Gas flow control design vapor deposition in chemical facilities

T Dermawan¹, N P Priambogo¹ and S Rianto²

¹ Polytechnic Institute of Nuclear Technology – National Nuclear Energy Agency of Indonesia, Jl. Babarsari, Caturtunggal, Sleman, Yogyakarta, 55281, Indonesia
² Center of Nuclear Fuel Technology – National Nuclear Energy Agency (BATAN), Kawasan PUSPIPTEK Gd. 20, Tangerang Selatan, Banten, 15310, Indonesia

E-mail: totoekerma@batan.go.id

Abstract. Design of gas flow control in LabVIEW based chemical vapor deposition facilities. To make the TRISO layer in nuclear fuel, argon, acetone, MTS, hydrogen and propelling gas are used. Currently, the regulation of gas flow in fluidized bed chemical vapor deposition facilities is done manually. Coating by adjusting the flow rate of 2 different gas alloys. The system is designed to obtain a proper coating, using Arduino to control the servo motor which regulates the gas valve. The results obtained that the valve can rotate between the range of 0 degrees to 180 degrees, with the addition of 0.5 degrees per step.

1. Introduction

Fluidized-Bed Chemical Vapor Deposition is a fuel facility for HTGR reactor fuel research. This facility is for the UO₂ kernel coating process by combining 2 different gases between the coating reactors called fluid bed reactors. The types of gas that are integrated into the FB-CVD device are argon, acetylene, and propelin. Gas flow at any time.

The flow rates of these 3 types of gas are arranged to make the main layer called tristructural isotropic (TRISO). The layer consists of a pyrolysis carbon layer (buffer PyC), an inner dense pyrolysis carbon layer (IPyC), a silicon carbide layer (SiC), and an outer dense pyrolysis carbon layer (OPyC). This layer serves to hold the nuclear radiation of the activated UO₂ kernel. If there is a leak, the radiation does not escape directly into the air but is held back by an outer layer called TRISO [2].

To form a buffer layer pyrolysis carbon layer (PyC buffer), it takes acetylene and argon gas heated at a temperature of 1260°C for 2.5 minutes. While the inner dense pyrolysis carbon layer (IPyC) layer requires propellant and argon gas to be heated at 1280°C for 12.5 minutes. While the silicon carbide layer (SiC) layer requires Methyl Trichloro Silane (MTS) and Hydrogen gas with a temperature of 1600°C for 150 minutes, and an outer dense pyrolysis carbon layer (OPyC) gas requires a mixture of propylene gas and argon gas heated at 1300°C for 12 minutes [3].

Manually regulating the gas flow rate causes the amount of gas flow into the coating reactor to be incorrect, causing uneven coating thickness, resulting in reduced effectiveness of the gas coating process. If there is a leak, it causes a work accident due to toxic and flammable gas. Therefore we need computer control to facilitate the operation of the facility.
2. Theory

2.1. FBCVD
Fluidized bed chemical vapor deposition (FBCVD), as shown in Figure 1, is a facility for coating nuclear kernel fuel (UO2) by heating gas in a reactor at high temperatures. This causes the deposited gas to become solid which covers the surface of nuclear fuel in the chemical reaction process [2].

Figure 1. Fluidized bed chemical vapor deposition.

In the Fluidized Bed Reactor (FBR) there is a nozzle for injecting reactive gas (MTS, and H) and fluidizing gas (Asetene, Propelin, and Argon) through the Chemical Vapor Deposition precursor. The fluidized gas will stick to the fuel and react to form a thin film on all surfaces of the fuel. Around the FBR there are coolers on the sides to maintain the temperature of the coating reactor [1].

