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Research Article

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Development of Mathematical Model to Predict a Cascade Control of temperature in a boiler

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Abstract Boilers are an integral part of process plants as they are used to produce steam of different grades (Low pressure, medium pressure and high pressure steam) which are used for a variety of heating purposes or for reactions such as steam reforming. However, to obtain steam of these grades, the use of cascade controller: where the output variable (temperature) adopting a slave master approach. In this work, we have been able to derive a mathematical model to predict the effect of a cascade controller on the process variable (temperature of a boiler system). The result obtained from the model simulation showed that such controller proved useful in regulating and stabilizing the output temperature of the steam as against the fluctuated output temperature (when there was no cascade controller) installed on the system.

Keywords Development, mathematical model, Predict, cascade control, temperature, boiler

Introduction

A heat exchanger is a piece of equipment built for efficient heat transfer from one medium to another. A solid wall may separate the media, so that they never mix, or they may be in direct contact. They are widely used in space heating, refrigeration, air conditioning, power plants, chemical plants, petrochemical plants, petroleum refineries, natural gas processing, and sewage treatment [1].

A steam boiler is a closed vessel, generally made of steel, in which water is heated by some source of heat produced by combustion of fuel and ultimately to generate steam. The steam produced may be supplied at low pressure for industrial process work in cotton mills, sugar industries etc. and for producing hot water which can be used for heating installations at much low pressure [2]. Steam is the gas formed when water passes from the liquid to the gaseous state. At the molecular level, this is when H_2O molecules manage to break free from the bonds (i.e. hydrogen bonds) keeping them together. In liquid water, H_2O molecules are constantly being joined together and separated. As the water molecules are heated, however, the bonds connecting the molecules start breaking more rapidly than they can form. Eventually, when enough heat is supplied, some molecules will break free. These 'free' molecules form the transparent gas we know as steam, or more specifically dry steam [3]. Steam is used in a wide range of industries. Common applications for steam are, for example, steam heated processes in plants and factories and steam driven turbines in electric power plants, but the uses of steam in industry extend far beyond this [4].

Classification of Boiler

Boilers can be classified in a number of ways, but the following are important from the subject point of view: Horizontal, vertical and inclined boilers, stationary, portable and marine boilers , water tube and fire tube boilers, single tube and multi tube boilers, internally fired and externally fired boilers. naturally circulated and forced circulated boilers, source of heat (solid fuel, liquid and gaseous fuel, electrical and nuclear energy) and low pressure, medium pressure and high pressure boilers

Composition and Working Principle of Boiler

A boiler is a heat exchanger that converts chemical energy released from the combustion of fuel (solid fuel, liquid fuel, and gaseous fuel) into heat energy and outputs hot water or steam. Boiler mainly by the 'pot' and 'furnace' composed of two parts. 'Pot' refers to the soft water flow system, which consists of water supply system (economizer, water wall), drum, super-heater, and re-heater composition. Water supply system 'furnace' refers to the combustion system and the main equipment is the furnace.

Figure 1: Boiler System [5]

First, the water after oxygen from the feed pump into the water supply control valve, through the water supply control valve into the economizer, cold water through the economizer in the process by the furnace discharge of the flue gas preheated into warm water into the drum, the steam is heated to boil to produce steam, in order to ensure the largest evaporation surface, so the water level to keep the boiler in the midline of the drum, the steam through the main steam valve output. The air enters the air pre-heater through the blower and is preheated by the flue gas discharged from the furnace during the passage of the air pre-heater into hot air into the furnace. Baotou thermal power plant combustion material is gas, with the same air into the furnace and air completely mixed combustion. In the process of burning heat generated in the heating drum water, while generating hot flue gas. Under the suction of the draft fan through the provincial gas and air pre-heater, the preheating conduction to the boiler into the water and air. In this way the heat of the boiler is saved [6]. After the cooling of the flue gas through the dust collector, in addition to sulphur and a series of purification process through the chimney discharge. In addition, the resulting water vapour through the super-heater and re-heater into the steam turbine, to promote the blade rotation work, driving the generator power generation.

Boiler Control System Overview

Boiler equipment is a complex control object, the main input variables are load, and boiler feed water, fuel volume, less water, air supply, and air volume. The main output variables include drum water level, superheated steam temperature and pressure. Therefore, the boiler is a multi-input, multi-output and interrelated complex control object.

Boiler control system, generally have steam pressure, drum level, furnace negative pressure, oxygen in addition to water level, pressure, steam temperature and combustion control system. Boiler combustion is essentially an energy balance system, which uses steam pressure as an indicator of energy balance, and constantly adjusts the amount of fuel in the air volume according to the change in steam pressure, while ensuring the full combustion of fuel and the full utilization of heat.

Cascade Control

Cascade control is one of the most successful methods for enhancing single-loop control performance. It can dramatically improve the performance of control strategies, reducing both the maximum deviation and the integral error for disturbance responses. Since the calculations required are simple, cascade control can be implemented with a wide variety of analog and digital equipment. This combination of ease of implementation and potentially large control performance improvement has led to the widespread application of cascade control for many decades [7].

