Automation and control of thermal processes in the furnace

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Abstract. In this paper, the main components of the thermal processes in the furnace are considered. Also, the review discusses existing control systems for thermal furnaces and their components. The modern thermal process control technologies are studied at the level of small developments, as well as at the industrial scale. This review is the basis for the design and development of software for monitoring thermal processes in a furnace as part of a scientific study.

1. Introduction

Furnace is an industrial device which is used in many chemical processes for heat transfer operation. In furnace, charge or process enters through one end. It is then heated to the required temperature in a carefully controlled manner. In the furnace, heat is provided by an energy released as a result of combustion of the fuel gas. The heat to the process fluid is transferred by flue gas to heat it to the required temperature. In furnaces, heat transfer and temperature control are very important for their efficient and safe operation. This is done by a system of instrumentation and control system which keeps the different process variables in a specified limit. The system measures the output performance of a device that is being controlled [1]. These measurements send the feedback to the input actuators that makes corrections towards desired performance. In the furnace, in most cases, the most controlled parameters are temperature and pressure [2].

2. Considerations in furnace control system

There are some considerations for control system in furnace:

- Heat energy is received by the charge at the proper rate. Here, outlet temperature of the charge is the controlled variable.
- The efficient combustion of fuel should be properly maintained. The regulation of the air-fuel ratio is necessary for proper combustion of the fuel.
- All phases of furnace operations should be safe to prevent explosion or fires.

These considerations can be better understood by taking an example [3]. Consider a furnace in the ammonia manufacturing process. Startup heaters are required in heating of an intermediate stream,
such as air or natural gas, which in turn heats another fluid or solid, such as a reactor catalyst. The control of a start-up heater used in ammonia unit is shown by the following P&ID below:

**Figure 1.** The control system of start-up heater.

### 2.1. Process control

Process control ensures that there should be proper consumption of heat energy by the charge. The exit temperature of the charge is the controlled variable. A fail-close temperature control valve is used to control and maintain this temperature by manipulating the burner flame [4].

### 2.2. Safety control

In order to ensure the safety in furnace operations, safety control is implemented. There are some potential sources of hazards which include:

- Tube rupture causes fire explosions. This occurs due to overheating of the tube. The overheating is caused by flame impingement or feed flow loss.
- Improper purge procedures, improper ignition or loss of flame causes explosion in the firebox.

The standard ANSI/ISA-84.01–1996, “Application of Safety Instrumented Systems (SIS) for the Process Industries,” is implemented to ensure the safety of a furnace operation. The SIS safety and shutdown system is usually located on a PLC that is separated from the control equipment. The normal operation of the furnace is directed by control equipment. Flame scanner is also included in such systems. As far as the processors and power supplies of PLC-based SIS systems are concerned, their reliability is increased by implementing them in redundant configurations. The safety of furnace operation is ensured by flow safety low switch for inlet charge flow and pressure safety low switch for inlet fuel gas. Fuel firing controls of a start-up heater operation play a very important role in both the process and safety control. Here the process temperature controller sets the fuel gas firing [5].

### 2.3. Burner Control Operation

Burners are controlled by controlling the air to fuel ratio to them. There are two ways of controlling the air to fuel ratio:
• There is a technique called pressure balance that modulates the flow of air, and pressure regulator is used to allow a corresponding flow of fuel. The fuel flow is always in accordance with the air flow.

• The other technique is to allow independent control of air and fuel flows. In this system an algorithm is implemented to determine the flows of each, so that that they can function somewhat independently of one another. This system is more flexible, versatile, and can handle a wide range of process requirements:

![Block diagram of burner control system](image)

**Figure 2.** Block diagram of burner control system.

2.4. **Digital Furnaces**

Digital twin of a production process involves the collection of all digital parts interconnected with the relevant generated data during the production process. Digital twin technique, representing an industrial furnace, requires accurate reproduction of all the physical components in an advanced computer. From the simulation point of view, digital twin is considered as a newly improved step in simulation technology due to the possibility of evolving physical systems in more complex entities by adding software functions in some parts, i.e. drives and sensors, and enforcing the connectivity through cyber-physical systems [6].

Linkage between the physical and the virtual industrial furnace is done through supervisory control and data acquisition (SCADA). The system has two phases, as shown in figure below:

![Industrial furnace as digital twin](image)

**Figure 3.** Industrial furnace as digital twin.
First phase is the observation phase. It involves a set of elements, generally in the basis of individual and interchangeable input and output cards which are responsible for capturing real-world physical conditions. They convert these conditions into data which can be analyzed in a computational domain [7]. This process, performed by a data acquisition system, can be divided into four steps represented in figure 4.

