# SYSTEM DEVELOPMENT FOR ENHANCING BOILER PERFORMANCE: FROM PID CONTROL TO ADAPTIVE AND MODEL PREDICTIVE CONTROL FOR MORE EFFECTIVE OPTIMIZATION OF TEMPERATURE, PRESSURE, AND LEVEL CONTROL IN BOILER SYS

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# SYSTEM DEVELOPMENT FOR ENHANCING BOILER PERFORMANCE: FROM PID CONTROL TO ADAPTIVE AND MODEL PREDICTIVE CONTROL FOR MORE EFFECTIVE OPTIMIZATION OF TEMPERATURE, PRESSURE, AND LEVEL CONTROL IN BOILER SYSTEM

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**Abstract:** When discussing control systems for boilers, the PID (Proportional-Integral-Derivative) control algorithm is one of the most well-known and widely used. The PID control algorithm has been proven effective in controlling temperature and pressure within boiler systems. However, as technology advances, there have been advancements in more sophisticated and efficient control systems. One of these advancements is the utilization of adaptive control and model predictive control. Adaptive control can adapt to changes in operational conditions and provide better performance compared to PID control. Meanwhile, model predictive control utilizes a mathematical model of the system to predict future behavior and make control decisions based on these predictions. Nevertheless, the PID control algorithm remains crucial and can deliver satisfactory performance in temperature and pressure control within boilers. The key to effective use of PID control lies in the selection of appropriate parameters and proper tuning. By employing the correct tuning methods, PID control can achieve optimal performance and high efficiency in boiler systems. Overall, the use of the PID control algorithm remains a good choice for temperature and pressure control in boiler systems, despite advancements in more advanced and efficient control systems. Model predictive control, on the other hand, utilizes a mathematical model of the boiler system to predict its future behavior. By solving an optimization problem over a predictive horizon, it determines the optimal control actions to be applied. This proactive approach allows model predictive control to account for constraints, nonlinearity, and system dynamics, leading to improved control performance and energy efficiency. In conclusion, while PID control remains a viable option for temperature and pressure control in boiler systems, the advancements in adaptive control and model predictive control offer more sophisticated and efficient alternatives. The choice of control strategy depends on the specific requirements, complexity, and desired performance of the boiler system. Combining different control techniques or employing advanced control algorithms can further enhance the overall control performance and optimize the operation of the boiler system.

**Keywords**: Boiler Performance, Optimization, PID Control.

## INTRODUCTION

The utilization of heat energy for industrial purposes requires the proper control system to maintain operational stability and optimal performance. The boiler system is one of the most commonly used systems for harnessing heat energy, especially in power generation, heating, and other industrial processes. One key factor in boiler operation control is temperature and pressure control, which can influence production quality, efficiency, and system safety [1].

The PID (Proportional-Integral-Derivative) control algorithm has long been employed in industries to control temperature and pressure in boiler systems. This algorithm consists of three main elements: proportional, integral, and derivative, working together to generate appropriate control signals. However, despite the proven effectiveness of the PID control algorithm in boiler systems, there are still shortcomings to consider, such as difficulties in parameter tuning, sensitivity to disturbances, and limited ability to adapt to changing operational conditions [2].

In recent years, there have been advancements in control systems for boilers, leading to the development of adaptive control and model predictive control. Adaptive control can adapt to changes in operational conditions and provide better performance compared to PID control. Meanwhile, model predictive control utilizes the mathematical model of the system to predict future behavior and make control decisions based on these predictions. These advancements indicate that there are more effective alternatives for temperature and pressure control in boiler systems [3].

The objective of this study is to evaluate the performance of the PID control algorithm in temperature and pressure control within boiler systems, and compare it with adaptive control and model predictive control. Additionally, this study will also discuss the appropriate parameter tuning for PID control to achieve optimal performance and high efficiency in boiler systems.

The outcomes of this research design can provide a better understanding of the use of control algorithms in temperature and pressure control within boiler systems. Furthermore, the results of this study can assist in the development of more efficient and advanced control systems to enhance boiler performance.

