International Journal of Innovation Scientific Research and Review
Vol. 05, Issue, 08, pp.4995-4998, August 2023
Available online at http://www.journalijisr.com
SJIF Impact Factor 2023: 6.599

Research Article

ISSN: 2582-6131

STUDY OF A PARTICULAR CASE OF DIFFUSION: OSMOSIS. APPLICATION TO PLANTS

*** Yosra Annabi**

Free researcher, Tunis, Tunisia.

Received 05th June 2023; Accepted 07th July 2023; Published online 30th August 2023

ABSTRACT

In nature, particles migrate in gaseous and liquid fluids by means of three mechanisms: convection, diffusion and dispersion. The kinematic study of these particles in their environment has made it possible to model these phenomena mathematically. Diffusion has a particular interest because it tends to homogenize the concentration of a solute in one or more solvents in direct contact or through a semi-permeable wall. In this work, the author presents osmosis as a particular diffusion phenomenon and applies it to plant water supply.

Keywords: osmosis, diffusion, plant, biomass, osmotic pressure, chemical potential, kinematic study, reverse osmosis.

OSMOSIS

The process by which plant roots absorb water from the soil is osmosis. This natural movement of water consists of the migration from an area of higher concentration, in the soil, to an area of lower concentration, in the root, through the root membrane. It continues in the trunk of the plant and its leaves, making it possible to supply all parts of the plant with water.In fact, this mechanism also exists in living organisms, it is called homeostasis. It is the passage of water between two zones separated by a semi-permeable membrane that allows plants and animals to maintain the balance of their water and nutrient levels.

> **Definition 1** Osmosis is the phenomenon of diffusion of matter characterized by the passage of solvent molecules from one solution to another through a semi-permeable membrane which separates these two solutions whose solute concentrations are different.

The overall solvent transfer then takes place from the least concentrated solution (hypotonic medium) to the most concentrated solution (hypertonic medium) until equilibrium is reached (isotonic media). This phenomenon concerns only the exchanges between two liquid solutions which have different concentrations of solutes, separated by a semi-permeable wall. In the following, we will study this phenomenon for plants.

OSMOSIS FOR PLANTS

Osmosis occurs in a plant in three forms: absorption by the roots, transpiration and infiltration by the leaves. The first phenomenon consists of an exchange of liquid water between the roots and the soil. The next two are gaseous exchanges between the leaves of the plant and the atmosphere. Indeed, thanks to small orifices present on the underside of the leaves, called stomata, these gaseous exchanges between the plant and the atmosphere are carried out. They are essential for the life of terrestrial plants. Transpiration transports the water vapor from the plant to the atmosphere. Conversely, the infiltration transports the water vapor from the atmosphere to the plant. It is carried out by desert plants. More generally, infiltration is the slow passage of a liquid through the interstices of a body. In this case, it is the infiltration of moisture; drops of water in the form of steam. Transpiration or evaporation is a reverse phenomenon in which the plant emits water vapor to the air.

Osmosis at the root level

The water penetrates into the roots by osmosis. A balance is therefore created between the water contained in the soil and that contained inside the roots. The minerals are present in small quantities in the soil water. They are concentrated by the selective membranes of plants. They go in but don't come out. These water and mineral reserves are then distributed to the stem and leaves. Finally, the water is released into the atmosphere, in the form of steam, by the stomata of the leaves. This is called transpiration of the plant. Thus, a continuous flow of water is created from the ground, through the roots, stems and leaves, to the atmosphere. This explains the feeling of freshness that can be felt under the trees during hot weather.

Osmosis at the level of the leaves

The leaves of plants have three main roles: photosynthesis, evaporation and cellular respiration. The first produces glucose to feed the plant. The second leads to the loss of surplus water in the form of steam. The third allows the gas exchange between oxygen and carbon dioxide.

Transpiration:

Transpiration results in the emission of water vapor at the level of the leaves. More than 98% of the volume of water absorbed by the roots is ejected in this way. The water vapor evaporates from the tiny pores on the surface of the leaves called stomata. The rate of transpiration in plants is affected by four main limiting factors: light intensity, temperature, humidity and wind speed. In times of water shortage, the stomata can close with guard cells to reduce water loss, because photosynthesis requires the stomata to be open so that carbon dioxide can enter and oxygen can exit. In addition, studies have shown an adaptation of plants to The desert environment. Deserts are biomes that receive less than 25 centimeters of rainfall per year.

