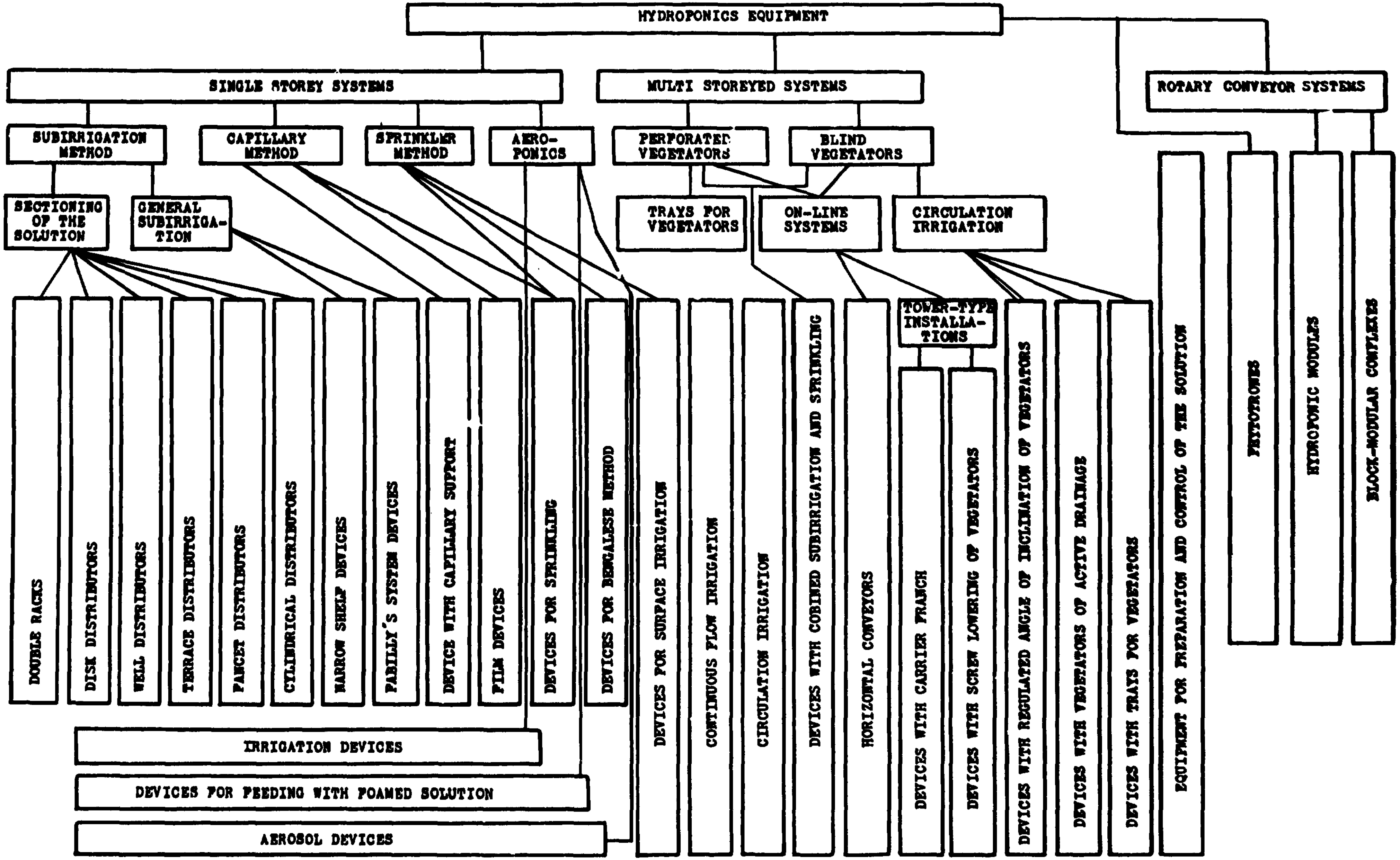


FIG. 13. CLASSIFICATION OF EQUIPMENTS FOR HYDROPONICS

Drainage time

$$T_c = \frac{2Sm\sqrt{H_a}}{\mu w \cdot \sqrt{2g}}$$

In the case of the substrateless crops (green forage) the equation for filling the growers is as follows:

$$Q_n dt = S\cdot m\cdot dh + KJ\cdot b\cdot h_0 dt ,$$

where t - time;
h - level of solution in the grower;
h_0 - level of solution above the drainage holes;
K - filtration coefficient;
y - hydraulic gradient of the grower;
b - width of the grower;
m - porosity of the root layer.

The equation for the grower drainage in case of the nutrient solution feeding interruption $Q_n = 0$

$$0 = K\cdot y\cdot bh dt + Smdh .$$

The section of the outlet hole is:

$$w = \frac{K(\Delta h + il)\sqrt{h_{oy}}}{N\mu_\varphi\sqrt{2g}} ,$$

where i - gradient of the grower;
l - length of the grower;
h_{oy} - head above the drainage holes;
N - length/width ratio;
μ_φ - coefficient of the outflow counting the filtration.

