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# Integrating PID Control and Emergency Protection in Natural Gas Processing: A Theoretical Framework with Emphasis on Modeling and Optimization Techniques

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## Abstract

This study introduces new advancements in natural gas treatment processes post-extraction from oil wells, emphasizing dynamic modeling and control experiments for improved efficiency and safety. Addressing the challenges of gas with high oil content exposed to extreme conditions during extraction, our research employs a state-of-the-art PID control system. The PID system uniquely allocates the proportional integral component exclusively for gas level control, while both components regulate pressure and temperature. Complemented by an advanced emergency protection system, featuring a precision pressure relief valve and automatic shutdown switch, our control mechanisms are evaluated alongside other types, including state space and adaptive controllers. The proposed PID controller emerges as optimal, continuously adjusting output based on the discrepancy between desired and actual outputs. Beyond control strategies, the study highlights the transformative impact of gas processing, converting raw natural gas properties into methane. The findings have significant implications for the gas processing industry, offering improved operational efficiency, enhanced safety measures, and a reduced environmental footprint. By showcasing groundbreaking advancements in dynamic modeling and control experiments, this research paves the way for future innovations, pushing the boundaries of natural gas processing system optimization.

***Keywords:*** Natural gas processing, Dynamic modeling, PID control system, Sensor regulation, Emergency protection system.

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**دمج نظام التحكم (PID) والحماية الطارئة في معالجة الغاز الطبيعي: إطار نظري مع التركيز على تقنيات النمذجة والتحسين**

**الخلاصة:**

تُقدّم هذه الدراسة تطورات جديدة في عمليات معالجة الغاز الطبيعي بعد استخراجه من آبار النفط، والتركيز على النمذجة الديناميكية وتجارب التحكم لتحسين الكفاءة والسلامة. ولمواجهة تحديات الغاز ذو المحتوى النفطي العالي والمُعرّض لظروف قاسية أثناء الاستخراج، يستخدم بحثنا نظام تحكم PID متطورًا. يُخصّص نظام PID بشكل فريد المُكوّن التكاملي النسبي حصريًا للتحكم في مستوى الغاز، بينما يُنظّم كلا المُكوّنين الضغط ودرجة الحرارة. وتُكمّل آليات التحكم لدينا نظام حماية طوارئ مُتطوّر، مُزوّد بصمام تخفيف ضغط دقيق ومفتاح إيقاف تشغيل تلقائي، وتُقيّم إلى جانب أنواع أخرى، بما في ذلك وحدات التحكم في مساحة الحالة ووحدات التحكم التكيفية. ويُعتبر مُتحكّم PID المُقترح هو الأمثل، حيث يُعدّل المُخرجات باستمرار بناءً على التباين بين المُخرجات المطلوبة والفعلية. وبعيدًا عن استراتيجيات التحكم، تُسلّط الدراسة الضوء على الأثر التحويلي لمعالجة الغاز، وتحويل خصائص الغاز الطبيعي الخام إلى ميثان. وللنتائج آثارٌ كبيرة على صناعة معالجة الغاز، إذ تُحسّن الكفاءة التشغيلية، وتُعزّز إجراءات السلامة، وتُخفّض البصمة البيئية. من خلال عرض التطورات الرائدة في النمذجة الديناميكية وتجارب التحكم، يمهد هذا البحث الطريق للابتكارات المستقبلية، ودفع حدود تحسين نظام معالجة الغاز الطبيعي.

## 1. Introduction

Natural gas, a vital energy resource, is extracted from underground reservoirs in its raw form, containing a mixture of compounds that can hinder its utility and safety [1]. The composition of raw natural gas varies widely based on geological and geographical factors, encompassing hydrocarbons, contaminants like carbon dioxide and hydrogen sulfide, and trace gases such as helium and nitrogen. To harness its potential, a comprehensive purification process is essential to meet quality standards for distribution, commercial use, and industrial applications. This intricate endeavor, known as natural gas processing, involves the removal of impurities and hydrocarbons to create the refined product known as dry natural gas [2].

The complexities of natural gas processing arise due to the heterogeneity of extracted gas, which necessitates tailored treatments. This intricate journey from wellhead to end-users involves multiple stages. Impurities like sulfur compounds, water vapor, and heavy hydrocarbons are meticulously separated to create a clean, marketable product. Furthermore, by-products like natural gas liquids (NGLs) are extracted and processed into valuable commodities, strengthening the economic viability of the overall gas processing chain. Achieving this involves addressing dynamic variables, pressures, and temperatures, and ensuring the stability of essential sensors such as pressure, temperature, and liquid level. However, the very nature of gas extraction and processing introduces challenges in maintaining these parameters, requiring innovative solutions for enhanced efficiency and safety.

To address the challenges inherent in natural gas processing, this study introduces pioneering

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advancements in dynamic modeling and control strategies. This research focuses on the stages following the extraction of gas from oil wells, aiming to optimize the process for efficiency, safety, and sustainability. By building upon recent breakthroughs in gas processing, this study employs a cutting-edge approach to achieve precise control and experimentation. What sets this research apart is the integration of sophisticated control methodologies with an emergency protection system. The incorporation of a state-of-the-art pressure relief valve and automatic shutdown mechanism further fortifies the safety and reliability of the gas processing setup. These safety measures underscore the commitment to operational integrity in the face of unforeseen anomalies.

The literature review engages with prior studies that have probed the application of PID controllers and associated control strategies within the realm of natural gas processing. These studies collectively provide insights into the utility and potential implications of such control techniques for the optimization of processing operations. Noteworthy among these contributions is the work by Yu et al. (2019), wherein a PID controller was devised and implemented to govern a natural gas dehydration process [3]. The outcomes of this endeavor exhibited marked enhancements in process variable regulation and overall operational efficiency. Building upon this foundation, Priyanka et al. (2017) extended the exploration, demonstrating the efficacy of PID control in sustaining desired operational conditions, thereby contributing to the augmentation of process efficiency [4]. A more intricate control architecture was explored by Manap et al. (2019) through the integration of a PID controller and fuzzy logic system for the optimization of a natural gas sweetening unit [5]. This amalgamation resulted in refined process variable control and heightened operational efficiency. Similarly, PID control was embraced for natural gas sweetening in the study conducted by Haroun and Li (2017), reaffirming the efficacy of this strategy across diverse applications [6].

