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Water Vapor Movement on Mass and Heat Transport in the Perspective of Water Vapor Buoyancy: A Review

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ABSTRACT

In 1957, the governing equation of mass and heat transport in the soil or porous media was popularised, now commonly referred to as PdV theory. This governing equation helps to quantify and simulate the water, vapor and heat in porous media. But at the same time, due to the fundamental uncertainty parameter in the equation, it was continuously updated. The equation predicting vapor flux movement in the soil has been the subject of many investigations. The vapor enhancement factor (VEF) was introduced to overcome the issue. When VEF was introduced, a few researchers were able to quantify the factor, but could not provide the guiding mechanism representing the observation. In the latest review from a literature study, we found a new form of equation to improve the VEF. It comes from the basis of the universal gas law, which describes the volume expansion from liquid water to vapor, and also the vapor buoyancy. This study aims to review water vapor movement and vapor buoyancy phenomenon. Also, to identify the parameters of the equations that contribute to the vapor buoyancy effect. The water vapor movement should not be neglected in the governing equation because its contribution to the overall mass movement is significant. Vapor buoyancy is possible to become a mechanism out from VEF. The parameters that contribute to vapor buoyancy effect are gravity, soil temperature, vapor density and water salinity. Clearly, understanding vapor buoyancy effect helps us better predict the distribution of soil temperature and soil moisture content.

1. Introduction

Soil and water resources are two components of earth's ecosystems that interconnected each other. This component playing critical role in sustaining life, supporting biodiversity, regulating

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climate patterns and providing essential to ecology. Protecting and conserving these resources are supreme for promoting environment sustainability, resilience to climate change and human well-being.

Firstly, study the capability to predict soil temperature and soil moisture content holds immerse value in managing soil and water resources effectively. This has many useful applications in land management and engineering applications. That resulted to introduction of the PdV theory, which refers to the governing equation of mass and heat transfer proposed by Philip and de Vries [1]. The main equation was modelled by Richards' equation, which refers to water movement [2]. With the presence of gravity, the water will be moving downward, this is known as water infiltration. While the evaporation prosses also happening and causing vapor movement in the pores of the soil. Different soil properties and soil textures will affect infiltration, evaporation and moisture content. Therefore, the study of the movement of water and heat in soil can be applied in agricultural, geoenvironmental, hydrology and other engineering fields [3-6].

In theory, the PdV equation simulation can be used to reproduce the field observation of moisture content and temperature. However, the discrepancy between experimental data and field observation was suggesting incomplete theoretical equation. Hence, vapor enhancement was introduced to overcome the limitation, for instance, liquid island effect. This does not seem to provide any closure to the problem due to excessive high vapor flux in the soil analysis. There is a need to improve the understanding of the guiding mechanism that contributes to the governing equation for mass and heat [1,7-10]. The uncertainty of vapor flux movement has become an interest in this paper. This paper aims to investigate the existing equation that is responsible for mass and heat movement in the soil and to review the equations of vapor buoyancy and its parameters.

2. Mass and Heat Transport

The mass and heat become fundamental importance in agriculture, material engineering and soil physical study for many applications. This fundamental can be coupled in simulations such as the weather forecast, floods, watering plants, and sea water evaporation [11-17]. Mass and heat transport models also are used to simulate at the wall concrete of a nuclear power plant and to monitor anthropogenic activities that will increase the naturally occurring radioactive materials (NORMs), which has a high risk of impacting humans [18,19]. Therefore, it is important to validate the simulation model. In soil treatment, one of the remedial technique is called Soil Vapor Extraction (SVE), which involves the combined mass and heat transport across solid, gas and liquid phases [20]. Various studies have investigated factors such as the effect of water content and enhanced thermal condition during SVE [21,22].

Focus on transport in soil describes the flow of several elements through the soil matrix, including air, water, nutrients, and contaminants. As the model enables the removal of surplus water and pollutants from the soil and the uptake of vital nutrients by roots, this transport is crucial for maintaining plant development and ecosystem function [3]. The mechanisms involved such as advection, convection, diffusion, dispersion, and conduction are a few of the mechanisms that contribute to mass and heat transport in soil. Diffusion refers to the transfer of compounds from regions of high concentration to regions of low concentration. Whereas advection refers to the movement of substances through the soil because of the bulk flow of water, and convection is the term for the movement of a fluid that results in the transfer of mass because of changes in the fluid's temperature. When solute is conveyed by the bulk of soil particles, dispersion occurs. Heat conduction occurs in a medium that in direct physical contact, such as soil between soil particles, water and air [23,24].