Cascade uses an additional measurement of a process variable to assist in the control system. The selection of this extra measurement, which is based on information about the most common disturbances and about the process dynamic responses, is critical to the success of the cascade controller. Therefore, insight into the process operation and dynamics is essential for proper cascade control design. Cascade control design considers the likely disturbances and tailors the control system to the disturbance(s) that strongly degrades performance. Cascade control uses an additional, "secondary" measured process input variable that has the important characteristic that it indicates the occurrence of the key disturbance [8].

The important feature in the cascade structure is the way in which the controllers are connected. The output of the exit temperature controller adjusts the set point of the flow controller in the cascade structure; that is, the secondary controller set point is equal to the primary controller output. Thus, the secondary flow control loop is essentially the manipulated variable for the primary temperature controller. The net feedback effect is the same for single-loop or cascade control; in either case, the heating oil valve is adjusted ultimately by the feedback [9]. Therefore, the ability to control the exit temperature has not been changed with cascade.

Materials and Methods

Design of Boiler Control System

Combustion Control System

The combustion process mainly adjusts the following three physical quantities: fuel regulation, air volume adjustment and air volume adjustment.

Fuel control system according to the operation of different units, the control of the task is also different. When the unit is operated in accordance with the control mode or the coordinated control mode based on this, the fuel control system is tasked with ensuring that the air pressure is stable according to the boiler command BD, which is the secondary circuit system of the unit pressure cascade control system. When the unit is operated by the turbine following the control mode or the coordinated control mode based on this, the fuel control task is to ensure the unit load according to the boiler instruction BD, which is a secondary circuit system of the unit power cascade control system.

The task of the air supply control system is to make the air supply volume V change in the quantity of fuel M, the system can use a single closed loop ratio control system or a feed forward - cascade control system. Single closed-loop control system is based on the measured amount of fuel as the air flow regulator set the value of the air supply as a feedback signal into the air flow regulator.

Steam Temperature Control System

The temperature of the superheated steam is an important parameter in the boiler production process and is generally determined by the process of boiler and steam turbine production. From the safety production and economic and technical indicators, it is necessary to control the overheated steam temperature within the allowable range and protect the super-heater so that the wall temperature does not exceed the allowable working temperature to ensure the safety and economy of the unit operation [9].

When the temperature of the super-heater is controlled by sprinkler temperature control, the single-loop control system cannot be well controlled because of the large delay and inertia of the object control channel and the smaller steam temperature control deviation in the operation.
In order to ensure the safety of the re-heater, the steam turbine and other thermal equipment, to improve the operational efficiency and economy of the unit, the outlet temperature of the re-heater is controlled. The control task is in a variety of operating conditions, so that the re-heater outlet steam temperature is within the allowable range, steady state is equal to the set value.
There are three main control schemes for reheat steam temperature: a reheat steam temperature control system for flue gas barrier adjustment, a reheat steam temperature control system for flue gas recirculation, a reheat steam for swinging the burner temperature control system.

Drum Level Control System

Drum water level is also one of the important parameters to control the operation of the boiler. Drum water level is too high, will cause the steam with water or full of water, so that deterioration of steam quality, pipe overheating or pipe, steam turbine water impact; water level is too low, will destroy the water cycle, or even burn water wall. The main factors affecting the change of water level are boiler load, drum pressure change speed, combustion conditions and water pressure disturbance.
The task of water level regulation is to adapt the feed water to the boiler's evaporation in order to maintain the drum water level within the allowable range [9]. The easiest way is to adjust the feed pump speed or feed valve opening according to the deviation of the drum level. In the automatic control is the use of the single impulse automatic regulator. The main problem with single impulse adjustment is that when the boiler and negative pressure change, the automatic control system cannot identify the resulting false water level phenomenon.
Thereby causing the adjustment means to operate in the wrong direction. The single impulse adjustment function is used for small capacity boilers with relatively large water volumes and relatively
stable loads. If the water level signal, plus a steam flow signal, then become a double impulse water supply system. When the boiler load changes, the steam flow signal than the water level signal in advance to reflect the false water level is not correct command. However, its drawback is that it cannot reflect and correct the disturbance of water supply in time (such as the increase or decrease of water supply due to changes in feed water pressure). So the double impulse system can be used for heavy load changes and large capacity of the boiler.
The most complete water level adjustment system is a three impulse system. In this system has increased the water supply signal.
Adjust the water supply. Taking into account the evaporation of the amount of water supply in the same principle and the size of the water level deviation, both to compensate for the reflection of false water level, but also to correct the water supply disturbance. In the control of the water level at the same time, pay close attention to the water flow in the steam flow difference.

Steam Temperature Control Design

Analysis of steam temperature control and Superheated steam temperature system overview

Superheated steam temperatures object characteristics:
a. Steam temperature (load) disturbance under the steam temperature characteristics
Static characteristics: According to the heating surface of the heat classification, this is divided into convection super-heater, radial super-heater and semi-radiation super-heater three. Figure 1 shows the effect of steam flow on the steam temperature characteristics of different super-heaters. The steam flow is a disturbance to the superheated steam temperature, so the static characteristic here is the static coefficient of the disturbance channel.
Dynamic characteristics: In the case of convection superheater, for example, when the boiler load is disturbed, the steam flow changes so that the steam velocity at the point above the length of the super-heater is almost simultaneously changed, changing the convective heat transfer coefficient of the super-heater, the steam temperature of the point changes almost simultaneously, so the steam temperature reacts faster.

b. Steam temperature characteristics under flue gas heat disturbance

Flue gas heat disturbance, because the flow rate and temperature changes are also along the entire super-heater at the same time change, and thus along the entire length of the super-heater so that the heat transfer heat also changes, so the steam temperature reaction faster, the time constant is less than 100s, delay time About 10 to 20s, the dynamic characteristics of the form of the same formula.

