First Automated Facility for Plant Growth Experiments in Space Research

Dr. Tania Nenova Ivanova, Plamen Todorov Kostov,
Svetlana Markova Sapunova, Ivan Wilhelm Dandolov

Space Research Institute, Bulgarian Academy of Sciences, Sofia, Bulgaria

SUMMARY

Higher plants are a basic link in a future Biological Life Support System (BLSS) intended to provide space crews with food and clear the air in spacecrafts as well. SVET Space Greenhouse (SG) - the first automated facility for higher plant growing under microgravity was designed in the late 1980s according to a joint Bulgarian-Russian project for future long term manned missions in Space. It was launched onboard the CRYSTAL module docked to the MIR Orbital Complex (OC) in June 1990. The first successful 54-days experiment with vegetable plants was carried out in 1990 in this equipment [1].

The experiments in SVET SG were resumed in 1995, when an American SVET Instrumentation System (SIS) was added to the existing Bulgarian plant life support system of SVET SG to significantly expand the range of plant environmental parameters being monitored. A three-month wheat experiment being a part of the MIR-SHUTTLE'95 fundamental biological program and named "Greenhouse" was started on August 10, 1995.

A set of SVET-2 SG equipment (a greenhouse of new generation) with improved technical characteristics was developed by Bulgarian scientists (financed by NASA) and launched onboard the MIR OC. Successful six-month wheat experiments for growing up of two consecutive crops were started on August 5, 1996 and four-month soya plant experiments - on May 31, 1997 as part of MIR-NASA-3,5 programs.

EQUIPMENT USED IN THE 1995 EXPERIMENT

The complex of equipment used in the 1995 experiment included the Bulgarian SVET SG used in 1990 and the new supplemented American SIS [2]. The block diagram is shown in Fig.1.

The Vegetation Module (VM) with about 0,1 m^2 plant growing area is located within the Plant Growth Unit (PGU). It consists of two sections K1 and K2 located side by side in a drawer that is inserted into the PGU. Each section is filled with substrate - granular zeolite material called Balkanine which has been charged with mineral salts to provide sufficient nutrients for 3 to 4 vegetations. Water is injected through a polyvinyl formal foam surrounded tube or hydroaccumulator located directly bellow the plants.

The necessary water portions and the air are supplied to the substrate during vegetation by using a hydro-air system (HAS), located on the PGU bottom. The SVET SG water delivery system consists of a pump and two solenoid valves which can be opened to allow water flow to each section. The pump is controlled by the Control Unit (CU) using signals from the SVET SG substrate moisture sensors located in the middle of each section. The sensors are surrounded by a layer of the wicking material which bridges the wicks attached to each of the hydroaccumulators [3].

The Illumination Unit (IU) is located in the upper section of PGU. It can be shifted vertically and fixed at three positions, at distances of 20, 30 and 40 cm from the VM surface. The purpose is maximum illumination to be attained during the different stages of the plant growth. The light is programmed to be on for 16 hours a day. A ventilator with a ventilation rate of about 2000 l/min ensures lamp cooling and air circulation within PGU.

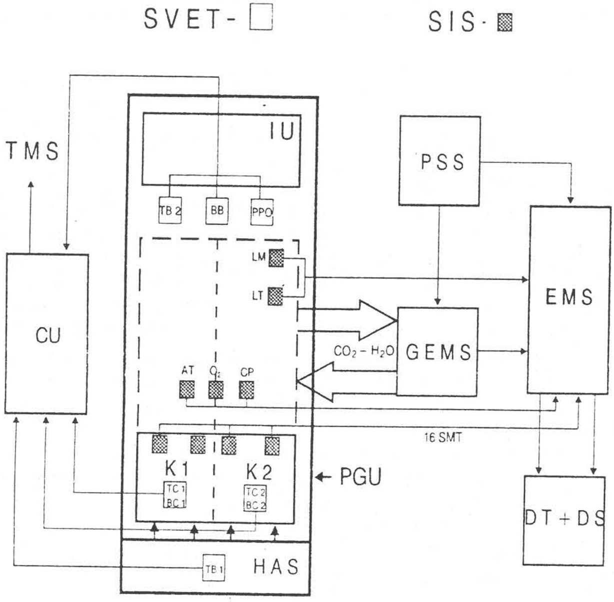

Fig. 1. Block diagram of the integrated system SVET SG – SIS and location of the sensors.