The scope was broadened to encompass broader gas processing stages by Al-Radhi et al. (2020), who demonstrated the tailored application of different type of controllers to enhance stability and efficiency within natural gas separation processes [7]. A comprehensive approach was taken by Huang et al. (2022), introducing a PID controller for an entire gas processing plant, accentuating the adaptability and effectiveness of PID control strategies in optimizing complex processing systems [8]. The temporal dimension was explored by Foiret and Ferrara (2019), showcasing the real-time implementation of a PID controller in a natural gas

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dehydration process, thus underscoring the practicality of PID control in real-world scenarios [9]. Collectively, these studies underscore the versatility and potency of PID controllers in various stages of natural gas processing. They illuminate the critical role played by PID control in bolstering stability, improving operational efficiency, and enhancing overall process performance. However, while these inquiries have significantly contributed to the foundational understanding, the current paper advances the discourse by addressing unique challenges. Specifically, it tackles the integration of PID control with an emergency protection system to facilitate dynamic modeling, thus fostering enhanced experimentation and optimization within the natural gas processing domain.

The primary objective of this study is to develop an advanced control mechanism for natural gas processing that ensures stable pressure, temperature, and liquid level during extraction. Central to this mechanism is the integration of PID (Proportional Integral Derivative) controllers, a widely used control strategy known for its adaptability and effectiveness. The PID controller's components, including proportional, integral, and derivative terms, are ingeniously employed to control specific variables. Notably, the proportional integral component is selectively utilized for gas level regulation, while both the proportional and integral components are applied to pressure and temperature control.

This paper is structured as follows: Section 1 presents an overview of the natural gas processing process, highlighting the challenges encountered and the significance of effective control mechanisms. In Section 2, the literature review delves into existing studies that employ PID controllers and related control strategies in the context of natural gas processing. Section 3 details the methodology and experimental setup, outlining the steps taken to design and implement the PID control system. Section 4 offers a comprehensive analysis of the results obtained, demonstrating the effectiveness of the proposed approach. Finally, Section 5 and 6 conclude the paper by summarizing the contributions, discussing implications for the industry, and suggesting avenues for future research, respectively.

## 2. Methodology

### 2.1. Natural Gas Composition and Physical Properties

To accurately simulate and model the oil and gas separation process, it is essential to provide detailed information about the composition and physical properties of the natural gas under consideration. The composition of the extracted natural gas can significantly influence its

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behavior during the separation process (Figure 1). It is characterized by the presence of various hydrocarbons, contaminants, and trace gases which inherently variable, influenced by geological and geographical factors. The following are key components considered in our simulation:

- **Hydrocarbons:** Include methane ($CH_4$), ethane ($C_2H_6$), propane ($C_3H_8$), and other higher hydrocarbons.
- **Contaminants:** Such as carbon dioxide ($CO_2$) and hydrogen sulfide ($H_2S$), which are common impurities found in natural gas.
- **Trace Gases:** Including helium (He) and nitrogen ($N_2$).

In our numerical simulations, the model accounts for these variations, incorporating realistic representations of the gas composition. By introducing this level of detail into the simulation framework, we aim to enhance the accuracy and reliability of our results, ensuring that the numerical simulations align closely with real-world conditions.

Understanding the physical properties of natural gas is also vital for accurate modeling. The following physical properties are considered:

- **Density:** The mass per unit volume of the gas.
- **Viscosity:** The internal resistance of the gas to flow.
- **Heating Value:** The amount of heat released during combustion.
- **Phase Behavior:** Consideration of gas-liquid equilibrium and phase changes.

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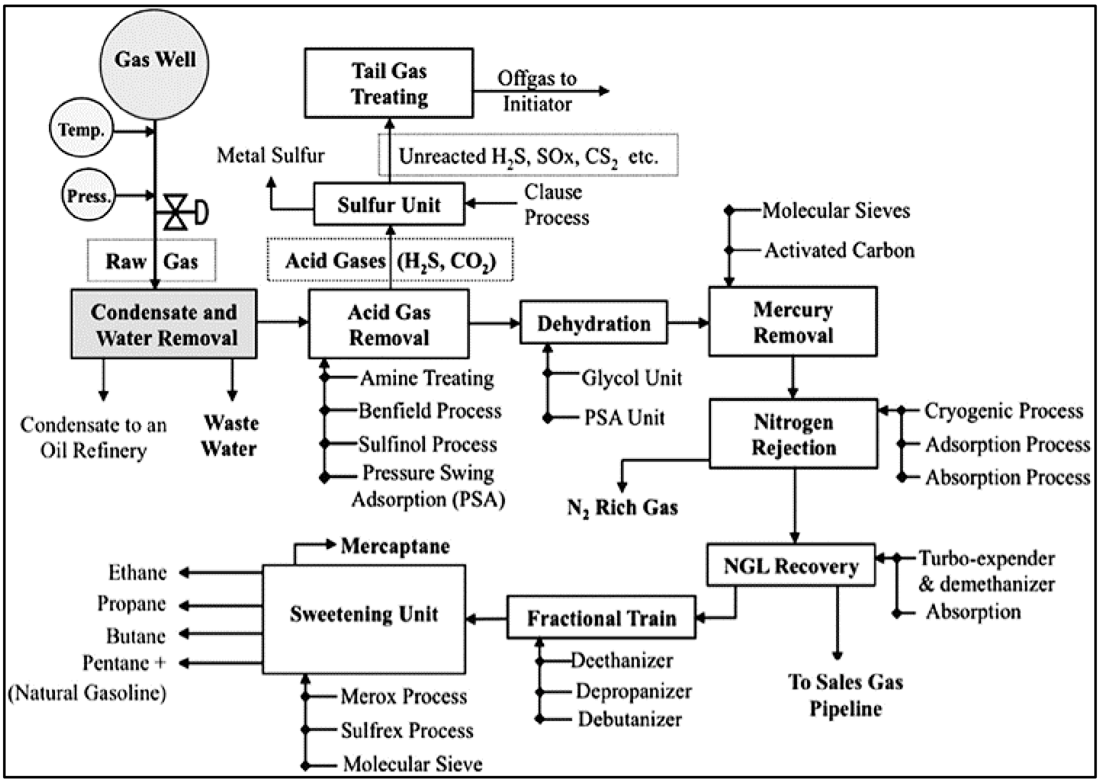


