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LabVIEW surface cooler modeling based on the heating-exchange efficiency of water method

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Abstract
The surface cooler is an important component of air handling in the HVAC system, and the performance of the air handling unit is directly affected by the heat transfer performance of the surface cooler. In this paper, the heat-exchange efficiency of water side method (HEW) was used to establish a LabVIEW-based model of the surface cooler, and the error with the experimental data was about 4.1% and 1.55%, the model accuracy is good, and it creates the conditions for the development of the simulation system of the air-conditioning system using LabVIEW software.
Keywords: *heat-exchange efficiency of water method (HEW); surface cooler; LabVIEW; thermal calculation*

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I. INTRODUCTION

In the preliminary stage of HVAC engineering design, the modeling simulation of the system has far-reaching significance for the optimization of the HVAC system and the overall control logic, which makes use of computer technology to simulate the operating environment of the system without the need for field experiments, which greatly saves energy consumption and costs. The simulation of components is an important part of the simulation of air-conditioning system construction, in which surface coolers are widely used in the system, such as air-handling units, fan coils, rotor dehumidifier systems, and so on. The operation of surface coolers is usually accompanied by heat and humidity exchange processes, so the simulation of surface coolers is necessary for the simulation of air conditioning systems.

Currently, heat transfer calculations for surface coolers are most widely used in the dry-bulb efficiency calculation method, the wet-bulb efficiency calculation method, and the water-side heat exchange efficiency method [1]. Among them, the dry-bulb efficiency and algorithm and the wet-bulb efficiency calculation method take the heat transfer process on the air side as the main calculation object, while the heat and humidity environment on the air side is quite complex, and there is great difficulty in the simulation and modeling, and the error of the thermal calculation is large due to the use of an excessive amount of approximation processing. Therefore, this paper adopts the heat-exchange efficiency of water method as the method of heat exchange calculation, which has the advantage of taking the water-side, which has only sensible heat exchange, as the main research object, and the simulation difficulty is lower and the accuracy is higher compared with the dry bulb efficiency calculation method and the wet bulb efficiency calculation method [2].

II. MATHMATICS MODELING OF THE SURFACE COOLER

2.1 Overview of the model

The heat transfer process of a surface cooler is a dynamic process that changes over time, and the temperature at the outlet changes whether it is the water side or the air side, so the model of the surface cooler is a dynamic model. The state of the air side and water side at the outlet of the surface cooler changes with time and eventually tends to stabilize a relatively stable state. In this paper, the air mass flow rate of the heat exchanger, the cold water mass flow rate, the air inlet temperature, and the cold water inlet temperature changes on the heat transfer are considered, and they are all used as input variables of the model, together with the parameters of the heat exchanger itself, to predict the air and cold water physical state at the outlet of the heat exchanger.

2.2 Model Description

For simplicity, the following assumptions are made about the model:

i. Simplified to an adiabatic system without consideration of heat loss;
ii. The density of air is a fixed constant, $1.29 kg/m^3$;
iii. External atmospheric pressure is standard atmospheric pressure, $101.325 kPa$;

The meaning of the symbols and units involved in the model are shown in Table 1：

Table 1 The meaning of the symbols and units involved in the model.

Symbol	Meaning	Unit
W_w	Cold water side volume mass in the surface cooler	kg
W_a	Air side volume mass in the surface cooler	kg
C_w	Specific heat of cold water, 4187 $J/kg\cdot℃$	$J/kg\cdot℃$
C_a	Specific heat of air, 1005 $J/kg\cdot℃$	$J/kg\cdot℃$
t_{w1}	Inlet temperature of the cold water side of the surface cooler	℃
t_{w2}	Outlet temperature of the cold water side of the surface cooler	℃
t_1	Inlet temperature of the air side of the surface cooler	℃
t_2	Outlet temperature of the air side of the surface cooler	℃
t_3	Surface water film temperature of the surface of the surface cooler	℃
i_1	Enthalpy of inlet air to the surface cooler	kJ/kg
i_2	Enthalpy of outlet air to the surface cooler	kJ/kg
i_3	Enthalpy of water film on surface of surface cooler	kJ/kg
G_w	Cold water mass flow	kg/s
G_a	Air mass flow	kg/s
τ	Time	s
Q	Heat transfer between water and air	W
ξ	Moisture separation factor	-
V_y	Air velocity	m/s
ω	Clod water velocity	m/s
A, B, m, n, p	Experimental parameters of the surface cooler	-
K	Surface cooler heat transfer coefficient	$W/(m^2\cdot℃)$
F	Surface area of heat exchange of the surface cooler	m^2
Δt_d	Average temperature difference between the inlet and outlet of the surface cooler	℃
E_w	Water-side efficiency of the surface cooler	-

