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OPTIMAL PRODUCTION SYNTHESIS OF LIQUEFIED PETROLEUM GAS IN A DEBUTANIZER TOWER

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Abstract. *The liquefied petroleum gas (LPG) is produced in a distillation column comprising a set of peripheral instruments. This tower, also known as debutanizer tower, is responsible for separating LPG from the other components by means of the variation of the temperature profile. Brazilian National Agency of Petroleum (ANP) regulates the specifications of LPG so that it can be commercialized. Currently the gas specification process is done manually through a standardized test called weathering test, which is performed in a few hours. During the sample test range, a large volume of gas is processed generating losses for the client or company depending on the specification of the processed gas. This study aims to suggest the implementation of a control strategy to optimize the production of LPG in order to decrease the chances of losses and reprocessing gas. In order to ease optimization procedure and solve the optimization problem, an Optimization Graphical User Interface (Op-GUI, an optimization tool under development at the Mechatronics and Signal Processing Laboratory, Instituto Federal Fluminense) is used to execute numerical optimization through MATLAB algorithms while meeting performance objectives.*

Keywords: *LPG Loss Reduction, Debutanizer Tower, Weathering Test, Optimal Production of LPG*

1. INTRODUCTION

LPG has a great importance in today's society and its application extends to several areas. LPG participates in the Brazilian energy matrix with 3.2% of total consumption Ben (2011). According to Sindigas (2011), more than 95 % of the population uses LPG, which gives it a household penetration even greater than electricity and running water. In 2010, Brazil was the fifth largest LPG consumer market in the world, behind the US, Japan, China and Mexico, with an annual consumption in 2010 million tons, according to MME - Ministry of Mines and Energy.

In the gas separation process for the production of LPG is necessary to make the separation of the fractions of the liquefied natural gas (LNG) in a tower called debutanizer tower. This tower is directly linked to the framework of LPG, which is the ideal composition for this gas. LPG is classified by the National Petroleum Agency (ANP) through the weathering analysis, which provides a parameter for the balance of the fractions of LPG according to propane (C_3) and butane (C_4) concentrations.

In the operation of the debutanizer tower, the LNG is heated and enters a heat exchanger, making propane and butane substances lighter than usual. At the top of the tower, these gases are collected and condensed again, generating the LPG.

The control of the entire process involving the debutanizer tower is done by independent control loops using conventional controllers. Despite the existence of PID controllers in the process, this control does not guarantee the framework of the gas, as operators have to be changing setpoints in terms of imbalances in the composition that are only detected from each result of weathering test.

The aim of this study is to propose the improvement of the automated control in debutanizer tower in a LPG production plant of a Condensate Processing Unit of Natural Gas (CPUNG), seeking to optimize the process, reducing the risk of loss due to the reprocessing of gas, and also reducing human intervention in the process.

In order to ease optimization procedure and solve the optimization problem, an Optimization Graphical User Interface (Op-GUI, an optimization tool under development at the Mechatronics and Signal Processing Laboratory, Instituto Federal Fluminense) is used to execute numerical optimization while meeting performance objectives.

2. PROBLEM STATEMENT

The column or distillation tower used as an object of study was the debutanizer tower, consisting of a basic unit for refining of natural gas and LPG production. Figure 1 generally illustrates a debutanizer tower and Fig. 2 presents the Simulink model of the system.