3. Temperature characteristics of superheated steam under reduced water disturbance:

Changing the amount of reduced water to change the inlet steam temperature of the super-heater, thus affecting the super-heater outlet steam temperature. The dynamic characteristics of the steam outlet temperature of the super-heater are related to the position of the desuperheater, the farther the desuperheater is from the outlet of the super-heater, or the overheat pipe is too long, and the delay in the steam outlet temperature of the super-heater is also increased.

Development of Process Model for the Boiler

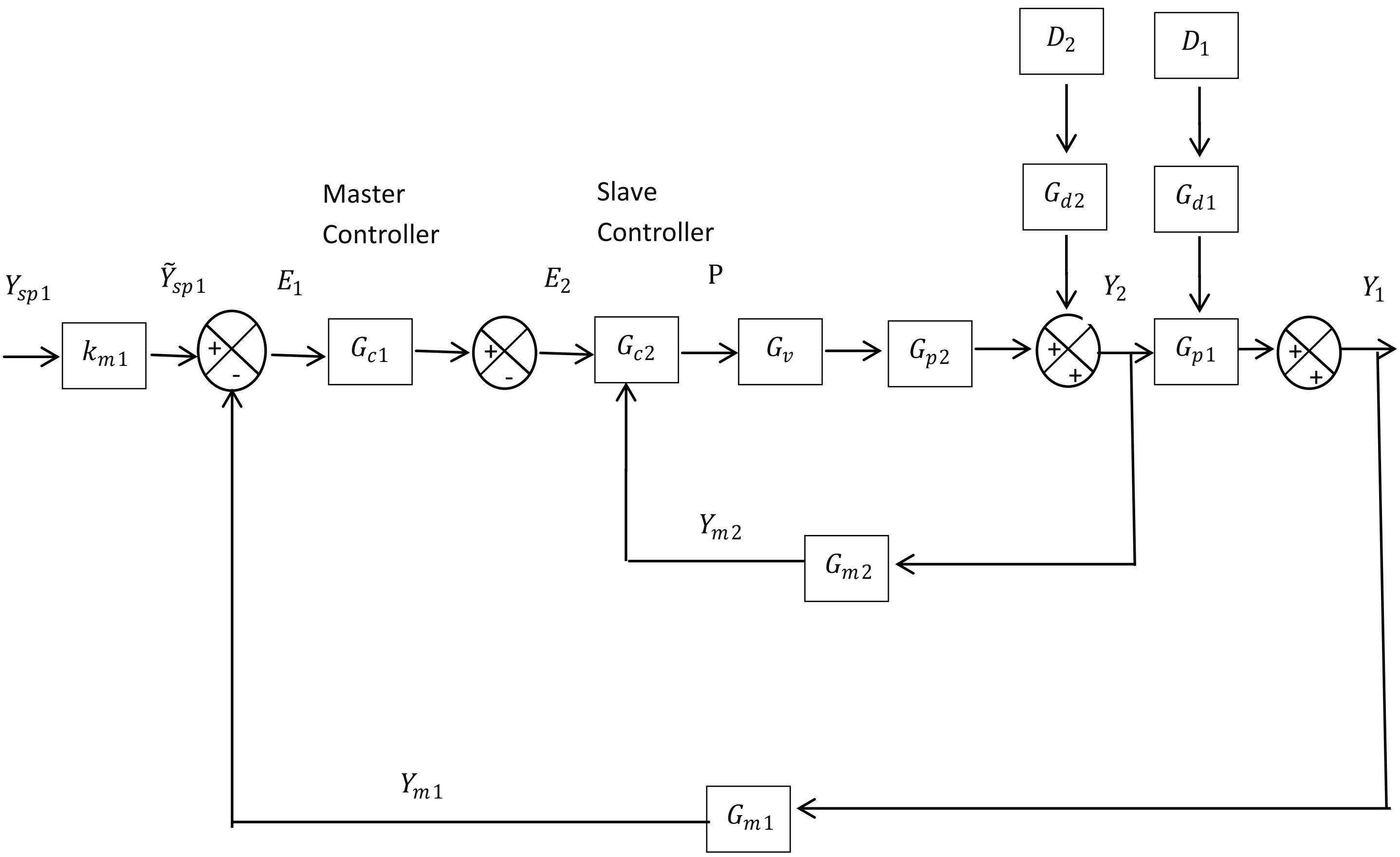

Figure 2: Block Diagram of Cascade Control System

In Figure 2: Disturbances in D_2 are compensated by feedback in the inner loop; the corresponding closed loop transfer function (assuming $T_{sp1} = D_1 = 0$) is obtained by block diagram algebra:

$$T_1 = G_{p1}T_2$$

$$T_2 = G_{d2}D_2 + G_{p2}G_vG_{c2}E_2$$

$$E_2 = T_{sp2} - T_{m2} = G_{c1}E_1 - G_{m2}T_2$$

$$E_t = -G_{m1}T_1$$

Eliminating all variables except T_1 and D_2 gives

$$\frac{T_1}{D_2} = \frac{G_{p1}G_{d2}}{1 + G_{c2}G_vG_{p2}G_{m2} + G_{c1}G_{c2}G_vG_{p2}G_{p1}G_{m1}}$$

