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MONITORING AND CONTROL OF ATMOSPHERIC GAS COMPOSITION IN SPACE PLANT GROWTH FACILITIES: SELECTION OF CO_2 SENSORS FOR THE SVET-3 SPACE GREENHOUSE

S. Sapunova, T. Ivanova, P. Kostov, Y. Naydenov, I. Ilieva, I. Dandolov

Abstract. A main motivation and final goal of all plant space investigations has always been to create advanced Biological Life Support Systems where plants have an essential role in keeping and supporting the astronauts' life. Small plant growth facilities with various levels of automation and control have been developed and flown on board the Russian Space Station MIR, the U.S. Space Shuttle and the International Space Station. The paper presents a survey of the atmospheric gas composition control systems used in these facilities. The objectives and first steps of the research work on developing a new generation of space greenhouse – SVET-3, are described, focusing on the channel for plant environment measurements. Considerations taken into account in the selection of CO_2 sensors are listed. Comparative assessment of the technical characteristics of CO_2 sensors is made to choose those that best meet the requirements.

Keywords: gas composition control, plant growth facility, ethylene, CO_2 sensors, SVET space greenhouse

1. INTRODUCTION

Although most past and present plant space experiments have focused on study of microgravity effect on plant physiological functions, a main motivation and a final goal of all these research have been to create advanced Biological Life Support Systems (BLSS) where plants have an essential role in keeping and supporting the astronauts' life. Small plant growth facilities with some level of automation and control have been developed and flown onboard the Russian Space Station MIR (SVET SG - the Bulgarian developed SVET Space Greenhouse), and the U.S. Space Shuttle (PGU - Plant Growth Unit, PGF - Plant Growth Facility, ASTROCULTURE™, PGBA - Plant Generic Bio Processing Apparatus). Other facilities (ADVANCED ASTROCULTURE™, BPS - Biomass Production System, CPBF - Commercial Plant Biotechnology Facility, PRU - Plant Research Unit, and LADA Space Greenhouse) are developed and some of them flied onboard the International Space Station (ISS). These plant facilities provide no more than 0.1 m^2 of growing area and have been developed under mass, volume and power constraints that spaceflight conditions impose on the equipment. Ground studies and conceptual designs have explored the possibilities of creating larger and more sophisticated plant growth facilities that could play a key role in future controlled ecological life support systems for operation onboard the ISS or for long-term Mars missions.

To compare plant growth results between Earth and space grown samples, and to ensure reproducible plant experiments, they must be conducted in a controlled environment. The main variables of the plant leaf environment affecting plant growth are temperature, humidity, carbon dioxide, oxygen and trace gas elements. The Plant Chamber (PCh) environment control system must maintain adequate CO_2 and O_2 levels and limit some volatile organic compounds such as ethylene which affects strongly plant growth but may be present in the crew cabin.

Photosynthesis and subsequent plant growth is strongly controlled by light and atmospheric O_2 and CO_2 concentration. Spaceflight plant growth chambers are typically located within the crew cabin atmosphere, maintained mostly at 101 kPa absolute pressure. CO_2 concentration in the crew cabin is higher when compared to Earth (350 ppm) and fluctuates with crew activity between 2000 and 7000 ppm onboard the Space Shuttle and MIR. Onboard the ISS CO_2 concentrations of 700 ppm have been measured.

Since the spacecraft environment itself is controlled to less stringent requirements than those required for scientific plant research, and since adequate environment have to be provided to protect the health and safety of the astronauts, spaceflight PChs are isolated from the crew cabin. This is necessary to achieve cabin-independent, accurate and regenerative control of CO_2 and O_2, as well as ethylene scrubbing.

