Justification of some design and mode parameters of a multi-section climate chamber for growing plants

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Abstract. The purpose of the research was to develop a design of a multi-section climate chamber, to justify the structure of the control system and simulate the heat balance with the use of the device proposed. To ensure the declared capability of the climate chamber, a structural diagram of the control system was developed, which takes into account the following capability list in the controlled volume: ozone concentration control, control of the air recirculation rate, air temperature control, indirect analysis of the temperature distribution, control of the illumination and illumination spectrum, possible secure remote on-line monitoring and control of the system via mobile applications, possible storage of a large set of climatic and regulatory parameters for up to 5 years with the sampling rate of no more than 5 minutes. A mathematical model of the heat balance has been developed, which allows to determine important parameters for a climate chamber consisting of several interacting sections, such as the total power of the heat radiation required and the necessary heat consumption to develop and maintain the plant activity under preset specific conditions.

1. Introduction

The most important task of agricultural production is to find effective ways to increase the output of crop production and reduce the costs due to implementation of promising production methods, namely, microcloning of improved cultivated plants with their planting into an artificial nutrient medium and subsequent growing in the conditions of controled climate [1-3].

It is possible to produce improved plants, which would provide high biological productivity in a short time, by using the optimal conditions of illumination intensity, humidity, and temperature at the stage of both planting a culture in vitro, and its further adaptation in a natural soil [4, 5].

It should be noted therewith that the existing high-tech methods to implement artificial climate and climate chambers, of both domestic and import manufacture, apply the same conditions within themselves over the entire operating volume: the temperature, humidity, etc., which forces the use of several climate chambers during researches, increasing costs due to their acquisition and subsequent inefficient use [6]. Also, the disadvantage stated makes it difficult, in general, to use modern climate chambers within a functional unit with several diverse research areas (microbiology, crop production, work with animals and plant cells). Besides, the disadvantage is also relevant in industrial enterprises with various capacities, for example, obtention of ecologically clean plants at public catering
enterprises to produce food products when several groups of plants are grown requires creating various soil and climate conditions, which is difficult with the use of modern chambers.

It should be noted that there is serial production of analogs of climate chambers – growboxes, which are produced both in Russia and abroad. However, such equipment can only be used for non-sterile conditions – when plants are grown in a soil, which introduces restrictions on their use in the effective cell biology.

It follows thence that the existing foreign and domestic climate chambers need to be thoroughly modernized and they are not free from shortcomings, which limits their use for research purposes. Therefore, a development of multi-section climate chambers implementing different microclimate parameters within each section is relevant and of great importance for national economies.

The purpose of the research was to develop a design of a multi-section climate chamber, justify the diagram of the control system, and simulate the heat balance by using the device proposed.

2. A structure diagram of a multi-section climate chamber and justification of its control system diagram

A multi-section climate chamber for growing plants is set out in figure 1, front view, main view.

The multi-section climate chamber for growing plants comprises working chamber 1 with ventilation holes 2, which are arranged in working chamber 1, temperature sensor 3, lights 4 including panels 5 and auxiliary panels 6 with LEDs 7, the control system of lights 4 (not shown in the figures); working chamber 1 includes two independent isolated sections 8 for creating its own microclimate parameters by means of individual climate modules 9 equipped with ozonation system 10, coal filters for clarifying, decontamination, and conversion of incoming and exhaust air 11; each of independent sections 8 is isolated from the ambient by means of pressure hatch 12 with closing device 13 on the front side of the sectional climate chamber; individual climatic modules 9 are closed with hatch 14 of compartment 15 of the artificial climate control system (not shown in the figure) on the back side of the sectional climate chamber.

![Figure 1. A multisection climatic chamber for growing plants: 1 – working chamber, 2 – ventilation holes, 3 – temperature sensor, 4 – backlight, 5 – panels, 6 – auxiliary panels, 7 – LEDs, 8 –](image-url)
isolated sections, 9 – climate modules, 10 – ozonation system, 11 – coal filters for clarifying, decontamination and conversion of incoming and exhaust air, 12 – pressure hatch, 13 – locking device, 14 – hatch, 15 – compartment of artificial climate control system.

The device operates as follows. Containers with plants were placed inside independent isolated sections 8 of working chamber 3 and lights 4 were switched on, the temperature conditions inside independent isolated sections 8 were maintained through climate modules 9 by means of temperature sensor 3 owing to the artificial climate control system (not shown in the figures). The required level of high biological purity was provided by ozonation system 10; air coming through ventilation holes 2 of individual climate modules 9 was converted into ozone and transformed into oxygen decontaminated from foreign organic substances by means of coal filters for clarifying, decontamination, and conversion of incoming and exhaust air 11.

A structure diagram of the control system (figure 2) was developed to ensure the capability declared of the climate chamber, which takes into account the following capability list in the controlled volume [7, 8]:

- control of the air recirculation rate;
- air temperature control;
- indirect analysis of the temperature distribution;
- control of the illumination and illumination spectrum;
- possible secure remote on-line monitoring and control of the system via mobile applications.
- possible storage of a large set of climatic and regulatory parameters for up to 5 years with a sampling rate of no more than 5 minutes.

