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Valve Position Control under pH Influence for PM Evapotranspiration Model

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Abstract
The productivity of soil largely depends on the optimum conditions of farmingincluding the water quality. With the proper pH values of the water-soil moisture maintained during the time of farming leads to absorption of right amount of minerals to the plant body which increases the productivity of the crop. Under normal practice, it is often found that the pH value of the irrigational water overlooked and hence the optimum conditions are maintained. In this article, a noble approach is taken to regulate the valve response so that this pH mismatch between the supplied water and soil can be rectified and the most suitable value can be preserved. While with the use of Penman-Monteith (PM) method, the water loss due to evapotranspiration is determined and water valves are operated to supply the necessary volume to eliminate the crop-water stress, an exhaustive fuzzy rule-base model is developed to control the opening and closing of the valves based of the pH value of the supplied water to maintain the optimal values. On evaluation of the designed model, it is seen that the PM model is successful is determining the water loss and the on encountering a surge in the acidic levels of the supplied water, the valve constricts to slow down the water flow and it inflates while the water is alkaline is nature. Thus the objective of the model is properly served and significant results are obtained.

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Keywords

Evapotranspiration;
Penman-Monteith Equation;
pH Values;
Valve Action.

Introduction

Evapotranspiration is defined as the loss of surface water from field and water bodies in the form of both evaporation and transpiration. Studies has revealed the underground freshwater storage is quickly getting exhausted.[1] Also due to different types of contamination, like Arsenic and other heavy metals, the natural salinity and pH are getting altered.[2]

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Due to the high salinity content, the evaporation rate is getting influenced and it is causing a change in the hydrological cycle.[3] Water loss due to evapotranspiration (ET) contributes significantly in resulting crop-water stress. Adequate water has to be supplied so that the crop-water stress is nullified and water wastage due to inundation of the field can be reduced. There exist a lot of method for the determination of evapotranspiration but the Penman-Monteith FAO 56 (PM FAO 56) is the most widely accepted method[4] in determining the ET losses. The PM FAO 56 model is principally dependent on five climatic factors which are atmospheric temperature, wind speed, relative humidity, solar radiation and atmospheric pressure. Crop type, nature of the soil, the growth stage of the crop also contribute to the ET loss, but the effects are negligible. The soil has its own pH value depending on the macro and micro mineral composition and also gets affected by the crops be cultivated on it. Reference Evapotranspiration is the loss registered by an extensive surface having uniform crop coverage of 0.12-meter height, adequately and fully shading the ground.[5-8]

The PM FAO 56 method is also known as the combination method and it can determine the ET losses based on five meteorological parameters which are air temperature, wind speed, solar radiation, relative humidity, and atmospheric pressure. The accuracy of measurement is very good although the results vary based on the geographical locations and other factors like leaf area index, canopy index and others. The PM equation[9] is shown in (1).

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad ...(1)$$

$\Delta = 4098e^0\ (T) / (T+273.3)^2$

$e^0\ (T) = 0.6108\exp\ (17.27T / (T+273.3)$

$\gamma = (C_p\ P)/\varepsilon\lambda$

ET_0 = Reference evapotranspiration [mm day^{-1}],

R_n = Net radiation at the crop surface [MJ m^{-2} day^{-1}],

G = Soil heat flux density [MJ m-2 day^{-1}],

T = Mean daily air temperature at 2 m height [°C],

u_2 = Wind speed at 2 m height [m s^{-1}],

e_s = Saturation vapor pressure [kPa],

e_a = Actual vapor pressure [kPa],

e_s-e_a = e^0(T) = Saturation vapor pressure deficit [kPa],

D = Δ = Slope vapor pressure curve [kPa °C^{-1}],

γ = g = Psychometric constant [kPa °C^{-1}].