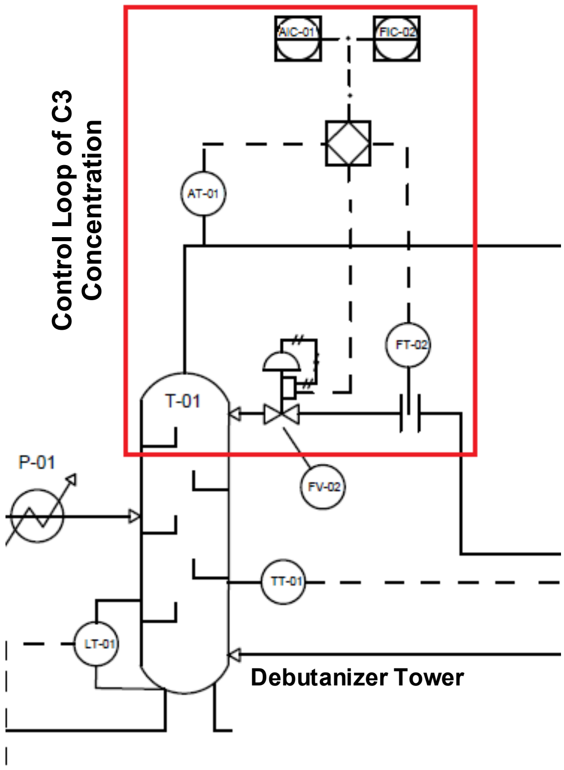

Figure 1. Overview of debutanizer tower and control loop of C_3 concentration

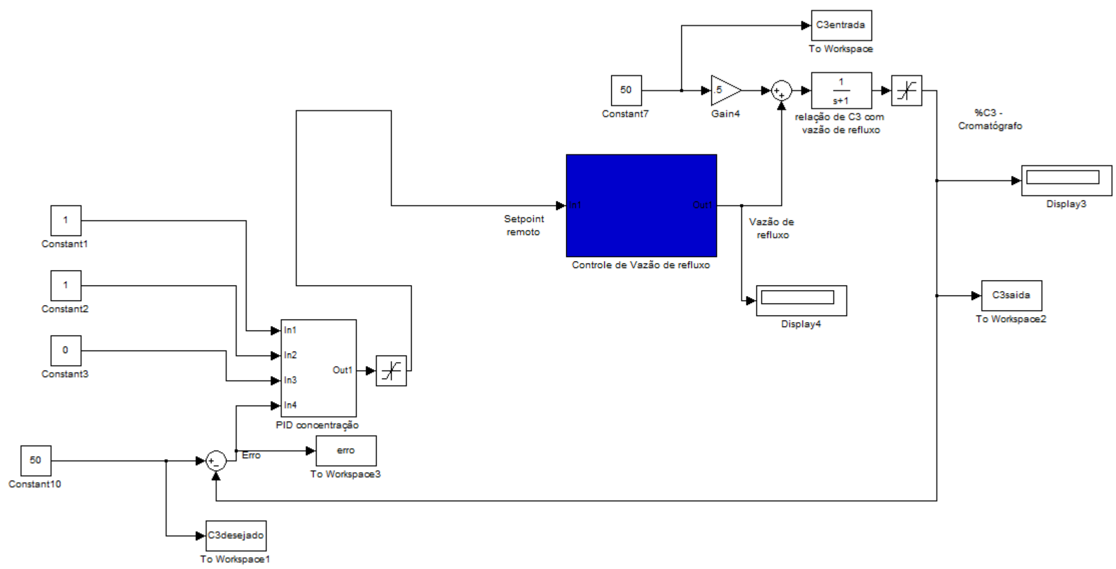

Figure 2. Simulink Model

This column has the input stream of LNG which is composed of a mixture of hydrocarbons (C_3+). In nature, this gas shows small amounts of diluted components such as nitrogen and water vapor. There are still contaminants such as hydrogen sulfide and carbon dioxide. Therefore, it becomes necessary to make an initial treatment in the gas to remove these contaminants in order to meet market specifications established by ANP.

According to Campos and Teixeira (2006), the debutanizer column basically has five degrees of freedom associated with the five controlled variables in this system: the column pressure control, bottom level control of the tower and the inlet flow. Proper control of these process variables ensures satisfactory operation of the overall process, preventing the occurrence of flood of dishes and capture vessels of the product. The other two variables that affect the quality and specifications of the final product. These variables are: the tower bottom temperature, which is regulated by the flow of thermal oil, and the reflux flow at the top of the tower, which is designed to purify the product.

The control of the tower bottom temperature, which is regulated by the flow of thermal oil, is responsible for the so-called "coarse tuning". It is so named due to the fact that the temperature is a slow variable, in which an intervention on its value takes a relatively long time to cause a change in the composition of LPG. Since the temperature of LNG increases at the bottom of the tower, the product vaporizes more quickly, causing an increase in the concentration of $C_3\%$.

