

Automation and supervision of an LPG extraction section: experimental control analysis

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Abstract. At the time when the oil and gas industry is facing increasingly stringent regulations, growing complexity in facilities and operations, and the pressing need to minimize shutdowns, optimization across all levels from exploration to refining, from storage to distribution, and in the modernization of facilities for new projects has become critical for a continuous development and performance enhancement. The international market demands precise handling, with transportation and distribution carried out via pipeline networks. Natural gas must meet specific quality standards, including the calorific value, C5+ content, and moisture content. To achieve specification-compliant gas, raw gas extracted from wells undergoes a series of treatment processes aimed at removing water and recovering heavy hydrocarbon fractions, such as condensates and liquefied petroleum gas (LPG). LPG is a mixture of light hydrocarbons stored in the liquid state, and derived from petroleum refining and more generally from the treatment of natural gas. Our paper focuses on automation and supervisory control of an LPG extraction unit based on a distillation process designed to separate the propane and light butane fractions from heavier hydrocarbons. We propose an approach that involves the development and implementation of a control strategy using the YOKOGAWA CENTUM Distributed Control System (DCS). Our program ensures an accurate control of the debutanizer column top temperature through a coordinated management of the reflux control loop and the iso-pentane withdrawal loop. The implemented control system enables an automatic adjustment of the operating set points, improves the process stability, reduces the operator intervention, and enhances the overall reliability and efficiency of the LPG extraction process. Our experimental analysis demonstrates the effectiveness of the proposed automation strategy under different operating conditions.

Keywords: LPG Extraction, Distributed Control System (DCS), Process Automation, Supervisory Control, PID controller.

Avtomatizacija in nadzor procesa pridobivanja utekočinjenega naftnega plina

Zaradi vse strožjih zahtev naftne in plinske industrije sta optimizacija procesov in zanesljivo delovanje naprav ključnega pomena. Zemeljski plin je treba pred distribucijo obdelati, da doseže predpisane kakovostne standarde, kar vključuje odstranjevanje vode in pridobivanje težjih ogljikovodikov, kot sta kondenzat in utekočinjeni naftni plin (LPG). V prispevku obravnavamo avtomatizacijo in nadzor naprave za pridobivanje LPG z destilacijo, pri kateri se propan in lažji butan ločujeta od težjih ogljikovodikov. Predstavljamo strategijo vodenja, razvito in izvedeno v porazdeljenem krmilnem sistemu YOKOGAWA CENTUM. Sistem zagotavlja natančno regulacijo temperature na vrhu kolone za odstranitev butana z usklajenim vodenjem povratnega toka in odvzema izopentana. Avtomatsko prilagajanje referenčnih vrednosti izboljšuje stabilnost procesa, zmanjšuje potrebo po posredovanju operaterja ter povečuje zanesljivost in učinkovitost naprave. Eksperimentalna analiza potrjuje učinkovitost predlaganega pristopa pri različnih obratovalnih pogojih.

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1 INTRODUCTION

Natural gas, a non-renewable primary energy source that is well distributed across the world, is clean and increasingly used. It has been known since antiquity, but its use became widespread especially after the Second World War. It offers numerous advantages: relative abundance, flexibility of use, and competitive pricing as a fuel. It is a mixture of gaseous components, consisting of 75% to 95% methane, a significant percentage of CO₂ and H₂O, and traces of certain metallic elements. In this raw form, it is practically unusable, so it must be processed to obtain consumable product ranges [1]-[3]. The international market requires a rigorous treatment, so that transport and distribution via natural gas pipelines comply with the imposed standards, particularly regarding the calorific value, C5+ content, and water content. To obtain "on-spec" gas, the raw gas extracted from wells undergoes a treatment process to remove water and recover the heavy hydrocarbon fractions

(condensate and LPG). The associated petroleum gases are classified as “rich” gases due to their high content of ethane, propane, butane, and other saturated hydrocarbons. These components are separated and a liquefied to produce liquefied petroleum gas (LPG) through a combination of compression, adsorption, absorption, and cooling processes [4].