***Corresponding Author: Yosra Annabi,**
Free researcher, Tunis, Tunisia.

The African Sahara receives only one to three centimeters of rain per year. In order to survive in these extremely dry climates, desert plants have developed adaptations to reduce transpiration while maintaining photosynthesis. These plants have different adaptations to reduce water loss and maintain cell turgor, such as developing smaller leaves with fewer stomata, or leaves transformed into thorns to reduce the surface of perspiration or developing thick cuticles to prevent water loss.

> **Example 1** *Cactus : Cacti are common in desert biomes. These fascinating plants have adapted by modifying their leaves into thorns, which are extremely small. The thorns not only have a very small area, which reduces sweating, but they also protect the cacti from ultraviolet rays and are a physical defense against herbivores.*
>
> **Example 2** *The cuticle : The surface of almost all terrestrial plants is covered by a layer called the cuticle. It prevents the loss of water by evaporation and constitutes a physical barrier against viruses, bacteria and fungi. A thicker cuticle makes it possible to reduce water loss more effectively than a thin cuticle. So it makes sense that this is another adaptation of desert plants.*
>
> **Example 3** *Mists are micro-droplets of liquid water in suspension. These droplets are in equilibrium with water vapor.*

Infiltration :

Infiltration of water vapor happens at the level of the leaves.

Example 4 : The leaves of geophytes

This example is extracted from [17].Plants that grow in dry places have developed a variety of strategies to absorb the little water that is there either in liquid form in the soil or in gaseous form in the air. For South African geophytes, it is not only about the conservation of water but also about its capture in the first place and its routing to their roots.Air usually contains water in two main forms: in the form of a gas (known as water vapor) and in liquidform in tiny suspended droplets. When air containing a lot of water vapor touches a surface colder than itself, the vapor can also condense to form liquid droplets.

South African geophytes cool down at night by releasing the heat of the daytime sun into the rapidly cooling air, creating conditions for dew to condense on their leaves. The extra surface they have due to their curls and their hairs helps them to evacuate the heat even faster. As a result, they are more adept than other leaves at collecting water vapor from the air.

The curls, the volutes and the hairs also help the geophytes to collect the fog. The water droplets in the fog attach easily to the surfaces they encounter. But the ability of a particular surface to collect fog droplets depends on its composition, area and orientation relative to the source of moisture. Wide surfaces tend to collect more moisture than narrow surfaces. And those perpendicular to the air flow tend to gather more than those parallel to it. By coiling and swirling, plants increase the variety of orientation of their leaves, improving the chances that fog droplets will meet them and stick to them.

The presence of water on the leaves helps the plants in three ways. First, it reduces the amount of water they lose from inside their tissues. Secondly, some of the water can be absorbed directly into the leaf tissue. Thirdly, water drips onto the soil under the plant, where the roots can absorb it and make it available for photosynthesis.

Plants in space

In space, water exists in three forms: liquid, solid and gaseous. The solid state is frozen water. The gaseous state is water vapor. The liquid state comes in two forms. When it is in a closed gravitational environment, it flows like on earth. When it is in a vacuum, such as inside a space station, it floats in spherical form. In the following, we will study the migration of water molecules by diffusion in space. The model studied is the absorption of water by a plant. In truth, it is not the plant that absorbs the water but it is the water molecules that migrate from a concentrated medium, for example the soil, to a less concentrated medium, the root of a plant, as explained in the previous paragraph.In the space station, several experiments were carried out to grow plants. It seems that in a closed gravitational frame in a space station, plants seeds have been planted. The results obtained and announced by the cosmonauts show that plants absorb water in the same way as on earth.