The reflux flow, however, presents a fast rate variation, being called fine-tuning. When the reflux flow increases, a portion of the LPG which came out of the tower is forced to return in the upper part of the tower, causing the final product to be even more purified. Because of this, the focus of this study was to control this variable.

Considering the adopted procedure in the case study, adjusting the parameters for control is time consuming. The operator needs to go to the work area to take a sample of LPG coming out on top of the tower. Then, it goes through weathering analysis. Finally, the operator makes adjustments according to this result.

The production does not stop while all this analysis is done, so in the case of LPG do not present a correct framework specification, i.e, it is produced out of specification, it can not be delivered to the consumer and misclassified gas portion must be reprocessed, spending much more energy.

2.1 Optimization-based synthesis

According to Stengel (1994), the optimization process describes the application of forces to a system in order to maximize some aspect of performance or for the purpose of minimizing the cost function $J(x)$.

In order to quantify the results it was necessary to use a reference metric. The chosen metric was the integral of Absolute Error (IAE). The IAE coefficient defined by the eq. (1) is an error rate from the signed error function. The lower the value the better the performance of the control loop.

$$IAE = \int_0^\infty e(t)dt \tag{1}$$

In this work, the optimization problem is described as

$$\min_x J(x) \text{ subjected to } lb \leq x \leq ub \tag{2}$$

where the lower and upper limits of the PID controller gains are denoted by lb and ub respectively and x refers to the gain vector. ($K_p = x_1$, $K_i = x_2$, $K_d = x_3$).

2.2 Optimization Problem Management

The Op-GUI, a graphical interface for optimization problem management currently being developed in the Mechatronics Laboratory of Signal Processing (MSP) of the Federal Institute Fluminense - IFF, is used to optimize parameters while meeting the detection performance objectives.

The Op-GUI is able to deal with constrained and unconstrained optimization problems. One of the main advantages of its use lies in the fact that it is not necessary to create a script or type commands in the MATLAB Command Window to perform tasks.

As presented in Padrao *et al.* (2015) the definition of the objective function, the optimization parameters and constraints and the development of optimization goals are made through point-and-click configuration. With this, the Op-GUI provides an easy, simple and interactive way for managing Simulink models in order to solve optimization problems. Figure 3 illustrates the layout of the Op-GUI and Fig. 4 shows a simplified flowchart illustrating how the graphical user interface works.

