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Water-side Heat Exchange Efficiency Method to Surface Cooler Modelling in LabVIEW

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Abstract

Surface cooler is a significant air handling component in the HVAC system, and air handling unit capacity is directly affected by surface cooler heat transfer performance. This paper employs the water side method (HEW) to gauge the heat-exchange efficiency of a surface cooler, establishing a LabVIEW-based model. The model's deviation from experimental data stands at approximately 4.1% and 1.55%, showcasing commendable accuracy. Moreover, this model paves the way for the advancement of a LabVIEW software-based simulation system for air-conditioning systems.

Keywords

Heat-exchange Efficiency of Water Method (HEW); Surface Cooler; LabVIEW; Thermal Calculation.

1. Introduction

During the initial stages of HVAC engineering design, modelling and simulation play a pivotal role in optimizing HVAC systems and overall control logic. Leveraging computer technology, these simulations replicate system operation without necessitating field experiments, leading to significant energy and cost savings. Among the components crucial for air-conditioning system simulations, surface coolers feature prominently. Found in various system elements like air-handling units, fan coils, and rotor dehumidifier systems, surface coolers facilitate heat and humidity exchange processes. Therefore, simulating surface coolers is imperative for comprehensive air conditioning system simulations.

Presently, heat transfer computations for surface coolers primarily rely on the dry-bulb efficiency calculation method, the wet-bulb efficiency calculation method, and the water-side heat exchange efficiency method [1]. Among these, both the dry-bulb efficiency algorithm and the wet-bulb efficiency calculation method predominantly focus on the heat transfer process on the air side. However, the heat and humidity conditions on the air side are notably intricate, posing significant challenges for simulation and modelling. Moreover, the excessive use of approximation techniques often results in substantial errors in thermal calculations. Consequently, this paper advocates for the adoption of the water-side heat-exchange efficiency method for heat exchange calculations. This method prioritizes the water side, characterized by sensible heat exchange only, as the primary research focus. Compared to the dry-bulb efficiency and wet-bulb efficiency calculation methods, it offers lower simulation complexity and higher accuracy [2].

2. Mathematics Modelling of the Surface Cooler

2.1 Overview of the Model

The heat transfer process of a surface cooler is dynamic, evolving over time, with outlet temperatures varying on both the water and air sides. Consequently, the surface cooler model is dynamic, reflecting

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these changes. The conditions of the air and water sides at the outlet gradually stabilize. This paper considers factors such as the air mass flow rate, cold water mass flow rate, air inlet temperature, and cold water inlet temperature, all influencing heat transfer. These variables, along with heat exchanger parameters, serve as inputs for the model to predict the physical state of the air and cold water at the heat exchanger outlet.

2.2 Model Description

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

1) Simplified to an adiabatic system without consideration of heat loss;

2) The density of air is a fixed constant, $1.29kg/m^3$;

3) External atmospheric pressure is standard atmospheric pressure, 101.325kPa.

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	Cold 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	-

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2.2.1 Heat Transfer Equation

Being a dynamic process where time τ serves as the dependent variable, and in accordance with the law of energy conservation, the differential equation governing heat transfer in a surface cooler can be expressed 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:

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

2.2.4 Calculation of Moisture Separation Coefficient

The traditional formula for the precipitation coefficient is:

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

In this context, i_2 represents the enthalpy of the air-side outlet. Deriving i_2 analytically, corresponding to the air-side outlet temperature t_2, poses considerable complexity and leads to significant relative errors. Conversely, the water-side heat exchange coefficient method adopts the water film temperature t_3 and its associated enthalpy h_3 on the surface of the cooler instead of t_2 and h_2 for calculating the precipitation coefficient ξ.

The air treatment process for heat exchange in the surface cooler is illustrated on the enthalpy-humidity diagram, depicted in Fig. 1. At the air inlet point 1, the dry-bulb temperature and enthalpy are denoted as t_1 and h_1, respectively. Correspondingly, at the air outlet point 2, they are represented by t_2 and h_2. The heat and humidity exchange occurring at the surface of the cooler can be viewed as an air mixing process between cooled air and the thin layer of saturated air on the

