

## Temperature Control of Evaporative Cooler (EC) for Converter Dry Dedusting

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### Abstract

*The converter dry dedusting is more complicated with higher requirements in automatic control than the wet dust extraction. The key difficult point is the EC temperature control. This paper puts forth a method to effectively deal with the fluctuated-dramatically temperature caused by control lagging at the EC outlet in the traditional converter dry dedusting. The EC outlet temperature can be under control of technological requirement by combining controls of proportion, empirical value, fuzziness and PID. The intelligent system is available with parameter auto tuning, which facilitates the on-site debugging greatly for operators. The result of the on-site application suggests that this method can be used to well handle some technological difficulties in the EC temperature control.*

**Keywords:** converter dry dedusting, EC temperature control, fuzzy control, PID, parameter auto tuning

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### 1. Introduction

With the boosting of China's energy-conservation and environment-protection policies in recent years, the converter dry dedusting technology is widely used in the domestic steel works [1, 2]. It has such advantages as less floor space, less water consumption, low power consumption, and low emission concentration (Less than 20 mg/nm<sup>3</sup>) as well as recycling for collected dust, compared with the wet dust extraction [3, 4]. However, the converter dry dedusting is more complicated with higher requirements in automatic control than the wet dust extraction. The key difficult point is the EC temperature control.

With an important status in converter dry dedusting, the evaporative cooler plays three roles of cooling, specific resistance regulating and rough dust extraction [5]. Smoke from converter are collected into an evaporative cooling stack by a moving gas hood at the furnace mouth, then into the evaporative cooler inlet after its temperature drops from around 1500°C to around 1000°C. After that, the smoke is evaporated by 100% instantly with a heat exchange with fine spray and gas ejected out from a bi-medium spray gun at the upper end of the EC inlet. The cooled smoke flows into an electric precipitator for further dedusting through the pipe via the EC outlet. It is required that the EC outlet temperature is not fluctuated drastically, otherwise, the wet dust is formed with the incompletely-evaporated water mixture at the EC bottom when the temperature is too low, so that the rough dust conveying device is blocked. When temperature is too high, the polar plates of the rear electric precipitator are distorted by heating, so that its service life is affected. It is very hard to control and keep the EC outlet temperature stable, because there is a longer lagging process from EC spraying quantity changing to EC outlet temperature changing. In addition, temperature and flow of smoke fluctuate greatly in the smelting process of the converter. In particular, most of steel works at home do not realize automatic steel making, where oxygen blast flow, auxiliary materials-adding time and weight, spraying height, and molten iron and scrap iron loading weight and proportion are different at each time. For this reason, the complex lagging temperature control becomes more complicated and changeable.

Currently, serial control is applied for EC temperature control in converter dry dedusting projects at home and abroad (Figure 1). The set point for primary PID controller is that of EC outlet temperature, and feedback value is the maximum one of the EC outlet thermocouple.

Primary PID controller output plus water flow is the set value of secondary PID controller, the feedback value is the flow of the bi-medium spray gun pipeline, and secondary PID controller output controls the frequency conversion of variable frequency pump. As a result, the control of EC outlet temperature is available [6-10].

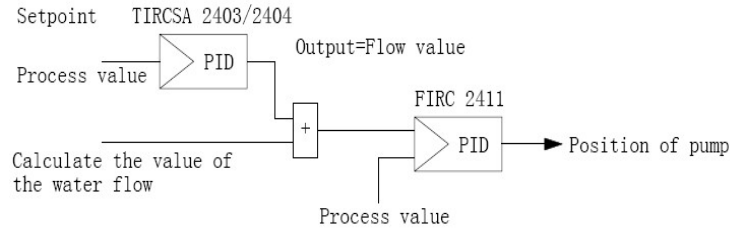


Figure 1. Serial Control Mode

In this control mode, the EC outlet temperature control lagging can be available by calculating the spraying quantity. Calculating water flow is according to EC inlet temperature, and the adjusted value is done according to EC outlet temperature and exhaust gas flow (Q) of electrostatic precipitator; injection water quantity (W) is calculated based on EC inlet temperature, and the set value of EC outlet temperature and exhaust flow (Q) through the electrostatic precipitator are calculated.

