

Flow vs. Cascaded Pressure Control in Multi-Train Sulfur Recovery Units of Jafurah Project¹

Nasser Mohammed Altamimi

*Master of Science in Electrical Engineering, Control Systems
Rochester Institute of Technology (RIT), New York, USA*

Abstract

This paper presents a comparative study of control strategies applied in multi-train Sulfur Recovery Units (SRUs) that share a common acid gas header. The focus is on the practical implementation and operational behavior of fixed flow control and cascaded pressure control, particularly in systems with three or more SRU trains. The study outlines configurations where the majority of trains operate under flow control while one train is assigned to cascaded pressure control to manage header pressure fluctuations. Detailed procedures for tuning, Distributed Control System (DCS) integration, and system response during normal and upset conditions are provided. The paper also examines the two-out-of-three (2oo3) method as an alternative strategy, highlighting its structure, reliability advantages, and its impact on system performance. The study emphasizes the importance of adopting flexible control architectures, precise loop tuning, and appropriate sensor placement to maintain system stability and ensure continuous, reliable operation in multi-train SRU environments.

Keywords: *Acid Gas, Control, Methods, Sulfur Recovery Unit, Setpoints, Flow, Cascaded Pressure, Instrumentation, Gas Plant, Header, Train, Valves,*

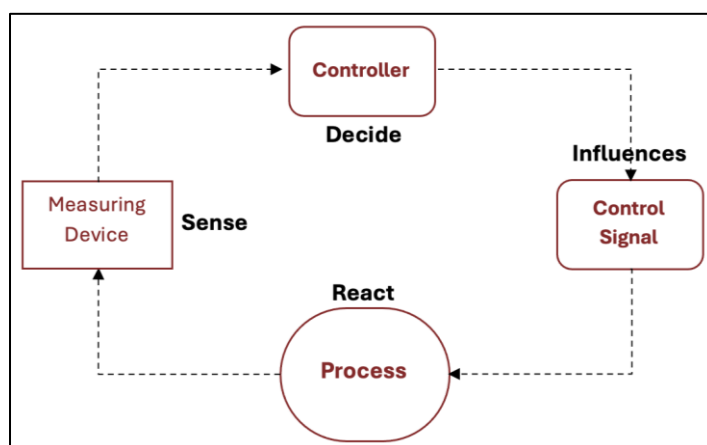
1. Introduction

Sulfur recovery unit is a critical component in gas processing plants to convert hydrogen sulfide-rich acid gas streams into elemental sulfur ensuring environmental compliance and efficient gas treatment. The Claus process is the primary industrial method used for

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this purpose, and its effective operation relies heavily on stable control strategies within Sulphur Recovery Units (SRUs). Maintaining header pressure stability and effective load distribution across multiple SRU trains is essential to ensure process reliability. This paper evaluates flow and pressure–flow cascade control strategies across systems with three or more trains, emphasizing the operational implications and control requirements in both standard and expanded multi-train configurations with the objective of enhancing process stability, system reliability, and operational consistency.

2. Control Strategies



Control strategies have evolved over decades, starting from simple manual adjustments to the advanced automated systems widely used in modern industrial plants. The development of proportional-integral-derivative (PID) controllers and the integration of Distributed Control Systems (DCS) have significantly improved precision, response time, and process stability. The “Proportional” part of PID responds in proportion to the error, the “Integral” part considers the accumulation of past errors, and the “Derivative” part predicts future errors based on the rate of change. Combined, these three components help the controller maintain the desired setpoint with high accuracy. In the upcoming sections, key control strategies commonly applied in Sulfur Recovery Units (SRUs) will be presented, including flow control, pressure control, cascaded pressure control, and alternative methods such as the two-out-of-three (2oo3) strategy.