> **Example 5** ***Suggested Experiment n◦1:*** *Watering a radish plant, daily. The plant exists in a simulated gravitational environment inside the space station. Do the water molecules migrate to the root of the plant? Expected result: The water molecules migrate to the roots by osmosis.*
>
> **Example 6** ***Suggested experiment n◦2:*** *Put the leaves of a radish plant in a plastic bag for 24 hours.The plant exists in a simulated gravitational environment inside the space station.*
>
> ***Expected result:*** *Drops of water exist on the walls of the plastic bag. So, the leaves eject water vapor via the stomata.*
>
> **Example 7** ***Suggested experiment n◦3:*** *The plant exists in a non-gravitational medium inside the space station.. A plant floats next to a spherical drop of water. Will the plant attract the drop to it? In other words, will the water molecules tend to homogenize their concentration between the space and the root of the plant?*
>
> ***Expected result:*** *The answer seems to be negative. In a liquid form and in the absence of gravity, the water molecules do not migrate osmosis to a root of the radish. However, the experiment was not carried out, to the best of the author's knowledge.*
>
> **Example 8** ***Suggested experiment n◦4:*** *The plant exists in a non-gravitational medium inside the space station. A plant floats next to a spherical drop of water. A person pushes the drop of water in the direction of the thirsty plant.*
>
> ***Expected result:*** *The answer seems to be negative. If a person pushes a drop of water in the directionof a radish, the drop is divided in half by the plant's body. It does not seem that water molecules have crossed the intrinsic medium of a root.*
>
> **Example 9** ***Suggested experiment n◦6:*** *Put leaves of a thirsty plant in a wet bag. Does the leaves absorb the water vapor from the bag? the experiment can be carried out in a simulated gravitational medium or in a non-gravitational medium.*
>
> ***Expected result:*** *In desert environments, there is a way used by plants to absorb moisture from the air in planet Earth via the stomata. Does this means persist in space? In a simulated*

gravitational framework, the vapor is absorbed. But without gravitation, it seems that the plant withers.

Suggested explanation: *The plant needs dense air molecules to attract water drops in the form of steam, by osmosis. This atmospheric density does not exist in the space station. But there are oxygen molecules, generated by an internal air conditioning system. It seems that these oxygen molecules do not favor the osmosis procedure via the stomata of the leaves.*

Conclusion 10*The force of Earth's gravity is important in the migration of water molecules inside the root of a plant. This is described in the experiments n◦1 and n◦3. The water molecules infiltrate into the root in a gravitational field and do not infiltrate into its absence.*

MODELING OF OSMOSIS IN THE PRESENCE OF GRAVITY

Osmosis is the phenomenon of diffusion of matter characterized by the passage of solvent molecules from one solution to another through the semi-permeable membrane which separates these two solutions whose solute concentrations are different. The overall solvent transfer then takes place from the least concentrated solution (hypotonic medium) to the most concentrated solution (hypertonic medium) until equilibrium is reached (isotonic media). This phenomenon concerns only the exchanges between two liquid solutions which have different concentrations of solutes, separated by a semi-permeable wall. The modeling of diffusion in a homogeneous medium is generally described by the Laplace equation :

$$\Delta u\,(x, y, z) = f\,(x, y, z) \qquad (1)$$

with u the velocity of the fluid and f a source that influences the speed by decreasing or increasing it.

The chemical potential

However, there is a formulation of the chemical potential during osmosis. When a solute is dissolved in a solvent, the disordered mixture of the two species produces an increase in the entropy of the system which corresponds to a reduction in the chemical potential μ. In the case of an ideal solution, the reduction of the chemical potential is equal to :

$$\mu = \mu(0) + RT\ln(1 - x) \qquad (2)$$

where R is the ideal gas constant, T the absolute temperature and x the concentration of the solute in terms of molar fraction. Most real solutions approach the ideal behavior at low concentrations. At high concentrations, the interactions between solutes are the cause of a deviation from the equation 3. This reduced chemical potential induces a driving force which is responsible for the diffusion of water through the semi permeable membrane. Indeed, a state of equilibrium between the media will be achieved for an equality of chemical potentials.

The osmotic pressure

The osmotic pressure is defined as the minimum pressure that must be exerted to prevent the passage of asolvent from a less concentrated solution to a more concentrated solution through a semipermeable membrane. In biophysics, we distinguish the oncotic pressure which corresponds to the part of the osmoticpressure due to proteins. The osmotic pressure materializes when the proportion of the molar fraction ofthe aqueous solvent is not equal to 1.

The osmotic pressure of an ideal solution is calculated by a formula developed by van 't Hoff in 1886and applying the second principle of thermodynamics.

$$\Pi \cdot V = -R \cdot T \cdot \ln(1 - x) \qquad (3)$$

where

- Π is the osmotic pressure, in Pa ;
- V is the molar volume occupied by the solvent;
- R is the ideal gas constant ;
- T is the absolute temperature, in K;
- x is the molar fraction of the solute.

