

# On the concept of ecohydrological separation of flows in ecosystems

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**Abstract.** In this paper, within the framework of the concept of ecohydrological separation, modeling of changes in transpiration flow velocity in a tree at fluctuations of relative humidity of the environment is carried out with the help of basic equations of fluid mechanics and gas mechanics. In a computational experiment, the result is determined by parameters that have a clear physical meaning and take into account the unique properties of tree pores and the solutions in them. The model can be used to identify the characteristic range for parameter values taking into account the influence of climate, soil composition, tree species and to form databases for research of transpiration processes and the influence of the environment on them.

## 1 Introduction

At all times there has been an urgent need for projects that can stimulate technologies in many areas of the world economy. At present, it is difficult to overestimate the problem of developing the concept of the mechanism of moisture exchange in the earth-atmosphere system for understanding the principles of life support of both ecosystems and humanity on our planet. Climate change and the need to control and neutralize the harmful effects of industry on the environment stimulate the development of research in the field of monitoring the condition of individual trees and forests in general. In turn, the growing demand for devices with controlled accuracy to determine the fluctuations of this state stimulates the development of methods for modeling processes charge redistribution processes in the wood of trunks [1-3].

In the cycle, water from precipitation enters ecosystems and then returns to the atmosphere through evaporation and transpiration to form clouds. Modeling the movement of transpiration fluxes is significantly limited to inconsistency of existing concepts of system description of mechanisms of their organization. Analysis of data on large lakes and rivers shows that about  $62,000 \pm 8,000$  cubic kilometers of water are annually discharged into the atmosphere, which consumes half of all solar energy absorbed by the land surface [3-5]. When developing climate models in the field of solving problems of water resources consumption forecasting, it is necessary to form an integrated approach to the processes of moisture redistribution in ecosystems under the influence of environmental factors. The concept of ecohydrological partitioning, which is based on the assumption that two types of flows fill underground water basins, can be realized at present. The first of them is formed in

the process of plant transpiration, and the second - by combined ground and river water flows. This idea of multicircuit water redistribution is confirmed by monitoring of various biosystems. The results of recent studies using isotopes show that salt solutions in transpiration flows of plants differ in composition from the moisture of ground and river runoffs. Therefore, to develop programs for numerical modeling of water redistribution in ecosystems, it is necessary to describe the transformation of salt solution composition in such a multi-loop flow system. The key point is a systematic description of the transpiration mechanism. It is noted in many sources that the existing methods of calculating evaporation from the land surface are mainly based on the use of water and heat balance equations and their influence on the regularities of moisture transport from the evaporating surface to the atmosphere [6-8]. At present, methods of direct measurements of water exchange parameters are being developed, for example, exchange parameters of a single leaf or determination of xylem flow velocity (sap flow measurement) at the tree level as a whole. Both approaches are associated with solving a number of problems, one of which is to identify the relationship between transpiration and meteorological factors, especially such as humidity [9-10]. The aim of this work is to model the change in transpiration rate under fluctuations in the relative humidity of the environment within the framework of the basic approaches of fluid and gas mechanics.

## 2 Theoretical part

Since transpiration is the process of water movement through plant tissues and its evaporation through leaves into the atmosphere, the main parameters of direct measurements are evaporation rate and leaf stomatal conductance, and environmental factors are photosynthetically active radiation (PAR) intensity, temperature and relative humidity. As a result, most models are formulated within the framework of heat and mass transfer theory. If the concept is based on the question of understanding the mutual influence of changes in temperature and humidity of the environment and the rate of movement of salt solution, then the equation of energy balance in an ideal environment can be used.