CU performs measurement of the environmental parameters in PGU, ensures appropriate substrate moisture and automatically controls the all executive systems (switches on and off the lamps, ventilator, pump and compressor). Special microprocessor programs ensure automation of all processes and give signals if failure has occurred. Visual control and manual guidance are also possible. CU measures the parameters of the vegetation process at each 4 hours, thus registering daily a telemetric frame with 6 columns of information. Each column contains data for the parameters measured within the 4-hour interval, day and column number. The information from the buffer memory at the CU output is continuously transmitted to Earth through telemetry. CU can operate in an automatic mode, following three programs:

PROGRAM 1 - autonomous test of CU and the all executive systems.

PROGRAM 2 - initial substrate moistening (lasts about 10 hours).

PROGRAM 3 - automatic control of all systems (lamps, ventilator, compressor and pump). The parameters measured by CU are as follows:

- Air temperature entering PGU-TB1;
- Air temperature within PGU-TB2;
- Substrate temperature in cell K1 of VM-TC1;
- Substrate temperature in cell K2 of VM-TC2;
- Relative air humidity within PGU-BB;
- Substrate moisture in K1-BC1;
- Substrate moisture in K2-BC2;
- Duration of the lighting period -PPO;

If TB2 exceeds a threshold of overheating a non-standard situation is indicated, the lamps are switched off and the ventilator keep working until the temperature becomes lower. The pump is switched on depending of the current measured values of BC1,2 and the assigned threshold levels.

The American SIS encloses two separate transparent bags, called leaf chambers which cover the plants growing in each VM section of SVET SG. It allows local gas exchange and leaf environment measurement.

SIS consists of four primary modules: a gas exchange monitoring system (GEMS), an environmental monitoring system (EMS), a power supply system (PSS), and a data collection and display system (DT+DS) [4].

GEMS has to provide accurate measurement of absolute and differential CO_2 and H_2O levels in the air entering and exiting the PGU as well as absolute and differential pressures in the measured gases. It is necessary to evaluate some prime indicators of plant health as photosynthesis, respiration, and transpiration. EMS measures the air and soil conditions in which plants are growing (inside leaf chambers).

SIS additional sensors give the possibility to have more information about the air and soil conditions for growing up of the plants. The additional variables being measured are:

- Plant air temperature (AT)
- Plant light monitor (LM)
- Plant leaf temperature (LT)
- Soil temperature and moisture (SMT)
- Cabin pressure (CP)
- Cabin O_2
- Cabin H_2O (air humidity)
- Cabin CO_2

SIS provides 16 additional substrate moisture sensors SMT (8 per section) to monitor the water distribution. They are designed to be integrated in the existing VM on flight.

OPTIMISATIONS OF THE SVET-2 SG HARDWARE FOR THE 1996-97 EXPERIMENTS

A greenhouse of new generation SVET-2 SG with improved technical characteristics was developed by Bulgarian scientists (financed by NASA) and launched onboard the MIR OC in 1996. For example, a new optimised

Illumination Unit (IU) with considerably improved technical and biotechnical characteristics was designed to meet the requirements of the plants [5].

The plants need light with determined quantity and quality. A photo–physiological inquiry shows that the plants consume energy mostly in two spectral bands – blue and red. The activity of some physiological processes depending on the effect of light of different wave length is shown in Fig.2 (curve 1 – phototropism and curve 2 – photosynthesis). Till the experiment in 1990 fluorescent lamps LB 8–6 (12 pieces) were used. The spectral–response characteristic of IU using these kinds of lamps is shown by curve 3. It is seen that almost the whole luminous energy is concentrated in minimum sensibility zone of the plants. That considerable discrepancy between the light source and plant needs was due to the lack of special lamps (during the period of development) with appropriate characteristics and save enough for the crew in case of breaking a lamp.

