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Considerations of Material Circulation in CEEF Based on the Recent Operation Strategy

ABSTRACT

In Closed Ecology Experiment Facilities (CEEF), with integrating the Closed Plantation Experiment Facilities (CPEF) and the Closed Animal Breading & Habitation Facilities (CABHF), closed habitation experiments without material exchange with the outside will be conducted after the 2005 fiscal year. Cultivation experiments of approximately 30 crops and the integrating test of the material circulation system required for the closed habitation experiments have been performed since fiscal year 2000. Using data reported in these experiments, material circulation in CEEF is simulated based on the recent operation strategy, and the storage capacity needed for the buffer of an air processing subsystem was estimated. In order for two humans to dwell for more than 120 days, the storage capacities of the carbon dioxide tank, the oxygen tank, and the waste gas tank in CPEF, and the carbon dioxide tank and the oxygen tank in CABHF are 820 g, 2830 g, 4425 g, 1780 g, and 1792 g, respectively. This implies the storage capacities needed under the best conditions. It is confirmed important to set the closing period of material circulation as the longest cultivation period of the crops, and to limit the processing amount of the wet oxidation processor to the quantity of waste product for one day.

INTRODUCTION

In the Closed Ecology Experiment Facilities (CEEF) of the Institute for Environmental Sciences (IES), with integrating the Closed Plantation Experiment Facilities (CPEF) and the Closed Animal Breading & Habitation Facilities (CABHF), closed habitation experiments will be conducted after the 2005 fiscal year [1]. Now, experiments to grow approximately 30 crops have been conducted in CPEF using part of the material circulation system such as a plantation module, an air processing subsystem, and a water processing subsystem. In this experiment, data about the production of the edible portion and inedible portion of plant biomass and the gas balance and water balance of a plant community are collected. Moreover, in CABHF, human and animal metabolic data are collected towards the future integration test.

Recently, ground experiment facilities, such as Japanese CEEF and the American Bioregenerative Planetary Life Support Systems Test Complex (BIO-Plex), have been established. In connection with this, investigation about the material circulation in these facilities by means of the simulation has been performed. Examples include the investigation of the equipment performance and the buffer size [3], the investigation of the influence of the plant cultivation procedure on the equipment performance and the buffer size [4,5,6], the investigation of the influence of the use procedure of the waste processing subsystem on the equipment performance and the buffer size [4,5,6], the investigation of the start procedure of an experiment [5,6], and the investigation on the configuration of material circulation in the air processing subsystem. There is it was examined also study about CEEF in which whether a necessary performance could be demonstrated based on design conditions [5,6]. Data about human, plant, and animal metabolism and equipment performance will be accumulated. Therefore, the expectation is that a simulation to integrate the equipment which has not yet been integrated is conducted, and the experiment and operation procedure are studied for future closed habitation experiments. In this report, the material circulation system in CEEF and its dynamic model are described, the material circulation in CEEF is simulated based on the recent operation strategy, and storage capability required for the buffer of the air processing subsystem is presumed.

TRIAL DYNAMIC MODEL

SYSTEM CONFIGURATION

CPEF consists of a plantation module, an air processing subsystem, a water processing subsystem, a waste processing subsystem and a nutrient processing subsystem, and CABHF consists of a habitation module, an air processing subsystem, a water processing subsystem and a waste processing subsystem. The configuration of a material circulation system is illustrated in Figs. 1.1 and 1.2. The material circulation system in CEEF consists of both continuous and batch processing equipment. This material circulation system is modeled using WITNESS (Lanner Group Ltd., Warwickshire, UK), a continuous and discrete system simulator, and the dynamic simulation of material circulation is carried out. The material which circulates in the material circulation system is quantified by the Biochemical Stoichiometry [8]. Every material is computed by the mass. Gases are computed by conversion into the mass in the standard atmosphere. The edible portion and inedible portion of crops are approximated with four materials, protein (C_4H_5ON), lipids ($C_{16}H_{32}O_2$), carbohydrates (glucides) ($C_6H_{12}O_6$), and carbohydrates (fiber) ($C_6H_{10}O_5$). Moreover, human excreta are approximated with urine ($C_2H_6O_2N_2$), feces ($C_{42}H_{69}O_{13}N_5$), and other organic substances ($C_{13}H_{28}O_{13}N_2$). Next, each subsystem is described.

HABITATION MODULE

In a habitation module, two humans dwell after the sequential cultivation of crops is completed. The habitation area and habitation volume are 56.1 m^2 and 134.6 m^3, respectively, and the environment is set up as, the O_2 concentration of 21±2.1 %, the CO_2 concentration of 300 $\mu L \cdot L^{-1}$, the temperature of 18 to 28 ^0C, and the humidity of 40 - 70 RH%. For human nutritional requirements, the criterion for a male in his 30s for life activity and strength II excerpted from the food composition table [12] is adopted. The two humans act on the same schedule, and human metabolism is treated as constant.

Two shiba-goats, bred in an animal breeding cage, are not included in this computation.

PLANTATION MODULE

The plantation module consists of four plantation chambers, A, B, C, and F, as shown in Table 1. The artificial light plantation chambers A, B, and C have 6 cultivation beds of 5 m^2, and the total area of each plantation chamber is 30 m^2. The natural light plantation chamber F has 12 cultivation beds of 5 m^2, and the total area of the plantation chamber is 60 m^2. On each cultivation bed, sequential cultivation of 28 crops shown in Table 1 is carried out. The food equivalent to 95 % of energy, 110 % of protein, and 81 % of lipids to two humans is supplied. Sequential cultivation is a procedure of carrying out cultivation and harvest continuously, dividing the planting and shifting it periodically in a cultivation bed. This procedure reduces the fluctuation of material circulation. In the settings shown in Table 1, the sequential cultivation is completed in approximately 120 days, and then the stationary state prevails. For the cultivation environment, the CO_2 concentration is controlled at 700±70 $\mu L \cdot L^{-1}$ in the light period and 700±70 $\mu L \cdot L^{-1}$ - 1500 $\mu L \cdot L^{-1}$ in the dark period, while the O_2 concentration and humidity are controlled in the light period at 20.0 - 20.8 % and 65±5 RH%, respectively.