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water film of the cooler's surface [3]. According to the principles of air mixing, the initial and final state points of the air treatment process, along with the surface's average state point 3, must align in a straight line [4]. State point 3, corresponding to the water film temperature, is saturated, thus making t_3 the wet bulb temperature of this point. Its associated enthalpy h_3 can be computed using empirical formulas, such as when the wet bulb $t_3 \in [10,20]$°C, then h_3:

$$h_3 = 0.0707t_3^2 + 0.6452t_3 + 16.18 \tag{7}$$

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 [5]:

$$t_3 = t_{w1} + \frac{t_{w2} - t_{w1}}{E_w} \tag{8}$$

Water-side efficiency E_W:

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

Then Eq. (6) is transformed into:

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

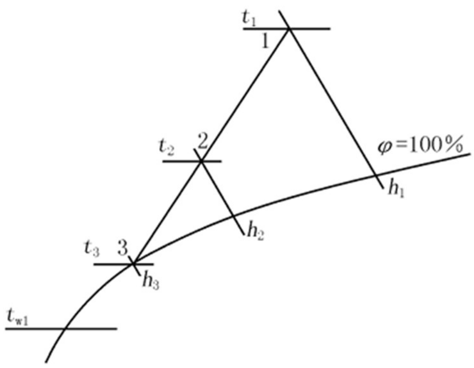

Figure 1. The process of air handling

3. LabVIEW Modelling

3.1 Overview of the Software: LabVIEW

LabVIEW (Laboratory Virtual Instrument Engineering) stands out as a prominent virtual instrumentation language in engineering endeavors. Its distinguishing feature lies in its graphical programming logic, contrasting with the conventional text-based approach found in languages like G language. Unlike the linear execution flow dictated by the sequence of statements and instructions in traditional text-based languages, LabVIEW operates on a data flow model. Here, the order of program execution is determined by the flow of data, enabling parallel execution. This characteristic, coupled

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with its logically structured interface, renders LabVIEW more user-friendly and facilitates swift initiation into programming tasks when compared to its text-based counterparts [6].

3.2 Overview of the Software: LabVIEW

Figure 2 depicts the simulation procedure of the model, wherein the program lists the heat transfer differential equations derived from the input parameters. Subsequently, LabVIEW's built-in functions are employed to solve these equations. The Runge-Kutta methods are utilized for solving the differential equations.

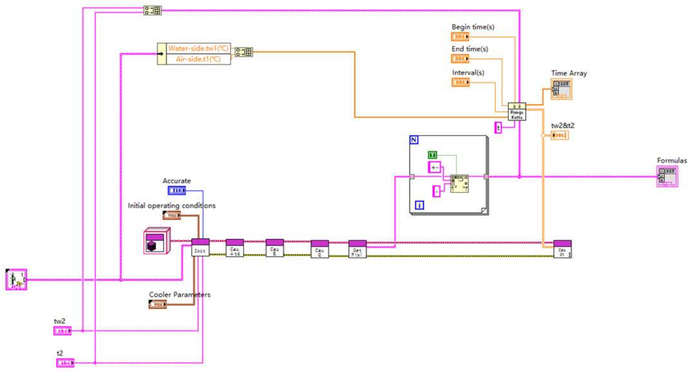

Figure 2. LabVIEW modelling of a surface cooler based on the heat exchange efficiency of water method

Figure 3 illustrates the simulation model of the surface cooler, utilizing the water-side heat exchange efficiency method. The left column showcases the model's input parameters, including the start time, end time, and simulation step size, along with coil parameters such as heat exchange area and coefficient, as well as fixed physical constants like specific heats and densities of water and air. Crucially, it also incorporates initial working conditions, serving as the interface with the air conditioning simulation system. Upon program execution, the right column displays output parameters at each time point, namely t_2 and t_{w2}, representing the air and chilled water temperatures at the cooler outlet.

