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Progress and prospect of research on controlled ecological life support technique

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A R T I C L E I N F O

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A B S T R A C T

Controlled ecological life support system (CELSS) is an effective way to guarantee the survival of astronauts for the long-term manned deep space exploration and the settlement on extraterrestrial planets. CELSS can provide almost all the most important life-sustaining materials by the continuous regeneration and self-cycle supply, such as food, oxygen and water, etc. In this paper, the basic developmental history and the currently important research progress of CELSS are expounded, and the main technical challenges and future countermeasures are put forward too. This review is aimed at laying a reference for the development and earlier application of CELSS in the future.

Contents

1. Introduction

There is no doubt that the long-term manned spaceflight and the extraterrestrial planet settlement are the inevitable trends of space technologies, which have become the focus of space powers [1]. However, there are also many challenges, and one of which is

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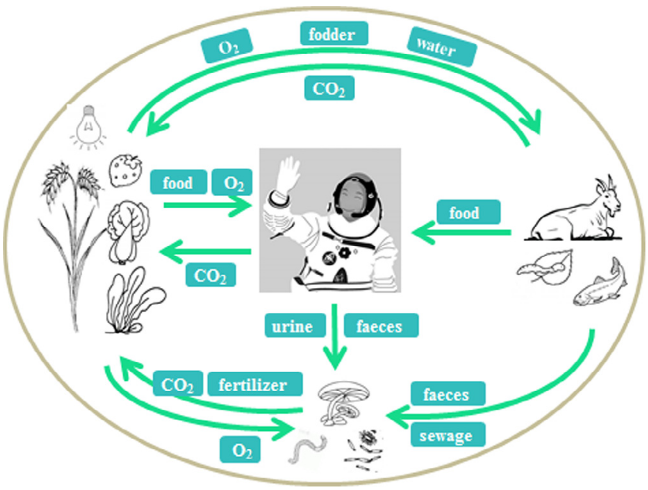

Fig. 1. CELSS operational schematic diagram.

how to achieve the continuous supply of life support materials, such as food, oxygen and water, in the condition that supplies are almost impossible to be added. Today, the environmental control and life support system (ECLSS) of the most advanced manned spacecraft can only achieve the regeneration of atmospheric and water, but without food [2].

It has been widely accepted that the fundamental way of solving this problem is to establish a controlled ecological life support system (CELSS) in outer space, and also known as a biological life support system (BLSS) or Bio-regenerative life support system (BLSS). According to the basic principles of the earth biosphere, CELSS combines "producer (plant)", "consumer (animal)" and "decomposer (microbial)" organically, as shown in Fig. 1. Through the introduction of biological components and food webs, CELSS can recycle the limited resources, so as to supply food, oxygen and water sustainably, so it is a fully enclosed and self-sufficient life support system (LSS) [3].

ECLSS has gone through the first generation of non-regenerative and second of physical-chemical. In order to improve the operational efficiency and reliability, it is necessary to integrate them into the CELSS. Therefore, CELSS is also called as the third generation of ECLSS. It is a multiple biological system involving plant, animal, microorganism, and also a complex engineering system with kinds of technical categories [4].

2. Basic developmental history

The United States and the Soviet Union had begun to consider the long-term LSS in space from the 1950s before their astronauts entered the space. As for now, it has gone through more than 60 years. Aerospace powers and organizations, such as the United States, Russia, Europe and Japan, focused on microalgae initially, because of its higher yields of oxygen and algal protein. However, due to the poor taste and deficient nutrition, microalgae can only be applied as the non-staple food. Since the 1970s, the research priorities have been transferred to higher plant, and the biodegradable waste recycling studies were carried out simultaneously. The basic developmental history of CELSS is as Table 1.

Table 1
Comparison of international integration technology research of CELSS.

Item	Russia BIOS-3 [19]	Biosphere 2 [9]	The United States ILSSTF [13]	Japan CEEF [43]	China Space Ecosystem I [67]	China Lunar Palace I [69]
Period	1960–1980's	1991–1994	1997	2000's	2012	2014
The number of crewmembers and days	2–3 persons/ 120–180 days	7–8 persons/ 7–21 months	4 persons/91 days	2 persons/7 days	2 persons/ 30 days	3persons/ 105 days
Gender composition	3 male	4 male and 3–4 female	2 male and 2 female	2 male	2 male	1 male and 2 female
Plants cultivation	Hydroponics2 kinds of grain (44 m^2)10 kinds of vegetable (10 m^2)1kind of oil crop (9 m^2)	Solid media cultivation (2000 m^2) 3 kinds of grain 23 kinds of vegetable 3 kinds of oil crop 9 kinds of fruit	Hydroponics 1 kind of grain (11.2 m^2) 1 kind of vegetables (0.7 m^2)	Hydroponics and solid media cultivation 2 kinds of grain (90 m^2) 20 kinds of vegetables (30 m^2) 1kind of oil crop (30 m^2)	Hydroponics 4 kinds of vegetables (lettuce, rape, Gynura bicolor r and bitter chrysanthemum, 36 m^2)	Solid media culture2 kinds of grain (46.6 m^2)15 kinds of vegetables (10.4 m^2)1kind of fruit (1.0 m^2) 2 kinds of oil crop (11.0 m^2)
Animals	–	4 (goats, fishes, pork and chicken)	–	Goats (2, Fed with straw, soybean foliage and peanut skin)	–	Tenebrio molitor (Fed with wheat straw powder and old vegetables)
Atmospheric regulation method	Gas exchange between humans and plants directly	Gas exchange among humans, animals and plants directly	*O_2supply:* membrane separation technique; water electrolysis. *CO_2purification:* molecular sieve; Sabatier technique.	*O_2 supply:* membrane separation technique; *CO_2 purification:* molecular sieve; Sabatier technique.	Gas exchange between humans and plants directly	Gas exchange among humans, animals and plants directly
Material flow closure degree	atmosphere: 100% water: 100% food: 80% solid waste: partly	atmosphere: ≈100% water: 100% food: 100% solid waste: partly	atmosphere: 25% water: 100% food: 6.25% solid waste: partly	atmosphere: 100% water: 100% food: 100% solid waste: partly	atmosphere: 100% water: 84.5% food: 9.3% solid waste: none	atmosphere: 100% water: 100% food: 55% waste: none