LabVIEW Application to Heat Balance Calculation of Thermal Treatment for Large Spherical Tank

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Keywords: LabVIEW, Large spherical tank, Thermal treatment, Heat balance calculation.

Abstract. Based on the basic formula of heat balance calculation, a computational simulation system is developed by LabVIEW, which is of thermal treatment for large spherical tank. This system takes full account of the size and material of spherical tank, and calculates the total quantity of heat and the consumption of oil for thermal treatment process of different spherical tank. This system solves these hard problems such as complex heat balance calculation process, a large amount of date calculation, dependence of personal experiences and so on. This system has been used for thermal treatment of spherical tank in practice. The calculation process is fast and reliable. In addition, the results can provide a strong help for the burner project bidding.

1. Introduction

With the formal establishment of the Asian Infrastructure Investment Bank (AIIB), as the second largest country of producing oil and chemical products, China need to promote the petrochemical products to the international. In petroleum refining industry and petrochemical industry, large spherical tanks are used for storage and transportation of liquid or gaseous materials widely, such as liquefied petroleum gas, liquid ammonia, oxygen, nitrogen. According to the production standards of the steel spherical tank, large spherical tank is manufactured by welding with arc steel plates [1]. So residual stress exists between these steel plates, which will reduce the rigidity and stability of structure. In order to eliminate the residual stress, the thermal treatment must be carried after welding [2].

The key of post-weld thermal treatment of spherical tank lies in obtaining the theoretical value of combustor oil consumption in advance. Given that if the temperature of sphere shell fluctuates drastically in warming stage and thermal insulation stage during thermal treatment process, thermal treatment stress shall definitely generate [3]. As a consequence, researchers shall calculate some theoretical value. Chen [4] had summarized the steps of thermal calculation. However, owing to multiple influencing factors such as size, material and environment, thermal treatment technique complicates thermal calculation simultaneously, there is no complete mathematical models concerning thermal calculation aiming at simplifying calculation process. At present, thermal calculation of large-scale spherical can only depend on manual calculation, but such kind of calculation is time-consuming, labor-consuming and inaccurate.

In conclusion, this paper adopts graphical programming (G language) and takes LabVIEW as the development platform software, which is a strong graphical user interface with various functions, constructing a system of simulation applied in thermal calculation during post-weld thermal treatment of large-scale spherical tank.[5]

2. Functions of Thermal Calculation System

Thermal calculation of large-scale spherical tank is the premise of reasonable selection of thermal treatment device, pipe specification and process control parameters. According to the requirements of process development, the thermal calculation system should have following functions:

Firstly, it shall select size of spherical tank independently and configure material of spherical tank randomly in order to satisfy different requirements of thermal calculation and realize universality.

Secondly, it can store relevant standard data into the data base, and consequently, the system shall automatically retrieve relevant data in data base according to parameters such as size of spherical tank and material set by users. Thereafter, the system can formulate corresponding thermal treatment process and thereby saving time.

Thirdly, it shall calculate thermal consumption amount and oil consumption amount during thermal treatment under complete working conditions and accordingly make consequences reports of thermal calculation. In accordance with calculation consequences, operators can reasonably control oil combustion amount during thermal treatment. In addition, designers can also set thermal treatment effects through controlling oil supply system fit for large-scale spherical in order to avoid thermal treatment stress.

3. Design and Realization of Thermal Calculation System

At present, the thermal balance basic formulation is the most common thermal calculation method [2]. Based on thermal balance basic formulation method, this paper completes software development through LabVIEW platform. LabVIEW is a software developed by American National Instruments Corporation characterized by explicit graphical programming language (G language) and ideal programming code, and simultaneously, its graphical source code is similar to data flow chart to some degree. That is why LabVIEW graphical source code is also known as program chart code [6]. This thermal calculation system integrates three function modules in user interface, including parameter setup module, automatic calculation module and automatic generation reporting module. Modules realize thermal calculation function through internal parameter transmission or iteration.

3.1 Technological Route.

As shown in Fig.1, this paper shall build a data base and store relevant standard data such as specific heat capacity and heat conductivity of various materials. The main program automatically selects relevant data as inline parameters according to user options, and further carries on thermal calculation based on parameters of thermal treatment set up by users as well as overall thermal calculation by calling subroutine. This system has a binary structure, among which the upper level is the user interface developed by LabVIEW working for parameter setup and display, and the lower level finishes thermal calculation report according to superior orders and relevant data.