The conveyer biotechnological systems of vertical type are statically more or less balanced systems since while one of the branches is raising the other is lowering. If the masses of both branches of the conveyer are equal (a desirable condition) the conveyer is statically balanced. Hence, the number of raising branches should be equal to the number of lowering branches. In this case in the regime of an established movement the energy is spent only to overcome the resistance on the sprockets.

These conveyers usually have a of reducing type drive, because they are low speed ($v < 0.05$ m/s).

Technical specifications of the conveyer.

Quantity of the mass transferred in a unit of time or "productivity"

$$Q = \frac{\sum \beta_i q_i \gamma_i}{L} V, \qquad \text{kg/s},$$

where β_i - coefficient of use of the i-nth vegetation tray in lift-capacity,

$$\beta_i = \frac{q_{max}}{q_i} \leq 1$$

(there q_i - real mass of load in the i-nth tray, kg; q_{max} - maximum possible load mass in the tray, kg);

γ_i - coefficient of loading of the conveyer,

$$\gamma_i = \frac{q_н}{q_{max}}$$

(there $q_н$ - nominall mass of load in the tray, kg);

L - length of the conveyer;

V - speed of movement of the conveyer, m/s.

It should be noted that since the vegetation mass on the conveyor is not constant, hence $Q = VaV$.

The load of the driving element of the conveyer is characterized by the coefficients of maximum tension $K_{ц}$ and equivalent tension $K_{эц}$

$$K_{ц} = S_{max} / S_{д} ;$$

$$K_{эц} = \frac{1}{T_{ц}} \sum_{i=1}^{n} \left(\frac{S_i}{S_д} \right) t_i ,$$

where S_{max} and $S_д$ - are maximum actual and admissible tension of the driving element respectively;

S_i - tension of the driving element on a separate portion of the conveyer;

t_i - time of action of S_i ;

n - quantity of portions of the conveyer with different tension S_i .

The influence of the environmental temperature is characterized by a temperature coefficient K_T , showing (in percents) the ratio between the duration of movement t_m of the carrying part of the conveyer in the zones of extreme temperatures and the time $T_{ц}$ of the whole cycle (complete turnover) of the carrying part of the conveyer

$$K_T = \left(\frac{t_m}{T_ц}\right) 100\% .$$

The influence of the environmental humidity is expressed in similar form:

$$K_w = \left(\frac{t_w}{T_ц}\right) \cdot 100\% ,$$

where t_w - duration of the carrying part movement in the zones of extreme humidity.

The static moment on the driving shaft of the conveyer at the starting (stopping) is:

$$M_{ст} = (Q_п - Q_o)\, gR = \Delta Q g R ,$$

where $Q_п$ and Q_o - total mass of the load in the raising and lowering trays, kg;
R - radius of the driving sprocket, m;
g - gravity acceleration, m/s^2.

In practice the conveyer is not fully balanced since the mass of loads in the trays along the whole length of the conveyer is not uniform due to different stages of development of the plants.

The statically unbalanced systems are efficient from the economic viewpoint if the mass of the driving member does not exceed the half of the useful load. If this condition is not observed the drive power increases more than by 15% and the coefficient of performance decreases more than by 10%.

For a statically unbalanced system the condition $\Delta Q \angle 0{,}5\, Q_п$ should be observed. In the designing of a conveyer it is necessary to ensure minimum energy consumption and maximum coefficient of performance.

In fig. 14 a real tachogramme of the conveyer work is shown. The acceleration (a), appearing in the elements of the conveyor in the starting regime is:

$$a = \frac{dv}{dt} = tg\gamma ,$$

where dv - change of speed in the starting regime for the time dt ;
γ - angle of inclination of the tangent to the tachogramme.