Similarly, the set point transfer functions for the outer and inner loops are

$$\frac{T_1}{T_{sp1}} = \frac{G_{c1}G_{c2}G_vG_{p1}G_{p2}k_{m1}}{1 + G_{c2}G_vG_{p2}G_{m2} + G_{c1}G_{c2}G_vG_{p1}G_{p2}G_{m1}}$$

$$\frac{T_2}{\widetilde{T_{sp2}}} = \frac{G_{c2}G_vG_{p2}}{1 + G_{c2}G_vG_{p2}G_{m2}}$$

For disturbance in D_1, the closed loop transfer function is

$$\frac{T_1}{D_1} = \frac{G_{d1}(1 + G_{c2}G_vG_{p2}G_{m2})}{1 + G_{c2}G_vG_{p2}G_{m2} + G_{c1}G_{c2}G_vG_{p2}G_{p1}G_{m1}}$$

The Cascade Control System has the characteristic equation:

$$1 + G_{c2}G_vG_{p2}G_{m2} + G_{c1}G_{c2}G_vG_{p2}G_{p1}G_{m1} = 0$$

Cascade Control of Boiler Temperature

From the principle of Conservation of Energy: Development of Boiler Model

$\{Rate of energy accumulation\} =$
$\{Rate of energy in by convection\} - \{Rate of energy out by convection\} +$
$\{Net Rate of heat addition to the system from the surrounding\} +$
$\{Net rate of work performed on the system by the surrounding$ (1)

Mathematically,

$Ah\frac{dT}{dt} = F_i(T_i - T) + \frac{Q}{\rho C_p}$ (2)

But $Q = UA(T_{st} - T)$ (3)

Putting 1.3 into 1.2

$Ah\frac{dT}{dt} = F_i(T_i - T) + \frac{UA}{\rho C_p}(T_{st} - T)$ (4)

$Ah\frac{dT}{dt} = F_iT_i - F_iT + \frac{UAT_{st}}{\rho C_p} - \frac{UAT}{\rho C_p}$ (5)

$Ah\frac{dT}{dt} = F_iT_i + \frac{UAT_{st}}{\rho C_p} - \left(F_i + \frac{UA}{\rho C_p}\right)T$ (6)

Rearranging equation (6), we have

$Ah\frac{dT}{dt} + \left(F_i + \frac{UA}{\rho C_p}\right)T = F_iT_i + \frac{UA}{\rho C_p}T_{st}$ (7)

But Ah = V

$V\frac{dT}{dt} + \left(F_i + \frac{UA}{\rho C_p}\right)T = F_iT_i + \frac{UA}{\rho C_p}T_{st}$ (8)

$\frac{dT}{dt} + \left(\frac{F_i}{V} + \frac{UA}{V\rho C_p}\right)T = \frac{F_iT_i}{V} + \frac{UA}{\rho C_p}T_{st}$ (9)

Let $k = \frac{UA}{V\rho C_p}$; $\frac{1}{\tau} = \frac{F_i}{V}$

$\frac{dT}{dt} + \left(\frac{1}{\tau} + k\right)T = \frac{1}{\tau}T_i + kT_{st}$ (10)

Let $a = \left(\frac{1}{\tau} + k\right)$

$\frac{dT}{dt} + aT = \frac{1}{\tau}T_i + kT_{st}$ (11)

Equation (1)1 is the mathematical model of a boiler with 't' as state variable.

Writing equation (11) in terms of derivation variables

At steady state, equation (11) becomes:

$$\frac{dT}{dt} = \frac{dT_s}{dt} = 0$$

$$T = T_s, T_i = T_{is}, T_{st} = T_{st,s}$$

Equation (11) becomes:

$\frac{d}{dt} + aT_s = \frac{1}{\tau}T_i + kT_{st,s}$ (12)

Subtract (12) from (11), we have

$\frac{d}{dt}(T - T_s) + a(T - T_s) = \frac{1}{\tau}(T_i - T_{is}) + k(T_{st} - T_{st,s})$ (13)

Let $T' = T - T_s$; $T_i' = T_i - T_{is}$; $T_{st}' = T_{st} - T_{st,s}$

Equation (13) becomes:

$\frac{dT'}{dt} + aT' = \frac{1}{\tau}T_i' + kT_{st}'$ (14)

Where T', T_i, T_{st} are deviation variables

Solving equation (14) using Laplace Transform method:

$\left[\frac{dT'}{dt}\right] + a[T'] = \frac{1}{\tau}[T_i] + k[T_{st}']$ (15)

$s\bar{T}'_{(s)} - T'_{(0)} + a\bar{T}'_{(s)} = \frac{1}{\tau}\bar{T}'_{i(s)} + k\bar{T}'_{st,(s)}$ (16)

where, $T'_{(0)} = 0$

$S\bar{T}'_{(s)} + a\bar{T}'_{(s)} = \frac{1}{\tau}\bar{T}'_i + k\bar{T}'_{st,(s)}$ (17)