The calculation formula is as follows:

$$W [\text{kg} / \text{h}] = \frac{Q_{dry} [\text{Nm} / \text{h}] \times \Delta T [\text{K}] \times c_p [\text{kJ} / \text{Km}]}{\text{const} . [\text{kJ} / \text{kg}]} \quad (1)$$

$$Q_{n,wet} [\text{Nm} (\text{wet}) / \text{h}] = \text{FIRQCSA } 2505 \times \frac{273,15^\circ \text{K}}{\text{TIR } 2506 + 273,15^\circ \text{K}} \times \frac{\text{PIR } 2504 + \text{PIRCSA } 2503}{1013,25 \text{ mbar}} \quad (2)$$

Where, *PIRCSA* 2503 : EP outlet pressure;

*FIRQCSA* 2505 : EP outlet temperature.

Exhaust gas flow through electrostatic precipitator is:

$$Q_{n,dry} [\text{Nm} (\text{dry}) / \text{h}] = Q_{n,wet} - \frac{\text{FIRC } 2411 + \text{FIRSA } 2420}{0,804} \quad (3)$$

Where, *FIRC*2411 : Injection water flow;

*FIRSA*2420 : Injection steam flow;

$\Delta T[\text{K}] = (\text{Higher EC inlet temperature value}) - (\text{EC outlet temperature setvalue})$

The corresponding  $c_p$  value for the calculated  $\Delta T[\text{K}]$  based on corresponding temperature difference is:

$$c_p [\text{kJ} / (\text{Nm}^3 (\text{dry}) \cdot \text{K})] = f_{\text{interpolation}} (\Delta T) \quad (4)$$

Where,  $\Delta T \leq 200$   $c_p = 1,433$

$\Delta T \leq 400$   $c_p = 1,476$

$\Delta T \leq 600$   $c_p = 1,512$

$\Delta T \leq 800$   $c_p = 1,545$

There are the following problems if the mode is applied:

a. The thermocouple installed at the EC inlet has a short service life only at less than three months as the EC inlet temperature changes drastically (200-1000 degrees) and dust concentration is greater (120-150g/nm<sup>3</sup>). However, the EC inlet temperature is very important for calculation.

- b. The lagging smoke quantity is calculated by the flow of the electric precipitator outlet. Generally, an electric precipitator is more than 30 meter long; so lag time for the electric precipitator is 30 seconds by the design wind speed at less than 1m/s at electric field.
- c. PID parameter setting for serial control system is very cumbersome.
- d. This serial control system only adopts one set of PID parameters, while smoke temperature and flow change greatly during smelting for the converter. As a result, it is hard to control temperature rising of the EC in the early stage of smelting. In the smelting process, it is difficult to adjust quickly and properly as smoke changes drastically. As a result, EC outlet temperature changes greatly.

**2. New Method for EC Temperature Control**

Aiming at the foregoing problems about the serial control in the EC outlet temperature control by the converter dry dedusting, we put forth a new method in this paper. The method is to apply controls of proportion, empirical value, fussiness and PID respectively as well as introducing adaptive functions in proportion and empirical value aiming at different smelting stages for the converter and deviation of EC outlet temperature. Taking an example of a 110-ton converter dry dedusting, the actual application for the new algorithm is described by Siemens S7-300PLC, and the EC outlet set value is 200 degrees with a smelting time of 15 minutes or so.

**2.1. Application of Proportion Control**

The proportion control is applied due to quicker temperature rising in the early stage of the converter smelting. The quick EC outlet temperature rising can be effectively controlled by the proportion control to track change rate of deviation quickly. The proportion control starts 2 minutes ahead of the converter oxygen blast at each time. Because the converter oxygen blast exceeds two minutes, the rate of change for EC outlet temperature will vary slowly with gradual increase of injection water quantity under the proportion control.

The output value for EC frequency conversion pump is:  $U_t = U_{t-1} + \Delta U$ , i.e. the last output value plus change value at this time. The change value at this time is:  $\Delta U = K_p (E_t - E_{t-1})$ , i.e. factor of proportionality times rate of change of deviation.

- Where,  $K_p$ : Factor of proportionality;
- $(E_t - E_{t-1})$ : Rate of change of deviation;
- $U_t$ : Output value

The main applied procedure is as follows:

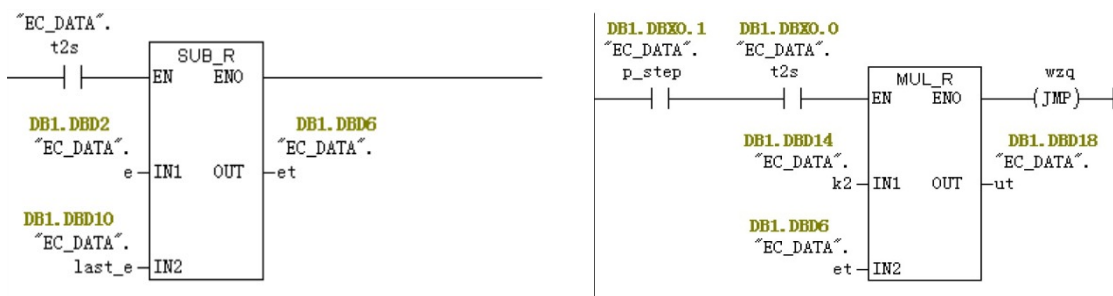


Figure 2. Main Procedure for Proportion Control

(t2s stands for 2-second pulse signal, e is the current temperature deviation, last\_e is the last temperature deviation, k2 is factor of proportionality, et is the rate of change of temperature deviation, and ut is the change value of control output, i.e. ΔU)

There is a certain temperature deviation at the EC outlet when the system completes proportion control. By the time, the deviation is recorded by procedure; if the deviation exceeds ±10°C, the value of the deviation times correction factor is used to correct the proportion factor,

that is to say, increasing proportion factor if the deviation is greater than 10°C; and reducing proportion factor if the deviation is less than 10°C. By this way, the proportion control ahead of two minutes of smelting is adaptive to a certain extent. The excessively high EC outlet temperature can be effectively controlled with the rising-drastically temperature in the early stage of converter smelting by using the procedure to correct proportion factor automatically.

## 2.2. Application of Empirical Value Control

The system completes the proportion control when the converter smelting exceeds two minutes. Based on current deviation, the system selects PID control if the deviation falls within  $\pm 20^\circ\text{C}$ , while the system selects fuzzy control if the deviation is out of  $\pm 20^\circ\text{C}$ . By this, the EC outlet temperature generally still keeps rising for a while, and the spraying water quantity becomes more. The EC outlet temperature is lagging to some extent. If the PID control is adopted at a current deviation of  $\pm 20^\circ\text{C}$ , the control parameters (Proportion factor and integral factor) are smaller with weak adjustment as the PID control goes by a fine adjustment. When EC outlet temperature falls back greatly, the system can't quickly adjust to reduce spraying quantity, so that the EC outlet temperature goes down drastically and is lower than temperature set value to great extent.

In light of above situations, the system should output an empirical value directly over 30 seconds when EC outlet temperature is in the peak value falling in order to avoid the system being oscillated significantly caused by time lag.

The given empirical output value is the one that the system outputs when the EC outlet temperature is stable (Before gas is recycled, the EC outlet temperature deviation lasts 20 seconds within  $\pm 5^\circ\text{C}$ ) in the previous smelting process.

Through intervention of empirical output value, the spraying water quantity can fall to a proper value quickly after quick temperature rising in the early stage of the converter smelting, so as to avoid excessive EC water spraying effectively. In addition, the control curve becomes gentle, which makes for shortening adjusting time.

## 2.3. Application for Combination of Fuzzy and PID Controls

There are more influencing factors for smoke from converter steelmaking, such uncertain factors as parameter time varying, non-linear controlled object and coupling. And it is hard to describe them by an accurate mathematical model. Moreover, different smoke working conditions are caused by the smelting situations for every furnace in converter steelmaking due to different charging and oxygen blast situations, so that the EC inlet temperature changes differently, and is hard to control.

The fuzzy controller can be used to simply and effectively control the complicated and unclear-model system, but the simple and fuzzy controller is hard to eliminate the steady state error completely without integration element. In not many variable classifications, the fuzzy controller is oscillated a little near the balance point.

In this system, PID and fuzzy controls can be combined as one control mode with both advantages. Based on deviation of the EC outlet temperature, the system can select PID control if the deviation falls within  $\pm 20^\circ\text{C}$ , while the system can select fuzzy control if the deviation is out of  $\pm 20^\circ\text{C}$ .

### a. Design of fuzzy controller

It is designed as a two-input and single-output structural mode, i.e. the fuzzy controller reads two input variables: temperature deviation and its rate of change, then solves the fustiness as an analogue value (Control variable output) after the calculation of fuzzy rules.

In order to realize the fuzzy controller, input variables should be fuzzified first, then, fuzzy decision can be made for output value by application of fuzzy relation matrix.

