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*International Journal of Current Research in Life Sciences*
*Vol. 08, No. 01, pp.2948-2949, January, 2019*

**ISSN: 2319-9490**

# RESEARCH ARTICLE

# LIMIT VALUES FOR CAPILLARY TRANSPORT OF SUBSTANCES IN THE XYLEM OF PLANT

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Received 20th November, 2018; Accepted 25th December, 2018; Published 30th January, 2019

## ABSTRACT

Based on a previously published expression for maximum water flow in variable-section xylem capillaries, this report analyzed the heat balance of plant leaves, in which the maximum length of xylem capillaries of a plant was determined as a function of stoma concentration on plant leaves, and the physical constants that characterize formulas obtained specific planet (acceleration of gravity g and the solar constant $H_S$).

***Key words:*** Plant Xylem, Maximum Capillary Length, Stoma Concentration Per Leaf, Solar Radiation Density, Free Fall Acceleration.



**Citation: Konstantin Ludanov.** "Limit values for capillary transport of substances in the xylem of plant, 2019" *International Journal of Current Research in Life Sciences*, 8, (01), 2948-2949.

## INTRODUCTION

It is well known that on Earth plants are the source of free oxygen both in the air of the atmosphere and in the waters of the world ocean. It is plants that "crush" carbon dioxide molecules from the air into oxygen and carbon due to the photosynthesis reaction: in microalgae and in the leaves of trees. At the same time, these plants accumulate carbon during their growth, and free oxygen is released into the environment as a "waste" of the reaction. In turn, it was the atmospheric oxygen that formed in the atmosphere a "screen" of ozone (the oxygen isotope $O_3$), which blocked the flow of hard ultraviolet radiation from the Sun and ensured the appearance of life on Earth's land. Therefore, it is the plants that will help mankind to slow down the increase in the concentration of carbon dioxide in the atmosphere (which provokes "climate warming") and thereby increase the oxygen concentration in the air and in the waters of the oceans.

## MATERIALS AND METHODS

The author in (Ludanov, 2014) for the maximum flow of water $V_{max}$ in a xylem capillary of variable cross section due to the process of transpiration of leaves obtained "law of the fourth degree":

$$V_{max}=2(g/\nu)\cdot(a^2\cdot cos\theta/h)^4/9, \qquad (1)$$

where g is the acceleration of gravity (for the Earth g = 9.8 $m/s^2$);
ν – kinematic viscosity of water; a is the capillary constant of water;

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θ – wetting angle of the capillary walls, degrees; h is the length of the capillary, m

Analysis of this expression shows that if we determine the value of $V_{max}$, then we can calculate the length of the xylem capillary and estimate the height of the plant itself.

## RESULTS

**Estimation of the maximum length of xylem capillaries in plants:** The heat that is supplied to each individual stoma on the leaf surface is directly proportional to the density of solar radiation incident on it and inversely proportional to the total number of stomata on the leaf. Therefore, we first consider the heat balance of a single leaf of a plant. If we assume here that the leaf temperature is equal to the ambient air temperature, then there are only two components of such a balance: heat, which is supplied to the leaf by solar radiation and heat, which is removed from the leaf by transpiration. It is obvious that the supply of heat $Q_+$ to each leaf of the plant is carried out by its absorption by the surface of the incident solar radiation. And the heat consumption Q– in the heat balance goes to the evaporation of water from the stomata of the leaf.

The heat of solar radiation that is absorbed by a single sheet is equal to:

$$Q_+ = H_S\cdot\tau\cdot F\cdot cos\varphi,$$

where F – is the area of a single leaf of a plant, $cm^2$;
$H_S$ – is the solar constant, $H_S$ = 0.136 $W/cm^2$;
τ – atmospheric carrying capacity, τ ≤ ¾;
φ – angle of incidence of solar radiation on the surface of the sheet, degree.