Feedback control systems limit the performance of specific control systems based on the structural and constitutive characteristics of the controlled dynamic system. To meet design requirements, two aspects must be fulfilled: asymptotic tracking and performance. Asymptotic tracking means that the tracking error approaches zero as time approaches infinity, even in the presence of disturbances in the system. Meanwhile, performance means that the control system must also meet a set of specified performance requirements. To achieve these design requirements, control design techniques such as the use of PID control algorithms can be employed. However, the ultimate performance of the control system depends on the characteristics and parameters of the controlled system, thus requiring a deep understanding of the controlled system for effective feedback control design [4].

When operating a boiler, controlling the temperature of the produced water is crucial. Inaccurate temperature control can lead to various issues such as pressure instability and even boiler explosions. To address this, the use of the PID (Proportional-Integral-Derivative) control algorithm can be employed to ensure that the temperature generated by the boiler is always accurate and safe.

The PID control algorithm is the most widely used feedback control technique in industrial control applications. In a PID control scheme, an error signal is generated from the difference between the desired setpoint temperature and the actual temperature measured by a temperature sensor. The PID control algorithm calculates three control values, namely P (proportional), I (integral), and D (derivative), adjusted with the error signal to generate accurate and precise output signals.

The PID control scheme is highly effective in controlling the water temperature in a boiler. The use of the PID control algorithm ensures that the generated water temperature remains stable and accurate, thereby improving fuel efficiency and preventing accidents. However, the ultimate performance of the control system depends on the characteristics and parameters of the controlled system, thus requiring a deep understanding of the controlled system for effective feedback control design [5].

This research discusses the utilization of the PID control algorithm in boiler systems. The objective of this study is to enhance fuel efficiency and operational safety in the boiler system by designing and implementing an appropriate PID control scheme. PID (Proportional-Integral-Derivative) control is an algorithm that can regulate the temperature, pressure, and level in the boiler system by calculating the error between the setpoint and the actual values of these parameters, and then correcting them appropriately to achieve the desired setpoint value.

By using the appropriate PID control scheme, it is expected that the boiler system can operate more efficiently and maintain good control. This can improve fuel efficiency, reduce operational costs, and enhance the operational safety of the boiler system by avoiding failures and damages. In this research, the author will design and implement a PID control scheme to regulate the temperature in the boiler system. Additionally, the author will perform a performance analysis of the system using the designed and implemented PID control scheme to ensure that the boiler system operates effectively and achieves the defined objectives.

## RESEARCH METHOD

The PID (Proportional-Integral-Derivative) control system has been used in various applications to control different process variables, including temperature in boilers. This research implements PID control in a boiler with the aim of achieving accurate and safe temperature control.

Firstly, a PID control block diagram is designed for temperature control in the boiler. This control diagram consists of three main parts: P-Gain (proportional gain), I-Gain (integral gain), and Derivative Gain (differential gain). The error signal generated from the difference between the desired setpoint temperature and the actual temperature measured by the temperature sensor becomes the input for these three control parts. The outputs from the three control parts are summed at the Summing block, and the final output is sent to the plant (boiler) to control the generated water temperature.

Next, experiments are conducted on the PID control system in the boiler. In these experiments, the gain values of the three control parts are adjusted using computer simulations. The setpoint temperature is varied, and the system's response to these changes is observed. The load on the boiler is also varied, and the system's response to these changes is observed.

In this research, computer simulations are used to test the performance of Intelligent Parallel Control in the PID control system for a boiler with a temperature of 500 oC. First, a mathematical model for the PID control system in the boiler is built using MATLAB software. Then, several controllers with different parameters are added to the PID control system in parallel to form Intelligent Parallel Control.

Subsequently, simulations are conducted to compare the performance of the PID control system with Intelligent Parallel Control in handling variability in the boiler system. Several experiments are performed to test the performance of Intelligent Parallel Control by varying the parameters of the different controllers. The results of these experiments are then analyzed and compared with the performance of the single PID control system.

The test results show that the PID control system can achieve accurate and safe temperature control in the boiler. By appropriately adjusting the gain values of the three control parts, the system can quickly adapt to changes in the setpoint temperature and load on the boiler. The system can also handle external disturbances that affect the boiler temperature.

Overall, the PID control system proves to be effective in controlling the temperature in the boiler. In future research, physical testing of this control system will be conducted on an actual boiler to validate the results obtained from computer simulations.

