The method of assessment of the balance of atmospheric O_2 and CO_2 in a forest

IMANTS LIEPA, LĀSMA ĀBOLIŅA
Forest Faculty
Latvian University of Agriculture
Akademijas street 11, Jelgava, LV-3001, Latvia

Liepa I., Āboliņa L. 1997. The method of assessment of the balance of atmospheric O_2 and CO_2 in a forest. *Baltic Forestry,* 1: 15-18.

Processes such as an increase in the amount of the atmospheric carbon dioxide and the removal of oxygen belong to the most of the terrible ones occurring in the present biosphere. These facts force quantitatively to evaluate the dynamics of the resources of these atmosphere constituents. Among terrestrial ecosystems, forests are the most important regulators of the mentioned gas equilibrium. Producing of the primary biomass ensures assimilation of CO_2 and release of O_2 and vice versa if the biomass decomposes.

Our methodical proposals have based on the summary equation of the photosynthesis, the elementary structure of the woody phytomass and possibility to determine growing stock and the annual volume increment of forest stand. These formulas have been elaborated and verified by the authors of this paper. The indicated equations are adequate for the calculation of the given gas amount expressed in the metric tons.

Key words: atmospheric oxygen and carbon dioxide: mentioned gas equilibrium; primary biomass; growing stock; the annual volume increment.

Our planet is considerably changed by humans. In our century many global processes with stable trends and increasing intensity have been noticed. Unfortunately, in most cases these changes are not favourable for the humans' existence, and in some cases changes in the biosphere are becoming serious threats for the physical chemical conditions of the life existence.

The role of the planetary processes caused in an anthropogenic way has not yet been completely perceived. It's because of the great number of the existing processes, their various influences and particularly - their complex impact, that sometimes even worsens the manifestations of the influences.

Without attempting to create the classification of changes in the biosphere, diversity of their influences and mechanism of their actions and trends, let us pay our attention to two indubitable truths that are highly associated with forests.

The investigation is conducted on the two systematic changes in the chemical composition of the atmosphere: *an increase in the atmospheric carbon dioxide (CO_2) and removal of oxygen.* Also conclusions are inferred. There are many analytical works (1) about the global consequences that are possible and real even in the nearest future (the hot-house's effect, melting of the icecups, increment of the water level in the World's ocean, destruction of the atmospheric oxygen O_2 and ozone layer O_3.

Different specialists have agreed that the question is not so simple: on the one hand because of the increasing number of fossil fuel the industrial use of O_2 and release CO_2 has increased, and on the other hand - increasing possibility of the regeneration of O_2 and assimilation of CO_2 due to the enormous area of destroyed forests and pollution of the World's ocean.

The danger of situation requires to be aware of what is happening and thoroughly conduct research on the quantity of decreasing O_2. Here one of the most important tasks is to investigate the O_2 and CO_2 balance in the forest.

In the calculation of the quantitative relationship of O_2 and CO_2 in every stand, there should be used the physiological conclusion that in order to form a certain amount of the prime product of photosynthesis - $C_6H_{12}O_6$ - certain amounts of CO_2 and H_2O (5) are used. Both substances are cloven in components C, H and O, that afterwards form $C_6H_{12}O_6$. C and H are completely combined, but O just partly, and that is why the rest of O is distributed in the atmosphere as O_2. The energetic of the process is guaranteed by the active photosynthesis radiation of the Sun, that is combined by the chlorophyll. The following equation illustrates the quantitative relationship between the substances mentioned:

$6CO_2 + 6H_2O = C_6H_{12}O_6 + 6O_2 - 672$ kcal.

Afterwards from $C_6H_{12}O_6$ and nutrients, that plants together with water have got from the soil, and really complicated prime production differring in the chemical structure is formed. We can divide our task methodically into three stages: the determination of the amount of plant biomass and determination of its increment; the chemical structure of the biomass, determination of the amount of the raw substances and products of photosynthesis; the mathematical equations, integrating the information above, would guarantee practicable and precise calculations of O_2 and CO_2

The determination of the amount of the biomass, that is formed by means of photosynthesis, is within the scope of the forest investigation. Our task is easier due to the fact that we are not interested in the whole biomass, just in the part that remains undivided for a longer period of time. For example, herbaceous plants and needles and leaves of trees are combining the assimilated CO_2 just for a short time, because when the organically substances are cloven, CO_2 is removed. Therefore, in determining the biomass we can consider only the stem, branches and roots of trees. This determination is not so easy to realise as it seems at the first moment. Nowadays investigation still has no practical formulas for calculating branch and root mass of trees and bushes in a stand. The xilometry method here can be used only as the means for working out some mathematical equations. Moreover, while considering the dynamics of O_2 and CO_2 it is more important to know the annual balance of this gas, but not its balance for the absolute time of stand's existence. It means that we should know the annual increment of mentioned parts of the stand, and this question is far from being explored comparing to the question about calculation of the stand volume. Although a part of the foresters does not consider yet the question about evaluation of all components of the stand as really important and needed to be practised, ecologists are aware of its priority and importance, because sound knowledge of all procedures in one stand can be referred to the forest as a whole. The difference between the combined CO_2 and released O_2 shows the contribution of the stand in the process of forming air composition in that particular state or region.