$(sta)\bar{T}'_{(s)} = \frac{1}{\tau}\bar{T}'_{i(s)} + kT'_{st(s)}$

$\bar{T}'_{(s)} = \frac{1}{(sta)\tau}\bar{T}'_{i(s)} + \frac{k}{(sta)}\bar{T}'_{st(s)}$ (18)

$\bar{T}'_{(s)} = \left(\frac{1/\tau}{sta}\right)\bar{T}'_{i(s)} + \left(\frac{k}{sta}\right)\bar{T}_{st(s)}$ (19)

Transforming equation (19) into the time domain by taking the inverse Laplace Transform we obtain:

$T'_{(t)} = \frac{1}{\tau}e^{-at}T'_i + ke^{-at}T'_{st}$ (20)

$T'_{(t)} = e^{-at}\left(\frac{1}{\tau}T'_i + kT'_{st}\right)$ (21)

Equation (21) represents the temperature of a Boiler without a controller.

Equation (21) is the dynamic temperature variation of a Boiler system without a controller.

Considering a General Closed Loop System

Use $y_{sp} = T_{sp}, y_m = T_m, y_{(t)} = T_{(t)}$

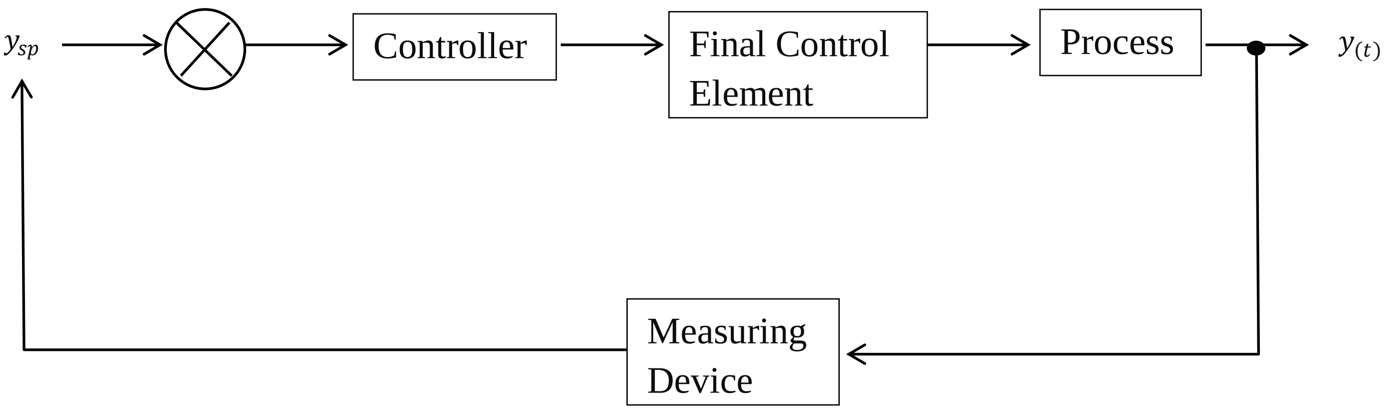

Figure 3: General Closed Loop System

There are four (4) components in the block diagram;

The Process, measuring device, controller and final control element, the corresponding transfer function relating its output to the input can be written as follows:

1) For the Process

$y_{(s)} = G_{P(s)}M_{(s)} + G_{d(s)}d_{(s)}$ (22)

2) For the Measuring device

$y_{m(s)} = G_{m(s)}y_{(s)}$ (23)

3) Controller Mechanism

$C_{(s)} = G_{c(s)}E_{(s)}$ (24)

$E_{(s)} = y_{sp(s)} - y_{m(s)}$ (25)

4) Final Control Element

$M_{(s)} = G_{f(s)} C_{(s)}$ (26)

where G_p, G_d, G_m, G_c, G_f are transfer function (ratio of output to input) of the process, disturbance, measuring device, controller and final control element.

Substituting (25) into (24), we have

$C_{(s)} = G_{c(s)}(y_{sp(s)} - y_{m(s)})$ (27)

Substituting (27) into (26), we have

$M_{(s)} = G_{f(s)} G_{c(s)} \left(y_{sp(s)} - y_{m(s)}\right)$ (28)

Putting (23) into (28), we have

$M_{(s)} = G_{f(s)} G_{c(s)} (y_{sp(s)} - G_{m(s)} y_{(s)})$ (29)

Substituting (29) into (22), we have

$y_{(s)} = G_{p(s)} G_{f(s)} G_{c(s)} \left(y_{sp(s)} - G_{m(s)} y_{(s)}\right) + G_{d(s)} d_{(s)}$ (30)

Expanding and Simplifying equation (30) and let $y_{(s)} = T_{(s)}$

$T_{(s)} = \frac{G_{p(s)} G_{f(s)} G_{c(s)}}{1+G_{p(s)} G_{f(s)} G_{c(s)} G_{m(s)}} T_{sp(s)} + \frac{G_{d(s)}}{1+G_{p(s)} G_{f(s)} G_{c(s)} G_{m(s)}} d_{(s)}$ (31)

Equation (31) gives the close loop response of Temperature Control of a Boiler System.

