AA 1668
pp: 1-6 (col.fig.: Nil)
PROD. TYPE: TYP
ED: SG
PAGN: Thanuja - SCAN: Nil

ARTICLE IN PRESS

PERGAMON

Acta Astronautica ▮▮▮ (▮▮▮▮) ▮▮▮–▮▮▮

ACTA ASTRONAUTICA

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Deuterium-free water (^1H_2O) in complex life-support systems of long-term space missions

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Received 12 May 2000

Abstract

Heavy water containing deuterium displays toxic property. It is stated that any quantity of a heavy isotope of hydrogen—deuterium—is undesirable to animals and plants. It was earlier shown by us that physical–chemical life support systems on board the "MIR" station fractionate (change) isotopes of hydrogen, oxygen and carbon. Therefore, the problem of regenerative systems in habitable space objects should include removal, from water, of a heavy stable isotope of hydrogen—deuterium. In this article we consider one method of obtaining deuterium-free water—decomposition of distillate water in an electrolyser to hydrogen and oxygen with subsequent synthesis in a catalytic or high-temperature reactor. The influence of deuterium-free water on the growth and development of Arabidopsis thaliana and Japanese quail is investigated. It is shown that with the help of the electrolysis method it is possible to fabricate water containing 80% less deuterium in comparison with SMOW. Experimentally, it is proved on a culture of Arabidopsis thaliana and Japanese quail that water with reduced contents of deuterium (80%) displays positive biological activity.

1. Introduction

Onboard an orbital complex (OC), "MIR" systems of regeneration of a water "SRW-C" (regeneration of potable water from a condensate of atmospheric moisture), "SRW-U" (regeneration of water from urine) and other systems [1–3] successfully function. The main problem in the creation of similar systems consists of the removal from waste of all harmful additives of organic and inorganic nature and entering into the cleared fluid of mineral salts and microelements.

However, the technologists and designers did not consider such characteristics of water as biological properties of its isotope composition. At the same time the usual natural water consists of nine isotope connections ($^1H_2{}^{16}O$, $^1H_2{}^{17}O$, $^1H_2{}^{18}O$, $^2D_2{}^{16}O$, $^2D_2{}^{17}O$, $^2D_2{}^{18}O$, $^1H^{16}O^2D$, $^1H^{17}O^2D$, $^1H^{18}O^2D$), in which there are two stable isotopes—protium (^1H) and deuterium (^2D). Taking into account a radioactive isotope of hydrogen–tritium (^3T)—the common number of isotope variants of water will be equal to 27.

Usual natural water and water containing a stable isotope of hydrogen—deuterium—differ in physical properties [4–6]. The distinction of freezing (melting) temperatures of usual and heavy (on deuterium) water equal to 3.79°C, temperatures of boiling are −1.41°C, temperatures of maximum density are 7°C, heat capacity is −2.13 cal/mol, melting heats of ice are 79 cal/mol, etc.

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PII: S0094-5765(02)00013-9

Especially, strong differences are displayed when comparing biological action of usual and heavy (on deuterium) water on alive organisms. So in the cultivation of alga on nutritious solutions containing D_2O, the negative influence of it on growth and development of cells was established, the depth of which depends on concentration of heavy water. Very sensing to D_2O has appeared Scenedesmus, growth and development of which ceased completely at 38.5% D_2O [7].

The photosynthesis will be always below, and the efficiency on gain of biomass will not exceed 1/3 from the control at concentrations of D_2O below 38.5% [8].

In papers devoted to the study of the influence of heavy water on plants, the questions of seed germination of plants in the presence of D_2O of various concentrations, the growth and development of germinators in these conditions, and also the effect of heavy water on the growth and reproductive ability of adult plants are investigated. The decrease of seed germination of plants is revealed as proportional to D_2O concentration. At D_2O concentrations equal to 100%, seeds of wheat and sunflower did not sprout [9]. The seeds of other representatives had a threshold of germination at 50–80% D_2O [10]. In some adult plants inhibition of growth and development was observed already at D_2O concentrations of 10–20% [11].

In all papers there was a marked delay of seed germination, decrease of percent of germinated seed, and delay of phases of development. The slow growth of plants is accompanied by large morphological and anatomic changes of all parts of plants and changes in the structure of biomass. The number of formed seeds in plants decreases proportionally with the concentration of D_2O. The majority of researchers consider that the main reason for the toxic action of D_2O on plants is the inhibition of mitosis in plant cells, which is caused by the strength of hydrogenous connections. It is shown that at high concentrations of heavy water, disturbance in mitosis begins in 30 min. In 8 h in cells the damage of nuclei and protoplasm is observed. The complete inhibition of mitosis occurs in 12 h, the synthesis of DNA ceases in 6 h, and RNA synthesis ceases in 24 h [10,12–14].