The equation applied to the real solutions is, for its part,

$$\Pi \cdot V = -R \cdot T \cdot \ln(1 - \gamma \cdot x) \qquad (4)$$

with γ is the activity coefficient of the solute. For a very dilute solution, x is close to 0, and $-\ln(1-x) \approx x$. By noting c_σ the molar concentration of the solute in compartment B, with the relation :

$$c_\sigma = \frac{n_\sigma}{V} \qquad (5)$$

we can also write the law of osmometry :

$$\Pi = c_\sigma RT \qquad (6)$$

If the two compartments both contain a solution of solutes which may be different but in the same solvent,then the total osmotic pressure exerted on the membrane is equal to the difference between the osmoticpressures exerted by the two solutions. We note :

- c_A the concentration of solute in compartment A (in mol/m3) ;
- c_B the concentration of solute in compartment B (in mol/m3) ;
- Π_A the osmotic pressure exerted by the compartment A containing the concentration solution
- c_A when compartment B contains the pure solvent ;
- Π_B the osmotic pressure exerted by compartment B containing the concentration solution
- c_B when compartment A contains the pure solvent ;

$$\Pi_A = c_A RT$$
$$\Pi_B = c_B RT \qquad (7)$$

The total osmotic pressure exerted on the membrane when the two compartments contain a solution is, taking compartment B as a reference medium (for example the cytoplasm of a cell in biology) :

$$\Pi = \Pi_B - \Pi_A \qquad (8)$$
$$= (c_B - c_A)\,RT$$

In conclusion, like hydrostatic pressure, osmotic pressure is also a mechanical pressure, exerting a force on the membrane. If the osmotic pressure difference is very large, this can lead to rupture of the membrane. Conversely, if mechanical (hydrostatic) pressure is exerted, it is possible to force the passage of species through the membrane.

Kinetics of the osmosis phenomenon

The filling kinetics of the tube B, z = f (t) is an exponential function of time with a negative exponent. To establish the law z(t), we will express the instantaneous rate of variation of z from the previous equation. Let s be the section of the tube B at the level where the heights z above the inlet of the tube are measured. The flow Jv of water which enters the tube during a short time interval dt, (it is therefore a differential equation) causes a variation in the level dz such that :

$$dz= \frac{Jv}{s}dt \quad (9)$$

The laws of diffusion make it possible to write the expression of the flow of water Jv :

$$J_V = SL_P(\Pi - \Delta P) \quad (10)$$

With :

Jv = water flow (m^3 m^{-2} s^{-1}) or (m s^{-1}) counted positively when the water enters the tube
S = surface area of the membrane (m^2)
L_p = hydraulic permeability of the membrane (m^3 s^{-1} MPa^{-1})
ΔP= the hydrostatic pressure difference (MPa)
p = osmotic pressure in B (MPa) counted positively

Let's replace Jv with its expression in the equation 9, we get the following differential equation :

$$\frac{dz}{dt} = \frac{S}{s}L_p(\Pi-\rho g z) \quad (11)$$

Knowing that the final height z_f is such that p = rgz_f , and let's call $1/_\tau$ the set (SpgLp/s), the equation 11 then becomes :

$$z-z_f= (1-e^{-t/\tau}) \quad (12)$$

The level z in the tube therefore rises by following this exponential law with a negative exponent as a function of time. It tends asymptotically towards the final height z_f , directly depending on the initial osmotic pressure. For more details, the reader can refer to [18].

REVERSE OSMOSIS, A DISTILLATION PROCESS

In the case of reverse osmosis, it is a hydrostatic pressure difference higher than the osmotic pressure between the two liquids that makes it possible to cause a movement of the solvent in the opposite direction to that of osmosis, until the osmotic pressure is as high as the hydrostatic pressure.