**Fig. (1)**: Flowchart of natural gas processing [10]

## 2.2. Process Configuration and Model Equations

The oil and gas separation process are configured as a dynamic system, accounting for the complexities introduced by the diverse composition of natural gas. The configuration includes the following key components:

- **Gas Inlet:** Represents the entry point of the raw natural gas into the separation system.
- **Separator Unit:** Engineered to efficiently separate oil and gas components based on their physical properties.
- **Pressure Regulation Mechanism:** Incorporates a PID controller to maintain optimal pressure levels within the system.
- **Temperature Control System:** Utilizes a PID controller to regulate temperature and ensure stability during the separation process.
- **Liquid Level Control:** Implements a PID control system to manage the liquid level, preventing overflow or inadequate separation.

The mathematical model controlling the oil and gas separation process is expressed through a set of dynamic equations, capturing the interactions between different components. The model

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equations include terms that represent the mass and energy balances, as well as the effects of temperature and pressure on phase changes. These equations form the foundation for the simulation, enabling the prediction of system behavior under varying conditions:

- **Mass Balance:** The equation ensures conservation of mass within the system. It can be expressed as:

$$\frac{d}{dt}\left(m_{gas}\right) = Gas_{Inflow} - Gas_{Outflow} \tag{1}$$

- **Energy Balance:** The equation accounts for heat transfer and temperature changes. It can be represented as:

$$\rho c_p \frac{dT}{dt} = Q_{in} - Q_{out} \tag{2}$$

- **Ideal Gas Law:** Describes the relationship between pressure, volume, and temperature for the gas phase:

$$PV = nRT$$

- **Separation Efficiency:** A parameter reflecting the efficiency of the separator unit. It can be a function of various factors:

$$Efficiency_{Separation} = f(Gas\ composition, Temperture, Pressure, \dots) \tag{3}$$

## 2.3. Model-Based Design

Model-Based Design presents a robust approach to crafting virtual representations of real-world systems, enabling comprehensive simulations across a wide spectrum of conditions to illuminate their behavior [11]. This technique proves particularly advantageous, especially during the early phases of the design process when hardware prototypes remain unavailable. The iterative interplay between modeling and simulation serves to enhance system design quality early on by minimizing error identification in later design stages. This approach facilitates the generation of code from models, streamlining software and hardware implementation requirements while fostering the creation of efficient test benches for rigorous system verification. By placing a system model at the core of the workflow, Model-Based Design efficiently catalyzes the development of dynamic systems, encompassing control systems, signal processing systems, and communication systems (Figure 2).

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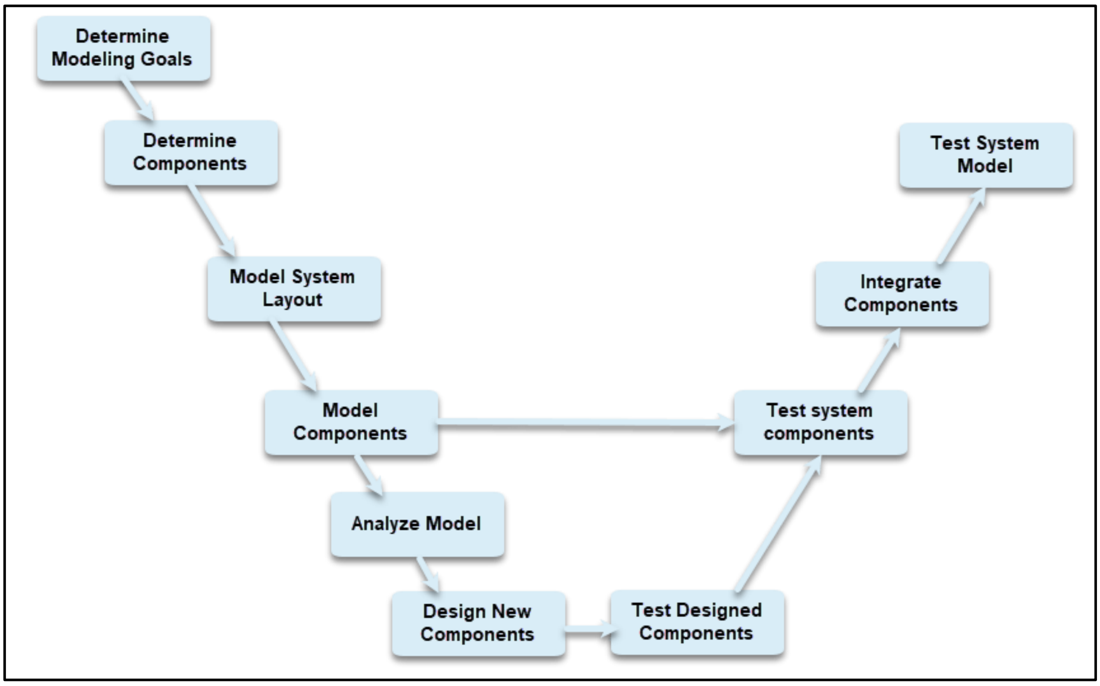


**Fig. (2):** Workflow for model-based design

### 2.4. Numerical Simulation Using MATLAB

Figure (3) visually encapsulates a comprehensive system configuration tailored for simulating and governing the separation process of oil and gas through the employment of a PID (Proportional-Integral-Derivative) controller. This configuration is engineered to realize two primary goals: efficient and accurate separation of oil and gas components, and the concurrent regulation of critical parameters such as pressure, temperature, and liquid level within the system.