In Our paper, we present an LPG extraction unit which is a distillation column designed to separate propane and light butane fractions from heavier components. It represents the final stage in the production process of pure LPG. The column receives two feed streams: a cold stream from the bottom of the debutanizer and a hot stream from the reboiler. We have developed a program to automate the temperature control and ensure a continuous supervision of this section of the process. The program implemented using the YOKOGAWA "CENTUM VP" distributed control and supervision system, which is widely employed in industrial automation. The objective of the program is to enhance the operational efficiency, improve the process stability, and ensure a precise monitoring and control of the critical temperature parameters within the unit.

2 MATERIALS AND TECHNIQUES

2.1 Operation Description of the Debutanizer

The G11-CB-32-01 debutanizer is a refluxed and reboiled distillation column equipped with 43 trays and two feed streams. The main feed enters the column at tray 28. Iso-pentane originating from the M4 separator located at the CINA CPF is transferred by the condensate export pumps (CINA 350-PA-35-05 A/B) through a dedicated 4-inch pipeline to supply the debutanizers of the three processing trains at tray level 4.

The operating pressure of the debutanizer is maintained at 17.9 barg through an overhead pressure control valve. The overhead vapor is fully condensed in the G11-GC-32 air cooler, and the resulting LPG is collected in the debutanizer reflux drum G11-VL-32-05. A portion of the condensed LPG is recycled to the top tray of the column by the reflux pumps G11-PA-32-03 A/B, while the remaining flow is routed to the LPG storage spheres 31-RD-33-01 A/B/C shared by the three processing trains.

An iso-pentane-rich side stream is withdrawn from tray 8 under flow control. This stream is subsequently cooled to 60 °C in the iso-pentane condenser G11-GC-32-03 and pumped by the iso-pentane transfer pumps G11-PA-32-04 A/B toward the LDHP oil export line.

The debutanizer reboiler G11-GA-32-06 is a kettle-type heat exchanger in which the bottom liquid from the column is partially vaporized using hot oil. The hot oil flow rate is controlled according to the temperature control scheme of a sensitive tray within the column. Under normal operating conditions, the bottom temperature is maintained at approximately 194 °C to

ensure the compliance with the condensate vapor pressure specifications. The generated vapor returns to the bottom section of the column to sustain the distillation process.

The non-vaporized liquid leaving the reboiler constitutes the condensate product of the debutanizer. The condensate is then cooled to 60 °C in the refrigerant exchanger G11-GC-32-04 before being directed to the common on-specification condensate header for storage and export. In the event that the condensate does not satisfy the required vapor pressure specifications, it is automatically diverted to an off-specification condensate header and transferred to a dedicated storage tank for a further degassing treatment [5]-[8].

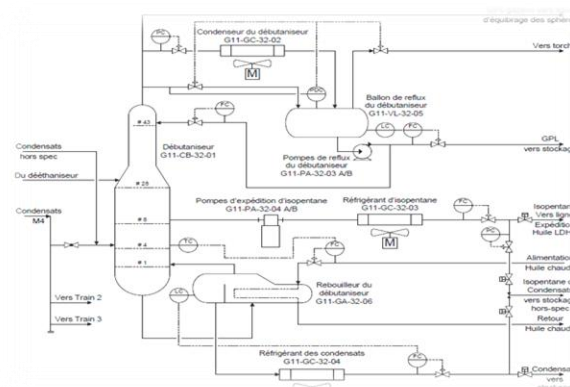


Figure 1. LPG extraction unit flow diagram.

Table 1. Main operating parameters of the G11-CB-32-01 debutanizer.