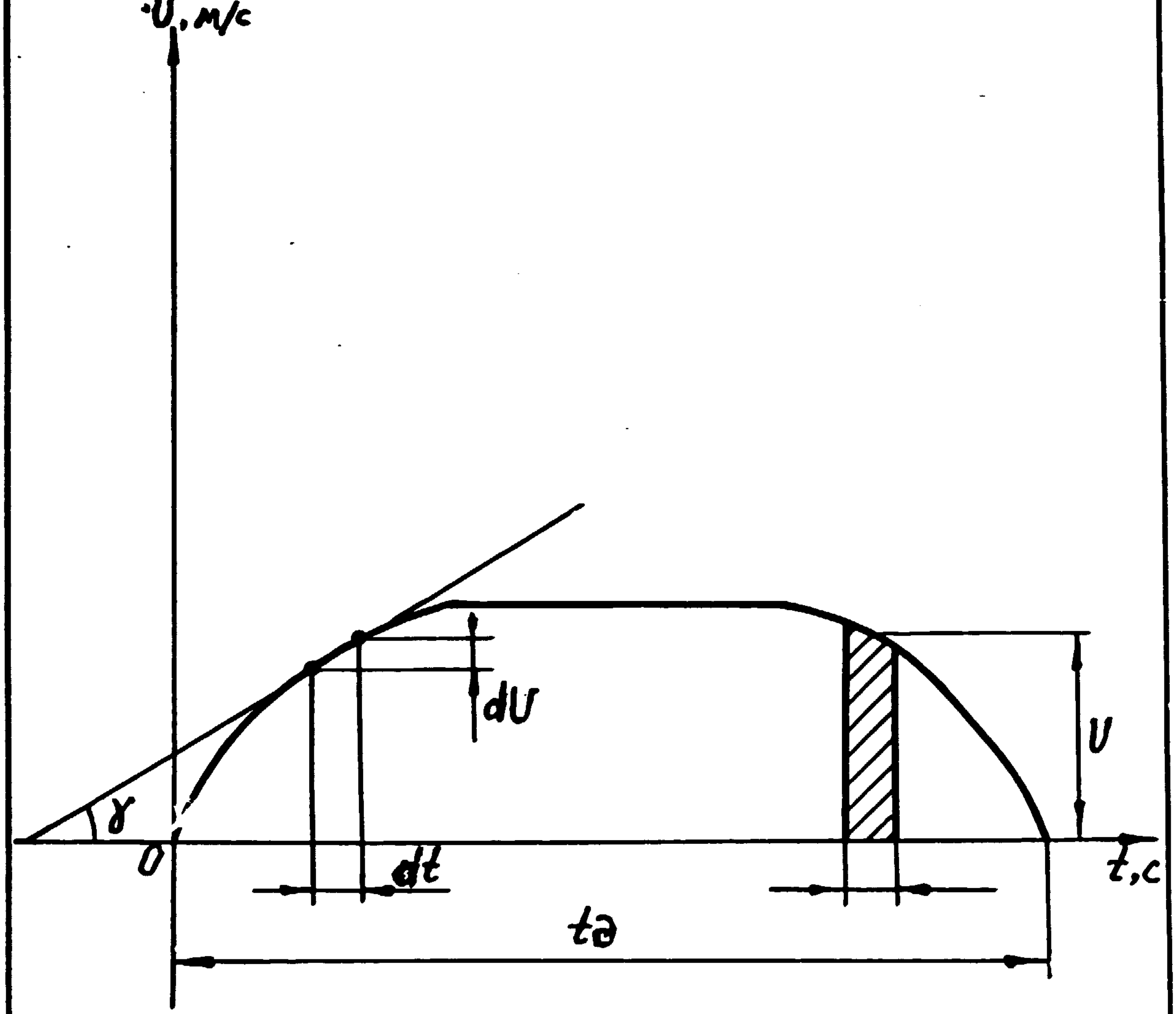


Fig. 14. Actual tachogram of the conveyor operation

The total path run during the whole period of tachogramme

$$H=\int_0^{t\partial} V dt=\int_0^{H} dX \cdot$$

The rectangular tachogramme (fig. 15) is a theoretical one since $a=tg\,90^\circ=\infty$, what is practically impossible.

Starting time is:

$$t_1=\frac{V_0}{a_{1H}}=\varepsilon_1\frac{V_{max}}{a_{1H}};$$

$$\frac{a_{1K}}{a_{1H}}=K_a \cdot$$

The length of path run by the i-nth tray during the starting time

$$h_1=V_{max}\,t_1\,\mu_1=\mu_1\varepsilon_1\frac{V^2_{max}}{a_{1H}},$$

where μ_1 - coefficient showing what part of the path of the uniform movement at a maximum speed constitutes the path run at a speed changing under a given law.

In stopping regime

$$t_3=\varepsilon_3\frac{V_{max}}{a_{3K}};$$

$$h_3=V_{max}\,t_3\,\mu_3=\mu_3\varepsilon_3\frac{V^2_{max}}{a_{3K}},$$

where $a_{3K}=tg\gamma_3=\frac{V_0}{t_3}$ - final deceleration.

Duration of the uniform movement

$$t_2=t\partial-(t_1+t_3)=t\partial-V_{max}\left(\frac{\varepsilon_1}{a_{1H}}+\frac{\varepsilon_3}{a_{3K}}\right).$$

The path run by the i-nth tray in uniform movement

$$h_2=V_{max}\,t_2=V_{max}\left[t\partial-V_{max}\left(\frac{\varepsilon_1}{a_{1H}}+\frac{\varepsilon_3}{a_{3K}}\right)\right].$$

The total path run during all the periods of tachogrammes

$$H=h_1+h_2+h_3=\mu_1\varepsilon_1\frac{V^2_{max}}{a_{1H}}+V_{max}\left[t\partial-V_{max}\left(\frac{\varepsilon_1}{a_{1H}}+\frac{\varepsilon_3}{a_{3K}}\right)\right]+$$
$$+\mu_3\varepsilon_3\frac{V^2_{max}}{a_{3K}}.$$