Mass transfer will affect the heat transfer. Therefore, Philip and de Vries introduced the governing equations for mass and heat in soil that was expanded from the diffusion equation. Today, it is known as PdV theory, which describes the movement of water and heat through the soil matrix [25]. For mass transport in soil, there are divided into two fluxes that involve water and water vapor [25]. This theory was applied to run a simulation of freezing unsaturated soil that combined the coupling of water, vapor and heat [26-31]. The theory also been applied in global climate model prediction to study the dry area [32], heavy meter migration in unsaturated soil [33] and stream disinfection transfer into soil for cropping [34] and multiple inquiry reviewed by Massman [35] such as wood drying, concrete fracturing and drying in high temperature and sand-water steam system.

There is a need to reduce the discrepancy between the simulation that is based on theory and field observation. Due to the limitations of experimental data, researchers have tried many approaches. This is noted in Heitman *et al.,* [36] work on comparing the theoretical equations used in simulation with the experimentally measured soil temperature and soil moisture content in transient conditions. They also develop an instrument by applying thermal-time domain reflectometry (T-TDR) to get the actual result of temperature and thermal conductivity [37]. Besides that, X. Zhang *et al.,* [38] also performed a study on two ways of simulating and measuring transport in mass (water), heat and salinity in bare soil. The result shows that higher salinity causes a higher temperature gradient, while it becomes the greater retention of water in soil. Simulation using the partial differential equation that governs liquid water, water vapor and heat flow, Teng *et al.,* [39] concluded that the heat diffusion coefficient and vapor flow have significant effects on evaporation from unsaturated soil. This finding aligns well with the study conducted by Izzati and Goh [40] where they argue that water vapor flux is an important factor that influences the transport of the mass and heat. Together, these studies underscore the interconnected relationship between the heat diffusion, evaporation from unsaturated soil and the impact of the vapor flux on mass and heat transport.

Izzati and Goh [40] incorporated the data from Heitman *et al.,* [36] who studied the relative importance of water vapor flux in the context of movement mass and heat in the soil by running a simulation using Eq. (1)-(3). This study focuses on silt loam and sandy soil. The result showed that water vapor flux was the most important factor among the other mass flux factors. In addition, water vapor heat flux became the second highest from 7 factor of heat flux. This shows an important thing that the vapor flux movement affects mass and heat transport.

For the liquid water flux, there are 3 factors that contribute, which is liquid water-mass flux [40]. See Eq. (1):

$$\frac{q_L}{\rho_L} = \underbrace{-D_{TL}\frac{dT}{dz}}_{1} \underbrace{-K\frac{d\psi_m}{dz}}_{2} \underbrace{-Ki}_{3} \qquad (1)$$

The liquid water flux, q_L in unit $kg\,m^{-2}\,s^{-1}$, ρ_L is refer to the liquid water density in unit $kg\,m^{-3}$. First factor liquid water-mass flux by a temperature gradient in unit $m\,s^{-1}$. The second factor refer to liquid water-mass flux by matric suction gradient in unit $m\,s^{-1}$ and third factor refers to liquid water-mass flux by gravitational force in unit $m\,s^{-1}$.

Meanwhile, there are two factors that contribute the equation which is vapor-mass flux. This equation exclude the effect of gravity on water vapor movement [40]. See Eq. (2):

$$\frac{q_v}{\rho_L} = \underbrace{-D_{Tv}\frac{dT}{dz}}_{1}\underbrace{-D_{mv}\frac{d\psi_m}{dz}}_{2} \tag{2}$$

The water vapor flux, q_v in unit $kg\,m^{-2}\,s^{-1}$. The first factor is vapor-mass flux by a temperature gradient and second is vapor-mass flux by a matric suction gradient, in unit $m\,s^{-1}$.