Equipment	G11-CB-32-01	
Service	Debutanizer	
Type	Tray Column	
	Top	Bottom
Operating temperature (°C)	73	194
Operating pressure (barg)	17.9	18.31
Diameter (mm)	2200	3200
Height (mm)	35350	

2.2 Issues to be solved

2.2.1 Controlling the flow of the reflux to the debutanizer

The flow rate of the debutanizer is measured by the flow transmitter 32-FT-01028, located on the reflux line, and controlled by the flow controller 32-FIC-01028 by action on the flow control valve 32-FV -01,028. The control objective is to maintain a constant reflux flow toward the Debutanizer.

When the flow is above the set point, the controller closes the control valve. When the flow is below the set point, the controller opens the valve. The 32-FIC-01028 reflux loop is designed to maintain a constant reflux flow for cooling the column head, yet, the loop is subject to

several operator set-point changes or may be put in a manual mode.

The purpose of our work is to find the relation between the loop and the other column parameters and adjust the set point automatically instead by the operator

2.2.2 Constraint

The column operates at the pressure of 17.9 bars, the alarm at 18.3 bars and the trip is trigger at 19.25 bars. As even a small change can activate the trigger, the operator's action to adjust the set point must be very fast. The pressure increase is due to the head temperature rise of the debutanizer. The increase in the pressure depends on the temperature variation. To avoid the tripping, we have programmed on YOKOGAWA CS3000 DCS, that the reflux flow controller set point changes automatically according to the temperature change of the head, i.e. if the temperature increases the flow controller set point 32FIC01028, then the reflux flow rate increases up to a certain maximum value (maximum reflux flow rate) which should not be exceeded, thus assuring the products compliance with the imposed standards.

When $F = 143 \text{ m}^3 / \text{h}$ and the temperature of the isopentane is withdrawn, which is the cause of the rise temperature by the clogging of the column, when the reflux rate reaches $143 \text{ m}^3 / \text{h}$ and the temperature is too high, which increases the pressure, the withdrawal flow is increased resulting in a higher flow controller set point 32FIC91002.

3 EXPERIMENTAL SETUP

A Distributed Control System (DCS) or Digital Control-Command System (DCS) is a system that provides both the real-time monitoring and the control of industrial process.

Supervision consists of translating the state of each instrument on the site in different forms and associating it with descriptive views or windows in order to have an animated site in real time on HIS to enable to the operator to monitor the site and take the necessary actions at a requested time (changing the PID set point, Auto \ Man mode, acknowledgment alarm ... etc.). The Real-time control consists of using the control or sequential calculation ensuring the system to meet the imposed specifications [9].

The rapid DCS development has been largely driven by the widespread availability of powerful computers and advanced microprocessors. At the DCS level, various suppliers compete in the market, with YOKOGAWA being one of the leading providers. A YOKOGAWA DCS is structured across multiple hierarchical levels, each fulfilling specific functions within the overall control architecture [10].

- Level1: where the measurement and transmission take place. It represents the instrumentations installed on the site.
- Level 2: the modules with analog and digital inputs and outputs for data acquisition.

- Level 3: the processing and execution of the control algorithms and the communication logic are performed via the FCS (Field Control System) control stations.
- Level 4: the visualization and flow of the control operations controlled by a display of the consoles to establish the communication between the operator and the control system.

3.1 Development and simulation of the project under CENTUM VP of YOKOGAWA

Simulation is a tool used to research or study a phenomenon or to design and improve systems.

We have developed a program on the YOKOGAWA CENTUM VP DCS to monitor the temperature of the debutanizer head and control the reflux and the isopentane loop, i.e. it adjustment of the instructions automatically instead of the operator.

Our project is created in the following steps:

- Starting-up of the view system.
- Creation of a new project.
- Creating of an FCS folder, with the necessary elements for programming.
- Creating of the HIS.
- Creation of a new node.
- Creation of a new IOM input / output module (with an analog input / output module: Analog input board AAI141-S and analog output board AAV542-S)
- Creation of a drawing (DR XXXX) which is a window in which the blocks are created i.e. PID, PVI, MLD, CALCU and DLAY.

The control blocks are the function blocks that calculate and control the processing. The calculation results are used for the process control. The control blocks perform the input processing, command processing and output processing.