P = Atmospheric pressure [kPa],

z = Elevation above sea level [m],

e^0 (T) = Saturation vapour pressure at the air temperature T [kPa],

λ = Latent heat of vaporization, 2.45 [MJ kg^{-1}],

C_p = Specific heat at constant pressure, 1.013 10-3 [MJkg-1 °C^{-1}],

ε = Ratio molecular weight of water vapour/dry air =0.622

On successful determination of how much water is lost due to evapotranspiration, it is important to take into account of the water quality that is to be supplied to compensate for this loss. A decision support system is built based on Fuzzy logic[10] to equip the control module of the model to make the necessary decisions.Regions which receive high seasonal rainfall develop acidic soil with a pH of 5.5 and less due to leaching of minerals like Calcium, Magnesium, Potassium and Sodium. Again humid regions with higher evaporation rates than precipitation also lead to acidic soil.[11-13] The toxicity of H+ ions proves to a limiting factor for proper growth of vegetation.[14] Soils across different regions have their own pH values that can be both acidic and alkaline. On supplementing the acidic soil with water in the acidic pH domain or vice versa, further deteriorates the condition. Neutralizing effects or sufficient time between watering interval and rate can reduce this noxiousness. The soil pH levels cannot be altered in a short period of time. Therefore regulating the water flow mitigates the situation significantly.

In subsequent sections, we will illustrate the model designed based on fuzzy rule-base in the materials and methods section, discussion on the results obtained and finally the conclusion.

Materials and Methods

As two factors are to be considered for proper utilization of water, also maintaining favourable mixing conditions, firstly the ET loss is determined by feeding on the required meteorological data to the PM FAO 56[9] model. Once the ET estimation block is configured, different acid combinations are generated to simulation a dummy environment. The output of the function block "detphwfd" emulates a practical scenario of water flow. The fuzzy controller runs a rule-base for different combinations of water-soil pH mixes. The fuzzy rule-base takes into consideration of the different sources of water and their pH values, and also keeps a knowledge-base to predict what value of pH is best suited for any particular crop type. This exhaustive knowledge-base then create the different valve positions which will function to provide the best possible results. The precision of the controller largely depends on how comprehensive the rule-base of the controller is. The flowchart as shown Fig 1 below depicts the process dynamics.

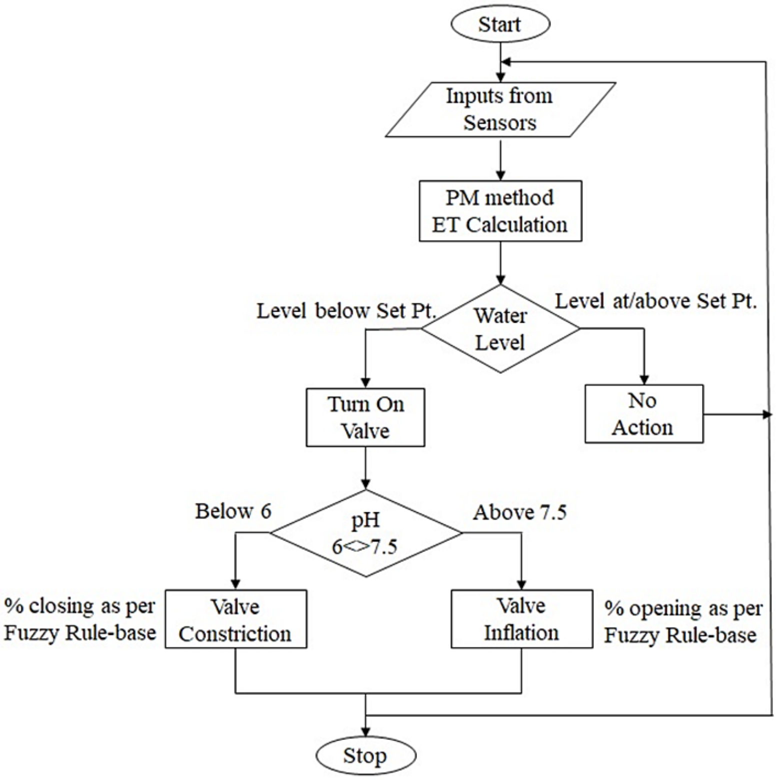

Fig. 1: Flowchart of process dynamics

A thorough illustration of the operation is elucidated in the algorithm. The algorithm dictating the terms for the control logic is given as below.

Step 1: The water deficiency is calculated by the PM FAO model.

Step 2: This data is forwarded to the control block, and provided with two separate disturbances of Gaussian followed by Rayleigh, to simulate a practical environment compensating for other factors.

Step 3: "detphwfd" function generates numerous combinations of the effluent water that vary from strongly acidic to strong alkaline.