There are seven factors that contribute to heat flux. See Eq. (3):

$$\begin{aligned} q_h = &-\left\{\underbrace{\lambda}_{1} + \underbrace{c_v(T-T_\circ)\rho_L C_{Tv}}_{2} + \underbrace{c_v(T-T_\circ)\rho_L D_{Tv}}_{3} + \underbrace{c_L(T-T_\circ)\rho_L D_{TL}}_{4}\right\}\frac{dT}{dz} \\ &-\left\{\underbrace{\left[L(T) + c_L(T-T_\circ)\right]\rho_L D_{mv}}_{5} + \underbrace{c_L(T-T_\circ)\rho_L K}_{6}\right\}\frac{d\psi_m}{dz}\underbrace{-c_L(T-T_0)\rho_L Ki}_{7} \end{aligned} \tag{3}$$

The heat flux, q_h in unit $J\,m^{-2}\,s^{-1}$. The first four are heat conduction, vapor enhancement factor vapor movement, vapor movement by diffusion alone and liquid movement. They are governed by temperature gradient in unit $J\,m^{-2}\,s^{-1}$. Terms 5 and 6 are under the matric suction gradient for vapor and liquid in unit $J\,m^{-2}\,s^{-1}$. Lastly, for the heat flux caused by liquid movement due to gravitational force in unit $J\,m^{-2}\,s^{-1}$.

The mass and heat transport equation can be used for agriculture, engineering, and also to study the effects of greenhouse gases and the environment. For example, X. Zhang *et al.,* [38] want to determine the water, heat and salinity in transporting bare soil for improving saline soil understanding, and same study conducted by Wen *et al.,* [41]. Also, study on modeling the vapor transfer in unsaturated freezing soil was found by Liang *et al.,* [27]. This knowledge was applied in the high-speed railway, which has significant importance because the railway faced changes in season and weather. The model on phase change behavior of ice crystal was run to study the mechanism in saturated soil [42]. Figures 1 and 2 show that the measured of daily evaporation (water vapor) is higher compared to diffusion equation simulation result. There could be other factors and mechanisms that contribute to the acceleration of water vapor movement during evaporation process. Despite that, due to complexity of water vapor movement and pretend vapor enhancement factor in the equation, this flow is continued to be discussed by researchers.

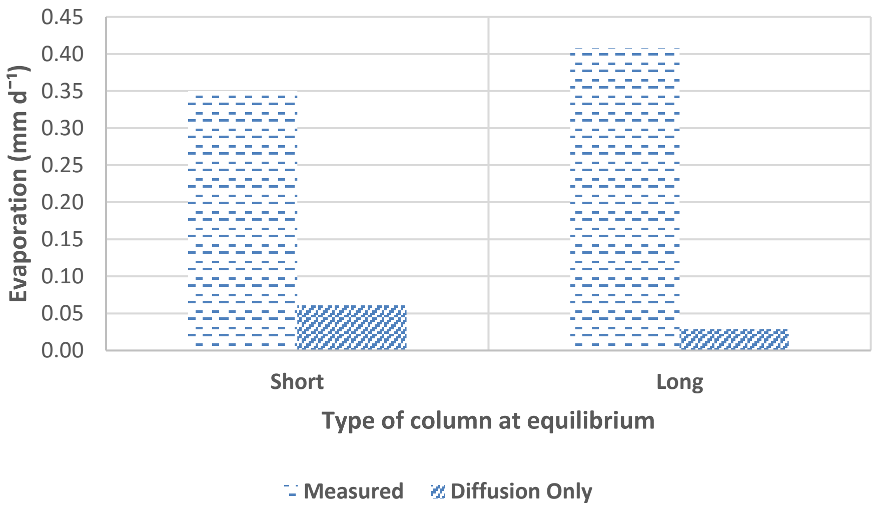

Fig. 1. Show the difference between the measured with simulating diffusion only at equilibrium. Short soil column have length 1 meter and long soil column 2 meter [43]