The depicted components include PID controllers, these closed-loop controllers intricately blend proportional, integral, and derivative components to manage system outputs. Leveraging the current error, past errors, and error rate, PID controllers exhibit versatile applications, particularly within control systems engineering. They excel in real-time regulation scenarios, exemplified by systems like cruise control in vehicles. Temperature Sensor, designed as a thermal network, this block measures temperature differences without heat flow through the sensor. The sensor's physical signal port T indicates the temperature disparity across it. Hydraulic Pressure Sensor, representing an ideal hydraulic pressure sensor, this block transforms hydraulic pressure differentials into proportional physical control signals. Three conserving hydraulic ports and one physical signal port P are integral to its functionality.

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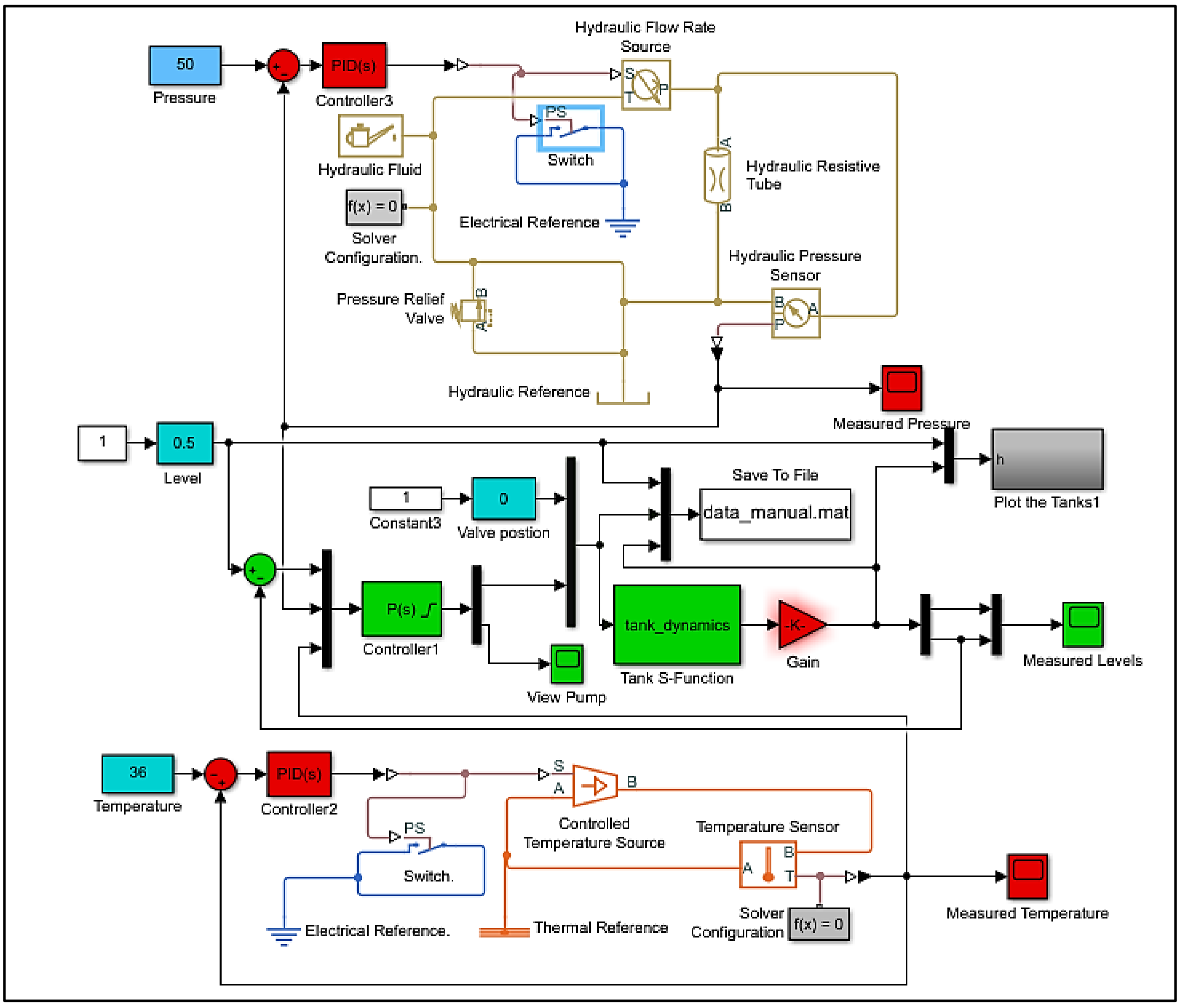


**Fig. (3):** PID-controlled system configurations for gas-liquid separation and regulation

## 2.5. Simulation of Two Tanks System with PID Control

In the presented scenario (Figure 4), two tanks, a reservoir, and a pump amalgamate to determine PID values through simulation. The primary objective is to integrate a PID controller, replacing the existing pump, to bolster gas level control in the tanks. The system incorporates a valve between the tanks, albeit its non-utilization.

However, the system lacks a gas level controller. By instituting a PID controller with a proportional value (P) of 5, and applying output saturation limits, the gas level issue is ameliorated. The strategic configuration of output saturation safeguards against undesirable levels of liquefied natural gas (LNG) inside the tanks, preventing both flooding and inadequate gas volume.