![Figure 2. Structure diagram of control system of multi-section climate chamber.](image-url)

3. Heat balance simulation with the use of a multi-section climate chamber
A heat balance diagram of a multi-section climate chamber is set out in figure 3.
Figure 3. A heat balance diagram of a multi-section climatic chamber: 1 – climate control unit, 2 – tubes with micro-plants, 3 – internal fence, 4 – individual section, 5 – individual section, 6 – external fence, $Q$ – heat air flow for individual section 4, $Q_{\text{conv}}$ – convective heat exchange with the internal air of individual section 4, $Q_{\text{vent}}$ – air exchange in individual section 4, $Q_{\text{ogr}}$ – heat flow reflected from fence of individual section 4, $Q_{\text{luch}}$ – heat exchange with the internal surface of the fence, $t_{\text{ogr}}$ – internal fence temperature for individual section 4, $t_{\text{n.v.}}, t_{\text{v.v.}}$ – temperature outside the device, $t_{\text{v.v.}}$ – temperature inside individual section 4, $\phi_{\text{n.v.}}, \phi_{\text{v.v.}}$ – relative humidity outside the device, $\phi_{\text{v.v.}}$ – relative humidity inside individual section 4, $Q_{\text{konv}}$, $Q_{\text{vent}}$, $Q_{\text{ogr}}$, $Q_{\text{luch}}$, $t_{\text{ogr}}$, $t_{\text{n.v.}}, t_{\text{v.v.}}$, $\phi_{\text{n.v.}}, \phi_{\text{v.v.}}$ – for individual section 5.

In a first approximation, we neglect the heat exchange between the airoponic elements and the atmosphere of the chamber after establishing the steady temperature condition.

Therefore, formula 1 looks like:

$$Q_{\text{tl}} = Q_{\text{ogr}} + Q_{\text{vent}} + Q_{\text{sek}}$$  \(1\)

where $Q_{\text{sek}}$ means heat exchange between the individual sections, W; $Q_{\text{tl}}$ means total heat flow from the heat source, W; $Q_{\text{ogr}}$ means total heat loss through the fences, W; $Q_{\text{vent}}$ means heat loss through the ventilation, W.

Heat loss $Q_{\text{ogr}}$ is calculated by the formulas, W:

$$Q_{\text{ogr}} = \frac{t_{\text{ogr}} - t_{\text{n.v.}}}{R_t} F_{\text{ogr}} (1 + \beta_{\text{inf}})$$  \(2\)

$$Q_{\text{sek}} = \frac{t_{\text{ogr}} - t_{\text{n.v.}}}{R_t} F_{\text{sek}} (1 - \beta_{\text{inf}})$$  \(3\)

where $F_{\text{sek}}$ means the square of the sections, m$^2$; $R_t$ means the heat transfer resistance of the fence, m$^2$-K/W; $F$ means the total area of the fences, m$^2$; $\beta_{\text{inf}}$ means the outside air infiltration coefficient.

The difficulty in finding heat flow $Q_{\text{ogr}}$ under formula (2) is related to unknown temperatures $t_{\text{ogr}}$ and $t_{\text{ogr}}$, which are found through the solution of a system of equations of the heat balance for the internal surface of the fence. Thereat, the first equation is expression (2) and the second one is [9]

$$Q_{\text{ogr}} = (1 - \frac{A_1}{k_{\text{kar}}}) Q_{\text{tl}} + Q_{\text{luch}} + Q_{\text{konv2}}$$  \(4\)

where $k_{\text{kar}}$ means the coefficient, which takes into account the multiple reflection of thermal radiation from the internal surface of the fence; it is set empirically with a further refinement; $A_1$ means the absorption coefficient of the internal surface of the fence; $Q_{\text{konv2}}$ means the heat flow from the convective heat exchange between the internal air and the internal surface of the fence, W.
In which case
\[ Q_{conv} = \alpha_{vn}(t_{v,v} - t_{ogr})F_{ogr} \]  \hspace{1cm} (5)
where \( \alpha_{vn} \) means the heat exchange coefficient of the internal surface of the fence.

The heat loss with outgoing ventilation air \( Q_{vent}, W \), is equal to the heat flow rate, which is used to heat the supply air coming into the section through the ventilation opening:
\[ Q_{vent} = G_{s}(h_{vn,v} - h_{n,v})Q_{vent} = G_{s}(h_{vn,v} - h_{n,v}) \]  \hspace{1cm} (6)
where \( G_{s} \) means the mass flow rate of the air involved in the heat exchange, kg/s; \( h_{vn,v} \), \( h_{n,v} \) mean specific enthalpy of the internal and external air, J/kg.

4. Conclusion
The multi-section climate chamber proposed provides carrying out necessary studies under conditions of controlled microclimate with flexible adjustment of each separate isolated section available, which will significantly reduce the time expenditures for finding the optimal microclimate conditions for each particular sample.

The treatment of the incoming air by means of ozone in combination with complete isolation of the sections from each other and from the ambient will achieve the high level required of biological purity.

The device proposed provides a wide range of climate conditions, as well as their combinations inside a single device, the processability of their implementation in growing crops in a climate chamber and it can be easily implemented in agricultural production for selective breeding of plants and for other purposes.

The mathematical model developed of the heat balance allows to determine important parameters for a climate chamber made of several interacting sections, such as the total power required of thermal radiation and the necessary heat consumption to develop and maintain the plant activity under preset specific conditions. The latter can include the temperature of the ambient air, the air exchange rate in the greenhouse and in the premise, the temperature of the active volume, etc. In the future, directions in the development of modeling heat-mass exchange processes, which occur in a chamber, can be graphs reflecting the nature of the changes in the dependent values due to variable values, refinement of the methods of determining moisture evaporation from the active volume, determining the heat reflection coefficient, and other refinement options.

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