The corresponding transfer functions are given as:

1) Transfer function for the set print $T_{sp(s)}$

$G_{sp} = \frac{G_{p(s)} G_{f(s)} G_{c(s)}}{1+G_{p(s)} G_{f(s)} G_{c(s)} G_{m(s)}}$ (32)

2) Transfer function for the load

$G_{Load} = \frac{G_{d(s)}}{1+G_{p(s)} G_{f(s)} G_{c(s)} G_{m(s)}}$ (33)

Let $G = G_{sp(s)} G_{f(s)} G_{(cs)}$ (34)

$G_{sp} = \frac{G}{1+G G_{m(s)}}$ (35)

$G_{Load} = \frac{G_{d(s)}}{1+G G_{m(s)}}$ (36)

Applying the above principle on our Boiler system:

From the general transfer function equation

$T_{(s)} = G_{(s)} F_{(s)}$ (37)

From equation (19), writing in terms of transfer function

$\bar{T}'_{(s)} = G_{1(s)} \bar{T}_{i(s)} + G_{2(s)} \bar{T}_{st,(s)}$ (38)

where $G_{1(s)} = \frac{1/\tau}{sta}$; $G_{2(s)} = \frac{k}{sta}$

$G_{d(s)} = \left(\frac{1/\tau}{sta}\right)$; $G_{p(s)} = \left(\frac{k}{sta}\right)$ (39)

Transfer function for the controller: Using a proportional controller

$G_{c(s)} = k_{c(s)}$ (40)

Transfer function of measuring device is given as:

$G_{m(s)} = \frac{kpa}{\tau^2 s^2 - 23\tau + 1}$ (41)

Similarly, Transfer function of final control element

$G_{f(s)} = \frac{kv}{\tau s + 1}$ (42)

Substituting equation (39), (40), (41) and (42) into equation (31), we have

$T_{(s)} = \frac{(k/sta)\left(\frac{kv}{\tau s+1}\right)(k_{c(s)})}{1+(k/sta)\left(\frac{kv}{\tau s+1}\right)(k_{c(s)})\left(\frac{kpa}{\tau^2 s^2 - 23\tau+1}\right)} T_{sp(s)} + \frac{\left(\frac{1/\tau}{s+a}\right)}{1+(k/sta)\left(\frac{kv}{\tau s+1}\right)(k_{c(s)})\left(\frac{kpa}{\tau^2 s^2 - 23\tau+1}\right)} d_{(s)}$ (43)

To simplify equation (43) we make the assumption that:

$$G_{f(s)} = G_{m(s)} = 1 \quad (44)$$

Putting (44) into (43) we obtain:

$$T_{(s)} = \frac{({}^{k}/_{sta})(k_{c(s)})}{1+({}^{k}/_{sta})(k_{c(s)})} T_{sp\,(s)} + \frac{\left(\frac{t/_{\tau}}{s+a}\right)}{1+({}^{k}/_{sta})(k_{c(s)})} d_{(s)} \quad (45)$$

Simplifying equation (45), we have

$$T_{(s)} = k.k_c \left(\frac{1}{(s+a)+1}\right) T_{sp\,(s)} + \frac{1}{\tau}\left(\frac{1}{(s+a)+1}\right) d_{(s)} \quad (46)$$

Let a = 1

$$T_{(s)} = k.k_c \left(\frac{1}{(s+2)+1}\right) T_{sp\,(s)} + \frac{1}{\tau}\left(\frac{1}{s+2}\right) d_{(s)} \quad (47)$$

Transforming to the time domain by taking the inverse Laplace transform of equation 47

$$T_{(t)} = k.k_c \int_{.}^{-1} \left(\frac{1}{(s+2)+1}\right) T_{sp\,(s)} + \frac{1}{\tau} \int_{.}^{-1} \left(\frac{1}{s+2}\right) d_{(s)} \quad (48)$$