Due to small pore sizes in the sapwood, the live sections of the steady-state transpiration flow can be considered as flat with a sufficiently high probability, and the movement as steady-state. Then a change in relative humidity  $\Delta\phi$  will lead to a change in pressure  $\Delta p$  on the leaf surface

$$\Delta p = \Delta\phi p_{nas} \quad (1)$$

where  $p_{nas}$  is the saturated vapor pressure, the value of which depends on the ambient temperature. As a result, there will be a change in the potential of forces  $\Delta\phi p_{nas}/\rho$  ( $\rho$  is the density of the solution), determined by the complex influence of meteorological factors. This will cause a change in the kinetic energy of a unit mass of moving solutions  $v\Delta v$ , which according to the Bernoulli equation is defined as [9],

$$v\Delta v = \frac{\Delta\phi p_{nas}}{\rho} - gh_l \quad (2)$$

where  $g$  is the acceleration of free fall, and  $hl$  is the friction loss on the length of continuous movement  $l$  in the flow averaged over all pore diameters of the live section  $d$ . According to Darcy's formula we have

$$h_l = \lambda \frac{lv^2}{4gd} \quad (3)$$

To estimate the coefficient of hydraulic friction  $\lambda$  in this case we can use Poiseuille's ratio for laminar flow [4], since in pores the velocity of solution movement according to the data of transpiration studies is low:

$$\lambda = 64/Re \tag{4}$$

here  $Re = \rho v d / \eta$  is the Reynolds number ( $\eta$  is the dynamic viscosity of the solution). As a result, from (3) taking into account (4) we can obtain that

$$gh_l = 16 \frac{\eta l v}{\rho d^2} \tag{5}$$

and from (2) taking into account (5)

$$v \Delta v = \frac{\Delta \phi p_{nas}}{\rho} - 16 \frac{\eta l v}{\rho d^2} \tag{6}$$

If the increment of velocity during the relaxation time  $\tau$  after a change in moisture content is estimated as  $\Delta v = dv\tau/dt$ , the relation (6) is transformed to the form:

$$v \frac{dv}{dt} = \alpha(1 - \beta v) \tag{7}$$

where is  $\alpha = \frac{\Delta \phi p_{nas}}{\rho \tau}$  parameter characterized by the rate of change of the potential of volumetric forces acting per unit mass and stimulated by fluctuation of relative humidity of the environment;  $\beta = 16 \frac{\eta l}{\Delta \phi p_{nas} d^2} = \frac{1}{v_\phi}$  ( $v_\phi$  is the maximum possible velocity of solution movement in the sapwood pores). The result of the solution of differential equation (7) with initial condition  $v=v_0$  at  $t=t_0$  will be a transcendental equation for the change in velocity:

$$(1 - \beta \Delta v) e^{\beta(\Delta v)} = (1 - \beta v_0) e^{-\beta^2 \alpha (t-t_0)} \tag{8}$$

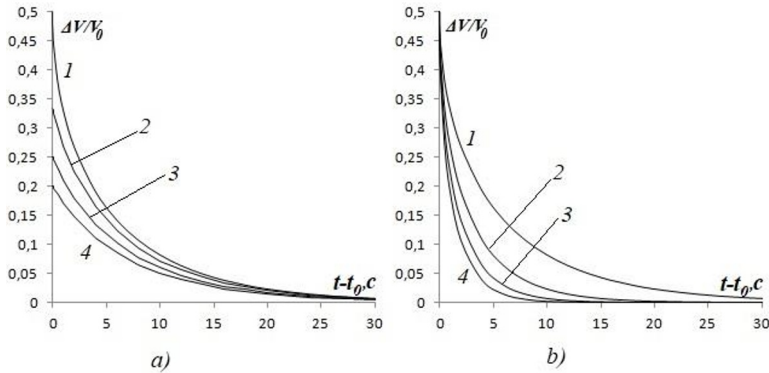
where  $\gamma = \beta^2 \alpha = a_\eta / v_\phi$  - a parameter characterizing the degree of deceleration of the velocity of movement of the solution ( $a_\eta$  - decrease in the velocity of movement per unit time) in the sapwood pores due to the influence of internal friction.