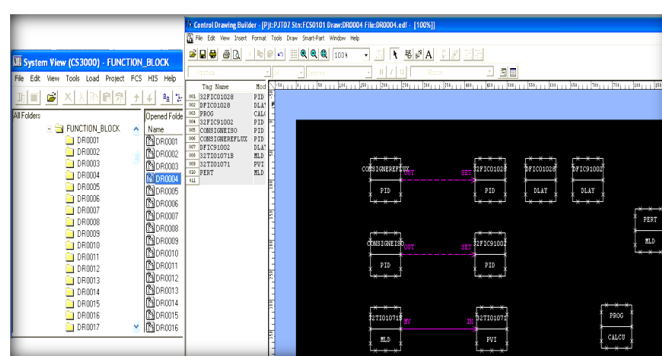


Figure 2. Control drawing builder used.

3.1.1 Calculator programming

The CALCUL block is used to define the variables and implement the functional links between the different control blocks. The developed control program is illustrated in the figure below.

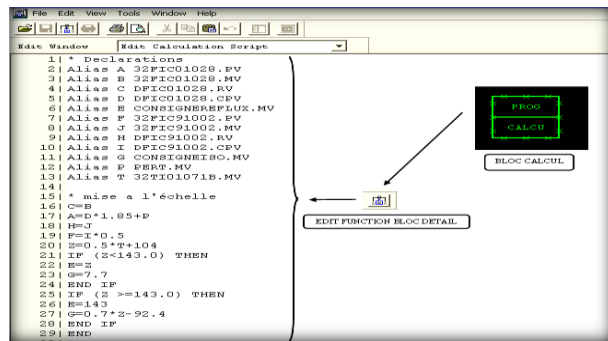


Figure 3. Developed program.

3.1.2 Identification of the controller parameters

The controller is the main controlling element of the control system. Its primary function is to compare the measured value of the controlled variable, received from the transmitter, with the desired setpoint. Any deviation between these two signals generates a corrective control action that is transmitted to the final control element, such as the control valve or another actuator.

In industrial processes, controllers may be installed locally within a units; However, they are most commonly located in the control room, allowing operators to continuously monitor the process variables and adjust the set points when necessary.

A Proportional–Integral–Derivative (PID) controller combines the three fundamental control actions: proportional (P), integral (I), and derivative (D). The main advantage of the PID controller is its ability to simultaneously improve system accuracy, stability, and dynamic response. An appropriate tuning of the controller parameters (K_p), (T_i), and (T_d) optimizes the control performance and enhances process control. [11]-[12].

After the process is identified, the characteristic parameters (static gain, time constant, etc.) are obtained, the actions to be displayed on the controller are calculated from them.

The actions and their parameters chosen, the desired behavior in the closed loop is obtained, compatibly with the desired performances and given specifications.

The disturbance effects must be minimized, preferably eliminated, as rapidly as possible and the set point changes should be tracked accurately and with a minimal delay. Achieving these objectives requires an appropriate selection of the controller actions (P, I, and D) and tuning the corresponding parameters (K_p), (T_i), and (T_d), compliably with the desired performance specifications.

The determination and adjustment of the controller parameters constitute a synthesis problem of the control systems. Numerous synthesis methods have been developed, making a rigorous classification difficult. These methods can be divided into two main categories [13].

The first category includes empirical methods, requiring no precise knowledge of the process model. The controller parameters are determined experimentally from process observations, such as the analysis of the step response. Their principal advantages are their simplicity and ease of implementation which make them widely applied in industrial environments, although they may not always provide an optimal tuning performance.

The second category includes the model-based methods which they rely on a mathematical representation of the system, typically expressed through transfer functions. The controller parameters are calculated in order to obtain the desired open-loop or closed-loop dynamic behavior and to ensure an improved control performance.

Depending on the type of process, stable or unstable, the value of the PID parameters is calculated according to the controller structure. For a stable process [14]:

If the process is stable, the following parameters are calculated from the constructions :

The static gain: $G = X / Y$. (X is the output, Y is the input)

The delay: $R = t_1 - t_0$.