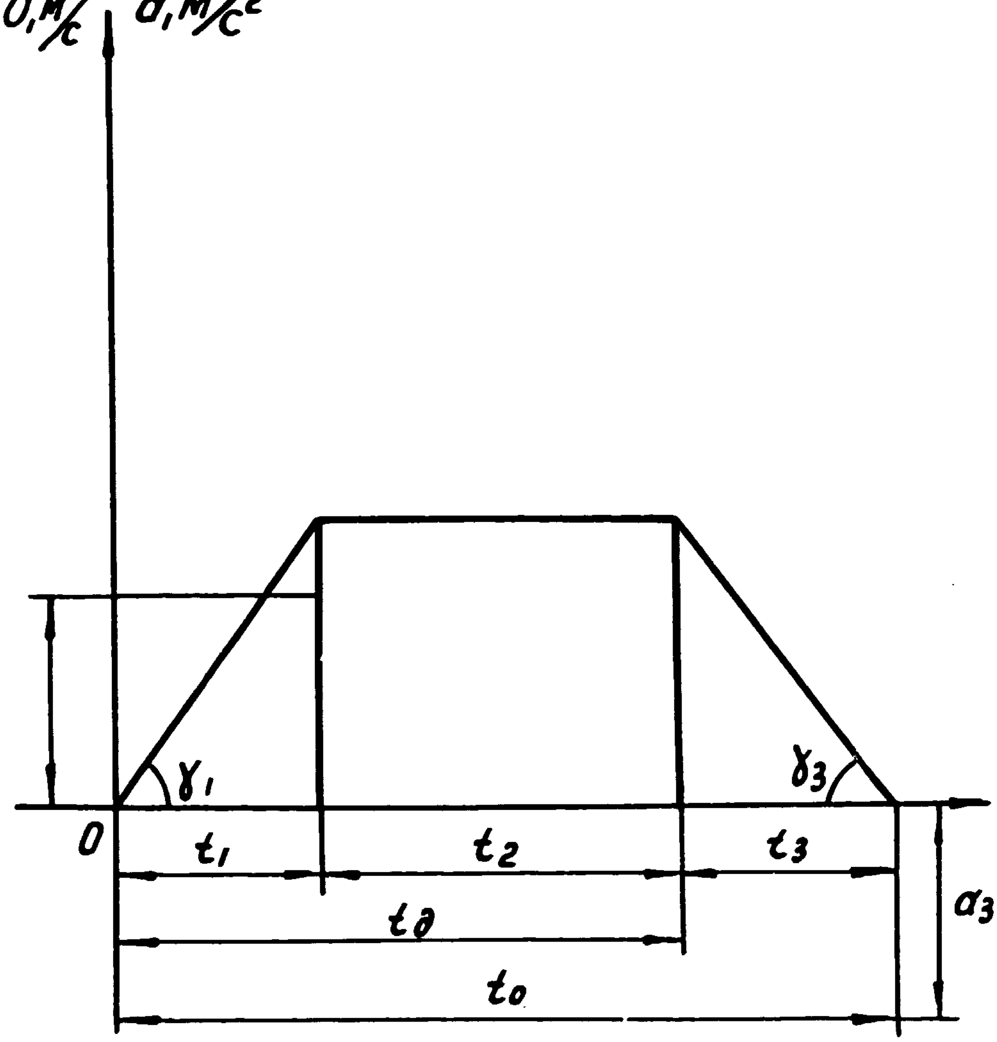


Fig. 15. Theoretical tachogram

After the transformations we shall have:

$$V_{max}^2\left(\varepsilon_1\frac{1-\mu_1}{a_{1\text{н}}}+\varepsilon_3\frac{1-\mu_3}{a_{3\text{к}}}\right)-V_{max}t_{\text{д}}+H=0\,.$$

It may be admitted that

$$a_{1\text{н}}=a_1=const\,;\quad a_{3\text{к}}=a_3=const\,,$$

when $V_0=V_{max}$; $\varepsilon_1=\varepsilon_3=1$; $\mu_1=\mu_3=1/2$, then the calculations can be made with the aid of the formulies:

$$t_1=\frac{V_{max}}{a_1};\quad h_1=\frac{1}{2}\,\frac{V^2max}{a_1},\quad t_3=\frac{V_{max}}{a_3}\;;$$

$$h_3=1/2\,\frac{V^2max}{a_3};\quad t_2=t_{\text{д}}-t_{max}\left(\frac{1}{a_1}+\frac{1}{a_3}\right)\;;$$

$$h_2=V_{max}\left[t_{\text{д}}-V_{max}\left(\frac{1}{a_1}+\frac{1}{a_3}\right)\right];$$

$$V'_{max}\left(\frac{1}{a_1}+\frac{1}{a_3}\right)-2\,V_{max}\,t_{\text{д}}+2H=0\,.$$

Force factors of a statically balanced driving member of the conveyer. According to the D´Alambert principle (fig. 16):

$$F_{\text{дв}}\cdot R+S_{\text{сб}}\cdot R=S_{\text{нб}}\cdot R+F_i\,R+X_{\text{вр}}.R\;,$$

i.e.