Fig. 1 System flow chart

3.2 Front Panel Design.

(1) Parameter setting module of spherical tank. Large-scale spherical tanks mainly refer to tank with a volume over 5000 cubic meter, such as spherical tank of $5000 m^3$, $6000 m^3$, $8000 m^3$ and $10000 m^3$ volume. As shown in Fig.2, users can select common specifications from menu in the interface. This module also offers other shell steel plates with materials such as 20R, 16MnR, Q345R, Q370R, and 07MnNiMoDR as well as materials of insulating layer such as micro-glass fiber and alumina silicate fiber. In addition, the paper designs user input parameters such as thickness of spherical shell and thickness of insulating layer.



Fig. 2 Parameter setting area of front panel

(2) Inline parameter display module. When the material of the tank is set, the system shall automatically represent reasonable thermal treatment process according to common-used steel types mentioned in *Welding Specification for Pressure Vessels* (NB/T 47015-2011) such as target temperature, holding time, average warming rate in each temperature range and warming time as shown in Fig.3. At the same time, the system will generate the curve of specific heat and heat conductivity of shell materials and automatically display the inner diameter, outer diameter and quality of the tank according to *Steel Spherical Tanks Type and Dimension Data Base* (GB/T17261-2011).



Fig. 3 Display Area of Inline Parameters in the front panel

(3) Display module of calculation results. Pursuant to input design parameters and data base search results, the system shall automatically calculate data and display results as soon as users operate the program. Specifically, thermal value required in combustion process and oil consumption amount in

unit time of each stage can be calculated and converted into overall oil combustion amount as shown in Fig.4. Then the system will generate thermal calculation report with user demands.

| Heat Loss Value (10000kcal/h) | | | | | | | |
|---------------------------------|----|---------------------|---|---|-------------------|------------------------------|----|
| Q 1 | Q2 | Q₃ | Q4 | Ç | Q5 (| Q6 | Qē |
| 0 | 0 | 0 | 0 | 0 | 0 | | 0 |
| Temperature range (℃) | | Heating t tm (h | Heating time Fuel consumption rat tm(h) Bn(kg/h) | | ion rate F h) | Fuel consumption B (kg) | |
| te~100 | | 0 | [] | 0 | (| 0 | |
| 100~200 | | 0 | [] | 0 | (| ט | |
| 200~300 | | 0 | [] | 0 | (| D | |
| 300~400 | | 0 | | 0 | (| D | |
| 400~500 | | 0 | [] | 0 | (| D | |
| 500~595 | | 0 | [] | 0 | (| D | |
| 595±25 | | 0 | | 0 | (| D | |
| Total | | 0 | ĺ | | (| D | |

Results of Heat Balance Calculation

Fig. 4 Display area of calculation results

3.3 Main Program Design.

First of all, data including thermal conductivity and specific heat capacity of different materials shall be filled in spreadsheet files. The main program will retrieve file content through "File I/O" function panel to further screen out required data and combine them in the form of array as inline parameters. Fig.5 reveals partial program chart.



Fig. 5 Read and screen data of Excel file

Secondly, researchers shall determine theory and experience equation in light of literature [2]. All necessary theories and experience equations in thermal calculation are all deduced on the basis of thermal balance basic formulation. During large-scale sphere post weld thermal treatment, overall thermal amount in unit time $\sum Q$ shall be calculated by the following equation:

$$\sum Q = Q_1 + Q_2 + Q_3 + Q_4 + Q_5 + Q_6 \tag{1}$$

Where Q_1 refers to effective thermal amount in unit time when large-scale sphere shell material is heated, Q_2 refers to missing thermal amount in unit time of insulating layer during thermal treatment, Q_3 refers to missing thermal amount in unit time of insulation layer during storing thermal amount process, and Q_4 and Q_5 refer to missing thermal amount in unit time of combustor fuel during incompelete combustion, and respectively represent chemical incomplete combustion thermal losses and mechanical incomplete combustion thermal losses. Q_6 refers to missing thermal amount in unit time during smoke extraction from sphere entrance. All above values and $\sum Q$ take kJ/h as the unit.

Calling subroutine shall be utilized in the calculation of values ranging from Q_1 to Q_6 as well as B_n .