The time constant : $T = t_2 - t_1$

Table 2. Dindeuleux settings.

	P	PI série	PI //	PID série	PID //	PID mixte
Xp		125GR/T		118GR/T	120GR/(T+0.4R)	
Ti	Maxi	T	1.25R	T	1.3GR	T+0.4R
Td		0		0.4R	0.35T/G	TR/(R+2.5T)

The test function identifies the controller parameters, when the controller is switched to a manual mode.

- Around the point of operation, the response of the system is noted, at a small step of the controller output signal MV (opening of the valve).
- When the process is stable, the next figure is given.

A 10% step is applied at time $T_0 = 17:32:10$ s and the response of the system is obtained (see Figure 4).

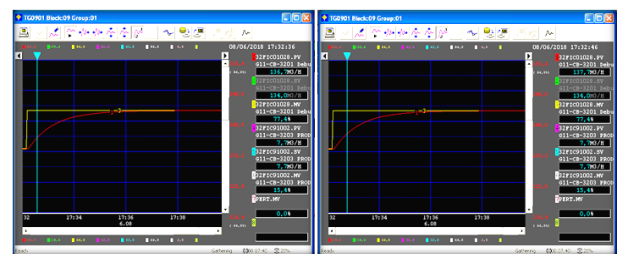


Figure 4. Variation of the reflux flow.

From the obtained response curve, the following parameters are determined:

$F_0 = 134.0 \text{ m}^3/\text{h}$; $T_0 = 17:32:10 \text{ s}$

$F_{\text{final}} = 143.2 \text{ m}^3/\text{h}$.

$F_{(28\%)} = 0.28(F_{\text{final}} - F_0) + F_0 = 136.5 \text{ m}^3/\text{h}$;

$T_{(28\%)} = 17:32:36 \text{ s}$.

$$F_{(40\%)} = 0.4(F_{\text{final}} - F_0) + F_0 = 137.86 \text{ m}^3/\text{h};$$

$$T_{(40\%)} = 17:32:46 \text{ s.}$$

The static gain: $G = 1$;

The delay: $R = 2.8(t_{(28\%)} - (t_0) - 1, 8(t_{(40\%)} - (t_0))$
 $R = 2.8(36-10) - 1.8(46-10) = 8 \text{ s.}$

The time constant: $T = 5.5(t_{(40\%)} - (t_{(28\%)})$

$$T = 5.5(46-36) = 55 \text{ s.}$$

From the T / R report, the corrector is determined using Table 2.

$T / R = 6.875$ (this value is between 5 and 10 so according to the formulas of the parallel PI controller are used).

The controller parameters are:

$$P = 125 \text{ R} / T = 18.18 \approx 18.2$$

$$I = 1.25R = 10$$

After determining the controller parameters, the control loop is closed and a step variation is applied to the input of the MLD block 32TI01071B in order to modify the debutanizer head temperature. The corresponding step response is then observed to validate the previously calculated controller parameters.

The obtained response exhibits a significant overshoot. To improve the dynamic performance of the system, a tuning refinement method is applied by progressively adjusting the P, I, and D controller parameters until a satisfactory performance is achieved in terms of the stability, response time, and overshoot reduction.

The system becomes more stable and responsive after the tuning adjustment, resulting in an improved control performance of the debutanizer head temperature.

The response of the controller before and after adjusting the parameters is shown in the Figure 5.