The following main types of plant growth chambers and atmosphere control systems [1], [4] have been used in the spaceflight plant facilities:

- Semi-open to cabin atmosphere (SVET-2+GEMS) – first gas composition and plant physiological parameters measurements using the American developed Gas Exchange Measurement System (GEMS).
- Open (PGU with atmospheric monitoring system) – not controlled, but passive adsorption of CO_2 and ethylene.
- Sealed (PGU) –works only for short periods of time and low light intensities, otherwise rapid depletion or accumulation of O_2, CO_2 and trace gases.
- Isolated (PGBA, PGF, BPS, CPBF and ASTROCULTURE^{TM}) – uses controlled intake of cabin air or pressurized pure CO_2 to maintain set point for CO_2 and O_2 concentration.

The process of gas exchange in the plant leaf environment is analyzed and the knowledge of atmospheric gas composition control in closed chambers in space is summarized in order to specify the requirements to the CO_2, O_2 and ethylene control systems. Objectives and first steps of the research work on the new generation SVET-3 SG development are described focusing on the channel for leaf environment measurements. Comparative assessment of the technical characteristics of CO_2 sensors is made to choose those that are most meeting these requirements.

2. A SURVEY OF ATMOSPHERIC GAS COMPOSITION CONTROL SYSTEMS IN PLANT GROWTH FACILITIES FOR SPACE APPLICATION

During photosynthesis plants absorb carbon dioxide and water and convert it into organic compounds with oxygen as a waste product. A net conversion of CO_2 into O_2 takes place in the PCh during the "day", while at "night" O_2 is consumed and CO_2 is produced. Depending on light intensity, day-night cycle, and environmental conditions (temperature, humidity, carbon dioxide, and oxygen concentration), a net oxygen production and net carbon dioxide removal from the chamber can occur during the "day". But in some earlier spaceflight plant growth facilities the low light intensities (below the compensation point, Fig. 1), lead to net oxygen use and net carbon dioxide production even during the "day". With higher light intensities and longer plant growth periods in the next generation plant growth chambers (PGBA, BPS, and CPBF), the total mass of CO_2-O_2 conversion and the regenerative equipment functions respectively increase. Net oxygen is produced and carbon dioxide has to be supplied to the PCh atmosphere [1].

At "night", the increase of CO_2 concentration due to respiration can be limited using scrubbers (lithium hydroxide – PGU or barium hydroxide - PGBA).

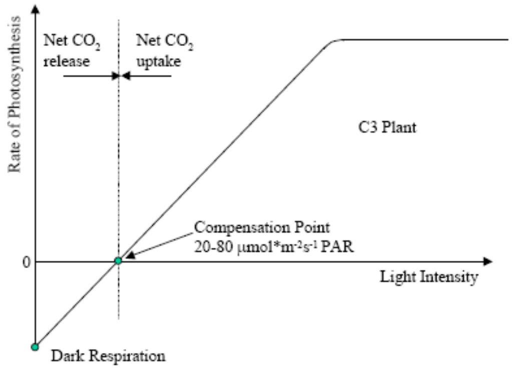

Fig. 1. Photosynthesis - simplified CO_2 exchange rate as a function of light intensity. At low intensities and at night, CO_2 is produced and O_2 is consumed. At intensities above the compensation point, net O_2 production and net CO_2 fixation take place.

CO_2 Control

During the "day" CO_2 is consumed in consequence of photosynthesis. Various approaches have been used in any particular plant growth facility to replenish the net loss of CO_2 in order to control CO_2 concentration in the chamber during plant growth:

- Some plant growth units (ASTROCULTURE^{TM}) use unpressurized pure CO_2 injection [2, 3]. CO_2 concentration is currently measured through an infrared gas analyzer and CO_2 gas is added to the chamber air if the concentration is less than the desired level. No provisions are included for CO_2 removal when the concentration exceeds the desired level, as it is the case during the dark periods.