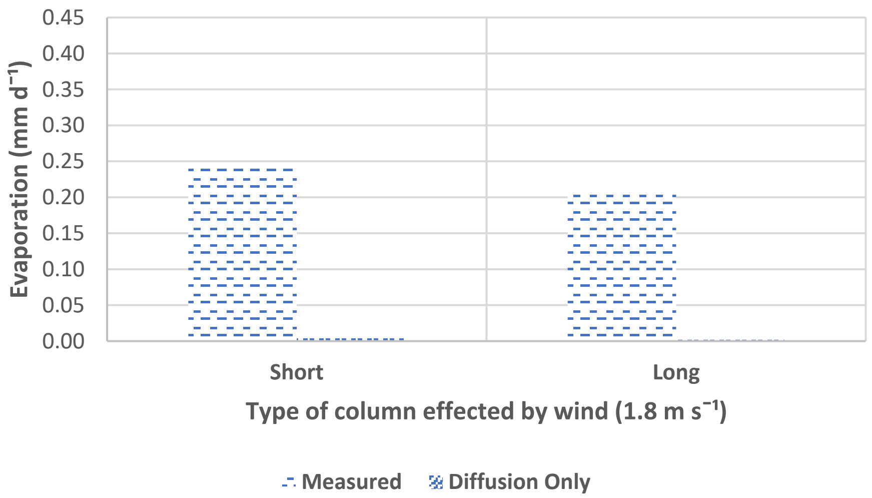

Fig. 2. Show the difference between the measured and simulated diffusion (only) where the soil surface exposed to wind blow [43]

3. Water Vapor Movement and Vapor Enhancement Factor

The phrase "vapor movement" is divided into two kinds, which are diffusion by matric suction and diffusion by temperature gradient. While the diffusion equation could refer to the movement of water vapor or other gaseous species in porous media and atmosphere [10]. The diffusion vapor flux becomes a complex issue in PdV theory. Vapor enhancement factor was commonly claimed due to the presence of liquid island effects and the higher temperature gradient in air space in porous media than the temperature gradient of soil solid medium. This leads to a multiplication factor from Fick's law diffusion equation. Philip and de Vries impose the vapor enhancement factor (VEF) to overcome this situation [1] and continue the approach for clay loam and medium sand [44]. Few researchers pointed to prove the enhancement factor, such as Cary and Taylor [45]; Cary [46-48]; Cass *et al.,* [49]; Cahill and Parlange [8]; Ho and Web [50]; Shokri *et al.,* [51]; Shahraeeni and Or [52]; Lu *et al.,*

[53]. Also, the vapor enhancement Eq. (4) was discussed by X. Zhang *et al.,* [38]. After more than a decade of discussions, there was still no clear explanation of the process involved [8,54].

$$\eta = \mathrm{K}_x + 3S_l - (\mathrm{K}_x - 1)\exp\left\{-\left[\left(1+\frac{2.6}{\sqrt{f_c}}\right)S_l\right]^4\right\} \tag{4}$$

where η is refer to vapor enhancement factor, K_x refers to the fitting parameter with a value of 9.5, f_c is the mass fraction of clay ($kg\,kg^{-1}$) and S_l is liquid water saturated ($m^3 m^{-3}$). This equation is among the latest equations cited in the paper compared to the VEF that used by Cass *et al.,* [49] and Lu *et al.,* [53]. Different fitting parameters can cause different values of mass and heat flux calculation.

In 1982, Milly proved that the diffusion equation in vapor phase must include the effects of latent heat, the heat of wetting, and water storage. This vapor flux movement becomes dominant in dry regions [7]. The vapor movement is faster in temperature gradient environment than the diffusion by Fick's Law in isothermal condition, and this is stated in the literature by Goh and Noborio [10]. Lopez-Canfin *et al.,* [55] study the link between water vapor absorption in dry areas and the carbon cycle. They found new mechanisms underlying water vapor absorption fluxes during hot and dry periods. Additionally, they proposed new models that predict the cumulative flux by diel coupling water vapor and carbon dioxide. Furthermore, they suggested conducting further investigations to observe soil water vapor and carbon dioxide absorption, that will distinguish between biotic and abiotic elements.