PLANT GROWTH MODEL

It is difficult to develop a plant growth model that can be used in every cultivation environment. In this report, the dynamics model of plant growth under the cultivation environment in CEEF is developed based on the reported plant cultivation data [2]. A plant growth model is made with the increment of biomass as the increment by assimilation of carbon dioxide, and with the carbon dioxide assimilation rate as a function of time. In case of computing biomass, the assimilatory rate multiplied by the conversion rate to biomass is regarded as the biomass increment per day. The carbon dioxide assimilation rate is influenced by carbon dioxide concentration, light intensity, temperature, and humidity. It is assumed that these environmental factors have the following characteristics under the cultivation environment in CEEF: carbon dioxide concentration may fluctuate continuously. It is therefore incorporated into the model as the influence function. The light intensity takes only four values, 475μmol·m^{-2}·s^{-1}, 950μmol·m^{-2}·s^{-1}, 1425μmol·m^{-2}·s^{-1}, and 1900μmol·m^{-2}·s^{-1}. It is therefore incorporated into the model as relative values to 1425μmol·m^{-2}·s^{-1}. Since the temperature is controlled at each preset value at light and dark periods, respectively, its fluctuation is not incorporated into the model. Furthermore, assuming the effects of such environmental factors are independent of the growth time, the carbon dioxide assimilation rate is expressed as,

$$R_{CO2}\left(t,x,y\right)=r_{CO2}(t)\cdot g_{CO2}(x,y) \quad (1)$$

where $r_{CO2}(t)$: carbon dioxide assimilation rate function by growth time [μmol·m^{-2}·s^{-1}], t: growth time of plants [day], x: carbon dioxide concentration [$\mu L \cdot L^{-1}$], y: light intensity [μmol·m^{-2}·s^{-1}]. The carbon dioxide assimilation rate function, which is a function of growth time, is approximated as

$$r_{CO2}(t)=a_{(CO2)0}+a_{(CO2)1}\cdot t+a_{(CO2)2}\cdot t^2+a_{(CO2)3}\cdot t^3 \quad (2)$$

at carbon dioxide concentration of 700 $\mu L \cdot L^{-1}$ and light intensity of 1425μmol·m^{-2}·s^{-1}. Next, assuming that the effects of carbon dioxide concentration and light intensity act independently, one has

$$g_{CO2}(x,y)=CO2N\cdot LTN \quad (3)$$

where, the influence function of carbon dioxide concentration $CO2N$ is approximated as

$$CO2N=a_{x0}+a_{x1}\cdot e^{-\frac{x}{350}}+a_{x2}\cdot\frac{x}{350}\cdot e^{-\frac{x}{350}} \quad (4)$$

and the influence function of light intensity LTN is approximated as

$$LTN=\begin{cases} a_{y01} & (0 \quad \mu mol\cdot m^{-2}\cdot s^{-1}) \\ a_{y02} & (475 \quad \mu mol\cdot m^{-2}\cdot s^{-1}) \\ a_{y03} & (950 \quad \mu mol\cdot m^{-2}\cdot s^{-1}) \\ a_{y04} & (1425 \quad \mu mol\cdot m^{-2}\cdot s^{-1}) \\ a_{y05} & (1900 \quad \mu mol\cdot m^{-2}\cdot s^{-1}) \end{cases} \quad (5)$$

Values a_{y01}, a_{y02}, a_{y03}, a_{y04}, and a_{y05} in this equation are the relative values to the value at the light intensity of 1425μmol·m^{-2}·s^{-1}.

Finally the increases of plant biomass are expressed with carbon dioxide assimilation rate $R_{CO2}\,(t,x,y)$ as

$$CGR(t,x,y) = MW_C \cdot \frac{R_{CO2}(t,x,y)}{BCF} \qquad (6)$$

MW_C and BCF represent the molecular weight of carbon and the ratio of carbon to biomass, respectively. The integration of CGR from time 0 to t_M, the time a fruit matures, yields the whole biomass, while the integration from t_E, the time a fruit starts to grow to t_M, multiplying edible ratio after t_E, yields the biomass of the edible portion. Tables 2, 2.1 and 2.2 show the parameters of the plant model of rice and soybean, and Table 3 shows the settings of light intensity in each plantation chamber. Since there is no necessary datum available, the other 26 crops are modeled with logistic equations.

AIR PROCESSING SUBSYSTEM

The air processing subsystem in CPEF consists of a CO_2 separator, an O_2 separator, a N_2 separator, a trace contaminant gas remover, an O_2 recovery processor, an air conditioner, an O_2 tank, a CO_2 tank, a N_2 tank, and a wet oxidation waste gas tank. All equipment except the air conditioner processes four plantation chambers, A, B, C, and F, alternately for every hour by one set. The equipment operation schedule is shown in Table 3. The air processing subsystem in CABHF consists of a CO_2 separator, a N_2 separator, a trace contaminant gas remover, an O_2 recovery processor, an air conditioner, an O_2 tank, a CO_2 tank, and a N_2 tank.

The CO_2 separator in each facility has an absorption and desorption process, and carries out continuous processing switching absorption and desorption alternately with two CO_2 canisters. This absorption ability is approximated by (7) and the Langmuir-Freundlich equation [9],

$$q = q_0 \cdot m \cdot c^n \big/ (1 + m \cdot c^n) \qquad (7)$$

where, q: equilibrium amount adsorbed[g], c: equilibrium concentration[%], and m[-], n[-], and q_0[g] are specific constants. The CO_2 separator in CPEF is set up as m = 2.21, n = 0.386, and q_0 = 20, and the CO_2 separator in CABHF as m = 2.21, n = 0.386, and q_0 = 20.

It is assumed that the O_2 separator, the N_2 separator, the trace contaminant gas remover, the O_2 recovery processor, and the air conditioner have performance characteristics independent of environmental parameters.

WATER PROCESSING SUBSYSTEM

The water processing subsystem in CPEF consists of a RO membrane filter, a purifier water tank, a condensed water tank, a clean water tank, an irrigation water tank, a waste nutrient solution tank, and a gray water tank. The RO membrane filter processes waste nutrient solution to recycle it as nutrient solution. The high concentrated solution generated in this process is sent to the gray water tank. The water processing subsystem in CABHF consists of a RO membrane filter, a clean water tank, a gray water tank, and a sewage tank. It is assumed that the RO membrane filter in each facility has a performance characteristic independent of environmental parameters.