Each strategy will be explained with its practical application and system response characteristics. The selection of the appropriate control strategy in industrial projects is typically determined by process engineers and control system specialists. This decision

is based on several factors, including system configuration, process criticality, safety requirements, reliability targets, and operational flexibility. Engineering best practices and project-specific needs guide the final selection to ensure that the control system supports stable, efficient, and safe plant operation.

2.1. Flow Control

Flow control is the process of regulating the rate at which a fluid—either liquid or gas—moves through a system. This control method relies on the coordinated operation of control valves, and sensors to maintain the desired flow rate, even when system conditions such as pressure and temperature fluctuate [1]. Flow control is considered one of the fundamental methods in process automation, supporting stable operation and ensuring consistent delivery of feed across various industrial systems. By regulating the flow, this control strategy optimizes resource utilization, reduces process variability, and enhances operational efficiency. Flow control is widely adopted across multiple industries, including chemical processing, oil and gas, and manufacturing, due to its simplicity and proven effectiveness in maintaining steady system performance [2]. However, flow control has certain limitations. In complex processes where pressure variations significantly influence system behavior, flow control alone may not be sufficient. In these cases, more advanced methods, such as cascaded pressure control, become necessary to achieve precise system stability. Flow control is often sufficient in simpler applications where pressure fluctuations have minimal impact on system stability. Examples include basic liquid transfer operations or certain water treatment processes, where maintaining a steady flow rate ensures process consistency without the need for additional control layers.

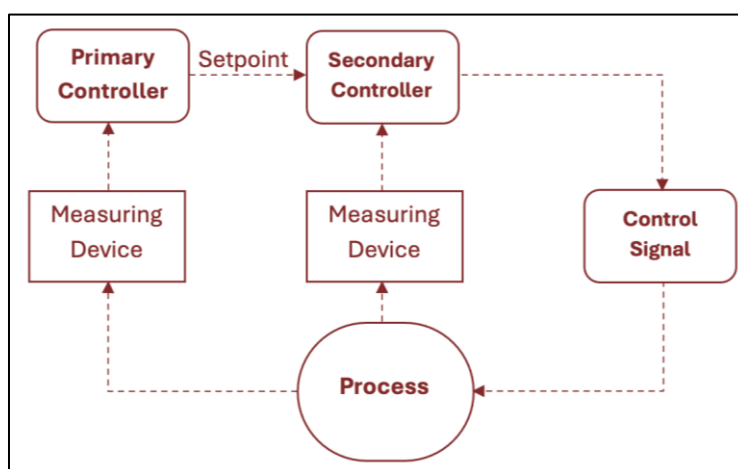
2.2. Pressure Control

Pressure control valves are vital in refinery operations, ensuring the accurate delivery of gases and liquids when properly configured and integrated [3]. Moreover, it is a key method used in process automation to maintain a stable pressure level within a system. One of its main advantages is its ability to ensure the safe and efficient operation of equipment by preventing pressure fluctuations that could lead to mechanical stress or potential safety hazards. This control method is particularly effective in processes where maintaining a specific pressure is crucial for product quality and consistency, such as in chemical reactions or gas processing.

However, pressure control also has its limitations. It may not always respond prompt enough to sudden changes in flow rates, which can lead to inefficiencies or instability in certain dynamic systems. In such cases, relying solely on pressure control might not be sufficient, and additional control strategies, like cascaded control, are needed to achieve better precision.

By integrating pressure control with other methods, like flow control, in a cascaded setup, it is possible to compensate for these limitations. This combination allows for more responsive and stable process control, ensuring that both flow and pressure are maintained within optimal ranges.