If we assume that the deviation of velocity from the initial velocity in practice is relatively small in magnitude, then  $e^{\beta(v-v_0)} \approx 1 + \beta \Delta v$ . Then from equation (8) can be obtained that

$$\Delta v = \frac{v_0}{2} \left( 1 - \frac{\sqrt{1 + 4(1 - \beta v_0) e^{-\gamma(t-t_0)}}}{\beta v_0} \right) \tag{9}$$

Relationship (9) is the basic one for modeling the relative change in the velocity of solutes in the sapwood pores. The steady-state velocity of solutions  $v_0$  in the sapwood pores is largely determined by the balance of heat and mass transfer and is actively studied [6]. Its value is influenced by the processes of charge redistribution in the xylem of trunks, which in turn is determined by changes in the ambient temperature [10-11].

### 3 Results of the model experiment



**Fig. 1.** Results of modeling the dynamics of relative change in the velocity of solution movement through the sapwood: (a) for  $v_\varphi/v_0 = 50\%$  (curve 1),  $v_\varphi/v_0 = 33.3\%$  (curve 2),  $v_\varphi/v_0 = 25\%$  (curve 3),  $v_\varphi/v_0 = 20\%$  (curve 4), assuming that  $a_{\eta t}/v_\varphi$  is 12% per unit time; (b) for values of  $a_{\eta t}/v_\varphi$  equal to 12% (curve 1), 24% (curve 2), 36% (curve 3), and 48% (curve 4) per unit time when  $a_{\eta t}/v_\varphi = 50\%$ .

The main parameters of the proposed model  $\gamma = a\eta/v_\varphi$  and  $\beta v_0 = v_0/v_\varphi$  are largely determined by the comparative relations of the influence factors of changes in humidity and ambient temperature ( $v_0/v_\varphi$ ) and viscosity of salt solutions ( $a\eta/v_\varphi$ ). In the computational experiment, the dependence of the change in the velocity change of salt solutions on these parameters was investigated. For this purpose, calculations were carried out for cases when  $v_\varphi$  is 50%, 33.3%, 25% and 20% of  $v_0$ , provided that per unit time the value of  $a\eta t$  is equal to 12% of  $v_\varphi$ . The results are presented in Fig. 4.2.1(a) (curves 1, 2, 3, and 4, respectively). Spreadsheets embedded in the office software package were used for the calculations. It was found that the relative change in the velocity change of the solutions corresponds to a relaxation process to the initial state over time, the duration of which, as well as the maximum value of the relative velocity change, is significantly affected by the  $v_\varphi/v_0$  ratio. Then, the dependence of the change in the movement velocity of salt solutions was obtained for the ratios  $a\eta t/v_\varphi$ , per unit time being 12%, 24%, 36%, and 48% under the condition that  $\beta v_0 = v_0/v_\varphi = 0.5$ . The results are presented in Fig. 4.2.1 (b) (curves 1, 2, 3 and 4, respectively). It was found out that the relative change in the velocity of movement of solutions corresponds to the process of relaxation to the initial state over time, the duration of which, as well as the maximum value of the relative change in the velocity of movement, is significantly affected by the ratio  $v_\varphi/v_0$ . Then, the dependence of the change in the movement velocity of salt solutions was obtained for the ratios  $a\eta t/v_\varphi$ , per unit time being 12%, 24%, 36%, and 48% under the condition that  $\beta v_0 = v_0/v_\varphi = 0.5$ . The results are presented in Fig. 4.2.1 (b) (curves 1, 2, 3 and 4, respectively). It was found that significant influence of the solution viscosity on the value of the velocity relaxation time after a change in the ambient relative humidity.

### 4 Conclusion

Thus, the model developed within the framework of basic approaches of fluid and gas mechanics allows us to estimate the influence of meteorological factors on the rate of movement of solutions through the sapwood of tree trunks and, consequently, on the process of transpiration. The proposed model operates with three parameters that have a clear physical meaning and take into account the unique properties of tree pores and solutions in them. At the same time, xylem fluxes in the sapwood are the object of study, while the stomatal conductivity can be accounted for by determining such parameters as the diameter

of the live section and the average length of continuous solute movement. The use of the proposed approach will make it possible to identify a characteristic range of values of model parameters taking into account the influence of climate, soil composition, and tree species and to form databases for further studies of transpiration processes.

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