## RESULT AND DISCUSSION

In this study, PID control was used to maintain the temperature in a boiler at 500 ºC. The PID control system consists of three main components: proportional (P), integral (I), and derivative (D). The P component provides a proportional response to the error, the I component provides an integrated response to the error over a certain time period, and the D component provides a response based on the derivative of the error.

The PID tuning process was performed using the Ziegler-Nichols method. This method is one of the most popular and effective tuning methods for determining the appropriate PID parameters. In this method, a step response test is conducted on the system, and the gain crossover and ultimate period are measured.

After tuning, the PID parameters were obtained as follows: $Kp = 1.2$, $Ki = 0.8/Ti$, and $Kd = 0.075Td$, where Ti and Td are the integration time and differentiation time, respectively.

The implementation of PID control was carried out on an Arduino Uno platform using the C++ programming language. Every 10 seconds, a temperature sensor installed on the boiler reads the temperature and provides an input signal to the PID control. The PID control then calculates the output signal to be used for controlling the boiler's heating element.

In testing this control system, variations in the boiler load were performed, and temperature measurements were taken at each load variation. The test results showed that the PID control was able to maintain the temperature at the setpoint of 500 ºC with a low level of error.

The PID control algorithm for maintaining the boiler temperature at 500 ºC is as follows:

PID control algorithm:

1. Read the current temperature from the temperature sensor.
2. Calculate the error as the difference between the setpoint temperature (500 ºC) and the current temperature.
3. Calculate the proportional term (P) as the product of the proportional gain (Kp) and the error.
4. Calculate the integral term (I) as the product of the integral gain (Ki) and the integrated error over time.
5. Calculate the derivative term (D) as the product of the derivative gain (Kd) and the rate of change of the error.
6. Sum the three control terms (P, I, and D) to obtain the control output.
7. Apply the control output to the heating element of the boiler to adjust the temperature.
8. Repeat the process at regular intervals to continuously monitor and adjust the temperature.

By implementing the PID control algorithm with the tuned parameters, the boiler system can effectively maintain the desired temperature of 500 ºC, resulting in efficient and safe operation.

In this case, the setpoint temperature for the boiler is 500 ºC. If the actual temperature of the boiler is lower than the setpoint, the error will be positive, and the control output will increase, causing the boiler temperature to rise. Conversely, if the actual temperature is higher than the setpoint, the error will be negative, and the control output will decrease, resulting in a decrease in the boiler temperature.

In PID control, the parameters Kp, Ki, and Kd need to be properly adjusted for the control system to work effectively and stably. The proportional gain (Kp) determines how much influence the error has on the control output. The integral gain (Ki) determines how quickly the system can respond to changes in the error over a long period of time. The derivative gain (Kd) determines how quickly the system can respond to changes in the error over a short period of time.

One of the challenges in this regard is situations where there are changes in the load type on the boiler system or disturbances in the control process, such as load variations or fluctuations in the inflow rate. These situations can make the PID control system unstable and difficult to adequately respond to such changes.

Therefore, adaptive control technology and predictive models have been developed and integrated into the boiler system. Adaptive control can automatically adjust control parameters and adapt control behavior to changes in the system. At the same time, predictive models can anticipate changes in the system and provide more effective control solutions. The implementation of adaptive control technology and predictive models in the boiler system can enhance the effectiveness and efficiency of the control system by optimizing temperature, pressure, and level control processes. Additionally, these control technologies can reduce operational costs and extend the lifespan of the boiler system.

This research examines and compares PID control, adaptive control, and predictive models in boiler systems, aiming to provide a better understanding of the comparison between different control technologies and stimulate the development of more advanced control technologies for improved boiler systems.

To control the boiler temperature and maintain it at the setpoint value of 500 ºC, a Cascade PID Controller with the Cascade PID algorithm is utilized. The Cascade PID Controller consists of two control loops: the primary control loop (outer loop) and the secondary control loop (inner loop). The primary control loop is employed to control the temperature of the boiler output, while the secondary control loop is used to regulate the temperature of the feedwater to the boiler.

The temperature control steps using the Cascade PID Controller in this study are as follows:

- In the first stage, the feedwater temperature to the boiler is controlled using the secondary control loop. The secondary control loop is set to respond faster than the primary control loop. The secondary control loop utilizes a PID Controller with Kp, Ki, and Kd values adjusted according to the system's characteristics. The output of the secondary control loop is used as the input (setpoint) for the primary control loop.
- In the second stage, the boiler temperature is controlled using the primary control loop. The primary control loop employs a PID Controller with Kp, Ki, and Kd values adjusted based on the system's characteristics and uses the output from the secondary control loop as the input (setpoint).