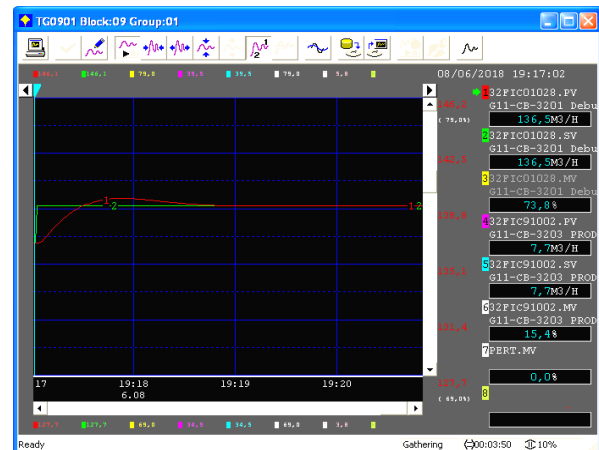
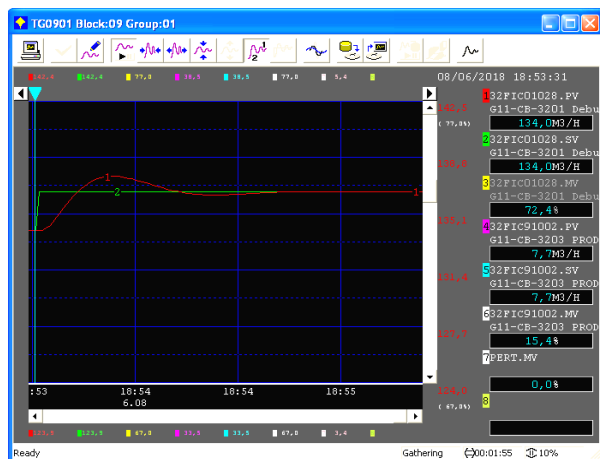


Figure 5. Response of the controller before and after the parameter adjustment.

3.2 Simulation Results and their Interpretation

3.2.1 The reflux flow rate changes and the flow of iso-pentane fixe (flow < 143m³ / h) is:

To evaluate the performance of the developed control program, a 5% step variation is applied to the input of the MLD block in order to increase the debutanizer column head temperature, thereby creating a cooling demand within the process.

The Figure 7 demonstrates the successful operation and effectiveness of the developed control program.



Figure 6. Group view of the control loops at 70 °C and 75 °C.

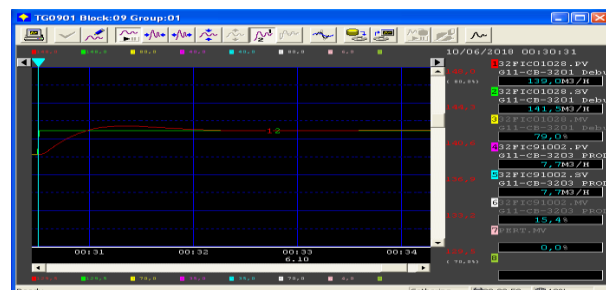


Figure 7. The variation of reflux flow.

The obtained results clearly demonstrate that the proposed control system is stable and accurate, with a negligible steady-state error. For the column head temperature of 70 °C, the calculation block automatically

determines the appropriate reflux-flow set point and generates the value of 139.0 m³/h, which is below the maximum permissible reflux flow rate of 143 m³/h. Consequently, the iso-pentane withdrawal flow rate remains fixed at 7.7 m³/h, where no further withdrawal is required.

When the column head temperature increases to 75 °C, the system automatically adjusts the reflux-flow setpoint to 141.5 m³/h to satisfy the increased cooling demand. Since this value is below the maximum reflux flow limit of 143 m³/h, the iso-pentane withdrawal operation is not activated. The system continues to exhibit a stable and accurate behavior throughout the process, confirming the effectiveness of the implemented control strategy.

3.2.2 Fixed (maximum) reflux flow and iso-pentane flow change:

When the debutanizer head temperature is further increased until the reflux flow reaches its maximum Permissible value, the available reflux can no longer provide the required cooling capacity. The control system then activates the iso-pentane withdrawal mechanism to extract an additional iso-pentane, thereby enhancing the cooling effect and maintaining the column head temperature within the desired operating range.