Besides that, Balugani *et al.,* [43] study the influence evaporation (water vapor) on the dry soil layer, divided into four situations. Which is the daily effect on evaporation and condensation; atmospheric pressure; wind effect; and nonlinear thickness of the dry soil layer. They conclude that atmospheric pressure becomes the main factor for water vapor to move out from the soil. This conclusion based on saturated water vapor from the air out when atmospheric pressure decreases and vice versa atmospheric increase pushing the water vapor inside the soil layer. Other evidence on water vapor movement shows the relative significance of water vapor in comparison with other mechanisms in the soil, as in [40]. Their studies indicate vapor movement is significant in mass transport relative to other mechanisms, similarly in silt loam and sand. Water vapor mass flux becomes the highest flux among the other mass fluxes and water vapor heat flux is the second highest among the seven heat fluxes. Other factors that dominate VEF show that VEF should separate to another phenomenon that contributes to diffusion governing equation. Goh and Noborio [54] hypothesize a new mechanism not yet consider in the PdV theory, which is vapor buoyancy under temperature gradient and isothermal condition. Vapor buoyancy potential could be affected due to soil properties. A bigger soil porosity potentially gives a higher vapor buoyancy effect, which allow the water vapor to move freely. See illustration at Figure 3, buoyancy effect allows water vapor to move upward and become higher at C, then B and final at A. B have higher porosity than A.

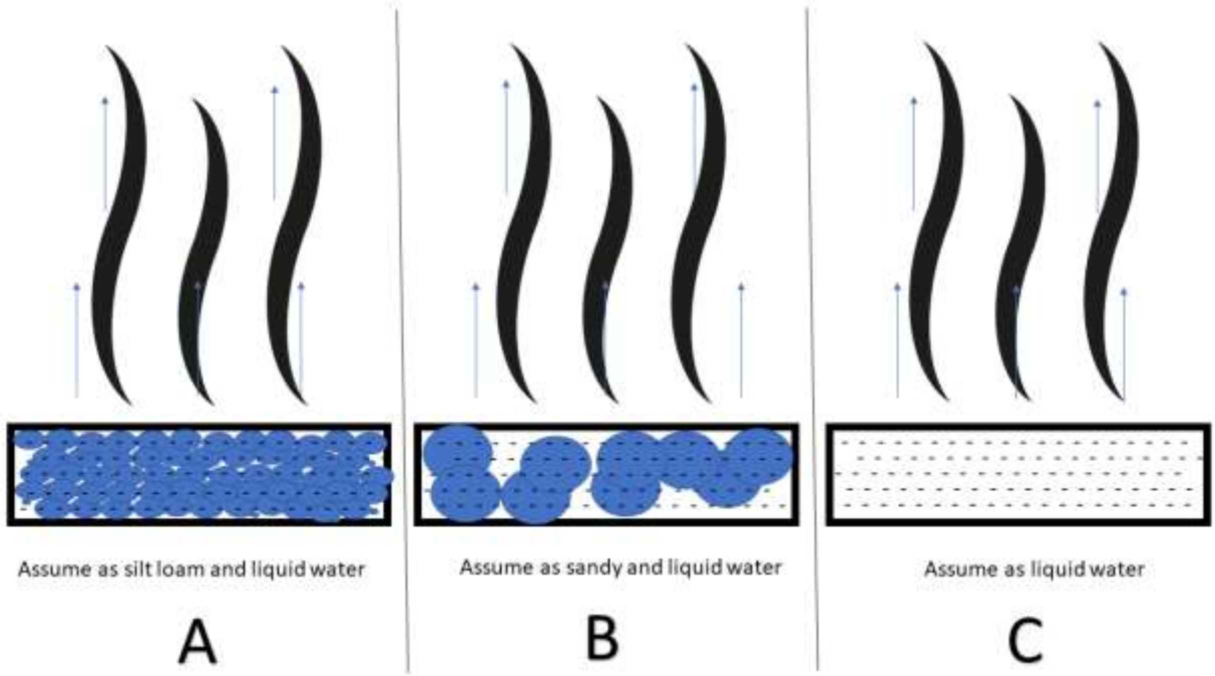

Fig. 3. Illustration of surface table silt loam soil [56], sandy soil [57] and water

After a decade of applying the vapor enhancement factor, there must be improvements to unravel the mechanism enhancing the water vapor movement. Based on the literature, a mechanism can be coming from the vapor buoyancy. This paper will list out the parameters and discuss the mechanism that contributes to the mass and heat transport equations from the perspective vapor buoyancy.