The heat required for the transpiration of water from the stomata of the leaf:

$Q_{-} = G \cdot L \cdot N = G \cdot L \cdot n \cdot F$

where G – is the mass flow rate of water from the stoma during transpiration, kg/s; $G = \rho' \cdot V$; $\rho'$– density of water, kg/m$^3$; V – rate flow, m/s;

L – is the heat of evaporation of water at 20°C, L = 2.45 MJ/kg;

N – is the total number of stomata of the leaf, $N = n \cdot F$, n – is the concentration of stomata on the surface of the leaf, pieces/cm$^2$.

In the adiabatic case, these components of the heat balance of the $Q_+$ and $Q_-$ sheet can be equated to:

$Q_+ = Q_-$.

Where does the expression follow for $V_{max}$:

$$V_{max} = ((L \cdot \rho' \cdot n \cdot F)/(H_S \cdot \tau \cdot F \cdot cos\varphi))^{0,25} = ((L \cdot \rho' \cdot n)/(H_S \cdot \tau \cdot cos\varphi))^{0,25} \qquad (2)$$

In this expression, the area of F is successfully reduced. If we now substitute the expression from (1) instead of $V_{max}$, then we obtain the following dependence for the length of the xylem capillary:

$$h_{max}=a^2 \cdot cos\theta/((3/\rho')^2 \cdot (\mu/g) \cdot (H_S \cdot \tau \cdot cos\varphi)/(2n \cdot L))^{0,25}, \qquad (3)$$

from which it is easy to calculate the maximum length of the plant xylem capillaries, if the value of stomata concentration on the leaf surface is substituted into formula (3). After all, it is a genetic characteristic and is individual for each plant variety (Ludanov, 2016).

**Example:** By the formula (3) it is possible to calculate, for example, the maximum length of the capillaries of an apple tree, for leaves of which n = 29,400 pieces/cm$^2$, (Weier *et al.*, 1970). At the beginning of the "space age", the song "And on Mars will be the apple trees blossom!" was popular in the SU. In this regard, it is interesting to calculate the limiting length of xylem capillaries of terrestrial plants, which will be grown by colonists from Earth on Mars as part of the Earth expedition to the "red" planet. The question is how tall the plants will grow on Earth from the seeds of the earth. Indeed, the values of gravity ($g_M$ = 3,72 m/s$^2$) and the density of solar radiation on Mars ($^M H_S$= 0,0586 W/sm$^2$) and Earth are significantly different. If we calculate the ratio based on (3), we get the formula:

$$(h_M /h_E) = ((^M H_S/^E H_S) \cdot (g_M /g_E)^3)^{0,25}, \qquad (4)$$

calculation which gives the value ($h_M /h_E$) = 2.55. Thus, the terrestrial plants on Mars will rise in two and a half times higher than on Earth.

**Recommendations**

**Using algae to reduce the concentration of $CO_2$ in the Earth's atmosphere and efficient reproduction of ocean biomass:** Analysis of the expression for the maximum flow mineral solution in separate capillary plant xylem (1) within the transpiration mechanism and hence biomass production efficiency due to solar radiation shows that the performance of its production, and hence the rate of atmospheric carbon sequestration (from $CO_2$) is inversely proportional to the fourth power of the capillary length. However, known plants in which the capillaries and generally no solar radiation, as well as minerals, are fed directly to chlorophyll via their surface (in this case refers to the alga Chlorella). In such cases, the performance of recycling atmospheric carbon by photosynthesis in Chlorella will obviously be much higher than in plants with xylem. Therefore, chlorella production could become a very promising trend of atmospheric carbon sequestration. If you bring effective strains of Chlorella consumed by plankton, and "sowing" of the surface of the oceans, the atmospheric carbon due to solar radiation and photosynthesis will communicate effectively transformed into "nutrient broth" for ocean plankton, which are mainly consumed by fish. Thus, it presents a very efficient way of linking the atmospheric $CO_2$, which will significantly increase the reproduction in the ocean fishing fish species by binding atmospheric carbon.

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