Step 4: The second logic controller instructs the final control element to regulate the opening based on the influent nature, to maintain a proper mix between the acidic and alkaline compositions.

Step 5: The valve position is observed under conditions of acidic and alkaline water supply.

The model block diagram of two different noise components is illustrated in Fig 2 and 3.

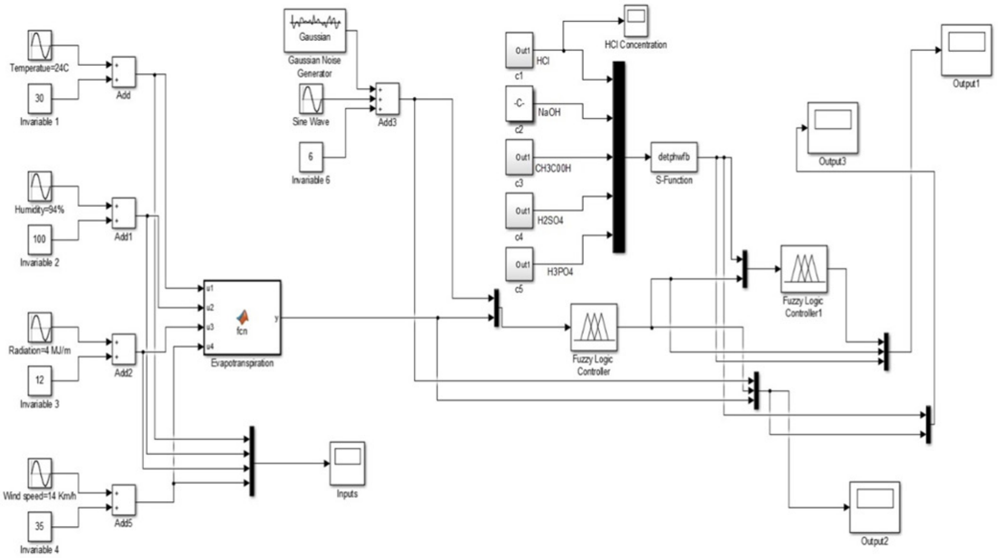

Fig. 2: Simulation block for the Valve response study under the effect of Gaussian noise

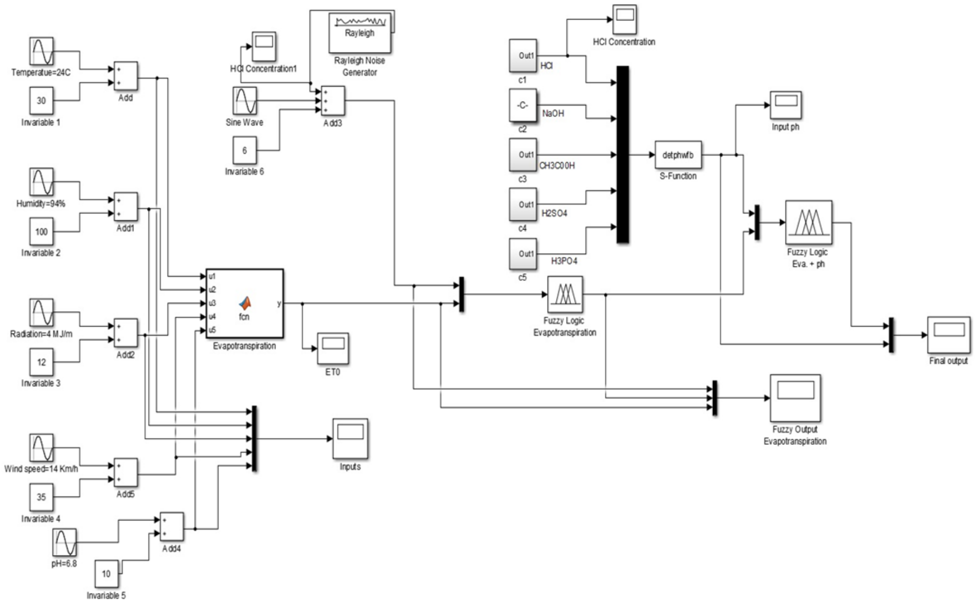

Fig. 3: The valve opening study in the presence of Rayleigh noise

Results & Discussion

The simulation results are recorded to check and validate for satisfying the aimed objective. Fig 4 corroborates the input response obtained from the imitative meteorological dataset. The output response of the "detphwfd" is obtained in Fig 5, with a zoomed-in response shown in Fig 6 indicating that acid response of the mix considerably dominant over the alkaline response. The reason for this kind of output is that titration simulation was carried out between strong acids and weak bases.