Thirdly, researchers shall complete calculation display function of front panel through display control as shown in Fig.4. Thereafter, "reporting generation" button shall be set up in front panel. Researchers can generate Excel reports through "reporting generation" function panel in program chart.

Finally, compiled programs have to be operated in upper computers in two ways. The first kind is to install LabVIEW, relevant driver and kit on target upper computers and then copy complete programs on them. The second one is to compile LabVIEW programs into independent executable programs (.exe file) on developing computers and thereby generating installation programs of executable programs and some relevant components [7]. In the second way, programs can be operated in target computers once the system is installed.

3.4 Subroutine Design.

Calling subroutine shall be utilized in the calculation of values ranging from Q_1 to Q_6 as well as B_n . Take the Q_1 calculation for example:

$$Q_{1} = \frac{m_{1}(c_{i+1}T_{i+1} - c_{i}T_{i})}{t_{m}}$$
(2)

Where m_1 refers to the mass of spherical tank, kg; T_i, T_{i+1} respectively refer to minimum and maximum temperature of *i* th range in the process of thermal treatment, $i = 1, 2, 3, \dots, C$; t_m refers to the time from minimum temperature to maximum temperature in the *i* th temperature range, *h*; c_i, c_{i+1} respectively refer to specific heat when the temperature is T_i and T_{i+1} , $kJ/(kg \cdot C)$. What should be paid attention to is that when i = 1, $T_i = t_e$. t_e refers to the ambient temperature.

Subroutine design is as shown in Fig.6, where three input ends and one output end are outlined by ligature panel on the front panel. Supposing that elected T_i and c_i exist in a form of array, then subroutine requires index array for further calculation in order to display calculation consequences in an integer. In comparison, the main program can directly adopt Q_1 to calculate subroutine.



Fig. 6 Program block diagram for Q_1 calculation

In consideration of the fact that the design method of subroutine Q_2 , Q_3 , Q_4 , Q_5 and Q_6 is similar to Q_1 and all of them utilize literature [1] as basic calculation formulation, the following sections shall not repeat such content.

4. Application Examples

Taking a $6000 m^3$ large spherical tank for example, select "6000" from "volume of spherical tank" menu in setting district, "Q370R" from "material of spherical tank" menu, and "Micro-glass fiber" from "the material of insulating layer" menu. In addition, the thickness of insulating layer has to be set up as 100mm, the thickness of the spherical shell 50mm, the ambient temperature 10 °C and wind speed 3m/s in the setting district. With the tank heat treatment parameters setting finished, run the program to get the inline parameter table and the thermal treatment process table of spherical tank as shown in figure 7.

After users selecting and inputting parameters, this design platform will calculate required thermal amount in each stage by iterative calculation during opening the "Calculate" page, as shown in Figure 8. Thereafter, required oil combustion amount under all working conditions can be calculated and calculation consequence reports can be generated. Calculation consequences are as follows:

The calculation consequence of Q_1 is $619 \times 10^4 Kcal/h$. The calculation consequence of Q_2 is $92 \times 10^4 Kcal/h$. The calculation consequence of Q_3 is $13 \times 10^4 Kcal/h$. The calculation

consequence of Q_4 is $65 \times 10^4 \text{ Kcal/h}$. The calculation consequence of Q_5 is $25 \times 10^4 \text{ Kcal/h}$. The calculation consequence of Q_6 is $301 \times 10^4 \text{ Kcal/h}$. The calculation consequence of B is 4286 kg.

Excel chart recording thermal treatment calculation consequences will automatically generate once clicking "report generation" button. Consequently, researchers can print large-scale sphere thermal calculation consequence reports if they input operator, company and table numbers in Office software or they just modify table form according to user demands.



Fig. 7 User interface of parameters setting and inline parameters display

5. Summary

In this paper, a system of simulation, which is used for thermal calculation of large spherical tank, is designed based on the heat balance calculation formula. This simulation system can get the same calculation results as the conventional thermal calculation methods do [8, 9]. No matter what capacity or material the spherical tank is, this system can calculate the total calories per unit time and total fuel consumption accurately and rapidly, which are important parameters in the process of heat treatment, with the process, thickness of the shell plate, material and thickness of the thermal insulation layer into consideration. This system possess good generality, scalability and adaptability, providing accurate theoretical reference for the automatic control in heat treatment of spherical tank.

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