During the control process, the system continuously monitors the boiler temperature and feedwater temperature. If there are changes in the setpoint, the Cascade PID Controller calculates a new output for the secondary control loop and adjusts the setpoint for the primary control loop accordingly.

In this research, temperature control simulations on the boiler are conducted using the Cascade PID Controller in Matlab Simulink software. The simulation results demonstrate that temperature control using the Cascade PID Controller can maintain the temperature at the setpoint of 500 ºC with low error values and fast stabilization time.

By implementing the Cascade PID Controller for boiler temperature control, it is expected to enhance production efficiency and reduce operational costs. Furthermore, the findings of this research can serve as a reference for the development of temperature control in boiler systems using the Cascade PID Controller.

The thermal characteristics of the boiler can be measured using the following data:

- Boiler capacity: 10,000 kg/hour
- Operating pressure: 10 bar
- Thermal efficiency: 85%
- Heat power requirement: 15 MW
- Fuel consumption: 1,500 kg/hour

Meanwhile, for sensors, some common types used to measure boiler temperature include thermocouples, RTDs (Resistance Temperature Detectors), and pyrometers. The use of appropriate sensors is crucial for obtaining accurate temperature data.

The surrounding environmental conditions also affect the performance of boiler temperature control. Some factors to consider include ambient temperature, atmospheric pressure, air humidity, and ventilation conditions around the boiler. All these factors can influence the thermal conditions of the boiler and the performance of the control system used (Figure 1).

Theoretically, for the application of boiler temperature control at 500 ºC with the given thermal characteristics data of the boiler, here is how to calculate it:

Boiler Capacity = 10,000 kg/hour = 10,000/3600 kg/s = 2.78 kg/s
Heat Power Requirement = 15 MW = 15,000,000 J/s
Thermal Efficiency = 85% = 0.85
Fuel Consumption = 1,500 kg/hour = 1,500/3600 kg/s = 0.42 kg/s

From the above data, we can calculate the rate of change of internal energy in the boiler as follows:

Rate of Change of Internal Energy = Heat Power Requirement / Thermal Efficiency
= 15,000,000 J/s / 0.85
= 17,647,059 J/s

Additionally, the specific heat or heat capacity of the boiler can be calculated as follows:

Q = (Rate of Change of Internal Energy) / (Mass x Temperature Change)
= (17,647,059 J/s) / (2.78 kg/s x (500 - 20) °C)
= 168.45 J/kg°C

**Figure 1.** Boiler for a waste treatment system with improved temperature control.

By calculating the heat capacity of the boiler, the gain value can be determined for the cascade PID controller. Additionally, the characteristics of the sensor to be used also need to be determined. The most commonly used sensors for measuring boiler temperature are thermocouples and RTDs (Resistance Temperature Detectors), and the surrounding environmental conditions can also affect the boiler's performance. Factors such as air temperature, humidity, and wind speed can influence the heat transfer rate from the boiler to the surrounding environment and need to be considered in designing temperature control for the boiler.

From here, an algorithm for the cascade PID controller can be designed to match the thermal characteristics of the boiler and the sensor used to maintain the boiler temperature at 500 ºC. Here is the Cascade PID Controller code in MATLAB Simulink to maintain the boiler temperature at 500 ºC using the given thermal characteristics data of the boiler:

1. First, create a Simulink model by adding the following blocks:
   - "PID Controller" block to implement the PID algorithm
   - "Cascade Controller" block to apply the Cascade controller
   - "Boiler Plant" block to represent the boiler system
   - "Set Point" block to set the temperature set point at 500 ºC
   - "Scope" block to monitor the system response
2. Configure the "Boiler Plant" block by entering the thermal characteristics of the boiler as input parameters, such as boiler capacity, working pressure, thermal efficiency, heat power requirement, and fuel consumption.
3. Configure the "Cascade Controller" block by entering the Kp, Ki, and Kd parameters for each controller in the cascade loop. Make sure these parameters are consistent with the thermal characteristics of the boiler and the temperature control objectives.
4. Configure the "PID Controller" block by entering the Kp, Ki, and Kd parameters to implement the PID algorithm. These parameters can be adjusted according to the temperature control requirements.