4. Vapor Buoyancy Mechanism and Relative Parameters that Contribute

The movement of water vapor upward in the soil as a result of differences in densities between the vapor and the soil's surroundings is referred to as "vapor buoyancy". In 2012, vapor buoyancy as a mechanism that separated from water, water vapor and heat was mentioned by Shahraeeni and Or [52]. This follows a hypothesis by Goh and Noborio [54] state that the lack of essential upward mass flux may exist for water vapor buoyancy. This hypothesis was validated after running a simulation using data from Heitman *et al.,* [36] to study of couple heat and water transfer theory under transient. Goh and Noborio [10] also completely replaced the VEF with an imaginable mechanism that included the vapor volume expansion with variable temperature, pressure and water content in the soil. An extended work was found in Othman and Giap [58] to compare buoyancy effect flux with other existing mechanisms. They hypothesized buoyancy vapor was one of the possible factors at the root of the fundamental problem in predicting moisture.

The significant presence in the movement of vapor buoyancy signifies the necessity for researchers to study water vapor buoyancy and the parameters that drive the mechanism. Water vapor buoyancy movement at atmosphere was introduced in parcel theory that plays an important role in the prediction of weather forecast [59]. This allows tracking the movement of a parcel of water vapor as it moves up or down, which is a crucial part of the parcel theory method for analyzing atmospheric air movement [60]. The liquid water phase will evaporate when it receives enough energy and allows the vapor to move around soil (porous media) and from the soil surface to the atmosphere. Besides the movement vapor buoyancy in the soil or on soil surface, the movement also happened at ocean and lake surface to the atmospheric, which comes together with the processes of evaporation and condensation [14,61]. The existence vapor buoyancy will give negative climate feedback, which it will stabilize climate [62].

Vapor buoyancy effect was described in literature to take place at various surfaces, for example, at the surface of soil, ocean, and lake. The laboratory studies also through series investigation shallow annular pool to understand effect of surface evaporation on thermocapillary buoyancy convection as reported Li *et al.,* [63]. Their consumption during the weak of evaporation, the flow destabilization can be suppressed by the effect of buoyancy and surface evaporation. The Table 1 summary of equation vapor buoyancy with respect the certain factors are taken into the equation.

Table 1
Shows the summary of equation relative to vapor buoyancy

No	Equation	Unit	Reference
1.	$Ra = \frac{g\beta\Delta T_S (h)^3}{va}$	Dimensionless	[64]
2.	$Gr = \frac{g\beta\rho^2\Delta T(D)^3}{\mu^2}$	Dimensionless	[65] [66]
3.	$B = \frac{\rho'}{\rho} g$	$m\,s^{-2}$	[67]
4.	$B = g\frac{T_v - \overline{T_v}}{\overline{T_v}}$	$m\,s^{-2}$	[67,68]
5.	$Wb = \left[\frac{\lvert g\rvert .z_i}{T_{vML}}.(\Theta_{v\,sfc} - \Theta_{vML})\right]^{\frac{1}{2}}$	$m\,s^{-1}$	[59]
6.	$B \approx g\frac{\gamma'}{\overline{\gamma}} - gl' \approx g\frac{T_v'}{\overline{T_v}} - gl'$	$m\,s^{-2}$	[69]
7.	$w^2 = \int_0^H \left[g\frac{T_v'}{\overline{T_v}} - gl' \right] dz$	$m\,s^{-1}$	[69]
8.	$B = C_w^{-1} g\alpha Q + g\beta_{sl}(E-P)s$	$m\,s^{-2}$	[61]
9.	$B = C_w^{-1} g\alpha(Q_B + Q_s + Q_l) - g\beta_{sl} sP + g(C_w^{-1}\alpha L_v + \beta s)E$	$m\,s^{-2}$	[61]
10	$B_s = \frac{g\alpha'\Theta}{Tc_p(p_{r,}\Theta)}(\mathrm{K} - \Delta \bullet F^{rad})$	$m\,s^{-1} \bullet m^{-3}$	[61]
11	$F_B = -V_p \frac{\partial p}{\partial x_i}$	N	[70]
12	$F_B = V \bullet \rho_a \bullet g$	N	[71]
13	$F_B = g\left[\frac{(\Theta - \Theta^e)}{\Theta_0} + \varepsilon(N_v - N_v^e) - N\right]$	kg	[72]