WASTE PROCESSING SUBSYSTEM

The waste processing subsystem in CPEF consists of a pulverizer, a wet oxidation processor, a concentrator, and a waste tank. The pulverizer mixes the inedible portion of crops with water, and grinds it. The wet oxidation processor converts it into CO_2, N_2, and water with the wet oxidation. The concentrator is the processor that concentrates the wet oxidized solution from the wet oxidation process and abstracts nutrient solution from the condensed solution. The waste processing subsystem in CABHF consists of an excrement and garbage pulverizer, a excrement and garbage wet oxidation processor, an urine wet oxidation processor, and a salt recovery processor.

The wet oxidation processor has a 6-hour process which consists of raw material introduction, heating, heating by O_2 introduction, reheating (repressurizing), the first reaction, the second reaction, cooling (depressurizing), waste gas discharge, and wet oxidized solution discharge. This equipment performs the process of 40 L/batch to mix the object (3 wt%) and oxygen (consisting of 90 % vol. O_2 and 10 % vol. N_2, 160 % of the oxygen additive ratio) with water twice per day. This is equivalent to the processing of the inedible portion of 2.4 kg/day (dry weight). Like the wet oxidation processor, the excrement and garbage wet oxidation processor processes 5 L/day twice per day, and the urine wet oxidation processor processes 5 L/day once per day.

NUTRIENT SOLUTION PRODUCTION SUBSYSTEM

The nutrient solution production subsystem consists of a water electrolyzer, an ammonium nitrate synthesizer, an ammonia synthesizer, an ammonium nitrate tank, an ammonia tank, a concentrated wet oxidized solution tank, and a mixing tank. The water electrolyzer electrolyzes water and produces O_2. The ammonia synthesizer produces ammonia from this O_2 and N_2 produced with the N_2 separator of the air processing subsystem, and the ammonium nitrate synthesizer produces ammonium nitrate. The ammonium nitrate synthesizer and ammonia synthesizer require 2 h of start up time and 17 h of cooling down time, so that it has a production capacity of 9 g/h as converted into the amount of N_2 fixation [11].

CONTROLLING

The ON/OFF control for each piece of equipment is carried out as a preset schedule like the operation schedule of the air processing subsystem shown in Table 3. The ON/OFF control for the tank level is carried out by the rule established for the criteria, such as the maximum, the maximum for normal use, the set point, the minimum for normal use, and the minimum.

RESULT

Figure 2.1 shows the fluctuation of carbon dioxide concentration in plantation chamber A. The carbon dioxide concentration was maintained at 700±70 $\mu L \cdot L^{-1}$ in the light period and 700±70 $\mu L \cdot L^{-1}$ - 1500 $\mu L \cdot L^{-1}$ in the dark period. Similar results were obtained for carbon dioxide concentration in plantation chambers B, C and F. The fluctuation of oxygen concentration in plantation chamber A is shown in Fig. 2.2. The oxygen concentration was maintained at 20.0 - 20.8 %. Similar results were obtained for oxygen concentration in plantation chambers B, C and F. Figure 2.3 shows the fluctuation of carbon dioxide concentration in the habitation chamber. Although the carbon dioxide concentration is controlled at approximately 300 $\mu L \cdot L^{-1}$, it goes up to nearly 1200 $\mu L \cdot L^{-1}$ temporarily when the waste gas by the wet oxidation flows into the habitation chamber. Figure 2.4 shows the fluctuation of the oxygen concentration in the habitation chamber. The oxygen concentration was maintained at 21±2.1 %. These results indicate that the carbon dioxide concentration and the oxygen concentration in the plantation chamber and the habitation chamber were controlled in the preset range.

The fluctuation of biomass in plantation chambers A, B, C and F is shown in Fig. 2.5. Rice is grown in plantation chamber A, while soybean and 26 other crops are raised in plantation chambers C and F, respectively. Since the carbon dioxide concentration in the plantation chambers is controlled in the preset range, the planned growth has been assured consequently. The biomass in plantation chamber F is bigger than in the other plantation chambers, because green vegetables containing a lot of moisture are grown, and the cultivation area is twice as large as the other plantation chambers. Figure 2.6 shows the fluctuation of the storage mass of the edible portion and the inedible portion after harvest. The edible portion for supplying two humans has been sufficiently secured. Although the first harvest takes place on the 28th day, the edible portion is processed with wet oxidation until habitation starts. The inedible portion for one day is processed in the operations with the wet oxidation processor twice per day. Figure 2.7 shows the fluctuation of the storage mass of human feces and urine. Urine for one day is processed in the operation of the wet oxidation processor once per day. In addition, feces for one day are processed in the operations of the wet oxidation processor twice per day.

The fluctuation of the storage mass of carbon dioxide and oxygen in the external tanks is shown in Fig. 2.8. The fluctuation of the storage in these tanks indicates exchange of oxygen and carbon dioxide between inside and outside CEEF. From the operation start until the 125th day, 282.1 kg of carbon dioxide was supplied and 223.0 kg of oxygen was discharged. The closing period of gas exchange with the outside was set as the longest cultivation period of the crops, so that the fluctuations of oxygen and carbon dioxide after the closure were reduced. The supply of leaked air is not included in the above-mentioned closure.

Figure 2.9 shows the fluctuation of the storage mass in the carbon dioxide tank and the oxygen tank in CPEF, and the fluctuation in the waste gas tank in CPEF and in the carbon dioxide tank and the oxygen tank in CABHF are shown in Figs. 2.10 and 2.11, respectively. In this simulation, the carbon dioxide tank in CABHF and the oxygen tank in CPEF were considered as tanks for absorbing the fluctuation of the storage. The fluctuations of the carbon dioxide tank, the oxygen tank, the waste gas tank in CPEF, the carbon dioxide tank and the oxygen tank in CABHF were 820 g, 2830 g, 4425 g, 1780 g, and 1792 g, respectively. Sequential cultivation and limiting the processing of the wet oxidation processor to the quantity of waste product for one day reduced the fluctuation of carbon dioxide and oxygen in each facility.