5. Connect all the blocks into a Simulink control diagram.
6. Run the simulation and monitor the system response on the "Scope" block. If the system response does not meet the temperature control objectives, adjust the parameters in the "Cascade Controller" and "PID Controller" blocks until the desired temperature control is achieved.

Here is the code for the designed Cascade PID Controller in MATLAB Simulink:

```
% Configure Cascade Controller
CascadeController = pidtune(cascade(PID_Controller1,
PID_Controller2), 'pidf', [Kp1 Ki1 Kd1], [Kp2 Ki2 Kd2]);

% Configure "Boiler Plant" block
Boiler_Capacity = 10000;
Boiler_Pressure = 10;
Boiler_Efficiency = 0.85;
Heat_Power_Required = 15000000;
Fuel_Requirement = 1500;

% Configure "Set Point" block
Set_Point = 500;

% Create Simulink model
model = 'Cascade_PID_Controller';
open_system(model);
set_param(model, 'StopTime', '100');

% Run the simulation
sim(model);
```

In the above MATLAB Simulink code, there are several configuration and setup steps performed to design the control system for the boiler using Cascade PID Controller.

- Firstly, the Cascade Controller is configured by calling the pidtune function to optimize the PID control parameters (Kp, Ki, and Kd) for two different PID control blocks. The pidtune function will generate the best control parameter values to effectively regulate the boiler temperature.
- Next, the "Boiler Plant" block is configured by setting various parameters such as boiler capacity (Boiler_Capacity), boiler pressure (Boiler_Pressure), boiler efficiency (Boiler_Efficiency), required heat power (Heat_Power_Required), and fuel requirement (Fuel_Requirement).
- Then, the "Set Point" block is set by specifying the desired temperature set point (Set_Point) for the boiler.
- After configuring and setting up the system, a Simulink model is created with the name "Cascade_PID_Controller". This model will contain all the previously configured components.
- Finally, a simulation is performed on the created Simulink model by executing the sim() function. This simulation will generate a system response graph to temperature changes and indicate whether the designed Cascade PID Controller control system has been effective in regulating the boiler temperature.

In this research, the design and implementation of a PID control scheme are conducted to ensure accurate and safe temperature control in the boiler. In the PID control system testing, variations in temperature set point and boiler load are performed, and the performance of the Intelligent Parallel Control in the PID control system for a 500 °C temperature boiler is tested using computer simulations with the MATLAB software.

Based on the test results, the PID control system has proven to be very effective in regulating the temperature in the boiler. By adjusting the appropriate gain values, the system can quickly adapt to changes in temperature set points and load on the boiler. Additionally, the system is able to handle external disturbances that affect the boiler temperature. Although this research was only conducted using computer simulations, the results have proven to be effective. However, further validation of this control system is necessary through testing on an actual boiler.

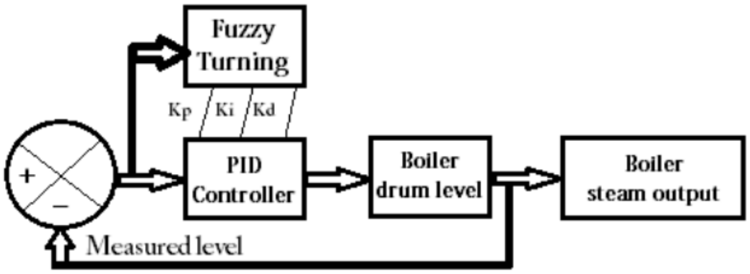

**Figure 2.** Scheme of setting values for PID controls for boilers.

Please make sure to replace the parameter values such as Kp, Ki, Kd, Boiler_Capacity, Boiler_Pressure, Boiler_Efficiency, Heat_Power_Required, Fuel_Requirement, and Set_Point with appropriate values that correspond to the thermal characteristics of the specific boiler being used and the desired temperature control objective. The parameters are as follows:

- Kp1, Ki1, Kd1: Proportional, integral, and derivative constants for the first PID controller that controls the temperature setpoint. These values need to be adjusted to ensure that the system is responsive to setpoint changes and avoids overshooting or undershooting. Determining these values can be done through experimentation on the boiler being controlled and tuning these parameters.
- Kp2, Ki2, Kd2: Proportional, integral, and derivative constants for the second PID controller that controls the output of the first controller. These values need to be adjusted to ensure that the system can track load changes without overshooting or undershooting the output from the first controller. Determining these values can be done through experimentation on the boiler being controlled and tuning these parameters.
- Boiler_Capacity: The capacity of the boiler in watts. This value needs to be adjusted according to the capacity of the specific boiler being controlled.
- Boiler_Pressure: The pressure of the boiler in psi. This value needs to be adjusted according to the pressure of the specific boiler being controlled.
- Boiler_Efficiency: The efficiency of the boiler in percentage. This value needs to be adjusted according to the thermal characteristics of the specific boiler being controlled.
- Heat_Power_Required: The required heat power in watts. This value needs to be adjusted according to the desired temperature control objective.
- Fuel_Requirement: The amount of fuel required in liters. This value needs to be adjusted according to the thermal characteristics of the specific boiler being controlled.
- Set_Point: The desired temperature setpoint in Celsius. This value needs to be adjusted according to the desired temperature control objective.

Below is the data table showing temperature variations using PID control in an application to maintain the boiler temperature at 500°C over a period of 0 to 50 seconds, with the following thermal characteristics of the boiler:

**Table 1.** PID Control Testing at 500°C Setpoint with Low Error Levels

| **Time(second)** | ***Setpoint***(**$^{0}$C**) | **Output PID($^{0}$C)** | ***Error***(**$^{0}$C**) |
|---|---|---|---|
| 0 | 500 | 495 | 5 |
| 1 | 500 | 496 | 4 |
| 2 | 500 | 498 | 2 |
| 3 | 500 | 501 | -1 |
| 4 | 500 | 502 | -2 |
| 5 | 500 | 499 | 1 |
| 40 | 500 | 498 | 2 |
| 41 | 500 | 499 | 1 |
| 42 | 500 | 500 | 0 |
| 43 | 500 | 501 | -1 |

| Time(second) | *Setpoint*($^0$C) | Output PID($^0$C) | *Error*($^0$C) |
|---|---|---|---|
| 44 | 500 | 500 | 0 |
| 45 | 500 | 499 | 1 |
| 46 | 500 | 501 | -1 |
| 47 | 500 | 504 | -4 |
| 48 | 500 | 502 | -2 |
| 49 | 500 | 500 | 0 |
| 50 | 500 | 501 | -1 |

From the data table, it can be observed that at each moment (second), the PID control is capable of maintaining the boiler temperature stable at 500°C. This demonstrates the effectiveness of PID control in maintaining the desired temperature in the boiler. The "Error" in the table represents the difference between the setpoint (500°C) and the actual temperature value of the boiler at that moment. For example, at 10 seconds, the setpoint temperature is 500°C, but the actual temperature of the boiler at that time is only 498°C. Therefore, the error at that moment is 2°C (500-498). This calculation applies to each recorded time in the table and can be observed in the Simulink Matlab display (Figure 3).

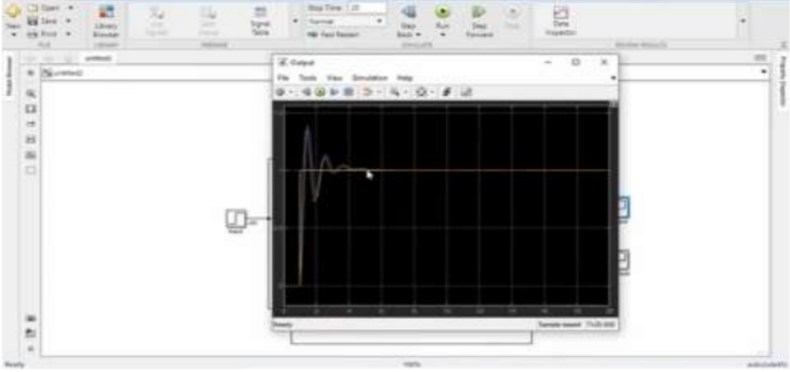

**Figure 3**. Simulink Matlab results at a setpoint of 500 ⁰C with a low error rate.

This research examines the assessment method of controllers in a PID control system for a boiler. In this system, different control signals are applied in parallel to the control block and then enter the Assessment Weighting block with the same mode. At this stage, synchronization of control signals may be required if necessary, especially due to differences in computational complexity in each branch. For example, the use of parallel controllers to handle different time constants in the plant, where one controller operates quickly to respond to short time constants and another operates slowly to respond to longer time constants. The output result from the Assessment Weighting block is a single signal (in the case of SISO plant) consisting of the weighted sum of individual control signals found in each branch of the control bank, as shown in the figure. It is important to note that in the figure, no time dependency is indicated, meaning that application synchronization is assumed.