2.3. Cascaded Pressure Control



To cascade controllers means to link the output of one controller directly to the setpoint of another, where each controller monitors a separate parameter of the same process. The first controller, often referred to as the primary (the master), effectively “instructs” the second controller, known as the secondary (the slave), by sending a remote setpoint signal [4]. Cascaded pressure control is an advanced method that integrates both flow control and pressure control to achieve precise regulation of gases and liquids in industrial processes. Cascade pressure control improves system robustness by using a fast inner loop—usually flow control—to buffer disturbances before they affect the slower outer pressure loop [5]. Using this approach, a primary controller manages the overall pressure setpoint, while a secondary controller adjusts the flow to maintain that pressure. This dual-

layer approach allows for more stable and responsive control, especially when dealing with varying conditions and setpoint changes. By leveraging the strengths of both control methods, cascaded pressure control enhances process efficiency and accuracy. It provides an effective method to manage flow and address process fluctuations during receiver feeding.

While there are limitations, such as the complexity of setup and the need for careful adjustment, these challenges are manageable with proper integration and maintenance. By quickly adapting to changes in pressure and flow, this method helps protect equipment and, more importantly, the people who operate it. In essence, cascaded pressure control helps create a smoother, safer, and more efficient process, benefiting both the operation and the people behind it. Overall, this method has proven highly successful in optimizing the control of gas flows in complex industrial environments.

3. Sulfur Recovery Unit Feed Turbulence

Sulfur Recovery Unit (SRU) is a critical component in refineries and gas processing plants. Its primary function is to recover sulfur from hydrogen sulfide (H₂S) and other sulfur-containing gases that are byproducts of processing crude oil and natural gas. The recovered sulfur is primarily used in the production of sulfuric acid, which is one of the most important industrial chemicals. Sulfuric acid is extensively used in manufacturing phosphate fertilizers, which are essential for agriculture. It's also crucial in petroleum refining to remove impurities from crude oil and in mineral processing to extract metals.

The SRU typically uses a process known as the Claus process, where H₂S is converted into elemental sulfur through a series of catalytic reactions. The SRU plays a vital role in reducing emissions and ensuring environmental compliance.

Managing feed gas flow into SRUs without modern control strategies introduces instability and reduced recovery efficiency [6]. While the target is assuring a steady supply, the header pressure is prone to large fluctuations during load changes. When all SRU trains operate in fixed flow control mode, applying pressure–flow cascaded control to at least one train can stabilize header pressure and absorb system disturbances. Upcoming sections will explore the control of flow feeding Sulfur Recovery Unit (SRU) that is supplied by a dedicated header which receive acid gas from the Acid Gas Recovery Unit (AGRU). Through the header, SRU is ensured to consistently fed with the necessary gas

to carry out sulfur recovery efficiently. The proposed configuration will examine how cascaded pressure method is introduced to control multi-trained SRUs feeder, its response during upset situations, and proposal of alternative control strategies that can be applied to the SRU's performance under various operating conditions.

3.1. Cascaded Pressure in SRU System

In the following system, the allocation of flow control versus cascaded pressure control is designed to remain consistent, irrespective of the total number of trains, whether that is 3, 4, or more. While the distribution between flow control and cascaded pressure control across multiple trains is not governed by a fixed standard or universal ratio, this selection is highly dependent on the plant's specific design, process configuration, and operational objectives. Engineering best practices and process stability considerations typically guide this decision. Commonly, the system is designed with the majority of trains operating under flow control, while one or a limited number of trains are assigned cascaded pressure control to maintain system pressure and absorb process fluctuations. The strategy employed here is to designate one train to operate under cascaded pressure control, while the remaining trains ($n-1$) are assigned to flow control only.

Eq.1: The number of flow-controlled trains (FC) is calculated as $FC = n - 1$, where n represents the total number of SRU trains in the operation