$$T_{(t)} = k.k_c e^{-2t} T_{sp\,(s)} + \frac{1}{\tau} e^{-2t} d_{(t)}$$

$$T_{(t)} = e^{-2t}(k.k_c T_{sp\,(t)} + \frac{1}{\tau} d_{(t)}) \quad (49)$$

Equation 49 represents the control model off Temperature in a Boiler

Results and Discussion

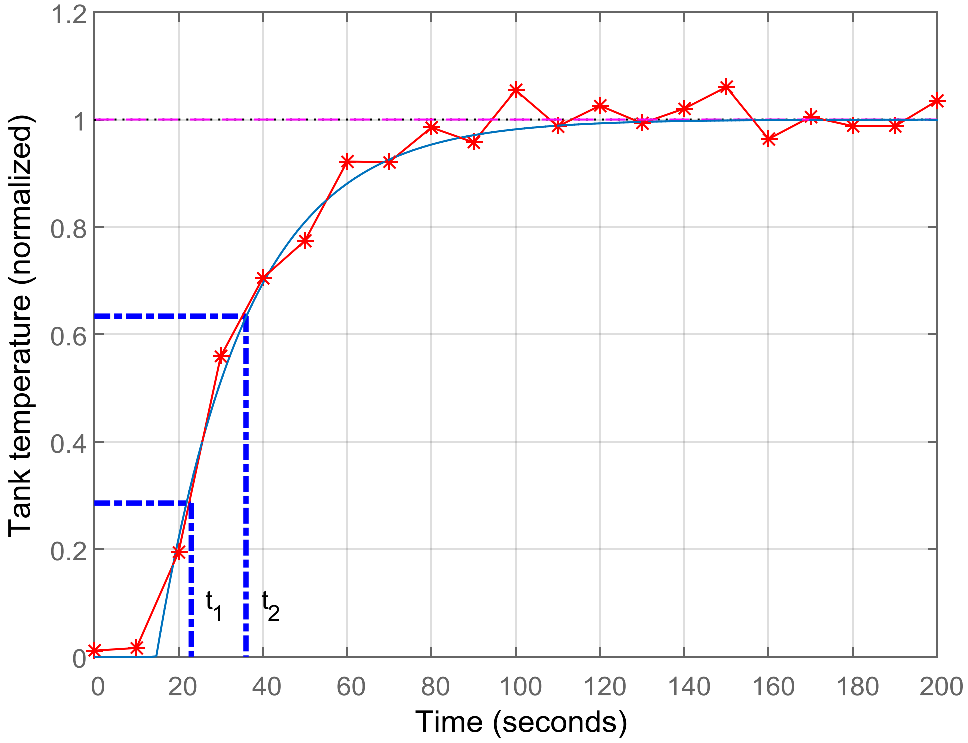

Figure 4: Step Response

Figure 4 illustrates the comparison of the profile of the models with cascade controller and that without a cascade controller. It is observed that the temperature increased exponentially with respect to time. And when the cascade controller was introduced, it nullifies the effect or error from the set point.

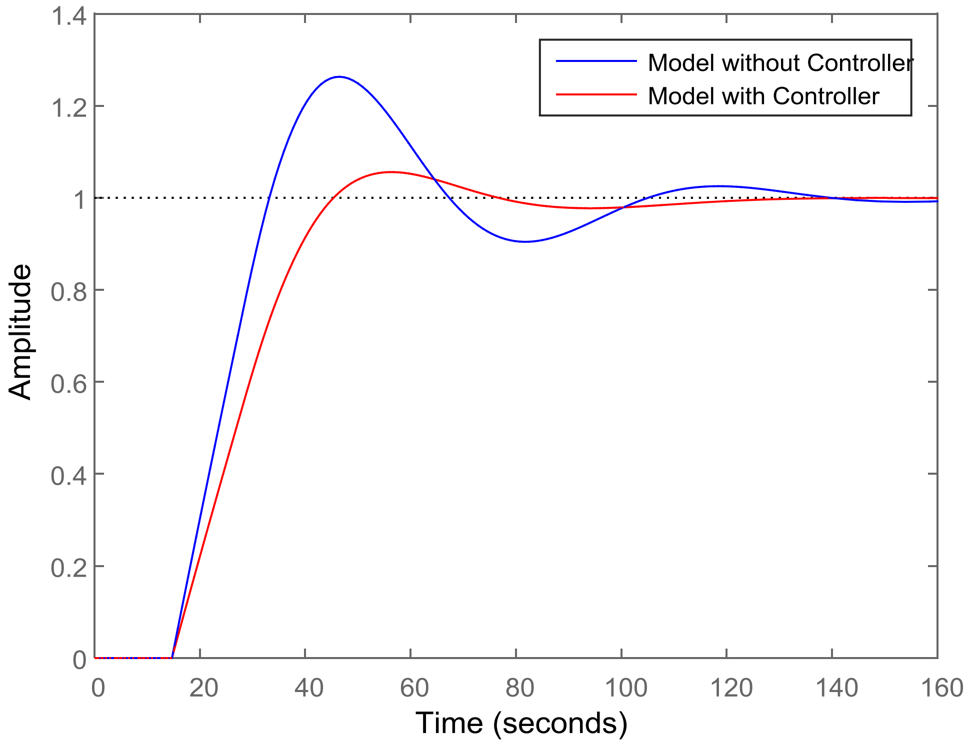

Figure 5: Step Response

Figure 5 illustrates a system with cascade controller and the one without a controller using the same system. Without a cascade controller in the above model, the signal amplitude increased more than the model with a cascade controller. The amplitude of the signal were modulated and smoothened by the cascade controller.

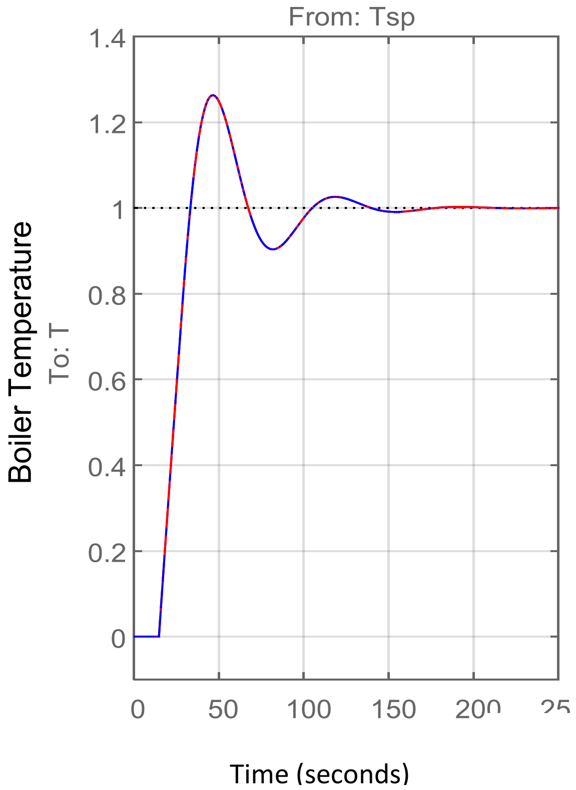

Figure 6: Close-loop response to set point and disturbance step change

In Figure 6, the temperature increased to an altitude of 1.3 and it decreases to 0.9 and thereafter increased to 1 and stabilised. The system stability is due to the effect of the installed cascade controller