Notes: Ra refer to Rayleigh number, Gr refer to Grashof number, B refer to vapor buoyancy flux, w^2 refer to kinetic energy of buoyancy, ρ refer to the density, B_s refer to buoyancy rate per volume, g refer to gravity ($m\,s^{-2}$), β refer to coefficient of the thermal water expansion (K^{-1}), β_{sl} refer to thermal expansion coefficient of salinity (K^{-1}), h refer to heigh layer (m), v refer to kinematic viscosity ($m^2 s^{-1}$), a refer to liquid thermal diffusivity ($m^2 s^{-1}$), D refer to surface characteristic dimension, μ refer to the kinematic viscosity ($\mathrm{m^2 s^{-1}}$), ρ refer to density ($kg\,m^{-3}$),

ρ' refer to perturbation density ($kg\,m^{-3}$), ρ_a refer to air density ($kg\,m^{-3}$), T_v refer to virtual temperature (K), $\overline{T_v}$ refer to virtual temperature at steady state/reference state (K), T_v' refer to Virtual temperature at constant pressure (K), $T_{v\,ML}$ refer to absolute virtual temperature in the mixed layer, ΔT_s refer to temperature between two layer (K), z_i refer to height of the atmosphere (m), Θ refer to potential temperature (K). $\Theta_{v\,s\,f\,c}$ as the potential temperature parameterization (K), $\Theta_{v\,M\,L}$ as the potential temperature mixes layer (K), Θ^e as the potential temperature for hydrostatically balance environment (K), Θ_0 as the base state temperature potential (K). While, α' refer to thermal expansion coefficient (K), α refer to thermal expansion coefficient of seawater at surface K^{-1}, γ' refer to specific volume of air at constant pressure ($m^3\,kg^{-1}$), $\overline{\gamma}$ refer to specific volume at steady state ($m^3\,kg^{-1}$), l' refer to liquid water content ($kg\,kg^{-1}$), C_w refer to specific heat of water ($J\,kg^{-1}\,K^{-1}$), E refer to evaporation rate ($m\,s^{-1}$), P refer to precipitation rate ($m\,s^{-1}$), s refer to surface salinity ($g\,L^{-1}$), Q refer to upward heat flux ($W\,m^2$), Q_B refer to upward flux of long-wave radiation from the ocean ($W\,m^2$), Q_s refer to upward sensible heat flux ($W\,m^2$), Q_l refer to absorption of solar radiation heat flux ($W\,m^2$), L_V refer to latent heat of vaporization (Jkg^{-1}), K refer to rate of heating per unit volume ($J\,K^{-1}\,m^{-3}$), F_B refer to force buoyancy, $\Delta\bullet F^{rad}$ refer to divergence radiative heat flux ($W\,m^2$), c_p refer to specific heat ($J\,kg^{-1}\,K^{-1}$) at reference pressure, p_r (Pa) and reference potential temperature. Other that, V is the volume (m^3), V_P refer volume of droplet (m^3), $\frac{\partial p}{\partial x}$ as pressure gradient ($Pa\,m^{-1}$), ε refer to the ratio gas constant water vapor over gas constant dry air minus 1, N refer to total condensate and precipitation liquid and ice mixing ratio, N_V refer to water vapor mixing ratio and N_V^e refer to corresponding environmental water vapor mixing ratio profile.

The first equation from Table 1 represents the Rayleigh Number (Ra). Rayleigh number is the ratio of buoyancy to viscosity. It is employed in some applications, including the transfer of water vapor, to analyze fluid dynamics and heat transfer. In the context vapor movement Ra can be used to predict the onset of buoyancy-driven motion in the atmosphere, which can help to understand and model the transport of water vapor and other gases in the atmosphere. This equation was used by Misyura *et al.,* [64] to study water droplet evaporation. With an increase in droplet diameter, the water droplet experiment showed that the rate of evaporation increased by 60% due to the vapor buoyancy; nevertheless, they assert that there is no buoyancy for radii less than 0.5-1 mm and that the buoyancy increases at radii of 2 mm.