- First step includes the identification of physical properties that describe the state of the physical system, such as pressure, flow, or temperature etc.
- The second step involves the installation of electronic hardware which is able to capture each tangible property converting it into an electrical signal. The electric signal can be in voltage or in current. Electrical excitation is typically required by this hardware.
- The third step prepares the electrical signal process through a signal conditioning step prior to the beginning of the Analog-Digital Converter (ADC) process. Some conditioning processes involve filters to remove noise in order to obtain the precise signal required. Also, sometimes, the electrical signal needs to be amplified to get a better signal matching ADC features.
- The fourth step transforms the electrical signal into a digital signal using an ADC device. Computers understand digital signal, and it can be easily shared and exchanged between them. Similarly, the acquisition & control system can generate signals to manage the actuators included in the process, typically, drives controlling the aperture or closing process valves [8,9].

2.5. Furnace Pressure Controllers
Pressure in the working chamber of furnace is maintained and stabilized by furnace pressure controllers. A pressure gauge is used in these controllers in the furnace chamber or duct, and the airflow is regulated to maintain a slightly positive pressure in the furnace chamber. There are draft fans and dampers which can regulate airflow for the exiting flue gas or the incoming air for combustion. For a natural draft furnace or oven, a barometric damper is an inexpensive option. Pressure controller can be automatic or manual. There is a dial on a control panel which is used to adjust the pressure in a manual system. It can be done by an equipment operator. In automatic system, there is a feedback loop which continuously monitors and regulates the pressure through an electronic control system. The output of the controller is based on the proportional and integral action of the controller to auto manual action [10,11]. PLC controls the inlet vanes of ID Fans.
2.6. Versatile control system in furnaces
There are also some advanced furnaces that are operated from a single control panel that controls all electrical functions of the furnace. The control system has four basic functional groups:

- Power controllers
- Energizers
- Temperature Controllers
- Calibrate/Test and Status

Industrial PLC or programmable logic controller integrate the various functions. On the control console, the process gas flow Control flowmeters are also located [12].

2.7. Energize lamps
From energize lamps, operator can control the mode of heat transfer in furnace as a conduction, radiation or mixed mode. There are different modes available to model the behavior of a radiant, convection or conduction furnace. This feature makes it an ideal all-around furnace for laboratory or production applications.

2.8. High Temperature Furnace
The Furnace can be operated in a mixed mode by enabling any combination of top and bottom lamps. This mode combines the characteristics of convection, conduction and radiant heat.

2.9. Infrared Furnace
By enabling top lamps, the furnace can be operated in radiant mode. This mode emphasizes fast response characteristics of radiant furnaces and de-emphasizes conduction characteristics.

2.10. Conduction Furnace
Furnace can be operated in both conduction and convection by using only bottom lamps.

2.11. Power Control
When power is applied from the facility circuit breaker, white lamp is always lit. Control light is lit when power is applied to the furnace systems. Green controls are pressed by operator to start belt motor controller, cabinet and cooling system fans, furnace zone temperature controllers and any optional equipment. Red control buttons are pushed to turn off the furnace.

2.12. Temperature Controllers
In heat treatment furnaces such as for normalizing process, control of temperature for each plate loaded into the furnace is quite important. There are two different contributors to a temperature deviation for temperature control:

- A thermal load is owned by furnace which specific to the furnace characteristics
- Once a plate is charged inside the furnace, the plate thermal load is added.

In order to manage these two different dynamic behaviors, a thermal model is used by temperature control system to predict the residence time and normalizing temperature. The plate should be at this temperature inside the furnace [13]. Because a constant temperature in the furnace is assumed by the thermal model to perform its calculations, the value is used as a reference by the temperature control. Therefore, the objective of the temperature control is to keep the temperature uniform, controlling the length of time that the burners fire within a given burner zone [14]. The requirements of a control system may depend on many factors, such as response to command signals, insensitivity to measurement noise, process variations, and rejection of load disturbances. Control system design
involves performs different aspects related to process dynamics, actuator saturation, and disturbance characteristics. The temperature control for the normalizing furnace uses a PID controller that manipulates the usable power signal [15]. This power signal is fed to the sequencer to develop a suitable firing rate for burner. In order to decrease the rise time, a fuzzy system is adopted to determine the value of the error signal during the transient response, and at the same time the overshoot and reducing the settling time as well.

2.13. Heat Control Sensor
A sensor is used to detect the temperature in different areas of furnace. The sensor is known as thermocouple. The sensor is connected to an indicator or a controller device to indicate the actual temperature. If the unit is a controller, then the information from the sensor can be compared with the set value [16]. The control then sends an output signal to the heating device to raise or lower the temperature.

3. Conclusion
The furnaces and their related control systems, as discussed above, show that how much care is taken off for the proper and efficient operation of furnace. From the temperature to pressure control of air flow and safety, all have vital importance for the proper furnace working at a desired temperature in order to get the required output from the process being performed in the furnace. All the controls are valid both by older sophisticated DCS or PLC systems and analogue instrumentation. With the increase in demands of production and manufacturing industries, involving the heat treatment furnaces, while taking full advantage of the basic controls, and to obtain more efficient and more economical furnace operation, the use of more advanced and model-based controls should be encouraged.

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