2.2.1 Heat transfer equation

As a dynamic process, with time τ as the dependent variable, and according to the law of conservation of energy, the differential equation for heat transfer in a surface cooler is as follows:

The differential equation for heat transfer on the cold water side is as follows:

$$W_w C_w \frac{dt_{w2}}{d\tau} = G_w C_w (t_{w2} - t_{w1}) - Q \tag{1}$$

The differential equation for heat transfer on the air side is as follows:

$$W_a C_a \frac{dt_2}{d\tau} = Q - \xi G_a C_a (t_2 - t_1) \tag{2}$$

The heat transfer equation between air and cold water is as follows:

$$Q = KF\Delta t_d \tag{3}$$

2.2.2 Average temperature difference between the inlet and outlet

The average temperature of the surface cooler heat transfer is calculated using the arithmetic mean temperature difference method:

$$\Delta t_d = \frac{(t_1 - t_{w2}) + (t_2 - t_{w1})}{2} \tag{4}$$

2.2.3 Surface cooler heat transfer coefficient

The heat transfer coefficients of the surface cooler are generally organized into a generalized form [3]:

$$K = \left(\frac{1}{AV_y^m \xi^n} + \frac{1}{B\omega^P}\right)^{-1} \tag{5}$$

2.2.4 Calculation of moisture separation coefficient

The traditional formula for the precipitation coefficient is:

$$\xi = \frac{i_2 - i_1}{c_a(t_2 - t_1)} \tag{6}$$

Where i_2 is the enthalpy of air-side outlet, and as the model output parameter air-side outlet temperature t_2 corresponding to the enthalpy, to calculate i_2 in an analytical way has a high degree of difficulty, and the relative error is large. The water-side heat exchange coefficient method, on the other hand, involves the water film temperature t_3 and its corresponding enthalpy h_3 on the surface of the surface cooler instead of t_2 and h_2 in the calculation of the precipitation coefficient ξ.

The air treatment process for the heat exchange of the surface cooler is presented on the enthalpy-humidity diagram as shown in Fig. 1. The dry-bulb temperature and enthalpy at the air inlet point 1 are t_1 and h_1, respectively, and the dry-bulb temperature and enthalpy at the air outlet point 2 are t_2 and h_2, respectively, while the heat and humidity exchange process at the surface of the surface cooler can be regarded as an air mixing process between the cooled air and the saturated air thin layer on the water film at the surface of the surface cooler [3]. According to the law of air mixing, the initial and final state points of the air treatment process and the surface average state point 3 must be in the same straight line [4]. Also the state point 3 corresponding to the water film temperature is a saturated state point, then t_3 is the wet bulb temperature of this state point, and its corresponding enthalpy h_3 can be calculated using the empirical formula, e.g., when the wet bulb $t_3 \in [10,20]$℃, then h_3:

$$h_3 = 0.0707t_3^2 + 0.6452t_3 + 16.18 \quad (7)$$

And the water film temperature t_3 can be calculated according to the water-side efficiency of the obtained, the detailed process is not repeated here, see literature [2]:

$$t_3 = t_{w1} + \frac{t_{w2} - t_{w1}}{E_w} \quad (8)$$

Water-side efficiencyE_W:

$$E_w = 1 - \exp(-\frac{BF\omega^{0.8}}{W_w c_w}) \quad (9)$$

Then Eq. (6) is transformed into:

$$\xi = \frac{i_3 - i_1}{c_a(t_3 - t_1)} \quad (10)$$

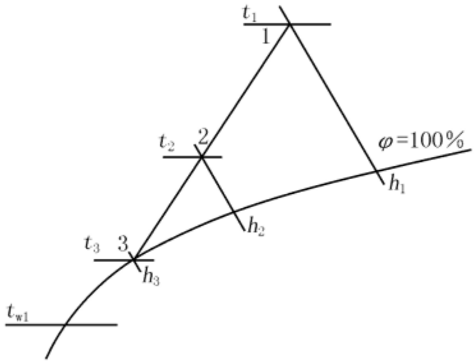

Fig.1: The process of air handling

III. LABVIEW MODELING

3.1 Overview of the software: LabVIEW

LabVIEW (Laboratory Virtual instrument Engineering) is one of the most widely used virtual instrumentation languages in engineering projects, which is characterized by the programming logic in the form of graphs instead of the traditional programming language's text-based mode, usually called G language. Compared with the traditional text-based language, G language, in addition to more clearly organized logic, more conducive to start, the traditional text-based language is based on the order of statements and instructions to perform operations, while the LabVIEW language is a data flow model, the data flow to determine the order of execution of the program, that is, parallel execution [6].

3.2 LabVIEW Programming

Fig. 2 shows the simulation process of the model, using the program to list the heat transfer differential equations based on the input parameters and solving the differential equations using LabVIEW's own functions, the method used to solve the differential equations is the Runge-Kutta methods.

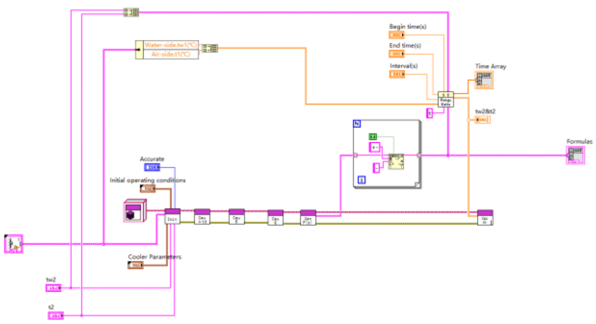

Fig.2: LabVIEW modeling of a surface cooler based on the heat exchange efficiency of water method

Fig.3 shows the simulation model of the surface cooler based on the water-side heat exchange efficiency method. The input parameters of the model in the left column include the start time, end time and simulation step size of the simulation model; the parameters of the coil itself, such as the heat exchange area, heat transfer coefficient, etc.; the fixed physical constants, such as the specific heats and densities of water and air; and most importantly, the initial working conditions, which is the interface with the air conditioning simulation system. After running the program, the output parameters are obtained in the right column: t_2 and t_{w2} at each time point, i.e., the air and chilled water temperatures at the outlet of the meter cooler.

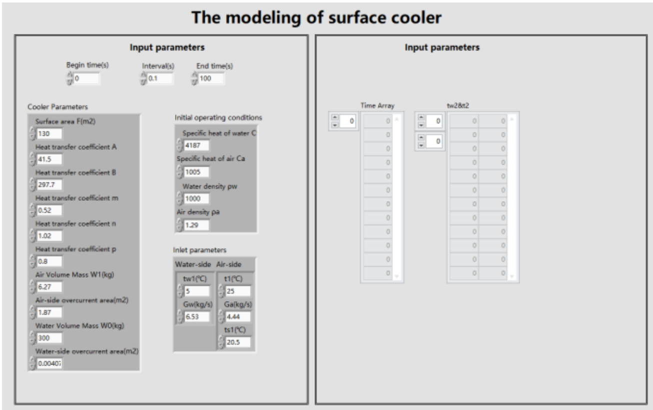

Fig.3: Model runtime interface

IV. MODELING VALIDATION AND ANALYSIS

4.1 Working condition parameter setting

Parameters were chosen to verify the accuracy of this model with data from the surface cooler selection chapter of the *"Practical Refrigeration and Engineering Handbook"*.