$$F_{\text{дв}}=S_{\text{нб}}-S_{\text{сб}}+X_{\text{вр}}+F_i\;,$$

where $S_{\text{нб}}, S_{\text{сб}}$ - are forces of the raising and lowering branches of the driving member on the driving sprocket, respectively;

$X_{\text{вр}}$ - resistance forces;

F_i - inertia forces;

$$S_{\text{нб}}=S_{\text{стнб}}+X_{\text{врнб}}-m_{\text{оп}}\frac{d^2x}{dt^2}\;;$$

$$S_{\text{сб}}=S_{\text{стсб}}-X_{\text{врсб}}+m_{\text{нф}}\frac{d^2x}{dt^2}\;.$$

For the rotating parts of the conveyer

$$F_i\,R=Y\frac{d\omega}{dt}\,,$$

where $Y=M_{\text{пр}}\cdot R^2$ - inertia moment of the rotating elements of the conveyer (there $M_{\text{пр}}$ - mass of the rotating parts reduced onto the driving sprocket);

$\frac{d\omega}{dt}$ - angular acceleration of the driving sprocket.

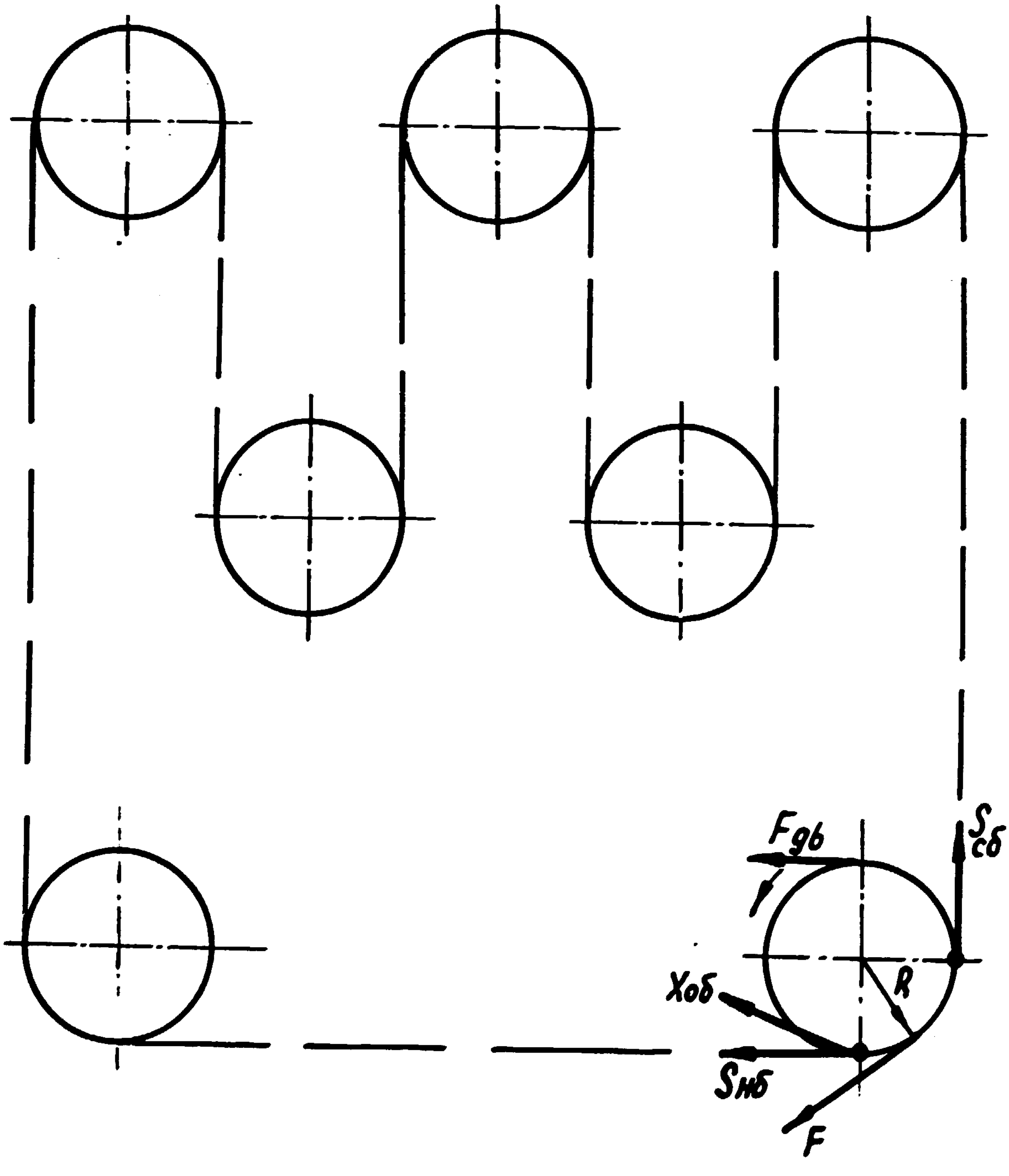


Fig. 16. Diagram of forces on the driving shaft of the conveyor

$$F_i = M_{\text{пр}} R \frac{d\omega}{dt} = M_{\text{пр}} i \frac{d^2 X}{dt^2} ,$$

where i - is the multiple of passes of the driving member branches.