For consideration of the research level, the method for calculating the released O_2 and assimilated CO_2 in the formation process of stand volume and its increment is presented. There is a great number of ways how to determine the stand volume and its increment, and everybody is allowed to choose the most comfortable method for himself. We just offer you some equations that are simple and convenient to use:

$$M = kG(H + 4) \quad (1)$$

$$Z_M = kG \{[2iu (H - 2Z_H + 4)] / (5D + iu)] + Z_H \} \quad (2)$$

$$ZH = 2iH(aD + b) / (cD + 100) \quad (3)$$

where

M - stand volume (the volume of stand's element - in mixed stands), m^3 / ha;

G - basal area, m^2 / ha;

H - the mean height of stand, m:

D - the mean diameter of stand, cm;

i - the mean annual diameter increment of stand, mm;

Z_M - the volume increment of stand, m^3 / ha;

Z_H - the height increment of stand, m;

k, a, b, c, p, q, w, u - Quotient for tree species (Table 1).

Table 1. Values of Quotients

Species	k	a	b	c	p	q	w	u
Pine	0.390	-0.03212	4.234	21.889	20.60	143.9	19.53	1.103
Spruce	0.415	-0.04620	4.802	31.203	5.25	117.6	5.00	1.046
Birch	0.385	-0.07276	-0.150	-35.714	0.20	110.2	0.02	1.095
Aspen	0.405	-0.03569	2.352	12.829	0.78	109.9	0.67	1.061
Black alder	0.400	0.00500	7.240	90.909	-0.55	119.0	-0.36	1.081
White alder	0.380	0.09580	3.478	45.988	-49.10	93.3	-45.83	1.050

It is important to remember that in formulas (1) and (2) stand volume and its increment are measured on the bark. On calculating the amounts of O_2 and CO_2 we must consider the fact that wood and bark are different according to their chemical structure, and therefore calculations of those substances should not include the bark. It is possible if *M* and Z_M are divided by the quotient of the volume of the bark s:

$$s = (pD + q) / (Wd + 100) \quad (4)$$

The chemical structure of wood is really complicated, but it is known that the elements of absolutely dry wood of different species has almost the same ratio of C, H and O. It is approximately 49.5 % of C, 6.3 % of H_2 and 44.1 % of O_2. Therefore, the amount of assimilated CO_2 and removed O_2 practically depends on the ability to combine those substances, and tree species play here almost no role. As stand volume and its increment are calculated by $m^3 \times ha^{-1}$, we need to get the mass of absolutely dry wood, which is expressed by *t*. That can be got multiplying *M* and Z_M by the quotient of density p_0 whose values are determinated by the state standard VS 3243-83 and given in Table 2.

Table 2. Values of Quotients

Species	Po	λ	δ
Pine	0.470	0.333	0.253
Spruce	0.400	0.301	0.229
Birch	0.600	0.419	0.319
Aspen	0.440	0.323	0.246
Black alder	0.500	0.363	0.276
White alder	0.500	0.345	0.262

To calculate how many tons of CO_2 are used and how many tons of O_2 are removed in the atmosphere for producing 1 ton of absolutely dry wood, we should use molecule mass and mole mass of all components from the equation of photosynthesis. As we know molecule mass is the relative value that shows how many times one unit of molecule mass of a certain substance is larger than one unit of atomic mass of the same substance. Mathematically molecule mass equals to the sum of the atomic masses of all those atoms that are included in the chemical elements of that molecule. Atomic mass is known as one of the characterising and most important measures for describing any atom. For example, atomic masses of H, C and O are the following: 12.011; 1.0079; 15.9994. Therefore the molecule mass of CO_2 is 12.011 + 2 x 15.9994 = 44.0098. Here it is helpful to remember - if mole mass is expressed by *g x moll^{-1}*, mathematically it equals to the molecule mass (2). In accordance with this the mass of 6 CO_2 moles from the equation of photosynthesis is 6 x 44.0098 = 264.06 g. Following the same pattern we can find out that the mass of 6 H_2O molls is 108.09, 6 O_2 molls - 191.99, one mole - $C_6H_{12}O_6$ (C - 72.07, H - 12.10, O - 95.99 g). The following calculations are based on these measurements and principle of solving the problems when 3 measures are given, but fourth must be found.

