Modeling and Simulation of Microclimate in Plant Factory

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Abstract: : ***In plant factory production, many environmental factors will affect the growth of crops. Based on the common methods of the greenhouse microclimate modeling, this paper uses the mechanism method to model the environmental microclimate of plant plants. This paper mainly studied the influence of various systems in plant factory on the environment of plant factory, and established the model of temperature and humidity system. Through the analysis and emulation experiments, the effects were basically conform what were supposed.***

Keywords: about four key words separated by commas

1. Introduction

In plant factory production, the environment involves a lot of factors, and the main factors affecting the crop are temperature, humidity, light and CO2 concentration. These environmental factors are not the accumulation of single factor to crops, but all environmental factors play a role in the yield and quality of crops. They interact, promote each other and restrict each other. In order to improve the effectiveness of environmental management and control, it is necessary to study the microclimate and crop models in plant factory [1-3]. Mastering the characteristics of environmental factors in plant factory provides a basis for the regulation and control of plant environment. In order to improve plant factory, it is necessary to analyze the plant microclimate model and add the appropriate control amount.

At present, the modeling of microclimate is mostly used in Greenhouse, There are three main methods: Mechanism model method, parameter identification of linear model and parameter identification of nonlinear model [4]. This paper uses the mechanism method to establish the microclimate modeling in plant factory. The mechanism modeling method is based on the principles of physics and crop physiology, such as heat transfer, mass transfer, transpiration, respiration, photosynthesis and so on, setting up a plant factory microclimate model through energy balance and material balance [5-6]. The mechanism model can be used to understand the nature of plant factory microclimate and simulate the microclimate system of plant factory. This paper uses the mechanism modeling method to establish the model of plant factory microclimate and simulate.

2. Analysis of Microclimate System in Plant Factory

It is well known from the mechanism model that the plant factory microclimate system is a dynamic system with strong nonlinearity, large delay, strong coupling and strong interference. Influence of microclimate environment factor (Indoor humidity Tin, relative humidity HR, in, CO2 concentration Cd, in) on control input and disturbance input in plant factory. The control input is the working state of the plant factory environmental control equipment, and the disturbance input is the uncontrollable factor in plant factory. Including plant transpiration, water evaporation, light plate heating and other effects on the temperature and humidity. In this plant factory, the control input can be controlled continuously, and when the environment regulation equipment is set in a certain state, the microclimate environment factor of plant factory is affected only by disturbance factors in plant factory, As shown in Figure 1.

Visible, Plant microclimate is a multi-input and multiple output system(MIMO) that can be decomposed into three multiple inputs but output systems(MISO). In this paper, we only study temperature subsystem and humidity subsystem of plant factory, selecting temperature and relative humidity as model output variables.

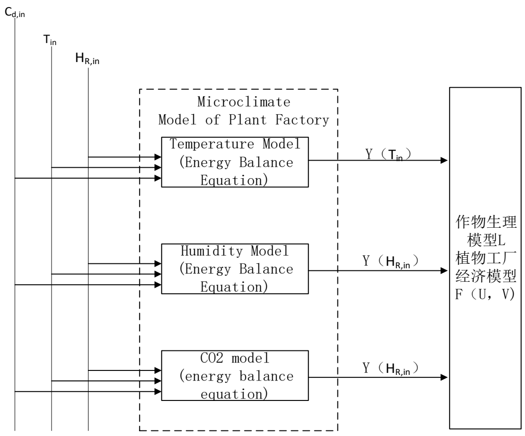

Figure 1: Structure sketch of microclimate system in plant factory

3. Mechanism Model of Plant Factory System

3.1 Test conditions and methods

The experiment was conducted at the plant factory laboratory of Tianjin University of Technology and Education, plant area 18m2. The heating pipe is used to heat the room in winter, air conditioning system humidification and cooling control in summer. The temperature and humidity of indoor air us detected by the temperature and humidity sensor installed in the room, and the data is automatically saved through the single chip microcomputer system.