$$\frac{d\omega}{dt} R = i \frac{d^2 X}{dt^2} .$$

Expressing all the resistances arising along the conveyer movement in fractions ξ of the part of the useful load Q/i, which acts on the working branches of the conveyor

$$X_{\text{пд}} + X_{\text{оп}} + X_{\text{бр}} = \xi \frac{Q}{i} .$$

Summing up all the masses of the moving parts of the conveyer

$$m_{\text{пд}} + m_{\text{оп}} + M_{\text{пр}} i = \left(\frac{m_{\text{пд}} + m_{\text{оп}}}{i} + M_{\text{пр}} \right) i = M i .$$

The general dynamics equation will be:

$$F_{\text{дв}} = S_{\text{ст нб}} - S_{\text{ст сб}} + \xi \frac{Q}{i} + M i \frac{d^2 X}{dt^2} .$$

The total coefficient of resistance

$$\xi = f_{\bar{\text{т}}} + f_{\text{нп}} + f_{\text{нз}} ,$$

where $f_{\bar{\text{т}}}$ - coefficient of resistance in the bearings of the shafts plus the resistance of the driving member to bending;

$f_{\text{нп}}$ - coefficient of resistance of the driving member along the guides;

$f_{\text{нз}}$ - friction in the bearings of the idle sprockets.

From the viewpoint of dynamics the electromechanical conveyer system of the principal vegetation block may be considered as multimass elastic system which includes, besides the reductor, the sprockets, driving members with the trays hinged to them and an electric drive.

Let us analyze a case when the conveyor is equipped with the electric drive system generator-motor (investigation carried out jointly with the Crimean Ag. Inst.).

The equation of balance of the electromotive forces is expessed as follows:

$$U = L\frac{di}{dt} + \tau i + C_e\frac{d\varphi}{dt} \quad ,$$

where U - tension fed to the electromotor;

L - coefficient of self-induction;

i - current intensity;

t - time;

τi - ohmic resistance;

C_e - constant of the electromotor;

$w = \frac{d\varphi}{dt}$ - angular speed.

The differential equation to determine the driving moment is as follows:

$$M_1''(t) + \frac{\tau}{L}\dot{M}(t)\frac{C_e C_M}{L}M_1(t) =$$

$$= \frac{C_M}{L}\dot{U} + \frac{R C_M C_e}{L J_{\text{пр}}}\left(S_{\text{стсб}} - S_{\text{стнб}}\right) - \frac{C_M C_e}{L J_{\text{пр}}}\cdot M_c ,$$

where $M_1(t)$ - driving moment reduced to the driving shaft, applied to the motor rotor;

M_c - total constant moment of the resistance forces to the conveyer movement;

$S_{\text{нб}}, S_{\text{сб}}$ - forces in the raising and lowering branches of the driving member;

R - radius of the driving sprocket;

C_M - constant of the electromotor;

$J_{\text{пр}}$ - moment of inertia of the conveyer reduced to the driving shaft.

In case of rectangular rheostatic characteristics of the asynchronous motor the driving moment

$$M_1(t) = M_e + M_д e^{-\tau_к t} \quad ,$$

where $M_д = m a_1 R$ - dynamic component of the driving moment;

m - reduced mass of all moving elements of the conveyor;

$a_1 = \frac{M_{max} - M_{ст}}{mR}$ - initial acceleration at each step of the rheostat;

M_{max} - maximum moment developed by the motor, constant at each step.

$$\tau_K=\frac{M_{max}}{m\tau_3 V_{on}}\ ,\quad V_{on}=V_0\left(\frac{M_{nep}}{M_{max}}\right)^{K-1},$$

where K - number of the rheostat step;

V_0 - speed of movement of the driving member, corresponding to the synchronous speed of rotation of the electromotor;

M_{nep} - driving moment developed by the motor when switching to the next step of rheostat, also constant in each step.