CONCLUSION

A simulation to integrate the uncombined wet oxidation processor was conducted for future closed habitation experiments, and the storage ability required for the buffer of an air processing subsystem for two humans to dwell for 120 days was presumed. As a result, under the scenario assumed at this time, the storage capacities of the carbon dioxide tank, the oxygen tank, and the waste gas tank in CPEF, the carbon dioxide tank and the oxygen tank in CABHF were 820 g, 2830 g, 4425 g, 1780 g, and 1792 g, respectively. This implies the storage capacities required under the best conditions. It was confirmed important to set the closing period of material circulation as the longest cultivation period of the crops, and to limit the processing amount of the wet oxidation processor to the quantity of waste product for one day. It is necessary in the future to reflect new experiment data, and to investigate the material circulation in corresponding to an unsteady state or unanticipated problem.

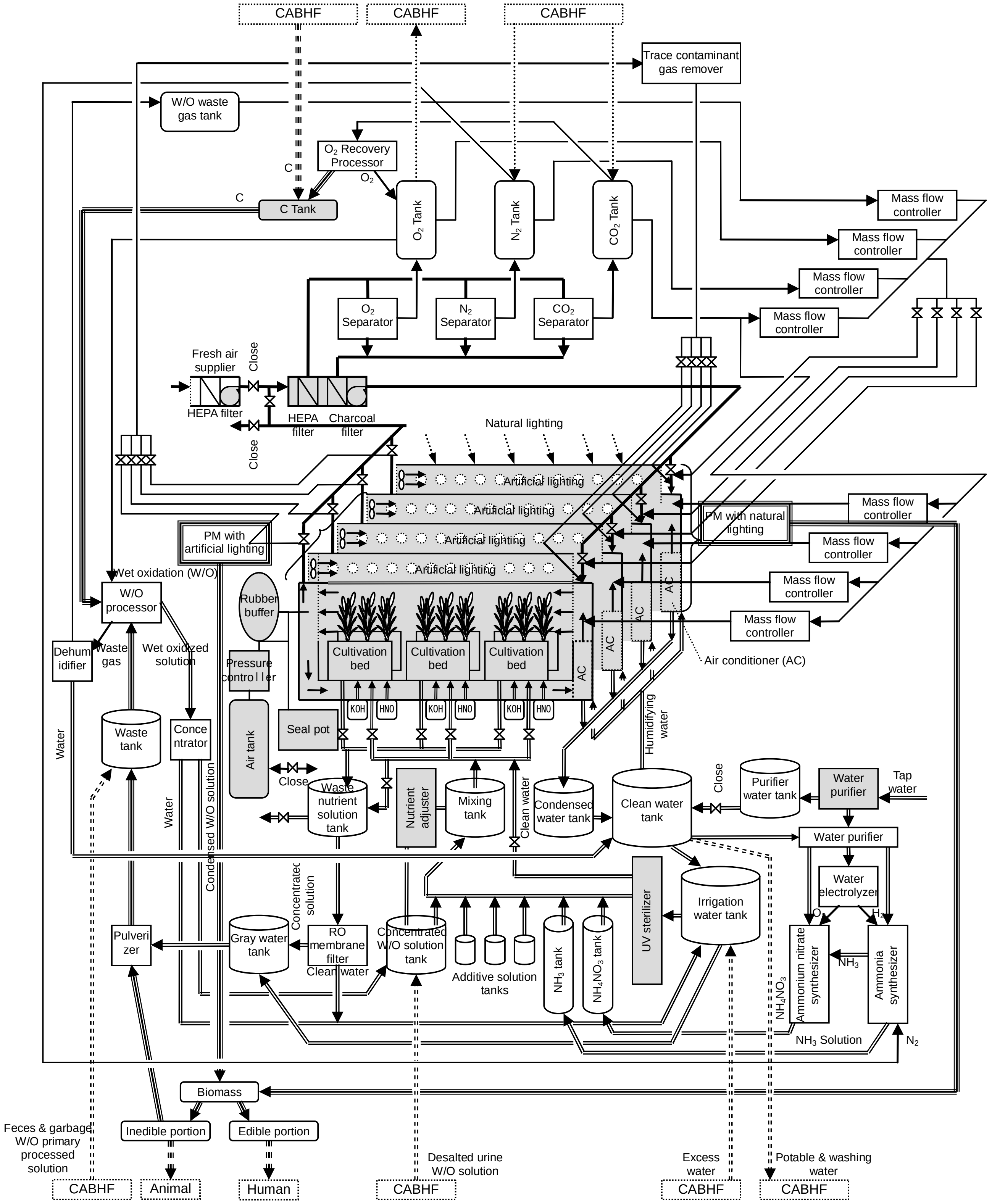

Fig. 1.1 Plantation Module and its Material Circulation System in CEEF [1]