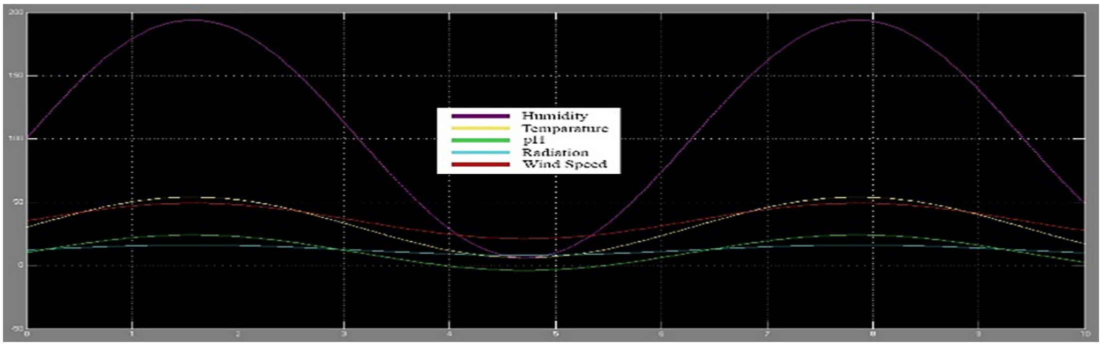

Fig. 4: Response of the Evapotranspiration Model

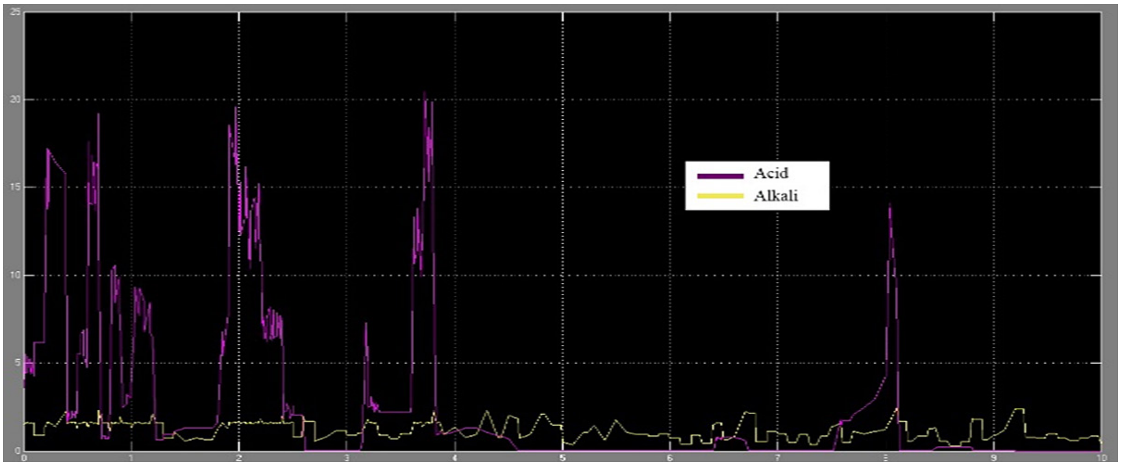

Fig. 4: Response of the Evapotranspiration Model

It is evident from Fig 7 that the valve deflates and inflates on encountering surge of acidic flow and alkaline flow, respectively.The reason behind restricting the water flow in case of high acidity is that, normally the farm lands which are situated in tropical to sub-tropical areas are rich in micro-nutrients which make up for the soil pH and make it acidic. High flow of acidic water will not provide sufficient time to the soil surface to adjust and materials like aluminum and others will form a precipitation layer blocking the root-zones necessary for mineral absorption. As the controller has considered the soil type under study to be acidic in nature, when the source of water is alkaline in nature, this leads to a natural process of neutralization and hence the valves not restricted.