3.2 Temperature Mechanism Model of Plant Factory

The environmental factors in plant factory interact with each other. There are physical phenomenon in plant factory and the physiological phenomena of some plants. Therefore, it is very difficult to establish a comprehensive and complete model for plant factory. Until the thermal equilibrium stable state method is introduced, it provides a new idea for plant factory modeling. Bot uses energy and material balance equations to describe greenhouse climate [7-9]. By using this method, the dynamic equation of gas temperature in plant factory can be obtained.

$$\Delta Q = Q_{heat} + Q_{vent} + Q_{led} + Q_{leaf} - Q_{cool} \quad (1)$$

Among, ΔQ is a sensible heat increment of plant factory air, Q_{heat} is heating energy, Q_{vent} is the heat exchange energy of external ventilation, Q_{led} is the radiation energy of LED plant lamp, Q_{leaf} is the heat conduction energy of indoor air and crop leaf surface, Q_{cool} is the energy taken away from the cooling equipment, Q_{tran} is the energy needed for crop transpiration, Q_p is the energy required for crop photosynthesis.
Assuming that the mixture of air and steam in plant factory is evenly distributed, the change of temperature in plant factory is determined by the change of energy in the plant microclimate system. According to the climatic conditions, The formula (1) model can be further analyzed.

(1) Heating energy in plant factory

The plant factory is heated by heating pipe system. Heat exchange of heating pipe and air in plant factory, the calculation formula is:

$$Q_{heat} = A_p h_p (T_p - T_i) \quad (2)$$

Style, A_p is the area of pipeline, T_p is the temperature of the pipe, T_i is indoor temperature, h_p is the coefficient of heat transfer.

(2) Heat exchange energy with external ventilation

The heat exchange between plant factory and the outside world is mainly reflected in the air convection caused by the exhaust fan, The calculation formula is:

$$Q_{vent} = \rho C_p \varphi_{vent} (T_i - T_0) \quad (3)$$

Style, ρ is outdoor air density, C_p is air constant pressure specific heat capacity, φ_{vent} is ventilation volume, T_0 is outdoor temperature.

Section
(3) Compressor refrigeration energy [10]
The test plant factory uses compressor to cool down the indoor temperature, The calculation formula is:

$$Q_{cool} = K_1 \cdot T_1 + K_2 \cdot w_1, \ K_1 > 0, \ K_2 < 0 \quad (4)$$

Style, K_1, K_2 is ratio coefficient; w_1 is the power of the compressor
(4) Heat dissipation of plant lamps
In plant factory, the use of LED matrix light source for the growth of plants, light energy consumption part of the conversion to energy, the rest is converted to heat, The calculation formula is:

$$Q_{led} = P \cdot (1 - \beta) \quad (5)$$

Style, P is the power of LED lamps, β is luminescence efficiency.
(5) Crop transpiration consumes energy
In plant factory, the transpiration of crops produces water vapor along with the production of heat, The calculation formula is:

$$Q_{tran} = [2500 - 2.44T_i] \times k_t (k_{SMC} T_i - k_{AH} RH_i) \quad (6)$$

Style, k_{SMC} is the conversion coefficient of saturated humidity; k_{AH} is the coefficient of Humidity Conversion.

The energy balance equation of the plant factory is obtained by introducing the above formulas into the (1) formula:

$$V\rho C_p \frac{dT}{dt} = A_p h_p (T_p - T_i) + \rho C_p \varphi_{vent} (T_i - T_0) + P(1-\beta) - K_1 \cdot T_1 + K_2 \cdot w_1 - [2500 - 2.44T_i] \times k_t (k_{SMC} T_i - k_{AH} RH_i) \quad (7)$$

3.3 Model of Moisture Mechanism in Plant Factory

The physical processes of microclimate in plant factories are influenced by factors, such as ventilator ventilation, air conditioning humidification, and crop transpiration. The dynamic equation of humidity gas in plant factory is obtained by means of the equation of material balance:

$$\Delta E = E_t + E_A - E_v \quad (8)$$

Among, ΔE is plant factory relative humidity increment, E_t is the release of steam from plant transpiration in plant factory, E_A is air conditioning to indoor environment humidification, E_v is the amount of water vapor loss caused by ventilation.
(1) Transpiration and release of water vapor from plant factory
Plant factory of Tianjin university of technology and education mainly plant leafy vegetables. Crop growth requires transpiration to operate nutrients and water. The study shows that only 1% of the water is absorbed from the roots, and the rest of the water is released by transpiration. It can be said that the transpiration of crops is an important factor affecting plant humidity and its production of water vapor:

$$E_t = \frac{\Delta R_n + \rho C_p [e_s(T) - e] r_b^{-1}}{\lambda [\Delta + [1 + \frac{r_s}{r_b}] \gamma]} \quad (9)$$