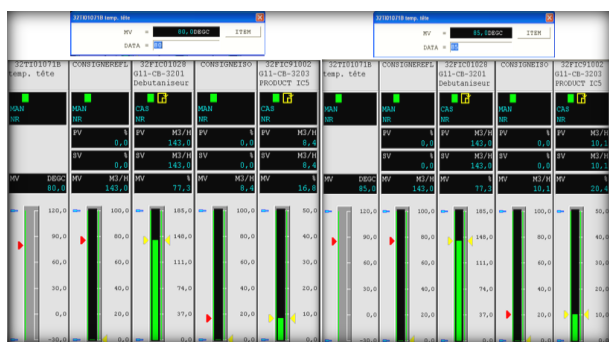


Figure 8. Group view of the control loops at 80 °C and 85 °C.

When the column head temperature increases to 85 °C, the reflux flow reaches its maximum permissible value of 143 m³/h and remains constant. To provide an additional cooling required, the control system automatically increases the iso-pentane withdrawal flow rate to 10.1 m³/h through an automatic setpoint adjustment. The results demonstrate that the proposed control strategy successfully maintains the desired operating conditions while preserving the system stability and accuracy, with no significant steady-state error observed.

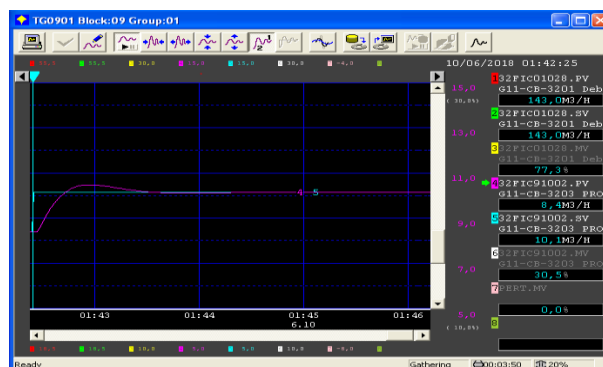


Figure 9. Iso pentane flow variation.

A 5% disturbance is introduced at T = 01: 49: 54 s to evaluate the robustness of the control system. The variation in the reflux flow rate is then monitored with respect to its set point as a time function.

The response curve shows that the disturbance causes a transient deviation and a temporary overshoot in the system response. However, the controller effectively compensates for the disturbance and drives the process back to its desired operating point. The system rapidly reaches a new steady state with a zero steady-state error, demonstrating a good disturbance rejection capability, stability and tracking performance.

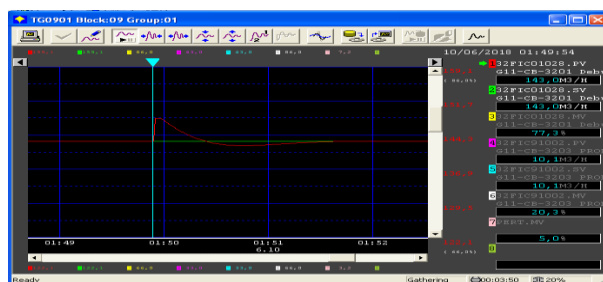


Figure 10. Dynamic response of the reflux flow rate to a 5% disturbance,

4 CONCLUSION

The paper proposes the design and implementation of an automated control and supervision strategy for the cooling system of an LPG extraction unit debutanizer. The strategy is developed using the YOKOGAWA CENTUM VP DCS to control the column head temperature through the coordinated management of the reflux-flow rate and the iso-pentane withdrawal flow rate.

The obtained results demonstrated the effectiveness of the developed control strategy at variable setpoint and disturbance states. The control system successfully maintains the desired operating temperature, ensures an accurate tracking performance with a negligible steady-state error, and exhibits satisfactory stability and disturbance rejection capabilities. The automatic adjustment of operating setpoints reduces the need for an

operator action and improves the overall efficiency of the process.

The proposed automation strategy provides a reliable and practical solution for enhancing the operational performance of the LPG extraction units. Its implementation contributes to improved process stability, increased operational safety, and more efficient utilization of cooling resources in industrial gas-processing facilities

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