In a study of the influence of heavy water on lower animals it is found that paramecli at a D_2O concentration of 92% perished in 48 h [15]. The flatworms at 90% D_2O concentration completely lost activity in 2 h, and perished in 3 weeks [16].

In experiments with higher animals it is shown that at invasion to mice of a D_2O parenteral solution at concentration 99.5%, the death of animals occurred on the 5th day [17].

In a series of experiments with mice and rats [17–20], heavy water was used as potable. It was established that 15–20% D_2O (from the common contents of water in the organism) in an animal was observed of biosyntheses processes in integrated biological–physical–chemical life support hyperexcitability. On replacement of water in an organism by D_2O in the range 20–25%, hyperexcitability in an animal became more expressed and spasms are observed. When 30% of water in an organism is replaced by D_2O, the animals are in comatose condition, refuse food, the body weight sharply drops, there is a decrease of erythrocytes, and atrophy of seminal glands is observed. The death of mice and rats is observed at a D_2O concentration of the order of 30–35%.

When the concentration of deuterium was 20–25% below usual, there was its positive biological activity [21,22]. The experiments were carried out with thawed water. It was shown that the force of growth of wheat at wetting of seed in thawed water exceeded by 41% the force of growth of seed wetting in usual water. The radish crop was 230% above of test. In experiments on mice using thawed snow water, the increase of sexual activity in mates and hyperploidy in females was established.

In papers [23,24] a number of installations on obtaining thawed water with reduced concentrations of deuterium and tritium, and also the results of research of its biological activity are described. On the basis of the technological schemes of the installations, the principles of natural fractionation of isotopes are fixed: evaporation, freezing, thawing, saturation of water by salts and gases. The authors have shown that water with ice structure and incorporating a reduced (in the opinion of the authors) concentration of deuterium has biological activity. In papers the measurements of isotope composition of the initial and cleared water are not carried out, and the assessment of the contributions in observed effects each of two parameters is not given: structures of water or reduced concentration→ deuterium and tritium.

In papers [25,26] it is suggested to use deuterium-free water in habitable space objects with purpose intensification systems, and also for increase of astronaut functionability.

It is necessary to emphasize that research of the biological properties of water completely deprived of deuterium or tritium was not conducted. Are there not developed effective methods of obtaining deuterium-free water?

In this article we have attempted to develop an electrolysis method of obtaining water with the contents of deuterium reduced by 80%, and assessment of its biological activity in experiments on higher plants and Japanese quail is undertaken.

2. Subjects and methods under study

2.1. Technique of obtaining deuterium-free water

The method of deuterium-free water fabrication is based on electrolysis of distillate water. This method was chosen because of its high coefficient of protium and deuterium isotope separation.

The experimental bench included an electrolyser with a circulating electrolyte, cathode and anodic space of which is divided by cation exchange membrane, circulating pump, two gas-liquid-propellant separators, two desiccants of gaseous products of electrolysis, catalytic reactor, condenser and acceptance vessel for deuterium-free water and also sources of a power supply.

The catalytic reactor contained aluminium oxide with platinum, and worked at a temperature of 120°C. The water with reduced contents of deuterium was ejected from the condenser and subjected to chemical and physical–chemical research.

In one version of the technological scheme of obtaining deuterium-free water, instead of the catalytic reactor the method of high-temperature oxidation (burning) of hydrogen in the gas torch was used.

The isotopic composition of the water samples was determined by the mass-spectrometric method. The small variations of isotope composition of hydrogen and oxygen were determined in relational units—promilles of deviation from standard.

A positive value of deviation shows enrichment of sample with heavy isotopes (D or ^{18}O) in relation to the standard, and a negative value of deviation shows enrichment of sample with light isotopes (^{1}H or ^{16}O).

In order to prevent influence of the structure of water, all samples were subjected to heating with subsequent cooling down to room temperature.