- Other facilities (BPS, CPBF) use pure CO_2 injection (pressurized) from stored CO_2 sources. The use of pressurized CO_2 requires additional systems to control the CO_2 flow, as well as resupply of CO_2 replacement tanks. On the other hand the O_2 produced by photosynthesis from pressurized CO_2 would need to be separated from the plant atmosphere, and ejected to the crew cabin, because high O_2 concentrations can limit the photosynthetic rates in some plants. Another possibility for the photosynthesis-produced O_2 is to be absorbed (oxidized) or converted (catalytic combustion) to produce CO_2.
- Some facilities such as PGBA use injection of CO_2-enriched cabin air to the PCh [4]. Since Earth CO_2 concentrations (≈350 ppm) are desired for the crew cabin but in the spacecraft atmosphere they are typically elevated (2000-7000 ppm on the Space Shuttle and 700 ppm on the ISS) it is possible to draw CO_2-rich cabin air into a sealed PCh to replenish CO_2, as long as a chamber concentration below cabin air is acceptable. The smaller the difference between cabin and plant atmosphere, the more open the system. Injection of cabin air automatically reduces the photosynthetically produced oxygen concentration inside the chamber to that of the crew cabin.

At night the increase of CO_2 concentration due to respiration can be limited using scrubbers, such as lithium hydroxide (PGU) or barium hydroxide (PGBA).

O_2 Control

In the past, PChs provided very low light intensities and oxygen production was not a problem during short spaceflight missions. With increased light intensities and extended growth periods with rapidly growing plants, oxygen concentrations need to be controlled. In a sealed chamber without oxygen removal, O_2 concentrations could increase to high levels within short periods of time, depending on the rate of photosynthesis of the plants inside the chamber (based on plant type and age, chamber volume, CO_2 concentration and light intensity). This requires availability of a controlled oxygen removal system, as high O_2 concentration can inhibit photosynthesis and limit the plant growth.

- Passive control: The simplest solution is to reduce the increasing O_2 content in the PCh to the one of the cabin air, by “opening” the chamber to the cabin.
- An active oxygen removal system based on O_2 absorbers (non-regenerative method) or semi-permeable membranes (regenerative method) allow achieving accurate and independent oxygen control.

Most plant growth facilities do not use oxygen control systems. PGBA uses passive oxygen control [4]. PCh is maintained at pressure equilibrium with the ambient cabin air. Relief valves ensure that for every volume of CO_2-rich cabin air taken in, equal volume of air is expelled from the chamber. Internal fans allow fast mixing between intake and chamber air. In this way the daytime O_2 concentration is approximately the sum of the external O_2 and the difference of CO_2 concentrations (external – internal) assuming 1:1 ratio of CO_2-O_2 conversion in photosynthesis.

Ethylene Control

Conducting plant research in microgravity requires a research facility that is enclosed and environmentally controlled. The use of sealed environments such as the ISS crew cabin and the sealed PCh leads to accumulation of trace contaminants (volatile organic compounds - VOC). A part of them is produced from offgassing of non-metallic materials within the PCh or introduced by incoming cabin air while another part is present as trace gases produced by the plants themselves, such as the plant hormone ethylene (C_2H_4). VOC, and especially ethylene, are of great importance for plant growth. Offgasing can be minimized using metallic materials instead of plastics.

Interactions between trace gases especially ethylene were investigated from two different viewpoints:

I. Ethylene above 50 ppb is toxic for plants.

An enclosed chamber may result in high concentrations of ethylene which can accumulate to levels well above the level what plants are able to adapt to. It is considered that ethylene concentrations above 50 ppb can harm plants. The physiological effects of excessive ethylene on plant development include induction of male sterility. Early experiments were hampered by high ethylene levels, which inhibited seed production. That was the case with the "Greenhouse 2b" experiment conducted on MIR-NASA-3 program in 1996-1997 in the Bulgarian SVET-2 Space SG [5]. Ethylene (300 ppb) was a problem due to the lack of an ethylene scrubber. Super-dwarf wheat plants, grown through a complete life cycle, produced considerable biomass and heads that proved to be sterile. Later a ground study was conducted in IBMP, Moscow to ascertain if Super Dwarf wheat responded to the 1.1 to 1.7 ì mol.mol^{-1} atmospheric levels of ethylene measured onboard the MIR prior to and during flowering. For that purpose plants were exposed to 0, 1, 3, 10, and 20 ì mol.mol^{-1} of ethylene gas and 1200 ì mol.mol^{-1} CO_2 from the 7th day after emergence to maturity. As in space the heads produced also exhibited 100% sterility.