Style, Δ is the slope of the saturation curve of the vapor pressure at the temperature of T, $\Delta R_n^{\wedge}$、 is the net radiation of crop canopy, e_s (T) is the saturated vapor pressure under the temperature of T, e is the actual water vapor pressure, r_s is stomatal resistance, r_b is the surface aerodynamic drag of the crop, γ is the energy coefficient of water evaporation.

per at the places where they are first

(2) The amount of steam loss caused by ventilation

When the fan is opened, it will cause air exchange in the room and outside, because of the difference of humidity inside and outside the plant factory, which leads to the change of humidity in plant plants. If the ventilation efficiency is high, the greater the change of indoor humidity. The calculation formula is:

$$E_v = \varphi_{vent}(x_i - x_0) \tag{10}$$

Style, x_i, x_0 are the internal and external air water content of plant factory.

(3)Humidification of air conditioning to indoor environment [10]

Humidification by air conditioning and humidification in plant factory of Tianjin University of Technology and Education, The calculation formula is as follows:

$$\begin{cases} t_2 = t_1 + k_1 \cdot w_2 \\ E_A = 100 - (100 - Rh_1)\frac{1}{1+k_2 w_2} \\ d_1 < d_2 \quad if\ w \neq 0 \end{cases} \tag{11}$$

Style, k_1、 k_2 are coefficients, w_2 is the power of humidifier.

In summary, The dynamic equation of air humidity in plant factory can be obtained by using the principle of mass balance:

$$\rho h \frac{dW_t}{dt} = E_t + E_A - E_v \tag{12}$$

The above formula is brought into the (12) formula:

$$\rho h \frac{dW_t}{dt} = \frac{\Delta R_h + \rho C_p[e_s(T) - e]r_b^{-1}}{\lambda[\Delta + (1 + \frac{r_s}{r_b})\gamma]} + 100 - (100 - Rh_1)\frac{1}{1+k_2 w_2} - \varphi_{vent}(x_i - x_0) \tag{13}$$

4. Model Simulation

In order to verify the feasibility of the model, the temperature and humidity model is simulated and verified. The specific parameters of plant factory model are shown in Table 1

Table 1: Plant Factory Model Parameters

Parameter	Symbol	Value
Plant factory Volume	V	$54m^3$
Air density	ρ	$1.2kg/m^3$
Heat content in the air	C_p	1006J/（kg • k）
Energy coefficient of water evaporation	γ	0.0646kPa/℃
Canopy extinction coefficient	Ks	0.7
Actual water vapor pressure	E	10.1×104Pa
Cooling power of air conditioning	W_1	2210W
Humidification power of air conditioning	W_2	1500W
Stomatal resistance	r_s	10s/cm
Aerodynamic drag of the boundary layer on the surface of a leaf	r_b	150s/cm
Leaf area coefficient	LAI	6

4.1 Simulation of Temperature Model

Figure 2 is a temperature simulation model, because the temperature model is very complex, the heating tube is not linear with the indoor temperature. It can be seen from the plant factory mathematical model that it is a nonlinear object, and the model cannot give the relationship between the heating tube and the indoor temperature Ti. In order to facilitate understanding and simulation, each formula is represented by a subsystem. Then, according to the control relationship among variables among subsystems, a modeling system of plant environment temperature and microclimate is built. The equation of the model is integrated with the Dormand-Prince algorithm of variable-step, The initial value of the integral is 22. To simplify the environment temperature microclimate model in plant factory, Max step size is 0.05, The minimum step length, initial step length and absolute error are set automatically, Relative compensation is 1×10^{-3}.