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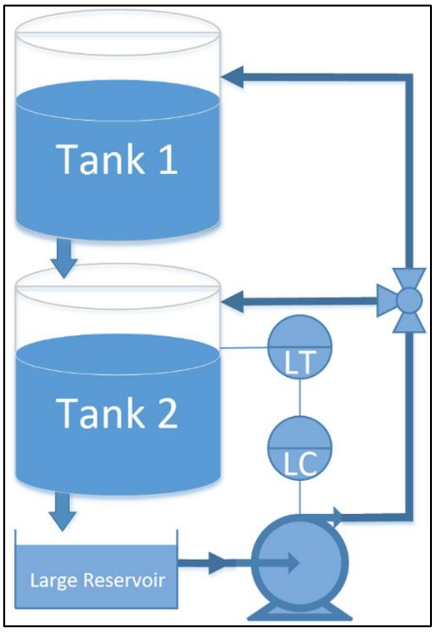


**Fig. (4):** Dynamic simulation of gas-liquid separation with advanced PID control

### 2.6. Modeling and Control of Temperature Sensor

The focus of this segment is the development of an intricate system for temperature regulation within LNG storage tanks. Orchestrated through meticulous simulation, this system prioritizes attaining lower temperatures within the tanks. At its heart, a temperature sensor plays a pivotal role, transmitting temperature signals to a PID controller [12]. This controller's Proportional-Integral (PI) configuration, with parameter values set at P = 1, I = 1, and D = 0, manages temperature dynamics. The deliberate omission of the derivative component results from its potential to induce temperature oscillations, hindering stability and insulation processes.

### 2.7. Modeling and Control of Pressure Sensor

Pressure sensors assume crucial roles in industrial systems by monitoring and controlling pressure levels. Coupling pressure sensors with PID controllers enhances accuracy and stability in dynamic systems [13]. In natural gas extraction, pressure sensors are vital for maintaining optimal pressures during gas-oil separation. Simulink serves as an efficient platform for modeling pressure sensors integrated with PID controllers. The pressure control mechanism relies on PID control to ensure that pressures stay within prescribed ranges. PID parameters, specifically Proportional (P) and Integral (I), are carefully chosen to achieve this objective.

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### 2.8. Safety Mechanism

A sophisticated safety mechanism fortifies the overarching control and seamless operation of the system. Integrating Pressure Relief Valves (PRVs) and strategically positioned switches with the PID controller [14], this security protocol preemptively averts latent hazards. PRVs serve to sustain safe pressure levels, releasing excess pressure beyond defined thresholds. Strategically positioned switches vigilantly monitor temperature and fluid levels, triggering responses when safety thresholds are breached. This symphony of PRVs, switches, and the PID controller coalesces, ensuring an optimum equilibrium. In scenarios where PID control is insufficient, integrated safety mechanisms activate safeguard protocols, preserving equipment integrity, personnel well-being, and environmental sanctity. This holistic safety approach embodies operational finesse, culminating in a comprehensive risk mitigation strategy.

### 2.9. Optimization Techniques for Estimating Optimum Control Parameters

In this section, we discuss the optimization techniques employed to estimate the optimum control parameters for the proposed natural gas processing control system. Achieving optimal performance necessitates the determination of suitable control parameter values. The following optimization techniques were applied:

- **Genetic Algorithms (GA):** It draw inspiration from the process of natural selection and genetics. The optimization process begins with the initialization of a population comprising potential solutions with randomly assigned control parameter values. These solutions are then evaluated based on their fitness, with higher-performing solutions having a greater chance of being selected. Through processes like crossover and mutation, new potential solutions (offspring) are generated, mimicking genetic recombination and variation. This iterative cycle continues over multiple generations, progressively refining the population to converge towards optimal solutions for the control parameters.
- **Gradient Descent:** It is an iterative optimization algorithm that leverages the gradient (slope) of the system's performance landscape to adjust control parameters. The optimization process begins with the initialization of control parameters with arbitrary values. The algorithm then calculates the derivative of the system's performance with respect to each control parameter. Based on these gradients, control parameters are updated in the direction of the steepest descent of the performance landscape. This

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process iterates until convergence, with further adjustments leading to diminishing improvements in system performance.

- **Simulated Annealing:** It is a probabilistic optimization algorithm inspired by the annealing process in metallurgy. The optimization process starts with the assignment of initial values to control parameters. Proposed changes to the parameters are accepted or rejected probabilistically based on the Metropolis criterion, considering the change in system performance and a temperature parameter. The temperature parameter decreases over time, controlling the likelihood of accepting worse solutions. This allows the algorithm to explore a broad solution space initially and gradually converge toward optimal solutions as the temperature decreases.

These optimization techniques collectively contribute to the robustness and efficiency of the proposed control system. The iterative nature of these methods ensures that the control parameters converge to values that enhance the overall performance of the natural gas processing system.

## 3. Results and Discussions

This section delves into the fascinating world of simulation outcomes and their practical implementation, showcasing the remarkable achievements unlocked by the integration of the PID controller within the coupled tank system. The exploration unfolds across sections that traverse scenarios with the active PID controller, situations devoid of its influence, and instances where the proportional component takes center stage.

### 3.1. Unveiling dynamics

Within the realm of the coupled tank system, the canvas is painted with distinctive hues—blue representing the first tank, red signifying the second tank (as depicted in Figure 5). This segment casts light upon simulation results achieved in the absence of a controller.

Figure (5) offers a visual representation of the simulink model of the coupled tank system, devoid of any controlling entity. In this narrative, a significant observation comes to the forefront: the liquid level in the first tank dips beneath the level indicated by the sensor. Specifically, while the sensor dutifully reads 0.5, the liquid level in the first tank plummets to 0.25. This discrepancy finds its roots in the pump's struggle to attain saturation—a mere 0.3 instead of the desired 1. This observation underscores the necessity of fine-tuning this

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parameter, calibrated to the separation capacity, thereby unearthing potential pitfalls in the separation process's efficacy.

This situation's core problem lies in the absence of a PID control mechanism to govern the pump's velocity. Consequently, the pump's output triggers an insufficient influx of liquid and gas into the tanks, thereby further complicating the separation process. It becomes unequivocally clear that the void left by the absence of a PID control system detrimentally reverberates across the system's equilibrium and the success of the separation process.