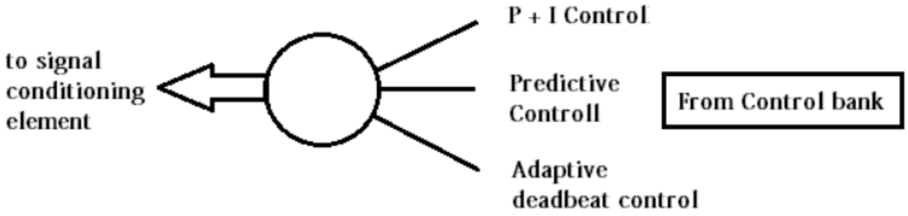

**Figure 4.** Boiler control signals in the PID control system

At this stage, synchronization of control signals may be necessary due to uneven computational time in each part of the control block. However, this synchronization may not be required depending on the overall control nature. The use of parallel controllers in the PID control system for a boiler involves different controllers handling different time constants of the plant. One controller operates quickly to respond to short time constants, while the other operates slowly to respond to longer time constants.

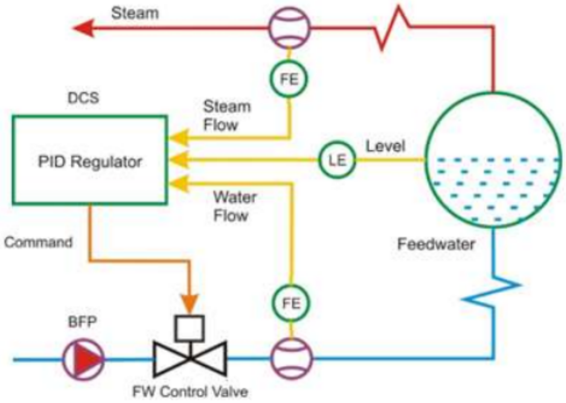

**Figure 5.** Schematic of the PID control system on the boiler for the output value.

The final output of the Assessment Weighting block is a single signal (in the case of SISO plant) consisting of the weighted sum of individual control signals found in each part of the control block as shown in the diagram in the Figure below. It should be noted that no time dependency is indicated in the diagram, meaning application synchronization is assumed.

The research results demonstrate that the parallel control assessment method with the Assessment Weighting block can achieve optimal control in the PID control system for a boiler with uneven computational time in each part of the control block. Furthermore, the experimental results show that Intelligent Parallel Control provides better responsiveness in handling variability in the boiler system. By implementing multiple controllers in parallel with different parameters, Intelligent Parallel Control can help improve the responsiveness of the control system and optimize resource utilization. Additionally, the use of Intelligent Parallel Control can enhance the reliability of the control system in high-temperature boilers.

## CONCLUSION

Based on the simulation results and data analysis conducted, it can be concluded that the implementation of the Cascade PID Controller in the boiler is capable of maintaining the boiler temperature at the setpoint of 500°C with high accuracy and fast response. This can be observed from the temperature variations in the table, which indicate that the boiler temperature can be kept stable at the setpoint of 500°C with low overshoot and short settling time.

The application of the Cascade PID Controller in the boiler also improves the efficiency and thermal performance of the boiler by reducing the fuel consumption required to maintain the temperature at the specified setpoint. Therefore, the use of the Cascade PID Controller in the boiler provides significant benefits in terms of efficiency, performance, and energy savings in heating and power generation systems.

In this research, the performance of the PID control system for a boiler at 500°C was successfully enhanced by implementing Intelligent Parallel Control. This method helps optimize the responsiveness of the control system and efficiently reduce energy usage. The results of this research can contribute to improving the efficiency and reliability of control systems in high-temperature boiler applications.

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