The experimental data for air and cold water are shown in Table 2 below:

Table 2 Air-side and water-side experimental data

Input/Output	Parameter Name	Value
Input	Air Inlet Dry Bulb Temperature t_1(℃)	25
	Air Inlet Wet Bulb Temperature t_{s1}(℃)	20.5
	Water inlet Temperature t_{w1}(℃)	5
	Water flow $G_w(kg/s)$	6.53
	Air flow $G_a(kg/s)$	4.44
Output	Air Outlet Dry Bulb Temperature t_2(℃)	10.5
	Water Outlet Temperature t_{w2}(℃)	9.7

Coil selection JW20-4 type 6-row surface cooler, coil parameters are as follows Table 3:

Table 3 JW20-4 type 6-row surface cooler, coil parameters

Parameter Name	Value
Surface area $F(m^2)$	130
A	41.5
B	297.7
m	0.52
n	1.02
p	0.8
Air Volume Mass $W_a(kg)$	6.27
Water Volume Mass $W_w(kg)$	300
Air-side overcurrent area $F_a(m^2)$	1.87
Water-side overcurrent area $F_w(m^2)$	0.00407

4.2 Data verification

The air-side and water-side input parameters in Table 2 and the surface cooler parameters in Table 3 are inputted into the model, and the simulation starting and stopping times and time intervals are set to run the model, and the dynamic response curves of the air-side and water-side outlet temperatures, t_2, t_{w2}, can be obtained, as shown in Fig.4 below, and the steady state response of the model is: $t_2 = 10.93℃, t_{w2} = 9.65℃$, and the comparison is made with the calibration calculation. The error is about 4.1% and 1.55%.

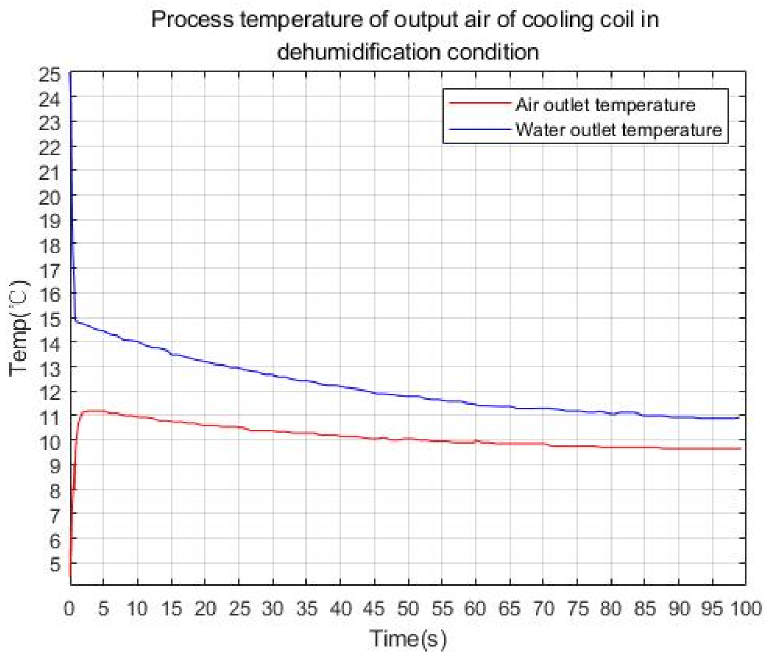

Fig.4: Dynamic response of the surface cooler

V. CONCLUSION

The heat exchange mathematical model of water-cooled surface cooler was established, and the water-side heat exchange efficiency method was adopted for the derivation of the mathematical model. Based on the mathematical description of the model, a simulation model of the water-cooled surface cooler based on the water-side heat exchange efficiency method was established using LabVIEW, and the model was verified using the measured data, which proved that the simulation accuracy of the model was high, and the deviation of the simulated values of the outlet air and chilled water temperatures from the actual values were about 4.1% and 1.55%, respectively. Based on this model, it is possible to continue to use LabVIEW to simulate the remaining components of the air conditioning system to obtain a complete HVAC simulation software, effectively reducing the difficulty and cost of engineering design.

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