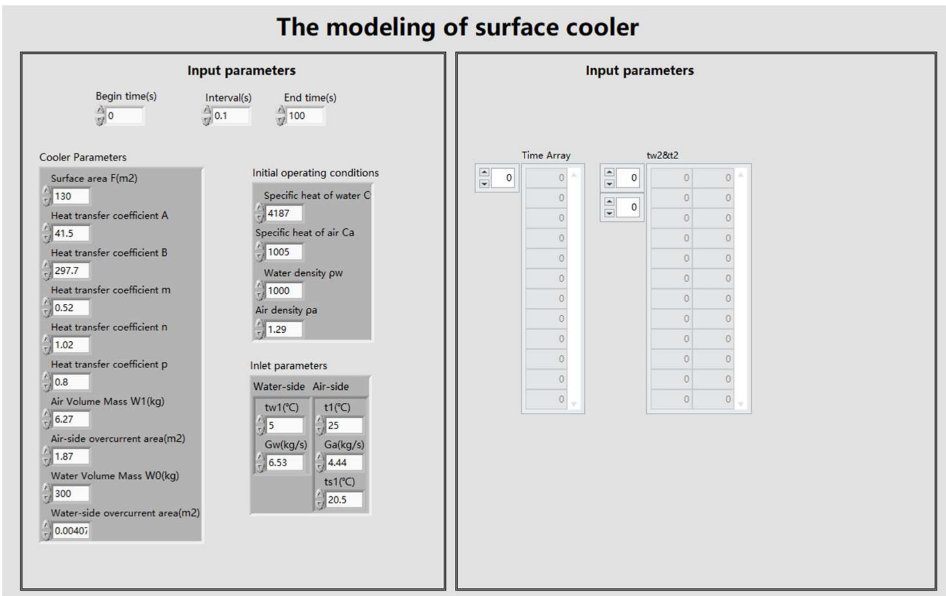

Figure 3. Model runtime interface

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4. Model 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(°C)	25
	Air Inlet Wet Bulb Temperature t_{s1}(°C)	20.5
	Water inlet Temperature t_{w1}(°C)	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(°C)	10.5
	Water Outlet Temperature t_{w2}(°C)	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 input parameters for both the air-side and water-side, detailed in Table 2, along with the surface cooler parameters listed in Table 3, are fed into the model. Setting the simulation start and stop times, as well as time intervals, initiates the model run. Consequently, dynamic response curves for the air-side and water-side outlet temperatures, denoted as t_2 andt_w2, are generated, as depicted in Fig.4 below. The model's steady state response yields t_2=10.93℃ andt_w2=9.65℃. A comparison with calibration calculations reveals an error of approximately 4.1% and 1.55%.

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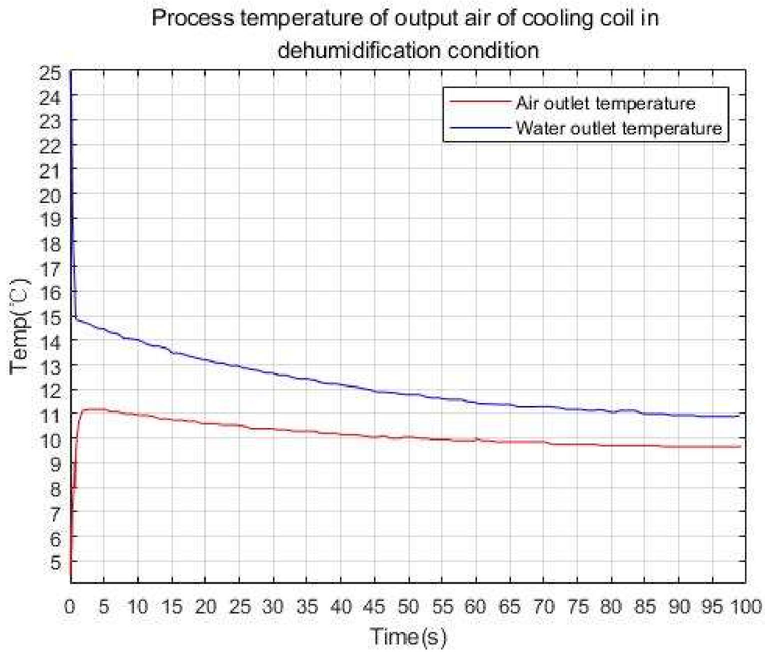

Figure 4. Dynamic response of the surface cooler

5. Conclusion

A mathematical model for heat exchange in water-cooled surface coolers was developed, employing the water-side heat exchange efficiency method. Leveraging this mathematical framework, a simulation model of the water-cooled surface cooler was constructed using LabVIEW. Validation against measured data confirmed the model's high simulation accuracy. Deviations between simulated and actual values for outlet air and chilled water temperatures were approximately 4.1% and 1.55%, respectively. This established model enables further simulation of additional components of the air conditioning system using LabVIEW, facilitating the creation of comprehensive HVAC simulation software. Such an approach effectively mitigates the challenges and costs associated with engineering design.

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