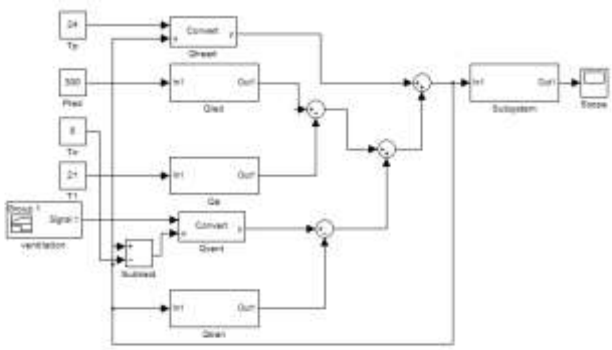

Figure 2: Temperature simulation diagram in plant factory

4.2 Simulation of Humidity Model

The humidity simulation model of Figure 3 is based on the formula (13). In order to facilitate understanding and simulation, each formula is represented by a subsystem. Then, according to the control relationship among variables among subsystems, a modeling system of plant environment humidity and microclimate is built. The equation of the model is integrated with the Dormand-Prince algorithm of variable-step, the initial value of the integral is 80. To simplify the environment humidity microclimate model in plant factory, Max step size is 0.05, The minimum step length, initial step length and absolute error are set automatically, Relative compensation is 1×10^{-3}.

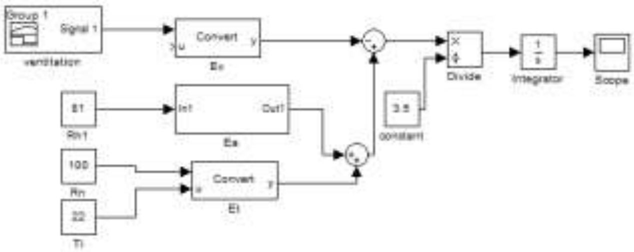

Figure 3: Humidity simulation diagram in plant factory

5. Results and Analysis

Figure 4 is the result of simulated temperature and temperature measurement in a plant factory based on a physical mode. The virtual line represents the simulated temperature and the real line indicates the measured temperature. As can be seen from the diagram, the maximum and minimum values of simulated temperature are within the allowable range of crop growth, The root mean square error between simulated temperature and measured temperature is 0.8, The simulated temperature is in good agreement with the measured temperature.

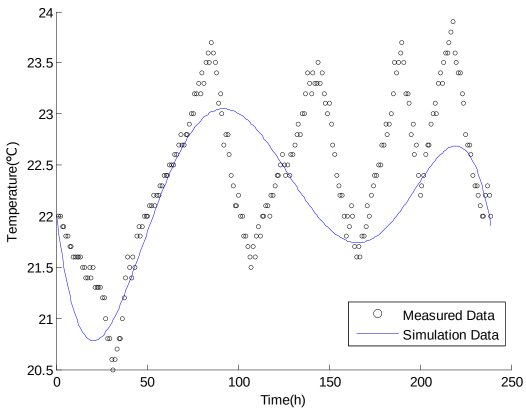

Figure 4: Simulation contrast diagram of plant temperature model

It is known from Figure 5, The plant factory humidity, which is simulated by the model, is basically consistent with the plant factory humidity, Because plant factory temperature is higher, the illumination of 12 hours make plant photosynthesis longer, Indoor humidity shows a downward trend, When the relative humidity in the room is below 40%, the air conditioning begins to humidification, So the relative humidity in the room began to rise. At the same time, the humidity in the measured plant factory is compared with the humidity in the plant factory simulated by the model. It is known that the simulated indoor humidity can reflect the changing trend in the plant factory, The root mean square error between simulated humidity and measured humidity is 1.9, The simulated humidity is in good agreement with the measured humidity.

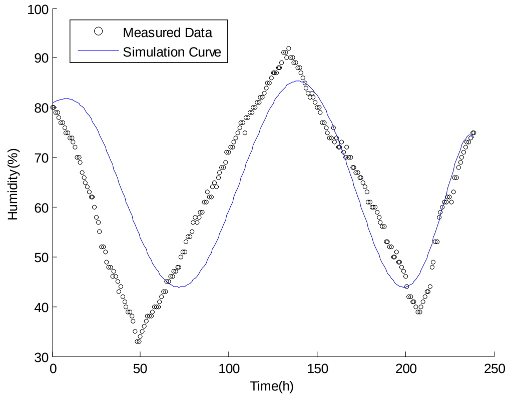

Figure 5: Simulation contrast diagram of plant humidity model

6. Summary

In this paper the microclimate characteristics of plants, based on mechanism modeling, according to the actual plant factory control equipment for large inertia ring, nonlinear multivariable, coupling, and plant factory system delay phenomenon, a simplified model of temperature and humidity, and the measured data of the model is verified by test. At the same time, it can be found that the model can reflect the temperature and humidity state of plant factory well by comparison between the measured data and the predicted data in plant factory. This provides a good basis for temperature and humidity monitoring and regulating plant factory.

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