$$FC = n - 1$$

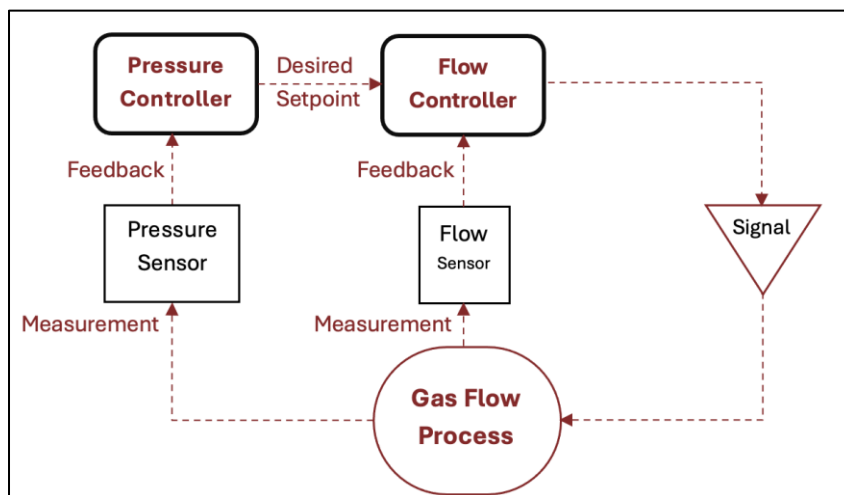
This approach ensures that the majority of the trains maintain a stable and consistent flow, while the single train dedicated to cascaded pressure control can precisely adjust the system's pressure and respond to any fluctuations. By structuring the system in this manner, a balanced and efficient operation is achieved to enhance overall control performance and system stability. This method also underscores that the specific number of trains does not alter the fundamental philosophy of the control strategy, making it adaptable and scalable.

3.1.1. Integration and Operation

Cascaded pressure control operates as a two-level control method, seamlessly integrating into a Distributed Control System (DCS). In this setup, a primary controller

determines the desired pressure setpoint, while a secondary controller adjust the flow to achieve and maintain that pressure. This combination of automation and human oversight ensures a dynamic and flexible approach to process control. Operators monitor system performance and can adjust setpoints as required to maintain process stability within the automated control framework. Although this approach might seem complex, the integration into the DCS streamlines operations, making it easier for operators to manage. This dual-layer control not only enhances safety and efficiency but also provides a reliable way to handle the complexities of industrial processes.

3.1.2. Normal vs. Upset Conditions



In the provided illustration, a cascaded control system is adapted for a gas plant environment. The “Primary Pressure Controller” establishes the desired pressure setpoint for the system. This setpoint is communicated to the “Flow Controller,” which modulates the gas flow to align with that pressure requirement. The “Gas Flow Process” symbolizes the actual regulation and movement of gas within the system. Continuous feedback is provided by the “Pressure Sensor” and the “Flow Sensor,” which measure the respective variables and relay this information back to their controllers. This system ensures that pressure stability is maintained and that the gas flow is meticulously controlled, thereby supporting optimal operating conditions. In the event of a disturbance or upset in the system, the cascaded control structure provides a fast and reliable response to maintain process stability. The system relies on continuous feedback from sensors that promptly detect deviations from the setpoints. The inner loop, managed by the flow controller

(typically a fast-responding PID loop), is the first to react by adjusting the gas flow rate to correct the immediate disturbance. The inner PID (managed by the flow controller) must be properly tuned with aggressive settings—higher proportional and derivative gains—to allow rapid compensation for short-term fluctuations without causing oscillations. If the correction by the inner loop is insufficient, the outer loop (the pressure controller) intervenes. The pressure controller adjusts the flow setpoint provided to the inner loop, driving the process back toward the desired pressure target. The outer PID is tuned with more conservative parameters to ensure a slower, more stable response that complements the fast inner loop. This tuning hierarchy is critical: the inner loop must be at least 3 to 5 times faster than the outer loop to prevent loop interaction and instability.

3.1.3. Cascaded Pressure Check Sequence

According to Control Automation Publication and Community [7], the typical methodical sequence for implementing and maintaining cascaded pressure control involves the following steps:

1. Inner Loop Tuning:

- I. Isolate the flow controller.
- II. Perform step tests to identify system dynamics.
- III. Apply aggressive PID settings to ensure quick response without overshooting.