Several methods have been applied in the plant growth facilities with an isolated PCh to control the ethylene level:

- Adsorption on activated charcoal.
- Oxidation by Potassium Permanganate (KMnO4), commercially available as Purafil™ (Activated Alumina impregnated with Potassium Permanganate).
- Photocatalytic conversion on Titanium Dioxide using UV-light.

In nature, the ultraviolet spectrum of the sunlight typically results in oxidation of some of the volatile organic compounds. To prevent the accumulation of ethylene to harmful levels the ASTROCULTURE™ unit uses an ethylene removal unit built on the basis of photocatalytic ethylene oxidation [2]. It contains a UV lamp and a modified titanium dioxide material that serves as a catalyst to oxidize the ethylene to CO_2 and water using UV radiation. Similar ethylene removal units have been used in BPS and CPBF plant growth facilities.

PGBA uses both a photocatalytic ethylene scrubber and an activated charcoal filter to further limit trace gas or contaminant buildup inside the plant growth chamber [4].

II. Ethylene release rate of plants can be utilized as a plant growth indicator.

In order to obtain data about ethylene evolution A. Tani et al. [6] grew Lettuce plants in a closed chamber under a controlled environment. It was proved that ethylene release rate highly correlated with plant growth parameters (dry weight, leaf area, and photosynthetic rate). As a result the measurement of ethylene concentration in CELSS was evaluated as one of the useful non-destructive measurement methods for plant growth diagnosis.

3. CURRENT ADVANCES IN THE DEVELOPMENT OF A GAS COMPOSITION MONITORING SYSTEM THE FOR SVET-3 SG

SVET-3 SG Conception

In most of the plant growth facilities (ADVANCED ASTROCULTURE™, Russian LADA SG, BPS etc.), flied onboard the ISS, environmental control comes down to maintaining environmental parameters at set levels considered adequate for normal plant growth. None of them include measurements of plant growth parameters. A part of them maintain constant root and leaf environment parameters and provide a possibility to change some of them so that taking samples for analysis at different stages of plant development to record the functional dependence of plant growth on these parameters. The end objective of all these facilities is to maintain a constant plant growth environment so that it would be possible to differentiate the influence of microgravity on the growing plants.

The future controlled plant growth facilities for long-term missions would have larger area and volume. Maintaining constant plant growth environment in such a large volume would require too much power.