In order to avoid the oscillating change of the driving moment the following condition should be abserved:

$$\sqrt{\frac{C_e C_M}{L}} < \frac{\tau}{2L}\,.$$

On the basis of the D'Alambert principle the system of the differential equations of the conveyor dynamics with the electrical drive generator/motor will have the following form:

$$\mathcal{J}_1\ddot{\varphi}_1+C_{12}(\varphi_1-\varphi_2)=M_1(t)\ ;$$

$$\ddot{M}_1(t)+\frac{\tau}{L}\dot{M}_1(t)+\frac{C_M C_e}{L\mathcal{J}_1}M_1(t)=\frac{e_M e_e}{L}\dot{U}+\frac{e_M e_e}{L\mathcal{J}_1}C_{12}(\varphi_1-\varphi_2)\ ;$$

$$\dot{U}+\frac{1}{T_2}U=\frac{K_2}{T_2}U_B\ ;$$

$$\left[\mathcal{J}_2+\frac{1}{2}(M_0-M_n)\tau_3^2\right]\ddot{\varphi}_2-e_{12}(\varphi_1-\varphi_2)+$$
$$+e_{23}(\varphi_2-\varphi_3)=\frac{1}{2}\left[(S_{CT\,HB}-S_{CT\,CB})\tau_3-M_c\right]\ ;$$

$$\left[\mathcal{J}_3+\frac{1}{2}(M_0-M_n)\tau_3^2\right]\ddot{\varphi}_3-e_{23}(\varphi_2-\varphi_3)=$$
$$=\frac{1}{2}\left[(S_{CT\,HB}-S_{CT\,CB})\tau_3-M_c\right].$$

If the conveyor drive has an asynchronous motor then the dynamic equation is as follows:

$$\mathcal{J}_1\varphi_1''-C_{12}(\varphi_1-\varphi_2)=M_c-M_g e^{-\tau_K t}\ ;$$

$$\left[\mathcal{J}_2+\frac{1}{2}(M_0-M_n)\tau_3^2\right]\ddot{\varphi}_2-C_{12}(\varphi_1-\varphi_2)+$$
$$+e_{23}(\varphi_2-\varphi_3)=\frac{1}{2}\left[(S_{CT\,HB}-S_{CT\,CB})\tau_3-M_{OT}\right]\ ;$$

$$\left[\mathcal{J}_3+\frac{1}{2}(M_0-M_n)\tau_3^2\right]\ddot{\varphi}_2-C_{23}(\varphi_2-\varphi_3)=$$
$$=\frac{1}{2}\left[(S_{CT\,нб}-S_{CT\,ст})\tau_3-M_c\right].$$

The type of the electrical drive of the conveyor system depends on the required power, dimensions and metal mass of the conveyor, its capacity, position of the conveyor and its separete units, simplicity and reliability. A structure of the automation system of the rotary biotechnological complex is determined on the basis of calculations and experiments - its type, number, control system.

The efficiency of the functioning of the automation complex is evaluated by the following criterion:

$$E(t)=\int_{\Theta_\pi,t} R_\pi(t)\,dh_\pi(t),$$

where $dh_\pi(t)$ - probability of that the complex within an interval of time from 0 to t had π-nth state;

$R_\pi(t)$ - canventional index of efficiency for this state;

Θ_π, t - space of all possible states of the automation complex.

The automation complex allows to control, regulate and maintain all the necessary technological parameters inside the module.

The terms of the investment returns from the modular complex are calculated with the following formula:

$$Э=(З_б-З_н)\,А\ ,$$

where $Э$ - annual return, roubles;

$З_б, З_н$ - reduced costs for the manufacturing of the basic and new (recommendable) complex, roubles;

$А$ - annual volume of production in natural units, tons.

The reduced costs of the modular complex

$$З=C+E_н\cdot K,$$

where $З$ - reduced costs;

C - cost of production per unit;

$E_н$ - normative coefficient of actual investments;

K - specific investments in productive funds.

More detailed information on the economic aspects of the modular complex is given in one of other reports.

The scientific thought is already wirking today on the creation of the automated conveyor, ecologically closed systems for growing not cnly vegetables but wheat, rice, cotton, medicinal plants and many other crops.

There is a positive experience of growing plants with the use of hydroponic biotechnolcgy at a depth of several hundreds meters underground, under water and in the cosmos.

The highest requirements should be met by the biological technique and technology for creation of an artificial autonomous life supporting system in cosmic vehicles and stations. In this case the artificial ecological system should transform the non-organic raw material into organic material rich in energy by means of photosynthesis and all the wastes will be returned in closed cycle into the initial non-organic state. Through the photosynthesis the plants will absorb CO_2, contained in the air exhaled by men, and release the oxygen.In fig. 17 a scheme of an artificial ecological system for cosmic ship is shown.

The history of development of mankind, to a significant degree, depends on the solution of the nutrition problem. The successes in the discovery and cultivation of the vegetable and animal food have been and will always be dependent on the geographical situation and natural environmental conditions. Up to the present time mankind has not been conscious about the losses and damages which arise as a consequence of human activity against the existing environmental conditions.

However, in future, when it fecomes more difficult to restore the ecological ties the man himself will have to create his own environmental media with widely expansible limits. The optimal solution of this problem may be realized only by creation and development of artificial, ecologically closed systems and one of the examples of such systems is the present biotechnology on the basis of modular rotary conveyor hydroponic system.