The increased supply of fluorescent lamps in the last years gave a possibility to conduct an extensive researches on the characteristics of the supplied kinds of lamps. The spectral–response characteristics of 12 kind of lamps in the band 400 – 600 nm were taken with the help of the Faculty of Physics at Sofia University. For some of them the measuring range in the blue and red region respectively was enlarged. The energy characteristics which are of particular importance when put to use the onboard power supplies were analyzed. The geometrical dimensions of IU narrowed the range of the used lamps too. The fluorescent lamp DS 11/21 of OSRAM (6 pieces) as a most suitable for our aim was chosen. At that the lamp spectrum was suitable for intensive photosynthesis as well as for providing phototropism of the plants, so important in conditions of a space flight (curve 4 of Fig.2).

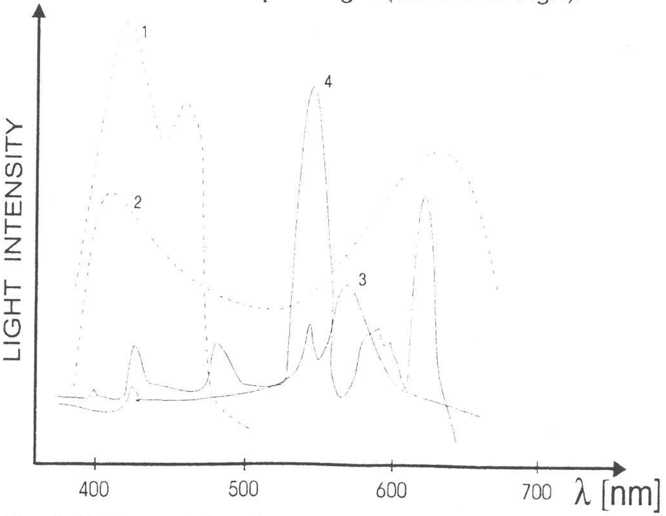

Fig. 2. Light wave lengths necessary for plant's: 1 – phototropism and 2 – photosynthesis; Spectral response characteristics of the lamps used in SVET SG (LB 6–8) - 3 and SVET–2 SG (DS 11–21) - 4.

When we were building the lamp's bodies we conducted two more important investigations – on a white reflecting paint, made to order, suiting very special requirements, and on a transparency coefficient of the plexiglas for proofing the separate illuminants. As a result of the investigations considerably (2,5 times) improved brightness characteristics of IU were received – at a distance of 15 cm from the illuminants the intensity was 27 000 lx (under 12 000 lx in SVET SG in 1990). In the circumstances we could expect considerable increase of the plant productivity (quantity of biomass) in the future experiments.

The larger warranted duration of work of the lamps DS 11/21 (8000 hours) ensured 5 times better reliability of the equipment. Besides the new IU had considerably better electrical characteristics - a fact which was of great importance because IU was the biggest energy consumer within SVET SG. For example the supply current of the unit (under ±27V_onboard supply voltage) was 2,5 times lower (3,5A under 9A in SVET SG) and the starting current was almost equal to the supply one. The newly developed IU had lower weight (2 kg) and much better mechanical characteristics. The mechanical structure was optimized and it was far more functional: IU could be easily moved and fixed within the Plant Growth Unit and the lamp's bodies were easy to change.

Some improvements were made in the rest units.

Software improvements in CU made the substrate moisture measurement more precise and provided a possibility for individual, consecutive and independent measurement of each VM sensor. Another software improvements enabled the PPO parameter (duration of the lighting period) to be changed when it is necessary. The lighting period can be changed within an interval of 1 ÷ 23 hours. A possibility of controlling the threshold of overheating (the temperature TB2 at which the lamps are automatically switched off in case of overheating) was provided in the IU to resolve the problems with the equipment temperature incompatibility. A new CU Second Power Supply with larger warranted duration of work and higher efficiency was developed to meet the stronger requirements of the new experiments.