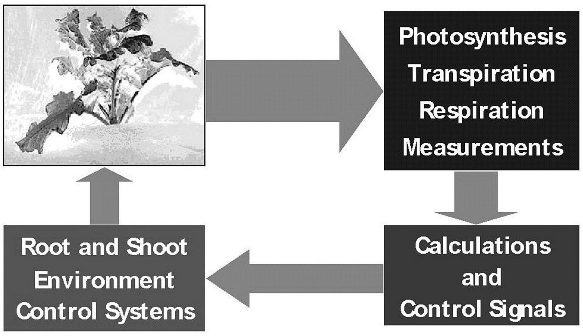

Fig. 2. SVET-3 SG conception

Photosynthesis is an excellent indicator for the physiological state of plants. A classical method to evaluate photosynthesis is plant CO_2 assimilation measurement requiring partially enclosure of the system. For that purpose the precise GEMS system, developed by American scientists on the MIR-NASA Program and added to the Bulgarian SVET-2 SG in 1995 provided two collapsible leaf bags which enclosed the canopy of the plants over the two root module sections. The first successful measurements of the plant leaf environment (CO_2 concentrations and water vapor fluxes), used to later calculate photosynthesis, transpiration and respiration, carried out during the "GREENHOUSE-2" experiments on MIR in the SVET-2+GEMS SG equipment in 1996-1997, show that it could be possible to monitor plant development in real time by measuring precisely the gas-exchange rates and without current sampling [7]. This suggests that it is possible to create an automatic space greenhouse that can measure currently the plant growth parameters and using these data to change adequately the plant root and leaf environment. A concept for an advanced SVET-3 SG with adaptive automatic environmental control is developed and described in [8] [Fig. 2]. The concept provides a feedback in the chain "monitoring – control" which allows optimizing plant growth conditions during the experiment. Measuring the plant growth parameters in real time and calculating the increasing plant needs, such an automatic system will maintain adequately the root and leaf environment in order to provide most favorable conditions for plant growth at every stage of plant development in autonomous mode. For that purpose the absolute parameters of the air entering and exiting PCh (CO_2 concentration, temperature, humidity, pressure, air flow rate) and some plant leaf parameters (leaf area and temperature) are measured and processed in real time. Control Computer collects the data, calculates transpiration and photosynthesis, evaluates plant status and performs adaptive environmental control.

First steps in the SVET-3 SG development

Achieving full automation of the process of environmental control requires some preceding activities and researches. SVET-2 SG has a PCh, open type, allowing contact with the cabin atmosphere. SVET-2 SG equipment provides measurement of Air Temperature within PCh. SVET-3 SG is based on a semi-closed PCh air volume with controllable air flow and filters for removal of contaminants from the cabin air.

The biological results obtained during the MIR experiments carried out using SVET-2 SG show that in the first place a wide and precise non-stop monitoring of the root and leaf environment is required so as to build a reliable, controllable system for plant growing under microgravity. Such monitoring would help the biologists to currently observe and evaluate plant biological status during the experiment. For that purpose a Leaf Environment Measurement System (LEMS) should be available in addition to the precise gas-analyzing system to achieve complete monitoring and registration of the shoots development environmental conditions [9, 10]. This system should be able to operate independently without the gas-analyzing system what would allow lowering power consumption during the more energy consuming measurements such as the gas-analyzing measurements, root environment moisture measurements etc. So our present efforts are directed at equipping the LEMS with additional sensors for more detailed monitoring of the plant biological status. The operating diagram of the channel for leaf environment measurements is shown on Fig. 3. LEMS includes two sub-systems: Meteorological Parameter Measurement System (MPMS) and Atmosphere Composition Measurement System (ACMS).

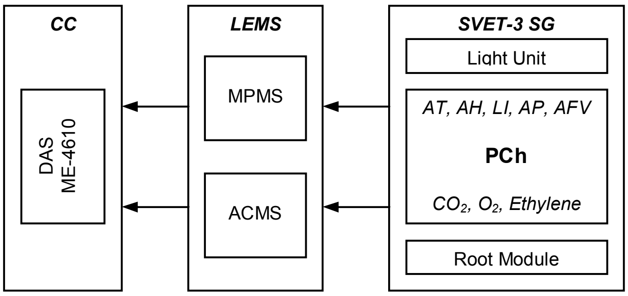

Fig. 3. Operating diagram of the SVET-3 SG Leaf Environment Measurement System.

As a first step MPMS was equipped with 5 sensor systems measuring the main meteorological parameters of the leaf environment: Air Temperature (AT), Air Humidity (AH), Light Intensity (LI), Air Flow Velocity (AFV), and Air Pressure (AP) [11, 12]. A standard ME-4610 PCI board is used as a Data Acquisition System (DAS) to collect sensor data and deliver them to the Control Computer (CC).