With fuzzification of temperature deviation, the temperature deviation which is less than  $-40^\circ\text{C}$  is considered as minus large deviation (nb1); the temperature deviation which is in between  $-40\sim-30^\circ\text{C}$  is considered as minus mid deviation (nm1); the temperature deviation which is in between  $-30\sim-20^\circ\text{C}$  is considered as minus small deviation (ns1); the temperature deviation which is in between  $20\sim30^\circ\text{C}$  is considered as positive small deviation (ps1); the temperature deviation which is in between  $30\sim40^\circ\text{C}$  is considered as positive mid deviation (pm1); the temperature deviation which is greater than  $40^\circ\text{C}$  is considered as positive large deviation (pb1).

With fuzzification of temperature deviation change rate, the temperature deviation change rate which is less than  $-1.5^\circ\text{C}$  per second is considered as minus large change (nb2);

the temperature deviation change rate which is in between -1.5~1.0°C per second is considered as minus mid change (nm2); the temperature deviation change rate which is in between -1.0~0.0°C is considered as minus small change (ns2); the temperature deviation change rate which is 0.0°C is considered as zero change (zo2); the temperature deviation change rate which is in between 0.0~1.0°C is considered as positive small change (ps2); the temperature deviation change rate which is in between 1.0~1.5°C is considered as positive mid change rate (pm2); the temperature deviation change rate which is larger than 1.5°C per second is considered as positive large change rate (pb2).

By combining the EC outlet temperature deviation and change rate in converter smelting, the matrix integrated with two input condition fuzzy variables is realized by the procedure to form control policy, so that output changes for the fuzzy controller are grouped into seven values(-6, -4, -2, 0, 2, 4, 6). The main procedures are as follows:

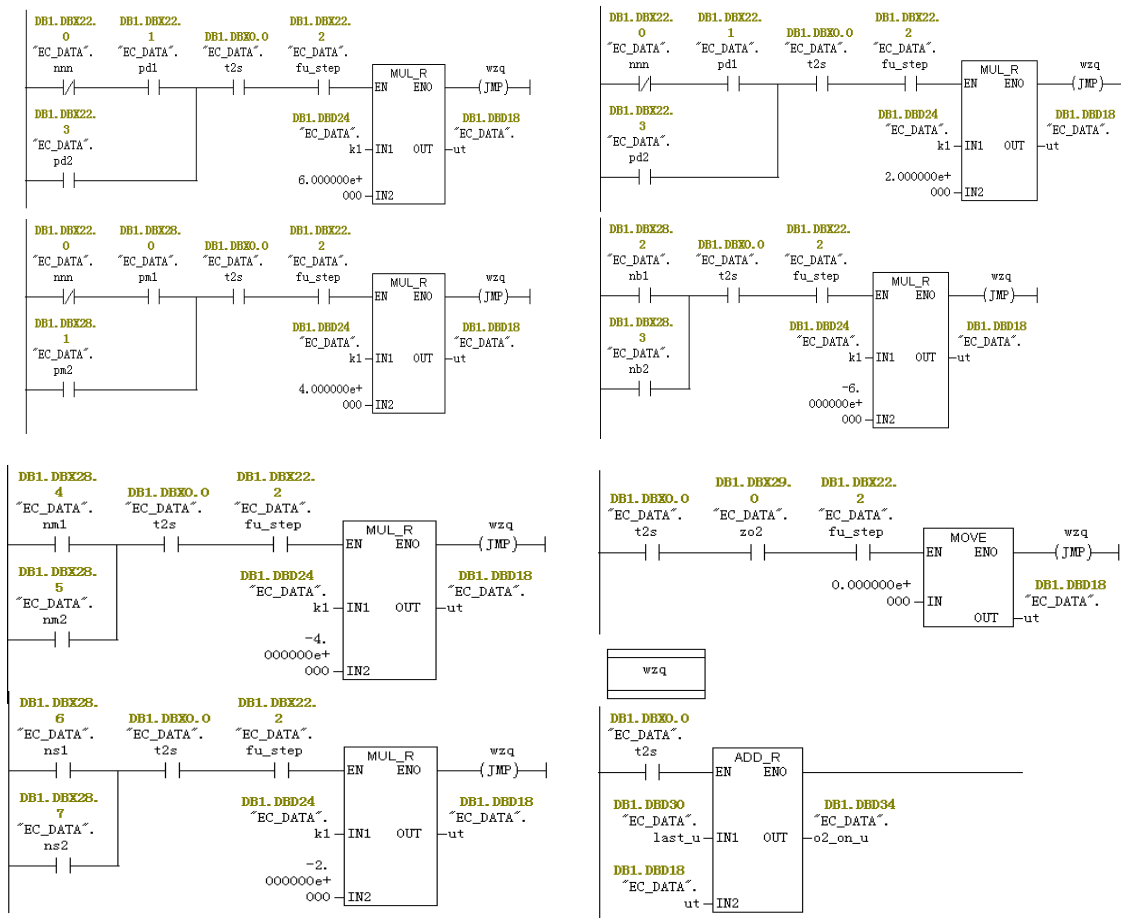


Figure 3. Procedure of Fuzzy Controller

(last\_u is the last controller output value, ut is the change value of controller output at this time, and o2\_on\_u is output of controller.)