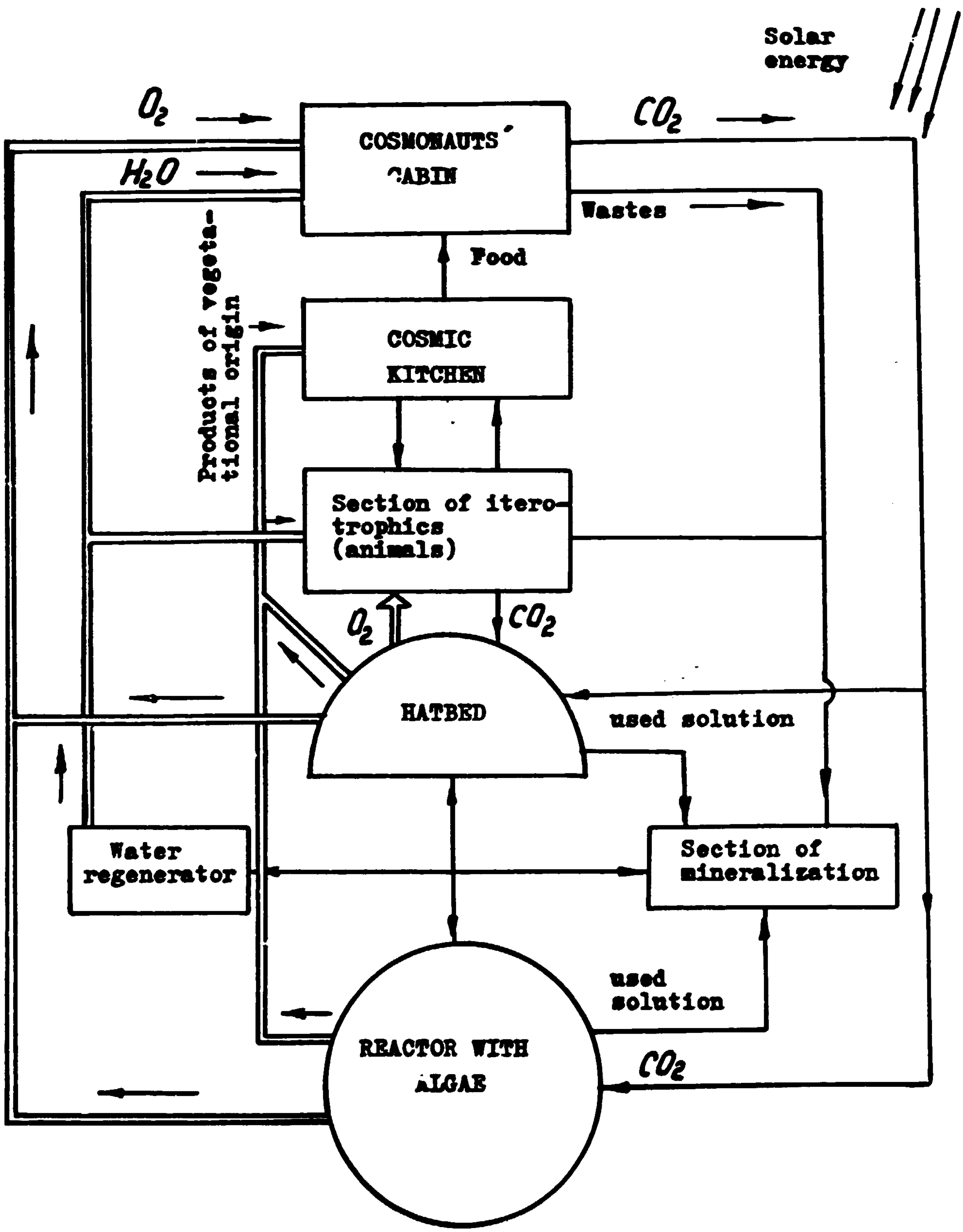


Fig. 17. Principle scheme of a artificial ecological system of a spaceship (by B.Mikay)

Conclusions

The following conclusions may be derived from all the abovesaid:

1. The problem of food provision of the rapidly increasing population of the world has become today vitally important.

2. As a result of the anthropogenic activities the ecological stresses on the environmental conditions of the Earth are constantly increasing.

3. The argicultural areas are progressively reducing.

4. The problems mentioned above may be solved only by means of simultaneous development of traditional agriculture and industrial biotechnologies based on the plant growing in artificial conditions which allow:

- to eliminate a number of technological operations (as compared with conventional greenhouses) - plowing, vapour treatment, fertilizer application, raising and lowering of the register of the oversoil heating etc.;
- to improve phytohigienic conditions in cultivation rooms and thus to decrease the illnesses of plants;
- to automate the processes of preparation, supply, control and regulation of the nutrient solution composition;
- to cultivate (besides the vegetables) oilseed, medicinal plants, wood seedlings, cotton, wheat and other crops i.e. practically any crop production;
- to save energy by means of its accumulation and repeated use.

5. The progress in all branches of science: mathematics, biology, chemistry, light technique, energetics, electronics and cybernetics will allow on the eve of the XXI century make the phytotechnology a highly efficient and the most rational ecologically biotechnological industry.