The second equation in Table 1 refers to Grashof number (Gr) dimensionless equation. This equation was mentioned by Rodrigues *et al.,* [65] in the book Fundamental Principles of Environmental Physics as the formula to approximate the ratio of buoyancy forces due to differences in density and viscous forces that either increase or decrease. Azizi *et al.,* [66] use Gr to study the effect of buoyancy in a vertical channel for mixed layer.

Doswell and Markowski [67] review the relative quantity for equation third and fourth from Table 1 show that the vapor buoyancy flux depends on fluid density and temperature. This will produce the unit $m\,s^{-2}$, this equation also noted by Yang and seidel. While, Stull [59] reviewed the air parcel theory, the buoyancy defined as the product of air that rises in the upward motion. Parodi and Emanuel [69] interpreted the vapor buoyancy, B using the modal of Weather Research and

Forecasting (WRF), which follows equation as in No. 6 in Table 1. By integrating the equation No. 6 in the table will get the vertical velocity as equation No. 7 which produces the terms of unit ms^{-1}. Then, the effect of solar radiation the vapor buoyancy on the surface ocean can be predicted using equation 8. The operation of this mechanism is intricately linked to surface salinity, denoting the concentration of dissolved salt in water [61]. Salinity plays a crucial role in influencing both density and water balance. An alternative equation as presented in No. 9, offers another avenue for consideration. The volume of buoyancy rate can be determined using equation No. 10. Buoyancy force for water vapor movement can be predicted using the equations No. 11 and 12 in the term of unit force, as in Newton (*N*), but in equation No. 13 buoyancy force was reported in unit kg.

From equations No. 1 and 2 in Table 1, buoyancy appeared in the form of ratio in comparison with viscosity, the higher the ratio value, the higher the potential to influence of vapor buoyancy. Therefore, the equations could not produce direct quantification of the vapor buoyancy without knowing the information of fluid viscosity. To express vapor buoyancy in Newtons, equations No. 11 and 12 from Table 1 can be utilized, with subsequent incorporation of unit mass as defined in equation No. 13 of the same table. Vapor buoyancy is viewed as the anti-gravity force, which is the force that attracts to object against the gravity. This suitable with unit of ms^{-2} as show from few equations in Table 1. But some equations unit as in ms^{-1} which is the velocity unit. This relates to the moving speed without accounting for the acceleration of the vapor due to buoyancy. When vapor buoyancy is represented, will affect the moisture content distribution in the soil and it is expected to have high evaporation rate occur on water surface such in ocean and lake.

Quantification of water vapor buoyancy is needed so that it can be distinguished from water vapor diffusion. To plan for the measurement unit for the future study, must consider few things: 1) phase transition effect from liquid water to vapor phase; 2) measuring vapor buoyancy in the presence of atmospheric air; 3) the effect of temperature gradient; 4) the effect of fluid density, and 5) design a pattern of measuring unit that able to distinguish the vapor buoyancy movement from that of vapor diffusion. A proper experimental design will allow the water vapor to move upward as the buoyancy mechanism to be predicted.

5. Conclusion

A few decades ago, VEF was used as the number factor in the transport equation, but regarding the model's prediction, there is a significant issue that contributes, especially the movement of vapor. Water vapor movement is an important factor contributing to the mass transport equation. From the review, we have suggested an unaccounted mechanism of vapor movement, namely vapor buoyancy. Even though this mechanism has not been proven yet by experiment, the current review from the literature clearly suggests that it is a likely unexplored mechanism to account for the VEF. There are three main factors that contribute to the vapor buoyancy such as gravity, temperature and density. Surely, in soil the porosity and water content also will appear as the contributing parameters. Then, the water phase that changes to vapor phase must follow ideal gas law that ultimately points to a liquid mass expanded in volume by evaporation contributing to vapor flux. For further studies, there is needed instrumentation design to quantify vapor buoyancy. The instrument measure that will be developed must be able to distinguish between vapor buoyancy and water diffusion mechanisms. The designing instrument study must completely understand the basic evaporation concept and Philip and de Vries theory. Fundamental research is crucial for gaining a thorough understanding of vapor movement in soils and atmospheres. Better model prediction by proper accounting mechanisms used in mass and heat transfer equation has a far-reaching application to real-world issues like soil conservation, crop productivity and environmental cleanup, including making better decision in overcoming the climate change effect.

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