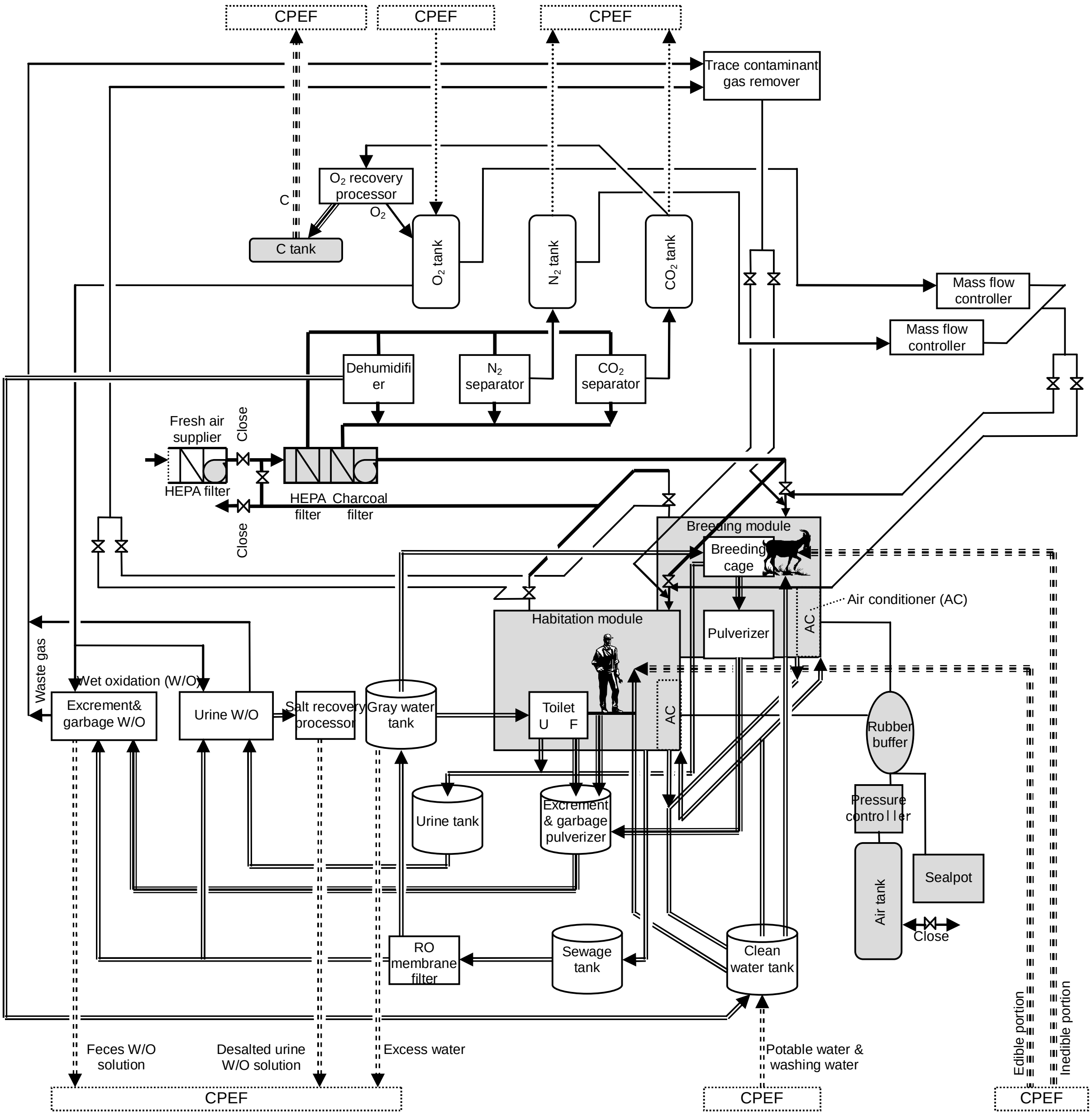

Fig. 1.2 Habitation Module and its Material Circulation System in CEEF

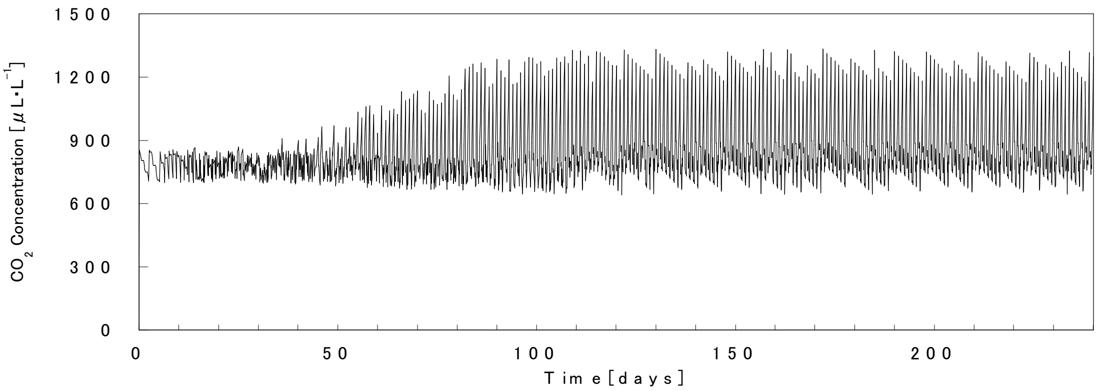

Fig. 2.1 Fluctuation of carbon dioxide concentration in chamber A

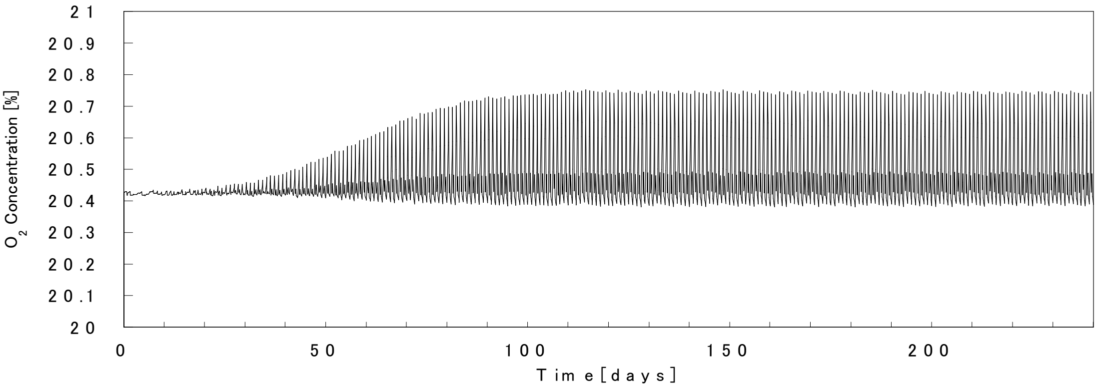

Fig. 2.2 Fluctuation of oxygen concentration in chamber A

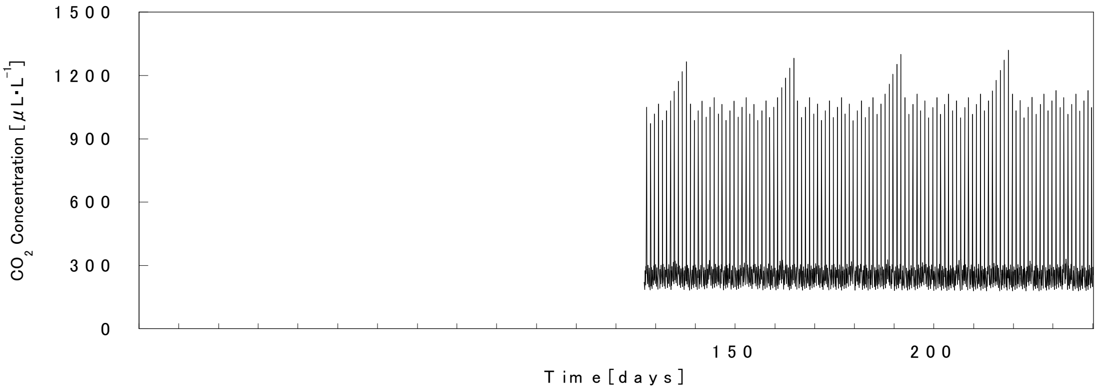

Fig. 2.3 Fluctuation of carbon dioxide concentration in habitation chamber

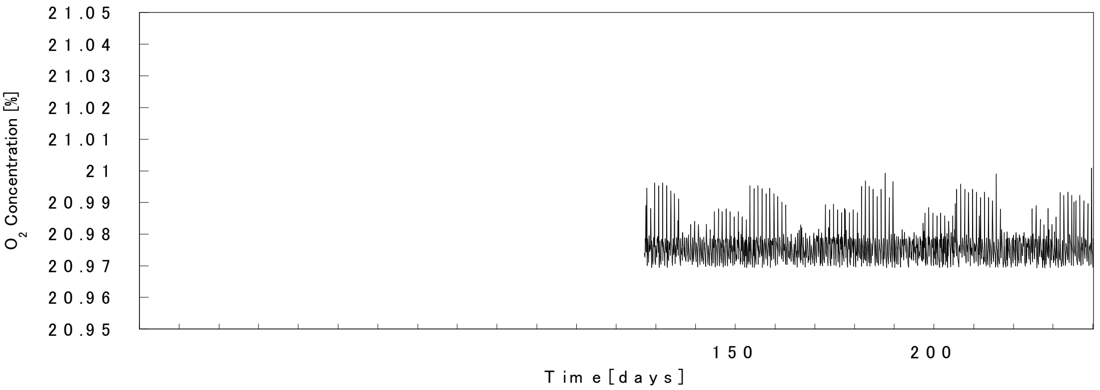

Fig. 2.4 Fluctuation of oxygen concentration in habitation chamber

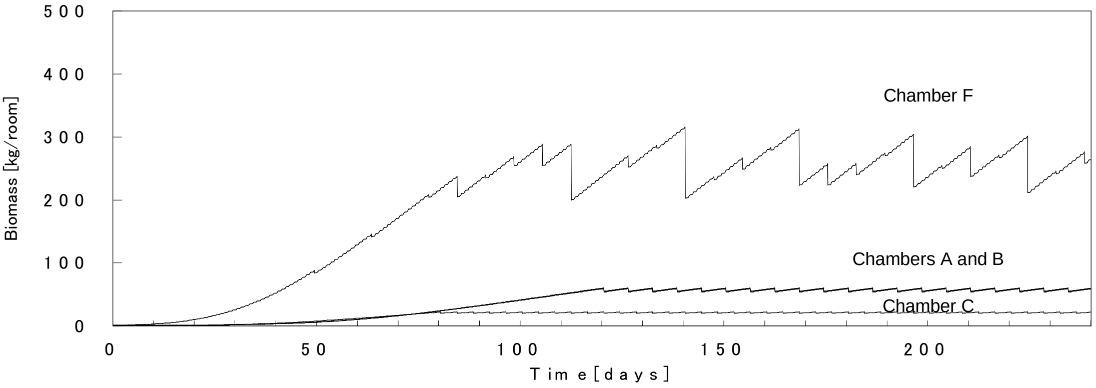

Fig. 2.5 Fluctuation of biomass in each chamber

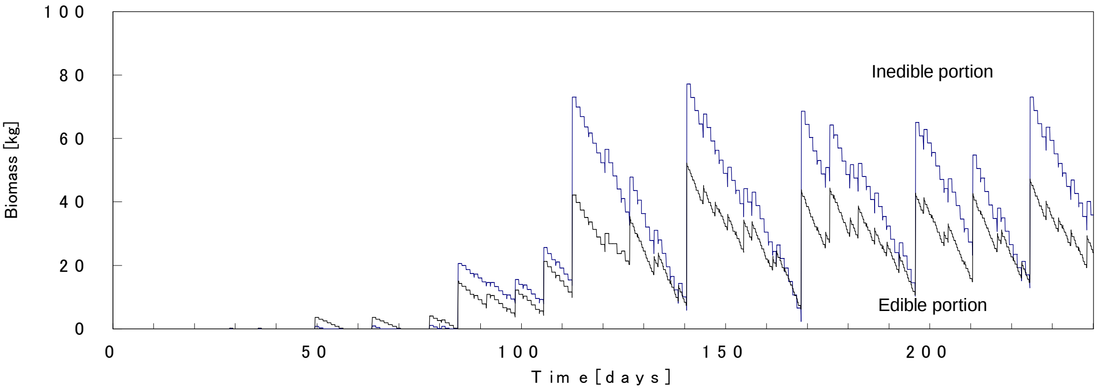

Fig. 2.6 Fluctuation of biomass in storage

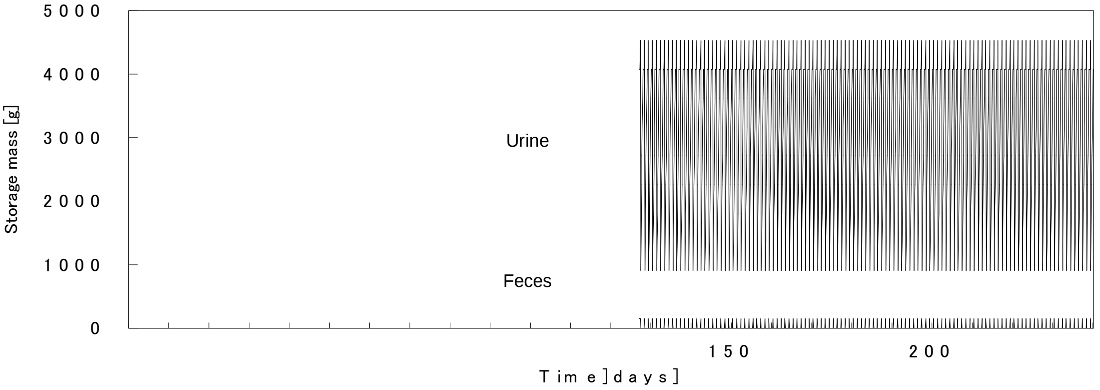

Fig. 2.7 Fluctuation of mass in feces storage and urine storage

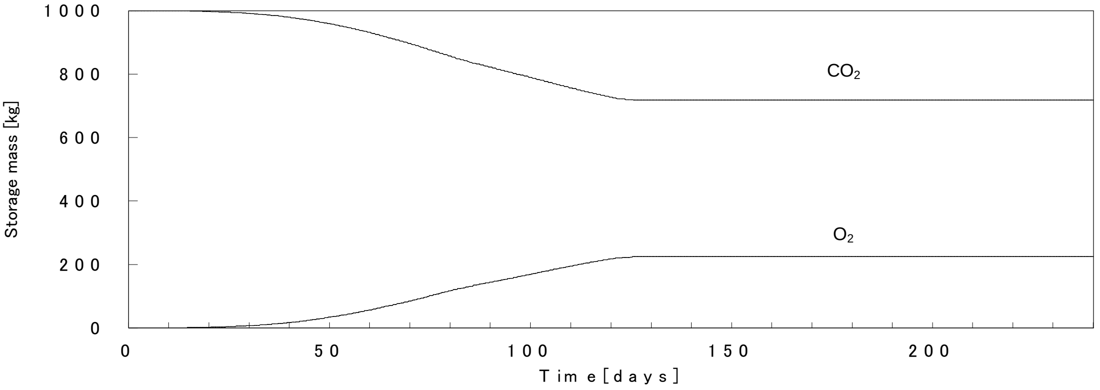

Fig. 2.8 Fluctuation of mass in external carbon dioxide tank and oxygen tank

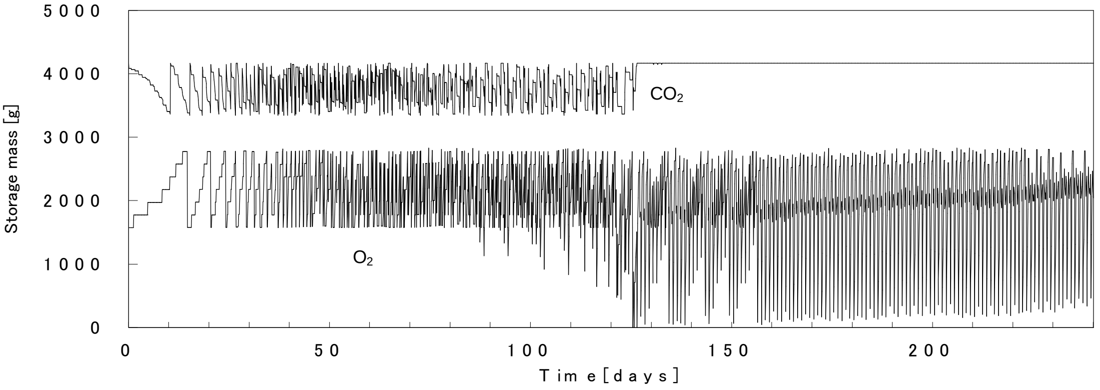

Fig. 2.9 Fluctuation of mass in carbon dioxide tank and oxygen tank in CPEF

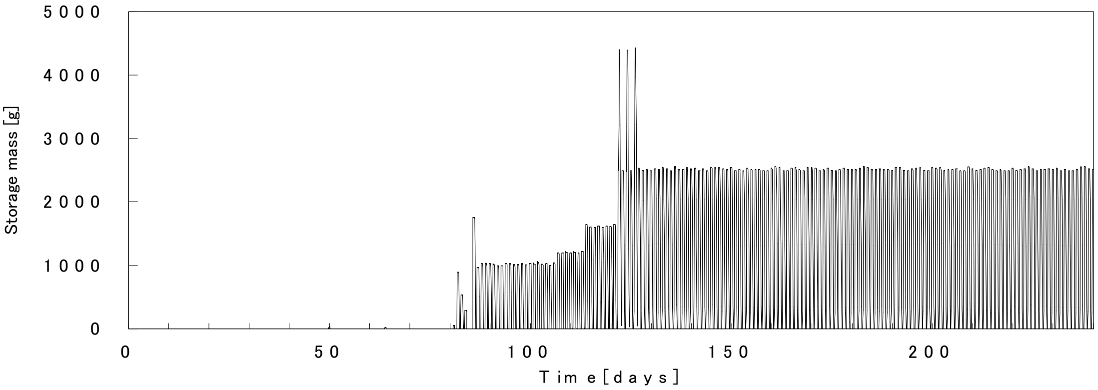

Fig. 2.10 Fluctuation of mass in waste gas tank in CPEF