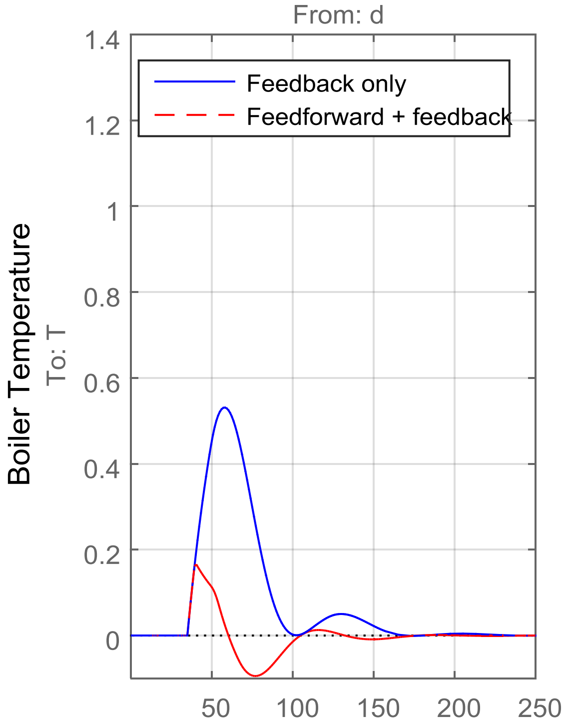

Figure 7: Close-loop response to set point and disturbance step change

Figure 7 shows the comparison between a feedback controller and feedback + feedforward controller system. The temperature increased rapidly to 0.55 at about 60 seconds and thereafter decreased sharply and stabilised at about 180 seconds for feedback controller system whereas for feed backward and feedforward the increased rapidly to about 0.19 and decreased sharply and stabilize at about 100^0C. The effect from the feedforward + feedbackward improved early stability of the system response. Therefore a cascade controller of feedback + feed forward effectively stabilise in the system better than the feedback controller only.

Conclusion

In any process especially the one involving temperature, Cascade Controller is always recommending in other to minimize or reduce error. A cascade of two or more control loops, each with its own input, in series forming a single regulating device. The product set-point temperature is set on the master control loop. This is compared to the product temperature, and the master's PID output is used to set the remote set-point of the slave.

In single-loop control, the controller's set point is set by an operator, and its output drives a final control element. In a cascade control arrangement, there are two (or more) controllers of which one controller's output drives the set point of another controller. However, in conclusion system with a controller can easily obtain stability than the one without a controller.

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Matlab Codes

(1)

```
heatex_plotdata
t1 = 21.8; t2 = 36.0;
tau = 3/2 * ( t2 - t1 )
theta = t2 - tau
s = tf('s');
Gp = exp(-theta*s)/(1+tau*s)
holdon, step(Gp), hold off
```

(2)

```
Kc = 0.859 * (theta / tau)^(-0.977)
tauc = ( tau / 0.674 ) * ( theta / tau )^0.680
C = Kc * (1 + 1/(tauc*s));
Tfb = feedback(ss(Gp*C),1);
step(Tfb), grid on
title('Response to step change in temperature setpoint T_{sp}')
ylabel('Boiler Temperature')
margin(Gp*C), grid
C1 = 0.9 * (1 + 1/(tauc*s));
margin(Gp*C1), grid
step(Tfb,'b', feedback(ss(Gp*C1),1),'r')
legend('Model without Controller','Model with Controller')
```

(3)

```
Gd = exp(-35*s)/(25*s+1);
F = -(21.3*s+1)/(25*s+1) * exp(-25*s);
Tff = Gp * ss(F) + Gd;

step(Tff), grid
title('Effect of a step disturbance in inflow temperature')
ylabel('Tank temperature')
Gd.u= 'd';  Gd.y = 'Td';
Gp.u = 'V';  Gp.y = 'Tp';
F.u= 'd';  F.y = 'Vf';
C.u = 'e';  C.y = 'Vc';
```

```
Sum1 = sumblk('e = Tsp - T');
Sum2 = sumblk('V = Vf + Vc');
Sum3 = sumblk('T = Tp + Td');
Tffb = connect(Gp,Gd,C,F,Sum1,Sum2,Sum3,{'Tsp','d'},'T');
C.u = 'e';  C.y = 'V';
Tfb = connect(Gp,Gd,C,Sum1,Sum3,{'Tsp','d'},'T');
step(Tfb,'b',Tffb,'r--'), grid
title('Closed-loop response to setpoint and disturbance step change')
ylabel('Boiler Temperature')
legend('Feedback only','Feedforward + feedback')
```