552-51

N96- 18145

SHORT REPORT

ENHANCEMENT OF EFFICIENCY IN THE USE OF LIGHT FOR CULTIVATION OF PLANTS IN CONTROLLED ECOLOGICAL SYSTEMS

A.L. Mashinsky*, V.I. Oreshkin*, and G.S. Nechitailo**

*Institute of Biomedical Problems, Moscow, Russia
**NPO Energiya, Kaliningrad, Moscow region, Russia

The problems of plant cultivation with the use of artificial lighting are related to energetics and, first of all, to the lack of effective sources for photosynthesis, secondly to the necessity to supply a system with a considerable power in the form of light energy and to remove transformed thermal energy, and finally to economic considerations. These problems are solved by three ways: by the choice of effective radiation sources, design approaches, and technological methods of cultivation. We shall consider the first two ways.

Analysis of the characteristics of available light sources (Table 1) shows that filament lamps have a low efficiency coefficient and high infrared radiation (IR). Metal halide lamps have a high efficiency coefficient (up to 38%), a continuous spectrum and a short life. Besides, their control scheme is rather complicated. Fluorescent high-pressure lamps have a low efficiency coefficient and a large size of the luminous body which interfers with the redistribution of their radiant flow. Compact KL 7-11 lamps have good prospects. They are characterized by a high surface radiation density and a small size permitting the redistribution of their radiant flow. However they have not been tested for their use in space. Fluorescent low-pressure lamps and sodium high-pressure lamps also appear to be promising. The main characteristics of fluorescent lamps and sodium high-pressure lamps are presented in Table 2. All these lamps are characterized by a high surface radiation density providing a radiation level sufficient for plant growth and development. It is known from ground-based experiments that the cultivation of plants requires a radiation level of no less than 70 W PAR/m^2 with a PAR/IR ratio of no less than 1:4. This means that for an area of 1.0 m^2, 88 lamps would have to be installed utilizing 0.7 kW of electrical energy. When using 11 W compact lamps, 40 lamps would be needed with a power demand of 0.55 kW.

Special 8 W white fluorescent lamps were designed for space plant growth units and also used as light sources for general use on the ground: SD 1-4 (1 lamp), SD 1-5 M (1 lamp), SD 1-7 (2 lamps) and PSB (6 lamps). The light device ARNIKA with a sodium high-pressure lamp, DNaT-70, was designed for space experiments.

Under ground-based conditions we carried out an experiment to estimate the efficiency of light devices SD 2-7, PSB (with white and red- and blue-colored lamps in the ratio of 3:2:1). In a mixed spectrum the productivity of lettuce was found to be increased by 20-25%. Also, some changes in the biochemical composition of plants were noted. The productivity of plants upon equalization of light power under DnaT-70 lamps corresponded to the growth with a mixed spectrum and significantly exceeded that under lamps with a continuous spectrum.

TABLE 1. Some characteristics of lamps for irradiation.

Class of lamps	Power range (W)	Life (h)	PAR:IR (400-700:700-1200)	Notes
Filament	unlimited	up to 2000	1:7	
Fluorescent				
Low-pressure	4-150	3000-15,000	1:0.05	used in space investigations
High-pressure	80-2000	15,000	1:1	
Metal halide	250-2000	200-2000	1:0.7	
Sodium high-pressure	70-1000	up to 15,000	1:0.4	prepared for the use in space investigations

TABLE 2. Main characteristics of Fluorescent lamps.

Type of lamps	Power, W	Size, mm	Power in the PAR zone,W	Superficial rediation density	Notes
LB4-2	4	16x160	0.6	90	
Fluorescent LB8-6	8	16x298	1.4	115	used in space investigations
L38	8	16x298	1.6	130	no analogs
LS8	8	16x298	1.2	100	no analogs
LK8	8	16x298	1.4	115	no analogs
KL/TBS	7	135x32x20	1.3	150	not tested in for space investigations
KL/TBY	11	235x32x20	2.5	190	

The first lighted unit used for plant cultivation under space flight conditions, Oasis-1, was placed aboard the first orbital station Salyut. the electric power demand of this apparatus was 30 W. Three SD 1-4 light devices with white fluorescent lamps were used. Nine plants provided with 6 cm^2 each, were placed within an irradiated area of 400 cm^2. The rate of the luminous flow reached 25±5 W PAR/m^2. Later on, modified light devices SD 1-5 M and SD 1-7 were used in Svetoblok, Fiton, Malakhit and in modified Oasis-1 AM aboard the orbital stations Salyut and Mir. Using white fluorescent lamps, LB 8-6, in the growth unit, Svet, aboard the station Mir, the power in the PAR region was increased up to 30±10 W/m^2 due to a more compact arrangement of lamps (6 lamps per 500 cm^2). This required the use of a heat removal system, thus the total energy in the vegetation chamber was increased. Fluorescent lamps were used in the American PGU. Light diodes have been used in the University of Wisconsin Astroculture flight unit.

With the above-mentioned devices, fundamental results in the field of space biology were obtained directly related to the development of maned space flights, particularly to the possibility of creation of biological life-support systems. A fundamental possibility of growth and development of plants under microgravitation conditions, including the stage of seed production, was demonstrated (Merkis, Laurinavichus, 1980; Mashinsky, Nechitailo et al., 1992; Nechitailo, Mashinsky, 1993). At the same time, the problem of lighting efficiency remains. As early as the middle seventies we began constructing a chamber to provide one astronaut with a daily ration of vitamins and a part of the vegetable ration, to improve the psychological comfort of astronauts, and to develop studies on the use under microgravitation conditions of higher plants as an element of the life-support system. The device was named KAMIN (by the first letters of the family names of the authors - Konshin, Alexander Mashinsky and Nechitailo).

Plants grown in Kamin are assumed to produce 20 g of dry biomass daily for 1.0 m^2 area under the following conditions: carbon dioxide at 0.3±0.05%, oxygen at 18±3%; air humidity at 80±15%; temperature at 20±5°C (the temperature difference between the vegetation and root zones should be no less than 2-5°C), irradiation at 100±20 W PAR/m^2. The basis of the device is a cylinder with a vegetation unit on its inner surface. The cylinder is able to rotate on bearings relative to the growth chamber body and the lighting unit, which is located excentrically in the cylinder, thus providing for even illumination of plants of different age in the units. The plants are grown in units by the conveyor method (each unit contains plants of different age).

We returned to the idea of using the new design units for improving illumination conditions when developing a modified Svetoblok-2 together with a group of U.S. scientists from the University of Utah. The leader from the U.S. side was Professor F. Salisbury. As a result of the joint work of the American and Russian scientists, a model was constructed to be used in joint Russian-American space research programs. The idea initially consisted in placing lamps vertically in an ellipse focus which formed a light-reflecting surface. In the other focus it was planned to place plants. Thus, the whole light energy reflected from the ellipse surface would remain in the vegetation zone. The data indicate that the given technological approach permits an enhancement of lighting efficiency providing for photosynthesis. Unfortunately, it should be stated that this work has not yet received further development as a cooperative Russian-American project for joint investigations aboard orbital stations. Therefore the Russian specialists offer to other interested scientists to continue this joint activity.