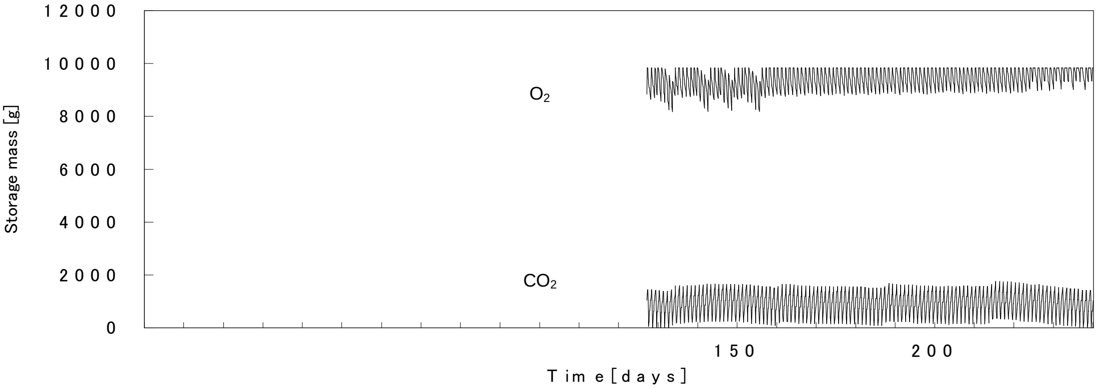

Fig. 2.11 Fluctuation of mass in carbon dioxide tank and oxygen tank in CABHF

Table 1 Cultivation bed assignments for each chamber and crop growth parameters

Chamber	Area	Bed	Crop	Area	Planting Period	Cultivation Period	Harvest Index	Yield
-	[m^2]	-	-	[m^2]	[day]	[day]	[-]	[$g \cdot m^{-2} \cdot day^{-1}$]
A	30	A - F	Rice	30	3.5	123	0.433	12.8
B	30	A - F	Rice	30	3.5	123	0.455	13.7
C	30	A - F	Soybean	30	3.5	77	0.425	7.1
F	60	A	Sweet potato	1	28	112	0.35	1.3
			Potato	1	28	112	0.35	1.3
			Sweet paper	2	35	114	0.25	2.27
		C	Cucumbers	2	28	86	0.33	5.24
			Perilla	1	56	103	0.09	1.08
			Tomato	2	28	105	0.22	5.80
		E	Pumpkin	2	35	108	0.54	24.78
			Aborigine	2	28	121	0.37	7.73
		G	Cabbage	1.5	14	91	0.36	1.53
			Onion	2	14	127	0.08	0.11
			Snow pea	1.5	14	82	0.4	7.77
		H	Peanut	5	28	112	0.4	7.1
		I	Welsh onion	0.5	7	71	0.91	6.81
			Lettuce	0.5	7	33	0.91	1.60
			Crown daisy	0.6	7	39	0.90	43.06
			Mitsuba	0.5	7	40	0.88	2.96
			Komatsuna	0.3	7	28	0.95	2.72
			Spinach	0.5	7	35	0.56	1.85
			Leek	0.6	14	113	0.58	8.61
		J	Carrot	1.5	14	82	0.48	2.12
			Sugar beet	2	14	127	0.58	2.27