New construction of the Vegetation Module was developed to make the equipment interchangeability easier. Besides substrate with new granule size composition (a fraction mixture of 1 – 2 mm granules) was used to improve the water distribution in weightlessness.

A Secondary Pump Power Supply (SPPS) with higher efficiency and higher starting current was developed to replace the SPPS unit standing on MIR within PGU.

RESULTS AND CONCLUSIONS

Plants grown in SVET SG equipment in 1990 and 1995 onboard the MIR OC were normally developed but they produced considerably smaller quantity of biomass compared to the ground control due to the insufficient substrate moisture in the condition of microgravity and light.

In the new SVET-2 SG are improved mainly this characteristics and together with the SIS increased the information possibilities of the equipment and helped us to achieve the 1996-97 experiments goals: to grow plants through a complete life cycle "seed-to-seed"; to document the environmental parameters that might impact plant growth (in addition to microgravity); to improve control and conditions for plant growth as much as possible. The last experimental unique results in the field of the fundamental biology proved that normal technical and technological conditions for plant growth in microgravity had been provided:

1. The six-month wheat experiments conducted as part of the MIR-NASA-3 program with the participation of the American astronauts Shannon Lucid and John Blaha in 1996-97 aimed to achieve a full life cycle "seed-to-seed". This experiment was not quite successful to this effect. The most surprising observation was that the heads, although they appeared to be healthy contained no seeds. The most likely reason was considered to be the presence of gas, ethylene, a gaseous plant hormone that is known to produce plant sterility but this still will be subject to verification in the future. At the moment SVET-SIS system continues to work onboard MIR OC and Greenhouse-4 experiment is carried out to check this effect in the period August-November 1998. But an undoubted success was the proof that the new developed Bulgarian SVET-2 SG equipment with improved hardware and biotechnology can be used to grow higher plants under weightlessness.

2. The four-month soya plant experiments were conducted as part of the MIR-NASA-5 program with the participation of the American astronaut Michael Foale in the same equipment onboard the MIR OC in 1997. An unique result in the field of the fundamental biology was achieved - a complete life cycle and plant reproduction was carried out in space (new plants were grown from seeds produced onboard). It was proved that there are not "show stoppers" in the lack of gravitational forces and that plants can be successfully used to clear the air in the future BLSS aimed to support crews during long lasting space flights.

A new generation SVET-3 SG equipment is to be designed for the future experiments onboard the International Space Station (2000 - 2010).

REFERENCES

1. T.N.Ivanova, Yu.A.Bercovich, A.L.Mashinskiy, G.I.Meleshko The First Vegetables Have been Grown up in the "SVET" Greenhouse by Means of Controlled Environmental Conditions. Microgravity Quarterly, Vol. 2, 1992, 2, 109-114.

2. T.Ivanova, P.Kostov and S.Sapunova. Renewing of the Greenhouse Biotechnological Experiments Onboard the MIR Space Complex. 46th Intern. Astronautical Congress, Oslo, Norway, 2-6 Oct.1995, Rep. IAF/IAA-95-G.4.01

3. T.N.Ivanova, I.W.Dandolov. Moistening of the Substrate in Microgravity. Microgravity Science and Technology. Volume V (3); October, 1992, 151-155.

4. T.Ivanova, P.Kostov, S.Sapunova, G. Bingham, S. Brown. Equipment for the Greenhouse SVET'95 Project and Some Optimizations for Future Experiments on Board the MIR Orbital Complex, Aerospace Research in Bulgaria, 14, 1998, 46-49.

P.T.Kostov, T.N.Ivanova, S.M.Sapunova. Adequate Substrate Moistening System and Artificial Lighting for the Growth of Higher Plants in the "SVET" Space Greenhouse. ACTA VET. BRNO, vol.65, 1, 1996, 19-25.