To form a tristructural isotropic (TRISO) layer, different gas alloys and coating reactor temperatures are required:

1. The first layer is the pyrolysis carbon layer buffer (PyC buffer). This layer requires a mixture of acetylene + argon gas in a ratio of 30%-40% for argon and 60%-70% for acetylene, which is heated at 1260°C for 2.5 minutes in the reactor.
2. The second layer is the inner dense pyrolysis carbon layer (IPyC). This layer requires a mixture of propelin + argon gas with a gas ratio of 30%-40% for argon and 60%-70% for propelin, which is heated at 1280°C for 12.5 minutes in the reactor.
3. The third layer is the silicon carbide layer (SiC) which requires a mixture of methyl trichlorosilane + hydrogen gas, heated at 1600°C for 150 minutes.
4. The fourth layer of the outer dense pyrolysis carbon layer (OPyC) which requires C3H6 + Ar gas with a gas ratio of 30%-40% for Ar and 60%-70% for C3H6 heated at the reactor temperature of 1300°C for 12 minutes [3].

Figure 2 is the process of the gas flow in a fluidized bed chemical vapor deposition facility.
2.2. Arduino Mega 2560
Arduino has the main parts, namely [6]:
1. USB Port, as a program delivery media and a serial communication port and power supply.
2. Digital and Analog Input/Output (I/O), are pins for connecting Arduino with digital/analog components or circuits, both output and input components.
3. Power Supply, as a voltage provider for components or circuits connected to Arduino.
   The Arduino Mega 2560 microcontroller is shown in figure 3.
2.3. *Labview*

Labview is software for process and visualization in the fields of data acquisition, instrumentation control, industrial automation [4]. Labview has several sections including:

1. Labview front panel.
   Is a place for users to create user interfaces. Shown in figure 4.

   ![Figure 4. Front panel LabVIEW.](image)

2. Labview block diagram
   The programming language used by Labview is shown in figure 5.

   ![Figure 5. Labview block diagram.](image)
3. Labview control palette
In the palette control in figure 6, there are controls and indicators for creating a user interface.

![Figure 6. Labview control palette.](image)

4. Labview function palette
The function palette in Figure 7 contains functions and constants that the user uses to construct a block diagram.

![Figure 7. The function of the LabVIEW palette.](image)

2.4. Motor Servo
Servo motor is used to determine the angular position of the motor output shaft. Servo motors have advantages namely, high efficiency, strong torque, low noise, and large power density [5]. Servo motors can rotate at 0 to 360 degrees, so as to support heavy enough loads.
2.5. Valve
Valve to control the flow of a fluidized gas by opening or closing part of the flow path. Ball Valve can withstand pressures up to 10,000 Psi and temperatures around 200 degrees Celsius. The ball valve is shown in Figure 9.

2.6. Flow meter
Flow meter to determine the flow of material in a path, including the speed of flow, and the total mass or volume of material flowing in a certain period [7].
3. **Research methods**

The stages of the study are shown in figure 11.

![Figure 11. Research flow.](image-url)
The control diagram is shown in figure 12.

**Figure 12.** Diagram of the control circuit.

4. Results and discussion
Servo motor angle settings are programmed using Labview 2018. Connectivity programs use Linx to communicate with the Arduino Mega 2560 microcontroller. Each block diagram is made as 4 angles of servo motor angle settings using analog channels 3, 5, 6, and 9. Com 3 for serial ports. The link between the microcontroller and the computer uses USB. The angle magnitude of the servo motor is set at $0^\circ$ with a PWM frequency value of 500 Hz. At an angle of $180^\circ$ using a PWM frequency value of 2300 Hz.

5. Gas flow measurement results
Measurements of the argon, acetylene, and propylene gas flow rates are shown in tables 1, 2 and 3.

| Table 1. Results of argon gas flow measurements using valve 1. |
|-----------------------------------------------|
| NO  | Valve angle | Gas Flow (LPM) |
|-----|-------------|----------------|
| 1   | 25          | 0              |
| 2   | 26          | 2,5            |
| 3   | 27          | 3              |
| 4   | 28          | 3,25           |
| 5   | 29          | 4,75           |
| 6   | 30          | 5,5            |
| 7   | 31          | 6              |
| 8   | 32          | 6,2            |
| 9   | 33          | 6,3            |
| 10  | 34          | 7,5            |
| 11  | 35          | 8,4            |