ACMS is designed to carry out monitoring of the atmospheric gas composition (O_2, CO_2, trace gases). As CO_2 assimilation measurement is critical for evaluating photosynthesis our first efforts were aimed at equipping ACMS with sensors for monitoring (and maintaining) CO_2 concentration in PCh. SVET-3 SG conception provides to maintain CO_2 concentrations by a fan controlling the rate of air flow entering the PCh from the cabin and appropriate intake valves. Below are described the requirements to the CO_2 sensors and other considerations taken into account when selecting suitable sensors.

Updated guidelines for measuring and reporting environmental parameters in plant growth chambers are published by T.W. Tibbitts et al. in [13]. According to these guidelines the carbon dioxide measurement should be made by an infrared analyzer with a range of 0-1000 ì mol.mol^{-1} or greater range provided they have the required sensitivity. The recommended instrument precision is ±1% and accuracy of reading ±3% of range. Measurements should be taken at the top of the plant canopy continuously during the period of the study. A time-sharing technique that provides a periodic measurement (at least hourly) in each chamber can be utilized. The average concentration and range for both light and dark periods of the study should be reported.

For precise CO_2 measurements used to calculate the plant physiological parameters (photosynthesis, transpiration and respiration of the growing plants) the PCh volume should be partially enclosed. The gas composition control system normally contains two infrared CO_2 sensors. One sensor measures the PCh CO_2 concentration (0-3000 ppm), and the second sensor measures the incoming cabin air CO_2 concentration (up to 7000 ppm on Shuttle). The cabin concentration is used to calculate the required valve opening time for CO_2 intake control. The first sensor's readings are used to control the chamber concentration at fixed set points. The two sensor's readings allow constant measurements of photosynthesis and respiration rates. To carry out precise photosynthesis and respiration measurements the sensor's system for CO_2 measurements should be designed to resolve small differences (of the order of 5 ppm) against a large background cabin air CO_2 concentration (up to 7000 ppm on Shuttle or 700 on ISS). In routine measurements, intended for monitoring of the plant leaf environment (and maintaining CO_2 concentration around fixed set points as it is planned), the requirements to the sensors for CO_2 measurements are less stringent.

For CO_2 measurements most plant growth facilities use small infrared gas sensors with an accuracy of 10-30 ppm (full range: 0-4000 ppm). These sensors measure partial gas pressure (mole density), rather than the typical volume percentages used by plant scientists (ppm). Their readings may vary according to absolute pressure and temperature changes. These effects can be eliminated by applying the ideal gas law and correcting the sensor readings using the measured temperature and pressure of the gas at the point of measurement to obtain the more customary volumetric ratio units (ppm). In some of the CO_2 sensor modules, available on the market, such compensation is a built-in option. Temperature and pressure compensation is of great importance especially when maintaining CO_2 by controlling the air flow rate from the cabin. It would be easier to compensate for temperature changes than the absolute pressure changes. Such changes may occur rapidly as a result of the redirected flow when actuating the intake valve or the CO_2 scrubbing valve. In addition to the pressure changes the response time of the CO_2 sensors, which is 30 sec and more for most sensors, complicates interpretation of the sensor readings what may lead to inappropriate CO_2 control commands.

The following considerations have been taken into account when selecting suitable CO_2 sensors for SVET-3 SG. Sensors should:

- Cover a range of 0-3000 ppm (0-0.3% Ñ Î$_2$) with accuracy of reading no less than ± 3% of range (including repeatability, non-linearity and calibration uncertainty);
- Be of diffusion aspiration technology type what eliminate the need of gas sampling system and the measurement error caused by pressure differences present in pump-aspirated measurement systems. At the same time sensors should have low response time what require a settlement by compromise.
- Operate properly at 0-50°C temperature, 0-99% relative air humidity and 0-2 bar pressure ranges;
- Have linear (or linearised) current or voltage analog output;
- Have low temperature, humidity and pressure dependence or built-in options for temperature,

pressure and humidity compensations in range that is wide enough if possible;

- Be suitable for continuous monitoring of the leaf environment and should have good long-term stability. They also should have small sizes and low weight.