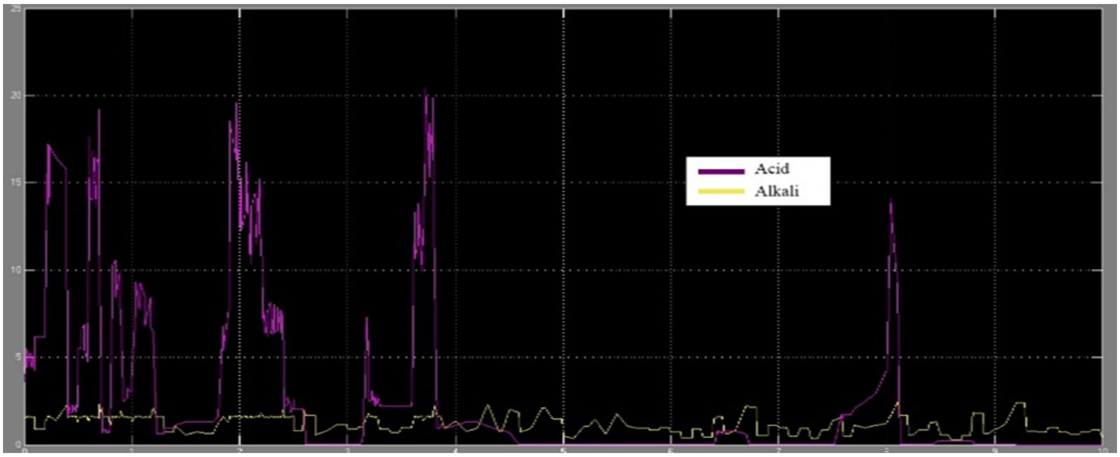

Fig. 5: Output response of "detphwfd"

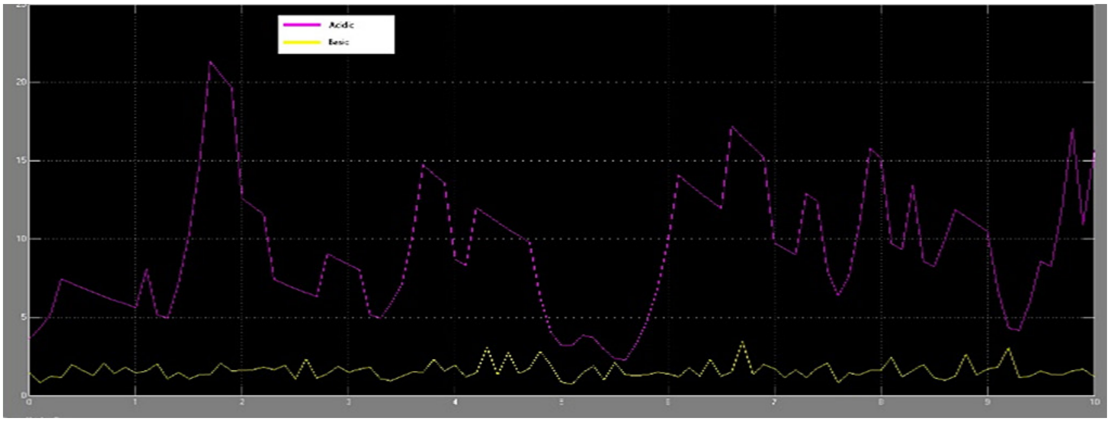

Fig. 5: Output response of "detphwfd"

Conclusion

The model designed has two functional blocks, one for the determination of ET loss, followed by valve-position control to regulate the water flow based on the rule-base determining numerous combinations of water-soil pH. Weather data as recorded by the sensors are fed to the PM ET block which determines the water loss and hence compensation required. And as the valve opens to compensate for the water loss, sensor measures the pH value of water and the controller operates on the position control of the valves by restricting and inflating with acidic and alkaline surge respectively. This model is therefore capable to monitor and control the flow of water maintaining the desired levels along with determination of water loss due to evapotranspiration. The pH of the soil-water combination is kept between 6 and 7.5 which is optimal for any cultivation. The results obtained are satisfactory and therefore the next step is to implement the prototype model of this controller for field validation.

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Conflict of Interest

The authors do not have any conflict of interest.

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