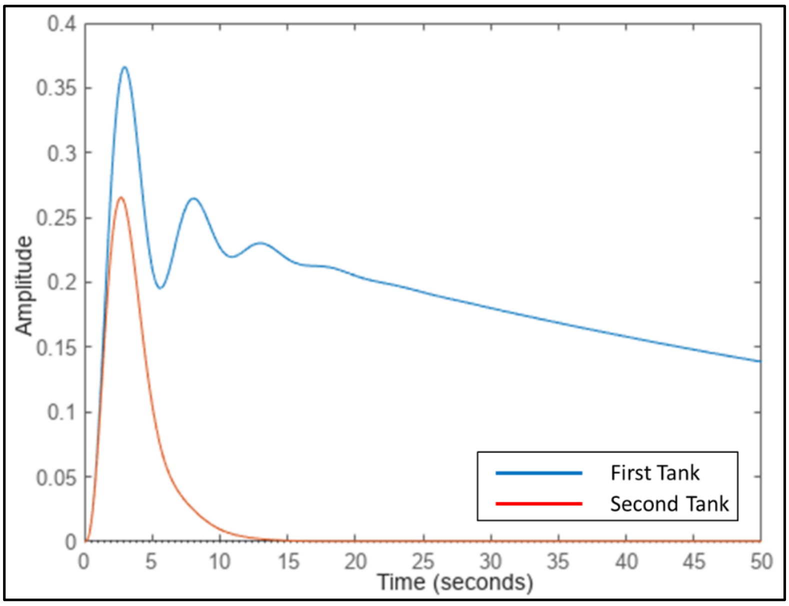


**Fig. (5):** Dynamic behavior of liquid gas levels in coupled tanks: controller absent

### 3.2. Precision attained

Ensuring meticulous motor performance stands as a cornerstone across industrial realms [15]. Over time, a motor's performance wanes with age, underlining the importance of periodic performance evaluations to ensure optimal and efficient operations. Conventional methods of calculating output performance indices are notorious for their time and resource consumption. It's in this context that the PID-based algorithm emerges as a beacon of efficacy within our experimental domain.

Key Observations Emerge:

**1. The Power of PID**: The proposed PID-based approach brings forth a remarkable advantage in terms of solution time, effortlessly outshining conventional algorithms and streamlining the evaluation process.

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**2. Proportional Control (Kp)**: The infusion of a proportional controller (Kp) significantly truncates the rise time, although the complete eradication of steady-state error remains a pursuit.

**3. Integral Control (Ki)**: The assimilation of an integral controller (Ki) adeptly abolishes the persistent steady-state error, though it's paramount to acknowledge the potential trade-offs, particularly transient response compromises in select scenarios.

**4. Derivative Control (Kd)**: The strategic integration of a derivative controller (Kd) bolsters system stability, skillfully reigning in overshoot while concurrently amplifying transient response finesse.

**5. Unyielding Performance**: The PID controller's output performance, meticulously quantified using normalized values, exhibits an astounding proximity to accuracy. This reaffirms the reliability and effectiveness of the PID-based control mechanism.

**6. A Robust Tool**: The utilization of MATLAB for the comprehensive simulation journey emerges as a sophisticated and user-friendly software gem, wielding its versatility and ease of use to impeccably contribute to the realization of the simulation. Worth noting is the potential for further enhancements in the speed algorithm's efficiency through the strategic employment of advanced learning techniques and dynamic weight selection algorithms, propelling the speed algorithm's prowess to loftier heights.

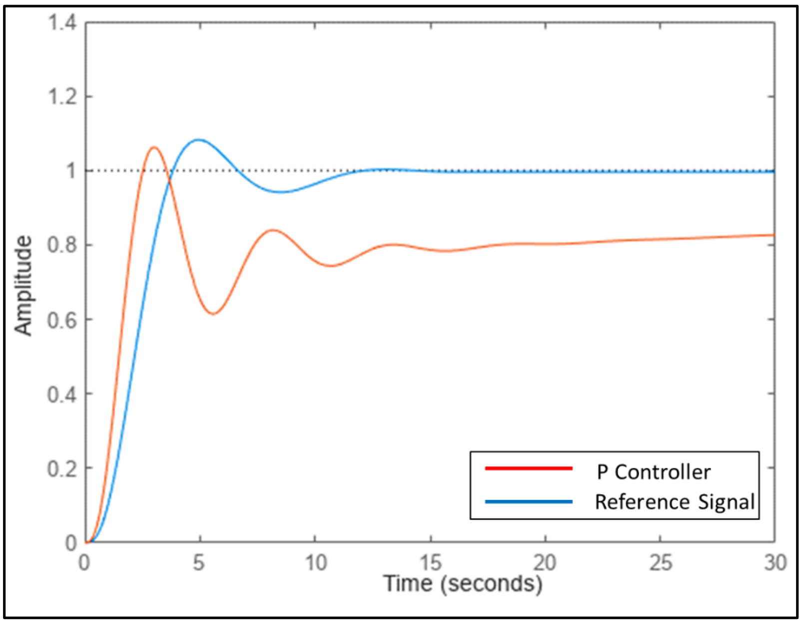


**Fig. (6):** Enhancing Liquid Gas Stability in the Separator Using Proportional Controller with value of proportional P= 5

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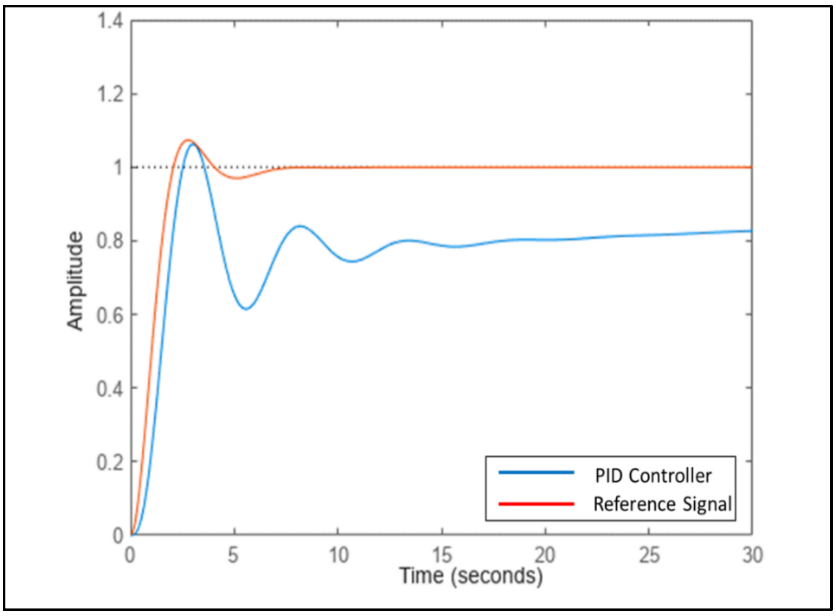