Example 10 *Reverse osmosis is a water purification technique; it is also a technique for desalination of seawater allowing the production of fresh water.*

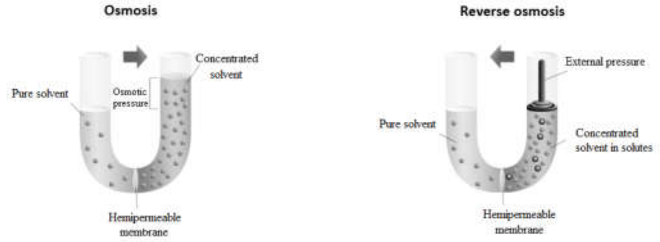

Figure 1 The hemipermeable membrane only allows the solvent (generally water) to pass through, and not the solutes (dissolved substances). This property is responsible for the phenomenon of osmosis and reverse osmosis.Photo taken from the site uae.fr

CONCLUSION

The ideas presented in this article describe osmosis as a particular phenomenon of diffusion. It treats a direct application on the absorption of water molecules by the root of plants. As well as a gaseous exchange of water vapor through the stomata. This phenomenon persists both on earth and in a microgravity environment. The new spherical shape of liquid water floating in a vacuum encourages the author to ask questions and suggest simple experiments to study osmosis.Expected answers have been written.

REFERENCES

[1] Annabi, Y. (2022). Hemodynamics: Macroscopic and Microscopic Modeling, In-ternational Journal of Innovationin Science and Mathematics, Volume 10, Issue4. URL : http://ijism.org/administrator/components/com_jresearch/ files/publications/IJISM_976_FINAL.pdf

[2] Taylor, C. (2017). What is astrobiology?.URL : https://www.academia.edu/ 33992482/Astrobiology_2_

[3] Annabi, Y. (2012). Introduction to Applied Mathematics, European University Editions, ISBN : 978-3-8417-8154-3.

[4] Annabi, Y. (2022). Introduction to multi-scale modeling, European University Editions, ISBN : 978-613-9-50445-9.

[5] Annabi, Y. (2022). Introduction to hemodynamic, European University Editions, ISBN : 978-620-3-43779-9.

[6] Offerdahl, Erika. Prather, E. and Slater, T. (2002). Students' Pre-Instructional Beliefs and Reasoning Strategies About Astrobiology Concepts. Astronomy Education Review. 1. 10.3847/AER2002002.

[7] BeluzzoDessen E. M., Oyakawa J. (2016). Observacao de osmose emcelulasvegetais, Man-ual, Genomahumano, moderna.com.br,

[8] (2019) Laouinate, Z and Khazzar H. Study of a seawater desalination unit by reverse osmo-sis.Manual. URL : academia.edu

[9] Deboeuf A. Gauthier G, Martin J. Morris J. (2009) Osmotic pressure measurement in macro-scopic suspensions. 19th French congress of mechanics.

[10] Dubois M. and Zemb Th. (1998) Mesure de forces moléculaires entre bicouches par diffusion de rayons X à pression osmotique contrôlée; Le Journal de Physique IV.

[11] Tarter J. C. (2004). Astrobiology and SETI. New Astronomy Reviews 48 (1543 - 1549).

[12] Al-Chwa,R (2009). Astrobiology, Sustainability and Ethical Perspectives. 2009, Sustainabil-ity,1, 1323-1330; doi:10.3390/su1041323.

[13] Pojman J. (2006). Miscible fluids in microgravity (MFMG). International space station re-search summary through expedition 10. NASA/TP2006213146.

[14] Robert C. Morrow, (2006). Biomass production system(BPS). International space station re-search summary through expedition 10. NASA/TP2006213146.

[15] VerKo, (2023). The ISS received oxygen from algae. Auteur: VerKo, Tags: Roscosmos, Rus-sia, Cosmos, Source: TASS

[16] kiko Harada-Sukeno, Shohei Kohno, ReikoNakao, Katsuya Hirasaka, Akira Higashibata, Takashi Yamazaki, Noriaki Ishioka, HiromiSuzuki, Toru Shimazu, Ayako Maita, YuushiOku-mura and Takeshi Nikawa, (2009). Myo Lab: A JAXA Cell Biology Experiment in Kibo (JEM) of the International Space Station . Biological Sciences in Space, Vol.23 No.4, 189-193. Mis-sion report.

[17] Mary Hoff, (2016). Geophyte leaves collect water from dew and fog using unusual leaf shapes. Journal article Asknature. Biomimicry Institute. URL : asknature.org

[18] daudet, F. A. and Cruiziat P. (2016). Properties of aqueous solutions and osmotic pressure. Plants and waters. URL : plantes-et-eau.fr

[19] (2022). Seeds of plants that have previously been in space will be sent to the ISS. News source: MIR 24. URL : cosmos-online.ru

****