			Green been	1.5	14	71	0.35	1.93
			Chinese cabbage	1.5	14	91	0.47	1.80
		L	Radish	1.5	7	50	0.44	2.47
			Turnip	1.5	7	50	0.61	1.23

Yield is dry weight. Taro data is used as Sweet potato and potato data and soybean data is used as peanut data.

Table 2.1 Calculated crop growth model parameters

Crop	$a_{(CO2)0}$	$a_{(CO2)1}$	$a_{(CO2)2}$	$a_{(CO2)3}$	a_{x0}	a_{x1}	a_{x2}
Rice	-0.55586	0.5139	0.0061464	-0.000069311	1.1981	-1.2828	-0.0027
Soybean	-0.28958	0.14044	0.017839	-0.00020296	1.4222	-1.4778	-0.5517

Light Intensity: $1425\mu mol\cdot m^{-2}\cdot s^{-1}$, Carbon dioxide concentration:$700\mu L\cdot L^{-1}$,
Temperature: Light period of rice 28^0C, Dark period 21^0C, Light period of soybean 24^0C, Dark period 17^0C

Table 2.2 Calculated crop growth model parameters

Crop	a_{y01}	a_{y02}	a_{y03}	a_{y04}	a_{y05}
Rice	-0.30	0.31	0.75	1.00	1.24
Soybean	-0.20	0.43	0.80	1.00	1.30

Table 3 Setting of Light Intensity and Operation schedule of CO_2 Separator and O_2 Separator

	Light Intensity[%]				CO_2 Separator				O_2 Separator			
Chamber	A	B	C	F	A	B	C	F	A	B	C	F
0:00-1:00	0	0	0	0	D	A	DC	DC	DC	C&O	DC	DC
1:00-2:00	0	0	0	0	DC	D&A	DC	DC	DC	C&O	DC	DC