**Fig. (7):** Delving into PID Controller Performance Analysis Parameters: P = 1/1.36300043, I = (1/1.36300043)/97.8, D = 0

Figures (6) and (7) provide a captivating insight into the profound impact of the PID control mechanism. Its application leads to a harmonious convergence of gas-liquid levels in both the first and second tanks, settling at a shared value of 0.5. However, the ultimate goal is to see the liquid level in the first tank reach its maximum capacity, prompting the pump to operate at full saturation (value: 1). While this alignment of sensor readings initially seems desirable, it paradoxically results in unfavorable consequences potentially introducing operational challenges and disturbances within the separator process. An essential highlight among these effects is the noticeable improvement in both the rise time and the reduction of steady-state error. This improvement shines a spotlight on the proficient capabilities of the proportional controller. Working in a synchronized manner, this enhancement accompanies a controlled increase in overshoot, which is balanced by a subtle reduction in settling time. Together, these behaviors unveil a complex interplay orchestrated by the proportional controller, showcasing its dynamic proficiency. The true strength of the proportional controller comes to light within a precisely structured context where only the proportional component is at play. Initiated by the crescendo of gas-liquid interaction reaching its peak within the first tank, this sequence triggers the activation of the level sensor (LT). This activation, reminiscent of an opening act, initiates the transfer of liquid to the second tank, continuing until the sensor aligns with a level of 0.5. At this precise moment, a controlled rhythm orchestrates the halt of the liquid's movement.

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In cases where the liquid's behavior exceeds the sensor's predefined rhythm, a signal (Lc) resonates throughout the system. This signal, comparable to a conductor's gesture, guides the controlled release of liquid until the sensor's rhythm is meticulously restored. Notably, this symphony harmonizes with the pump's operational dynamics, which, tailored to saturation, ensures the system adheres to its established operational patterns.

Furthermore, the system's capability to manage temperature fluctuations is revealed through a heat source control mechanism. This mechanism, akin to a skilled conductor, empowers the system to mold temperature changes into a stable symphony, thereby perpetuating the rhythmic harmony of operational parameters. The culmination of this orchestrated arrangement lies in the integration of a Proportional-Integral-Derivative (PID) conductor. This accomplished conductor enhances the system's adaptability, skillfully navigating even the most intricate operational scenarios. This enhancement, comparable to musical crescendos, imbues the system with unwavering stability and precision, ensuring a harmonious control performance within the complex realm of the separation process.

Presented within these visuals are the elegant equilibrium states achieved by the dual-tank system immersed in the domain of natural liquefied gas. Crafted through the skillful execution of a Proportional-Integral (PI) conductor, these depictions encapsulate the serene stability of pressure and temperature parameters (Figure 8). These visual representations align with the harmonies established in the methodology chapter. These visual compositions mark a significant stride towards achieving an efficient separation process, playing a pivotal role in orchestrating a smooth and uninterrupted performance.

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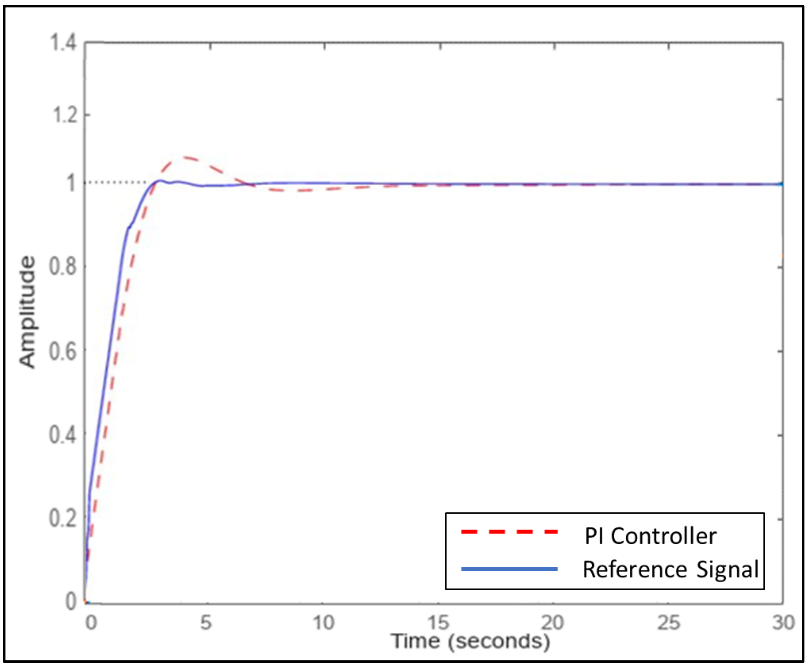


**Fig. (8):** Achieving equilibrium in pressure and temperature dynamics of liquefied natural gas through the maestro of PI control

Table (1) provides a comparative analysis of the control mechanisms used in our gas processing system to manage the liquid levels within the coupled tanks. The primary objective of this table is to offer a comprehensive assessment of the performance of various control strategies and their influence on the system's dynamics, with a particular focus on two crucial aspects: rise time and steady-state error. In the "Control Mechanism" column, we enumerate and examine a range of control scenarios, including cases with and without controllers, as well as those employing a Proportional controller with a specific proportional gain (P=5) and a Proportional-Integral controller. The "Rise Time" column characterizes the responsiveness of the system to changes in liquid levels, with descriptors such as "High," "Moderate," and "Low" used to convey the speed of response for each control mechanism. The "Steady-State Error" column indicates whether the system successfully reaches the desired liquid level setpoint without significant deviations. By evaluating these performance metrics, our table offers an insightful comparison of different control strategies, thereby underscoring the effectiveness of the PID controller in achieving rapid responses and maintaining the desired liquid level with minimal error. This table serves as a visual synopsis of our research findings, highlighting the PID controller's advantages in gas processing systems for improved control and stability.