2.2. Technique of research of biological activity of deuterium-free water on higher plants

Arabidopsis (Arabidopsis thaliana, race Dijon) was chosen as the vegetative object for research of the growth and development of higher plants. Cultivation of Arabidopsis was implemented in glass vessels of diameter 20 sm and substrate height about 2 sm. Salt-saturated arcelite (surface) was used as substrate. Tablets of osmocote (fertilizer of long-term action) in quantity 0.5 g/vessel were served as a source of mineral feed. The illumination by intensity 40 W/m^2 of physiological active radiation was day–night, temperature of cultivation was 23°C, concentration of CO_2 was 0.03%, and density of crop was 50–60 plants/vessel.

Three variants of water were used: (1) deuterium-free water fabricated by a method of electrolysis ($dD = -815\%$), (2) distillate water ($dD = -72\%$) and (3) water with increased contents of deuterium ($dD = +355\%$).

2.3. Research of the influence of deuterium-free water on the physiological status of Japanese quail

The representative of the higher heterotroph Japanese quail is one of the candidates in a structure integrated biological–physical–chemical life support system. And chickens are one of the most convenient test—organisms for the realization of biological research, since they have a high intensity of growth and accumulation of body weight and are rather sensitive to the quality of food and water.

The technique consists of the following: hatched out nestlings within 5 days were in usual conditions (adaptation period); till expiry of the period of adaptation, experimental groups with a minimum divergence in weight as inside, and between groups were formed; in each group there were 10 birds; daily the nutrient vessel was filled up with water—deuterium free or distillate (as the control). The dynamics of the

weight of birds, structure of blood, and condition of internal organs was investigated.

3. Results and discussion

3.1. Physical–chemical characteristics of water with reduced contents of deuterium, fabricated by a method of electrolysis

The contents of deuterium in water fabricated by a method of electrolysis are reduced by 82% in comparison with the standard SMOW. In distillate water the decrease of deuterium concentration on 7% is marked, that it is possible to explain both process: distillation and that fact, that the initial natural water has the little bit reduced contents of a deuterium in comparison with SMOW.

It is interesting to note that while the isotope fractionation of hydrogen (protium and deuterium) by the electrolysis of water enables one to reduce the concentration of deuterium for one stage by 82%, a significant decrease of concentration of heavy oxygen ^{18}O is not observed.

Water with reduced contents of deuterium on 82% was used for research of its biological activity on higher plants and Japanese quail.

3.2. Deuterium-free water influence on growth and development of Arabydopsis thaliana

An investigation of the relation of duration of a full cycle of vegetation and its separate phases under the effect of various concentrations of deuterium in water is carried out on Arabydopsis. It is established that the use of water with changed isotope composition has resulted in a change of the cycle of development of Arabydopsis . So, the approach of the most important phase of development—flowering—is marked in the age of 17 days in variants with deuterium-free water, per 19 days in test variant and in 21–22 days in variants using water with an increased concentration of deuterium.

The data of the morphological analysis are given in Table 1.

With decreasing concentration of deuterium in water, plants with large parameters of weight, number of stems, pods and seed are formed. Cumulative seed production of one plant Arabydopsis has made on an average 322 seeds at a pour by deuterium free water, 141 seeds at a pour by usual distillate water and 95 seeds at a pour by water with increased (dD=+355%) contents of deuterium.

3.3. Influence of deuterium-free water on the physiological status of Japanese quail

The experimental data by biological assessment of the deuterium-free water have shown a positive influence on the growth and development of Japanese quail. The growth rate of the birds that used the deuterium-free water was above the growth rate of birds that used distillate water.

The positive influence of deuterium-free water on the efficiency of birds is marked:

- egg-laying of females using deuterium-free water was begun on the 44th day, and on the 49th day using distillate water;
- production of eggs by birds using deuterium-free water for 25 days was 65 eggs, while it was 46 eggs for birds using distillate water;
- fertility of the female, using deuterium-free water set in on the 44th day, and 7 days later using distillate water;
- survival of nestlings of the 2nd generation for the group using deuterium-free water was 88.2%, and for the group using distillate water was 52.9%.

The condition of internal organs, their weight, and the calculation of an index of weight—the relation of weight of an organ to common weight—were conducted.

The results of the influence of the deuterium-free water on common weight and internal organs of the Japanese quail are shown in Table 2. The results show that common weight of birds and weight practically of all internal organs of birds using deuterium-free water were higher in comparison with the weight of birds using distillate water.

Visual inspection and weighing of internal organs of birds has shown that males using deuterium-free water had well-advanced gonad, in contrast to birds using distillate water, where the rudiments of gonad were marked only.

its influence on biological objects obtained in the space program can find application on Earth in medicine, agriculture and other areas.

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