Manufacturers, experienced in developing and manufacturing high quality reliable gas sensors based on non-dispersive infrared technology, should be selected. The GMM12 Vaisala's sensors have been used in PGBA while ASTROCULTURE^{TM} unit uses CO_2 sensors of Valtronics Inc. Edinburgh Instruments Ltd. etc. also offer high performance CO_2 sensors.

An inquiry made selected three models of CO_2 sensors as most meeting the requirements mentioned above. Table 1 gives a possibility of comparative assessment of the different model's technical specifications.

Table 1. Comparative assessment of the different model's technical specifications.

Technical specifications	Company / model		
	Edinburgh Instruments / GasCheck 3000ppm diffusion	Vaisala Instruments / GMP343 / diffusion	Vaisala Instruments / GMM222
Measurement Range	0 – 3000 ppm	0 – 1000, 2000, 3000 or 4000 ppm	0–2000, 3000, 5000, 7000 or 10 000 ppm
Accuracy	±3% of range	at the CO_2 calibration points: ±1.5% of reading below 300 ppm CO_2: ± 5ppm	±(1.5% of range + 2% of reading) at 25°C and 1013 hPa
Stability	±5% of range over 12 months	< ±2% of reading/year	< ±5% FS/2 years
Response Time	260 sec.	30 sec.	30 sec.
Operating Temperature	0 – 45°C	−40 – +60°C	−20 – +60°C
Humidity	0 – 99% non-condensing	0 – 100% RH	0 – 100% RH non-condensing
Pressure		Operating range: 0 – 5bar; Pressure compensation range: 700 - 1300hPa	700 – 1300 hPa
Output Signal	4 – 20 mA linearised	Current output: 4 – 20 mA; Voltage output: 0 – 2.5 V or 0 – 5 V; resolution 14 bit; linearised	Current output: 4 – 20 mA; Voltage output: 0 – 5 V; resolution 12 bit; nonlinearity ±0.5% FS; resolution 0.03% FS (12 bit)
Compensation Options	Without compensation	Compensation options for temperature, pressure, humidity and non-linearity	Without compensation; temperature dependence -0.1% FS / °C; pressure dependence; +0.15 of reading/hPa
Operating Voltage	24 VDC	11 – 36 VDC	11 – 20 VDC or 18 – 30 VDC
Power Consumption	0.9 W	< 1 W	< 2.5 W
Dimensions	128 × 50 × 30 mm	length: 180 mm; diameter: Ø55 mm	length: 145 mm; diameter: Ø18.5 mm
Weight		360 g	200 g

4. DISCUSSION

In contrast to the other models the Vaisala GMP343 CO_2 probe provides many possibilities of configuring the measurement output by the user. The output can be configured to have raw data without filtering, or compensation for destabilizing factors such as pressure, temperature, relative humidity, O_2 concentration or linearization of the output. On the other hand the user can set the filtering level. The instrument can compensate the measurement with an internal temperature measurement and user-set relative humidity, pressure and oxygen values. These compensations are a built-in option. The user can enable or disable the internal linearization function. The analog output can also be configured as a voltage (0-2.5V; 0-5V) or current (4-20mA) output. Due to its compact metal structure the sensor can be installed directly into the plant leaf area.

The GasCheck CO_2 sensors of Edinburgh Instruments and the GMM220 Vaisala modules do not provide an option for internal compensation. The basic GasCheck is available in three ranges 3000 ppm, 3% and 10% CO_2. The option of a diffusion assembly is available for the 3000 ppm unit but this diffusion model has too high response time (260 sec).