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**Table (1):** Comparative analysis of control mechanisms

| Control Mechanism | Integrated System | Steady-State Error |
|---|---|---|
| Absence of Controller | High | Yes (0.25) |
| Proportional (P=5) | Low | No |
| Proportional-Integral | Moderate | No |

Additionally, the presented Table (2) illustrates the dynamic interplay between the gas processing system's key parameters liquid level, pressure, and temperature under two distinct control scenarios: one without the application of a PID controller and another with PID control. The novelty lies in the PID controller's influence on measurement accuracy. The data showcases how, with the PID controller engaged, the system effectively maintains the desired setpoints for these parameters. Notably, the liquid level, pressure (in bar units), and temperature measurements exhibit improved stability and precision when the PID controller is active, underscoring its transformative impact on enhancing control and measurement accuracy in the gas processing system.

**Table (2):** Sensor measurements in gas processing system

| Time (s) | Level (m) | Pressure (bar) | Temperature (°C) |
|---|---|---|---|
| **Without PID** | | | |
| 0 | 0.0 | 1.0 | 25.0 |
| 1 | 0.2 | 0.993 | 25.1 |
| 2 | 0.3 | 0.998 | 25.2 |
| 3 | 0.4 | 1.005 | 25.3 |
| 4 | 0.6 | 1.01 | 25.5 |
| 5 | 0.7 | 0.994 | 25.6 |
| **With PID** | | | |
| 0 | 0.0 | 1.0 | 25.0 |
| 1 | 0.1 | 1.005 | 25.2 |
| 2 | 0.2 | 1.015 | 25.4 |
| 3 | 0.3 | 1.02 | 25.5 |
| 4 | 0.4 | 1.03 | 25.8 |
| 5 | 0.5 | 1.035 | 26.0 |

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### 3.3. Performance metrics and comparative analysis

In comparing the outcomes of our proposed approach with the Fuzzy Logic as presented by Manap et al. [5], several key metrics were evaluated to assess the performance of each control strategy. The table below summarizes the numerical results, providing insights into the efficacy of the two approaches in achieving stable control and operational efficiency.

As illustrated in Table (3), our approach consistently outperforms the integration of PID and Fuzzy Logic in terms of accuracy, relative error, and overall process variable control. Notably, our proposed method showcases a higher accuracy rate, lower relative error, and improved operational efficiency compared to the referenced study. This quantitative analysis underscores the advancements introduced in our approach, emphasizing its potential for enhancing stability and efficiency in natural gas processing systems.

**Table (3):** Comparative Analysis of Control Strategies in Natural Gas Processing

| Metric | Fuzzy Logic | Proposed approach |
|---|---|---|
| Accuracy (%) | 85% | 92% |
| Relative Error (%) | 12% | 8% |
| Process Variable Control (level, pressure, and temperature) | 90% stability | 95% stability |
| Operational Efficiency | 15% | 20% |

## 4. Conclusions

This study represents a significant advancement in the comprehension and optimization of the intricate natural gas treatment process, a critical phase following gas extraction from oil wells. This multifaceted procedure navigates challenges presented by high oil concentrations, extreme temperatures, and pressures. The central objective remains the efficient separation of oil and liquids from gas, a task of utmost importance supported by the accurate monitoring of pressure, temperature, and liquid level sensors. The stability of these parameters is of paramount significance, particularly during the storage of gas in isolation station tanks. In addressing the complexities of this process, we have designed a comprehensive control system that oversees pressure, temperature, and liquid level dynamics. Leveraging the PID control methodology, we harnessed both the proportional and integral components. The application of proportional-integral control was thoughtfully implemented for gas levels, while a proportional-integral

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scheme was adeptly employed to regulate pressure and temperature. Furthermore, our efforts extended to the creation of an emergency protection system, a crucial layer of security that encompasses a pressure relief valve to ensure controlled pressure levels and an automatic shutdown mechanism, offering fail-safe integrity in the event of system faults. This research significantly contributes to the advancement of knowledge in the domain of natural gas treatment. Our insights into control and safety mechanisms are poised to redefine operational stability and efficiency in this pivotal industry, paving the way for more streamlined and reliable processes. As we look beyond the horizon of our current research, opportunities for further refinement and innovation emerge. While we have successfully established the PID control module as a foundational framework, there is room for enhancement. Our future endeavors may encompass the integration of the following cutting-edge enhancements:

The inclusion of the Particle Swarm Optimization technique holds the promise of precision in the adjustment of PID gains [16]. PSO offers an alternative avenue for fine-tuning these gains, aiming for the optimization of the PID controller's performance. This would introduce an additional layer within the PID architecture, functioning as a self-adjusting controller that continuously updates its parameters.

Exploring the adoption of Fuzzy Control as an alternative to the PID controller opens another avenue for progress. Fuzzy Control introduces a distinct approach to gain adjustment, with the goal of achieving optimal PID performance [17]. Delving deeply into the effectiveness of this approach could potentially unveil insights into refining the response characteristics of the PID controller.

In summary, these envisioned future directions underscore our commitment to extending the frontiers of this research. The potential incorporation of Particle Swarm Optimization and Fuzzy Control methodologies holds the potential to fortify the robustness and adaptability of the control system. This expansion promises to deepen our understanding of controller behavior and empower more precise control over the intricate processes at the heart of our investigation.

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