Let us calculate the amount of CO_2 that is used to provide 49.5% CO_2 in 1t of absolutely dry wood:

$m_{CO2} = 0.495 \times 264 : 72 = 1.815\ t / m^3$

H_2O mass needed to combine 6.3 % of hydrogen:

$m_{H2O} = 0.063 \times 108 : 12.1 = 0.562\ t / m^3$

O_2 can be released in two ways - when CO_2 and H_2O have cloven. Oxygen that supplements the atmosphere, by assimilating 1.815t of CO_2 is:

$m_{O2(CO2)} = 1.815 \times 192 : 264 = 1.320\ t$

O_2 that is formed, when 0.562t H_2O have been cloven, is:

$m_{O2(H2O)} = 0.562 \times 96 : 108 = 0.500\ t$

As we know there are 44.1 % O_2 in the structure of wood, and the total amount of O_2 that is released in the air, is:

$m_{O2} = 1.320 + 0.500 - 0.441 = 1.379\ t / m^3$

To determine the mass of CO_2 that has been assimilated in the process of stand volume formation, quotient *k* in equation (1) is substituted by l = 1.815 x *k* x p_0, but to fix the amount of annually given by this stand, *k* should be substituted by l in equation (2). Similarly the amount of released O_2 can be calculated only here instead of applying *k* d = 1.379 x *k* x p_0 (Table 2) should be used. We should bear in mind that in equation (1) and (2) the stand and its increment ob are shown. Therefore, to escape the impact of the bark, the result should be divided by the quotient of bark volume s (formula (4)).

Quotients *l* and *d* characterise the ability of each tree species to combine CO_2 and release O_2. That is why those measurements can be used in order to arrange the species according to this ability in either - increasing or decreasing order. By comparing the values of mentioned ability, we see that birch is most productive. It is understandable and can be explained by high density of absolutely dry wood (p_0 = 0.600 (Table 2)). Assuming that k of birch is the highest possible, we get that birch is 100%; black alder - 86.6%; white alder 82.3%; pine 79.5%; spruce 71.8%.

Sometimes there is necessary to express the amount of gas by the units of volume. It can be realised if gas mass is divided by its density. In our case previously calculated masses of CO_2 and O_2 (expressed in t) should be divided by 0.00143 and 0.00198 respectively, and as a result of this we will have volumes of gas expressed in m^3.

In this paper the method of calculating the amount of assimilated CO_2 and released O_2 by one stand (element of stand) is presented and analysed. It is adequate to many other groups of stands in that particular country or region as well. The only difference is in determining the level of stand and its increment. The problem of disability to determine the volume increment of roots and branches should be mentioned as theoretically unsolved. The most rational solution would be to express those measurements as the function of investigation's elements that would be easily measured in the forest. This is the task of the nearest future. It is also the only task before we will be able to express by figures the contribution of any territory in decreasing the amount of CO_2 and increasing the amount of O_2 in the atmosphere.

References

Environmental affects of ozone depletion: 1994 assessment. 1995. In *Ambio* Vol. 24 No 3. P. 138-196.
The handbook of physics. (Fizikas rokasgrāmata). 1985. R.: Zvaigzne. P. 452.
Vaņins S. The science of wood. (Koksnes zinātne) 1950 LVI, Rīga. P. 464.
Antanaitis V. V., Zagreev V. V. The increment of forest. Forest Industry, Moscow. (in Russian). P. 200.
Liepa I. Dinamics of growing stock. Prognosess and ecology. Rīga: Zinātne. (in Russian). P. 172.

МЕТОД УСТАНОВЛЕНИЯ БАЛАНСА АТМОСФЕРНОГО O_2 И CO_2 В ЛЕСАХ

И. Лиепа, Л. Аболиня

Резюме

Процесс увеличения содержания атмосферного CO_2 и уменьшения содержания O_2 является частью всеобщего процесса, происходящего в настоящее время в биосфере. Эти факты вызывают необходимость количественной оценки динамики ресурсов данных составных частей атмосферы. Среди наземных экосистем наиболее важными регуляторами равновесия указанных газов являются леса. Продуцирование первичной биомассы включает ассимиляцию CO_2 и выделение O_2 и при разлагании биомассы имеет место обратный процесс.

Наши методические предложения заключались в представлении уравнения фотосинтеза, первичной структуры лесной фитомассы и возможности обосновать объем и годовой объем массы древостоя. Данные формулы выведены и обоснованы авторами статьи. Приведенные уравнения соответствуют измерению количества данных газов, выраженного в метрических тоннах.

Ключевые слова: атмосферные кислород и двуокись углерода: равновесие указанных газов; первичная биомасса; объем; годовой прирост массы.