It is known from above procedures that the change value of fuzzy controller output can be adjusted by adjusting factor K1, to control the adjusting strength of fuzzy controller.

b. Design of PID controller

After previous proportion control, empirical value control and fuzzy control, it is indicated that temperature is in stable state if EC outlet temperature deviation is within ±20°C. The EC outlet temperature is adjusted finely through PID controller, and its output formula is as follows:

$U_t = U_{t-1} + \Delta U$ ,  $\Delta U = K_p[(E_t - E_{t-1}) + K_i E_t]$ , and the procedure realization is similar to the proportion control procedure.

In order to avoid the oscillation of the system because of the EC outlet temperature lagging, the PID controller's output value should not be adjusted too large. It is suggested according to actual experience that the proportion factor should be 0.02 or so, integration factor be around 0.002, and sampling period be 2 second.

### 3. Actual Effect of the System

With actual application of three sets converter dry dedusting system made by Jiujiang Wire Co., Ltd. it is believed the evaporative cooler operates best in this control mode. The curve for the EC outlet temperature in the smelting process is as follows:

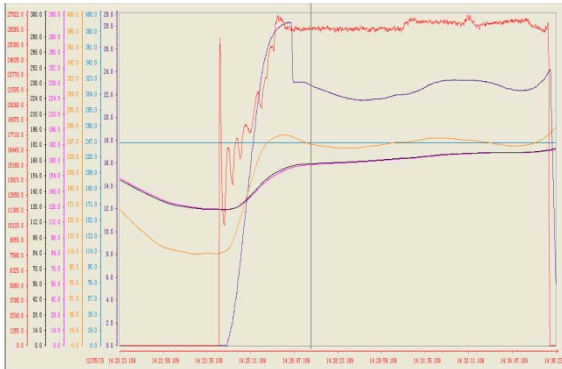


Figure 4. EC Outlet Temperature Variation Curve 1

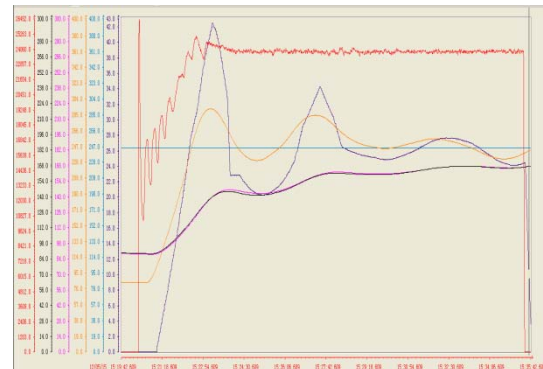


Figure 5. EC Outlet Temperature Variation Curve 2

(Orange line is EC outlet temperature, transverse line is EC outlet set value, red line is the converter oxygen blast quantity, and blue line is output value of spraying water quantity under the control mode.)

It is known from Figure 4 that when the converter starts oxygen blast, the EC outlet temperature goes up quickly. The spraying water quantity becomes large accordingly under the control, till temperature changes gently.

When the EC outlet temperature starts falling from the peak, the system gives a 30-second empirical value to interfere (See a small piece of transverse line of output curve of spraying water quantity). Through empirical value control, the EC outlet temperature is further stable.

For the time being, temperature deviation fall in adjustable range of the PID controller, and the temperature is always in stable state through fine adjustment of PID controller.

In the smelting process, the temperature is adjusted by fuzzy controller once it exceeds the adjustable range of PID controller with its drastic changes. As the fuzzy controller's adjustment changes with temperature difference and change rate, the temperature deviated from the set value is adjusted back quickly as shown in Figure 5.

### 4. Conclusion

In the control with dominant time delay process and more secondary disturbance quantity, it is hard to reach the good control effect by one control mode and one set of control parameters. Aiming at different smelting stages and the EC outlet temperature deviation of the converter in this paper, the EC outlet temperature is controlled within the range of technological requirements by combining controls of proportion, empirical value, fuzziness and PID, where, parameter auto tuning can make the system intelligent. With actual application, the EC operates well in the control mode, so that the EC temperature control is available.

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