2:00-3:00	0	0	0	0	DC	D&A	DC	DC	DC	C&O	DC	DC
3:00-4:00	25	0	0	0	DC	D	A	DC	DC	DC	C&O	DC
4:00-5:00	25	25	0	0	DC	DC	D&A	DC	DC	DC	C&O	DC
5:00-6:00	50	25	25	75	DC	DC	D	A	DC	DC	DC	C&O
6:00-7:00	50	50	25	75	DC	DC	DC	D&A	DC	DC	DC	C&O
7:00-8:00	75	50	50	75	DC	DC	DC	D&A	DC	DC	DC	C&O
8:00-9:00	75	75	50	75	DC	DC	DC	D&A	DC	DC	DC	C&O
9:00-10:00	75	75	75	75	A	DC	DC	D	DC	C&O	DC	DC
10:00-11:00	75	75	75	75	D&A	DC	DC	DC	C&O	DC	DC	DC
11:00-12:00	75	75	75	75	D&A	DC	DC	DC	DC	DC	C&O	DC
12:00-13:00	75	75	75	75	D&A	DC	DC	DC	C&O	DC	DC	DC
13:00-14:00	50	75	75	75	D	A	DC	DC	DC	C&O	DC	DC
14:00-15:00	50	50	75	75	DC	D	A	DC	DC	DC	C&O	DC
15:00-16:00	25	50	50	75	DC	DC	D	A	DC	DC	DC	C&O
16:00-17:00	25	25	50	75	A	DC	DC	D	C&O	DC	DC	DC
17:00-18:00	0	25	25	75	D	A	DC	DC	DC	C&O	DC	DC
18:00-19:00	0	0	25	75	DC	D	A	DC	DC	DC	C&O	DC
19:00-20:00	0	0	0	0	DC	DC	D	A	DC	DC	DC	C&O
20:00-21:00	0	0	0	0	DC	DC	DC	D&A	DC	DC	DC	C&O
21:00-22:00	0	0	0	0	A	DC	DC	D	DC	DC	DC	DC
22:00-23:00	0	0	0	0	D&A	DC	DC	DC	DC	DC	DC	DC
23:00-24:00	0	0	0	0	A	DC	DC	DC	C&O	DC	DC	DC

Light intensity $1425\mu mol\cdot m^{-2}\cdot s^{-1}$ is 75%
A : Adsorb, D : Desorb, DC : Disconnect, C&O : Connect & Operation