2. Outer Loop Tuning:

- I. Activate the pressure controller after stabilizing the inner loop.
- II. Perform step changes in pressure setpoint while monitoring flow loop performance.
- III. Apply conservative PID tuning to allow the pressure controller to make slow, stable adjustments.

3. Loop Interaction Check:

- I. Validate that the inner loop responds significantly faster than the outer loop.
- II. Confirm that the pressure setpoint changes drive flow adjustments smoothly without causing hunting or oscillations.

4. DCS Integration:

- I. Ensure both loops are properly linked in the Distributed Control System (DCS).
- II. Configure alarms, override conditions, and fail-safe modes.

5. Upset Management Testing:

- I. Simulate disturbances to verify that the flow controller reacts immediately.
- II. Confirm that the pressure controller only intervenes when the inner loop cannot fully stabilize the system.

3.2 Alternative: 2oo3 in SRU

The two-out-of-three method is a control strategy that enhances reliability by using redundancy. In this approach, three sensors measure the same parameter, and the system relies on the majority reading to make decisions. This ensures that even if one sensor fails or gives an inaccurate reading, the system continues to operate correctly by trusting the other two sensors. The two-out-of-three voting architecture enhances measurement reliability by mitigating the impact of single-sensor failures [8]. In a scenario of three SRU trains, each train would be equipped with three sensors monitoring the same variable, and each train would use a flow controller. This means that if any one sensor on a train gives a faulty reading, the system will still function correctly by relying on the other two sensors. This setup is cost-effective because it reduces the need for more complex control strategies like cascaded pressure control. It also simplifies the overall system, making it easier to maintain and operate. The advantage is that it's reliable and straightforward, reducing complexity and potential points of failure. However, the 2oo3 method may not provide the same level of precision and responsiveness achieved with cascaded pressure control systems. Overall, this approach prioritizes reliability and operational simplicity, making it a practical option in systems where fine pressure regulation is not the primary concern.

4. Conclusion

This paper has explored the various control strategies for multi-train Sulfur Recovery Units (SRUs), specifically focusing on the implementation and operational differences between flow control, pressure control, and cascaded pressure control. By comparing

these methods, it has been shown that each strategy has distinct advantages depending on the specific requirements of the SRU configuration.

Flow control has been highlighted for its simplicity and reliability in maintaining consistent feed rates, making it a suitable choice for processes where pressure variations are minimal. Pressure control, on the other hand, ensures that systems maintain stable pressure levels, which is crucial for process safety and equipment protection. Cascaded pressure control has been demonstrated as an effective approach for managing complex systems, allowing for precise control and enhanced stability by combining both flow and pressure regulation.

The study also addressed the two-out-of-three (2oo3) method as a reliable alternative, enhancing system redundancy and ensuring operational continuity. The findings underscore the importance of selecting a control strategy that aligns with the specific process requirements, system configuration, and operational goals. In conclusion, the choice of control strategy in multi-train SRU systems plays a critical role in ensuring process stability, safety, and efficiency. Future studies should investigate the application of advanced supervisory control, machine learning, and predictive maintenance technologies to further optimize SRU performance.

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About the Author



Nasser Altamimi

Kingdom of Saudi Arabia



Nasser Altamimi is an Associate Engineer in the Jafurah Gas Project, specializing in control and instrumentation systems. He is part of the Control and Instrumentation team and serves as the champion of the Central Control Building and the Process Interface Building for the Sulfur Recovery Unit Train. Nasser holds a Bachelor's degree in Electrical Engineering and a Master's of science in Electrical Engineering with a focus on Control Systems and Instrumentation from Rochester Institute of Technology, graduating in 2019. He has five years of industry experience, starting his career as an Energy Efficiency Engineer at the Ministry of Commerce before joining the Jafurah Gas Project in 2022. He holds NEBOSH and OSHA certifications and is a member of the Saudi Council of Engineers.

He can be contacted at natamimi1@gmail.com