**Figure 13.** Graph of argon gas flow using valve 1.
In Table 1, the gas flow starts to be seen at an angle of 26\(^0\) with an amount of 2.5 LPM and at a maximum angle of 35\(^0\) of 8.4 LPM. The amount of gas flow increases with increasing valve angle with an average increase in argon gas flow of 0.76 LPM. The measurement of argon gas flow is shown in the graph of Figure 13, which obtained the value of \(y = 0.7168x + 0.5427\) and the value of \(R^2 = 0.9416\). The \(y\) value indicates the argon gas flow rate and \(x\) indicates the valve angle change.

Table 2 shows the flow of gas starting to be seen at an angle of 42\(^0\) with an amount of 2.5 LPM and a maximum at an angle of 51\(^0\) of 6.5 LPM. The amount of gas flow increases with increasing valve angle. The average increase in acetylene gas flow was 0.59 LPM. The graph of the acetylene gas flow measurement in Figure 14 shows the value of \(y = 0.5136x + 1.5773\) and \(R^2 = 0.7863\). The \(y\) value indicates the argon gas flow rate and \(x\) indicates the valve angle change.

Table 3 shows the gas flow seen at an angle of 42\(^0\) with an amount of 2.5 LPM and a maximum at an angle of 46\(^0\) of 0.6 LPM. The amount of gas flow increases with an increasing valve angle with an average propelin gas flow increase of 0.55 LPM. The graph of the measurement of propellant gas flow

| NO | Valve Angle | Gas Flow (LPM) |
|----|-------------|----------------|
| 1  | 41          | 0              |
| 2  | 42          | 2.5            |
| 3  | 43          | 4              |
| 4  | 44          | 4.5            |
| 5  | 45          | 5              |
| 6  | 46          | 5.25           |
| 7  | 47          | 5.5            |
| 8  | 48          | 5.75           |
| 9  | 49          | 6              |
| 10 | 50          | 6.25           |
| 11 | 51          | 6.5            |

Figure 15. Graph of propelin gas flow using valve 3.
is shown in Figure 15, the known value of \( y = 0.5373x + 1.31 \) and the value of \( R^2 = 0.7901 \). Where the \( y \) value indicates the argon gas flow rate and \( x \) indicates the valve angle change. Retrieval of the flow rate data of argon, astelin, and propelin gas by adjusting the magnitude of valve 1, valve 2 and valve 3 through the LabVIEW program on the computer. In the data, the turbulence of gas flow occurs due to the difference in gas pressure from the cylinder to the valve with the gas pressure from the valve to the flow meter.

From the results of measurements of airflow and gas flow shows a difference in both the flow pattern and the value of the flow rate that can be seen from the graph of measurement of air and gas flow. Factors that cause these differences are the effects of large and small air and gas pressure at the time of measurement. The greater the air and gas pressure, the greater the amount of flow (flow rate) that comes out with each change in the valve angle.

The squared regression value \( (R^2) \) from the measurement of valve 1, valve 2, valve 3 and valve 4 airflow is 0.9682. While the regression value from the measurement of argon, acetylene and propelin gas flow is 0.9416; 0.7901; 0.7863. The linearity of gas flow with a regression value of 0.7901 and 0.7863 can be said to be non-linear, what can be done so that the gas flow can be linear by increasing the gas flow pressure so that the flow rate increases, and improving the angular deviation that occurs when the servo motor moves the valve.

6. Conclusion
A gas flow control has been made at the Fluidized-Bed Chemical Vapor Deposition facility using LabVIEW to control the gas flow rate, which is used to make the TRISO coating. The system is designed to obtain an appropriate coating, with Arduino to control the servo motor that regulates the gas valve, but the gas flow rate has not yet been obtained based on changes in valve angle. Although the control system can work according to the program, the precision of servo angle rotation with the valve is not precise due to the angle division distance of the acrylic knob valve player. The results obtained valve can rotate from a range of 0 degrees to 180 degrees, with the addition of 0.5 degrees per step.

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