The GMM222 modules consist of a component board, cable and CO_2 probe connected to the cable by waterproof connector. This enables true interchangeability of the probes. The probe features a non-volatile memory for storing the calibration parameters what allow easy calibration. Although the GMM222 modules do not provide internal compensation the output temperature and pressure dependence as well as non-linearity are given by the manufacturer

5. CONCLUSION

The Vaisala GMP343 probe was selected as most suitable for measurement and maintaining the CO_2 level in the SVET-3 SG and will be used in the presence of a financially supported project. The research work for O_2 sensors selection is still in progress.

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ÌÎÍÈÒÎÐÈÍÃ È ÓÏÐÀÂËÅÍÈÅ ÍÀ ÃÀÇÎÂÈß ÑÚÑÒÀÂ Â ÊÎÑÌÈ×ÅÑÊÈ ÓÑÒÀÍÎÂÊÈ ÇÀ ÎÒÃËÅÆÄÀÍÅ ÍÀ ÐÀÑÒÅÍÈß: ÏÎÄÁÎÐ ÍÀ CO$_2$ ÑÅÍÇÎÐÈ ÇÀ ÊÎÑÌÈ×ÅÑÊÀ ÎÐÀÍÆÅÐÈß ÑÂÅÒ-3

Ñ. Ñàïóíîâà, Ò. Èâàíîâà, Ï. Êîñòîâ, É. Íàéäåíîâ, È. Èëèåâà, È. Äàíäîëîâ

Ðåçþìå. Ñúçäàâàíåòî íà óñúâúðøåíñòâàíà Áèîëîãè÷íà ñèñòåìà çà îñèãóðÿâàíå íà æèâîòà, â êîÿòî ðàñòåíèÿòà èãðàÿò ñúùåñòâåíà ðîëÿ çà çàïàçâàíå è ïîääúðæàíå íà æèâîòà íà àñòðîíàâòèòå âèíàãè å áèëî îñíîâíà ìîòèâàöèÿ è êðàéíà öåë íà âñè÷êè êîñìè÷åñêè ðàçðàáîòêè. Ìàëêè óñòàíîâêè çà îòãëåæäàíå íà ðàñòåíèÿ ñ ðàçëè÷íî íèâî íà àâòîìàòèçàöèÿ è êîíòðîë ñà ðàçðàáîòâàíè è ëåòÿëè íà áîðäà íà Ðóñêàòà êîñìè÷åñêà ñòàíöèÿ ÌÈÐ, Àìåðèêàíñêèòå êîñìè÷åñêè ñîâàëêè è Ìåæäóíàðîäíàòà êîñìè÷åñêà ñòàíöèÿ. Ñòàòèÿòà ïðåäñòàâÿ åäèí îáçîð íà ñèñòåìèòå çà êîíòðîë íà ãàçîâèÿ ñúñòàâ íà àòìîñôåðàòà â òåçè óñòàíîâêè. Îïèñàíè ñà öåëèòå è ïúðâèòå ñòúïêè â èçñëåäîâàòåëñêàòà ðàáîòà ïî ðàçðàáîòêàòà íà íîâî ïîêîëåíèå Êîñìè÷åñêà îðàíæåðèÿ ÑÂÅÒ-3 àêöåíòèðàéêè âúðõó êàíàëà çà èçìåðâàíå íà ïàðàìåòðèòå íà âúçäóøíàòà ñðåäà, â êîÿòî ñå ðàçâèâàò ðàñòåíèÿòà. Èçëîæåíè ñà ñúîáðàæåíèÿòà ïðè èçáîðà íà äàò÷èöè çà èçìåðâàíå íà ÑÎ$_2$ è å íàïðàâåíà ñðàâíèòåëíà îöåíêà íà òåõíè÷åñêèòå õàðàêòåðèñòèêè íà ïðåäëàãàíèòå äàò÷èöè çà ÑÎ$_2$ ñ öåë äà ñå èçáåðå òàêúâ, êîéòî â íàé-ãîëÿìà ñòåïåí äà îòãîâàðÿ íà èçèñêâàíèÿòà.