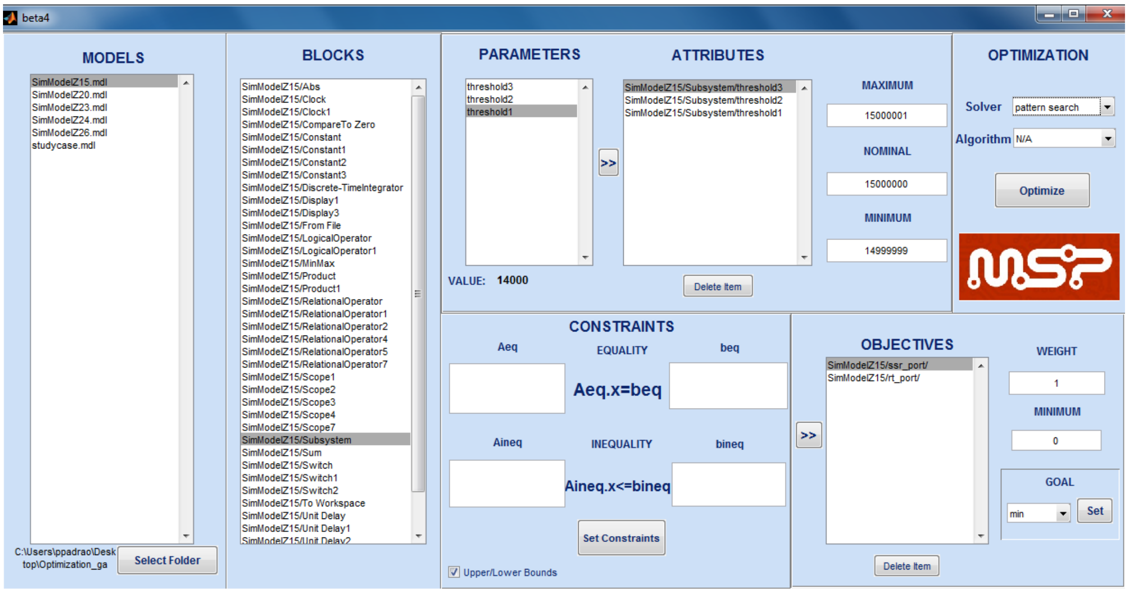

Figure 3. Op-GUI Layout Overview

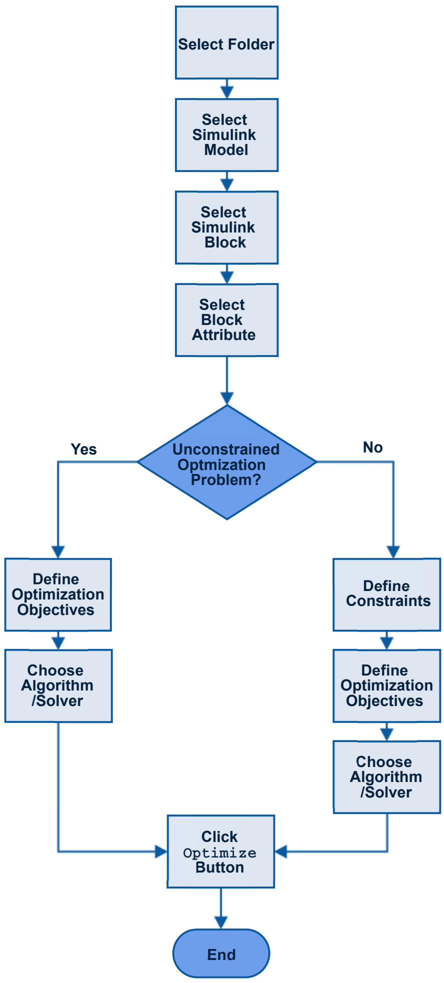

Figure 4. Simplified Flowchart of the Op-GUI

3. RESULTS AND DISCUSSION

For solving the optimization problem described by Eq. (2), the values of the constraints of the used PID controller gains as well as their nominal values are shown in the Tab. 1. The working experience of the authors shows that this an industrial manual process and the range of PID gains are usually set from 0 to 10. The operator manually tunes the PID gains by trial and error method.The nominal values of K_p, K_i and K_d were obtained through trial and error method.

According to Audet (2013) , pattern search is a method for solving optimization problems that does not require any information about the gradient of the objective function. Here it is used to solve an optimization problem for which the objective function is not differentiable. Unlike more traditional optimization methods that use information about the gradient or higher derivatives to search for an optimal point, a direct search algorithm searches a set of points around the current point, looking for one where the value of the objective function is lower than the value at the current point. Besides that, the trial and error method is usually time consuming and not necessarily achieve the optimal choice for the PID gains. On the other hand, pattern search is implemented by using point-and-click through a graphical interface. Consequently, MATLAB coding is not required for setting up the optimization problem, saving time for simulation analysis.

This work used the IAE value as a system performance metric. However, the maximum overshoot (M_p)and settling time (t_s) are two design requirements widely used in control processes. According to Ogata (2010), the maximum overshoot (in percentage) is the maximum peak value of the response curve measured from the unit. If the final value of the steady state response differs from the unit value, then it is common to use maximum percentage of overshoot as defined by:

$$M_p = \frac{c(t_p) - c(\infty)}{c(\infty)} * 100\% \tag{3}$$

The settling time (t_s) is the time required for the system response in order to reach and stay within a range of certain percentage (usually 5% or 2%) of the final value.

Figure 5 presents the system output response for initial values of the PID gains. Regarding the setpoint tracking, the system response shows an overshoot of 25% and a settling time value for the criterion of 2% of 36.41 s.

Figure 6 shows the variation of C_3 concentration error values for K_p, K_i, and K_d obtained through trial and error methods. The IAE value using this metric was 84.03.

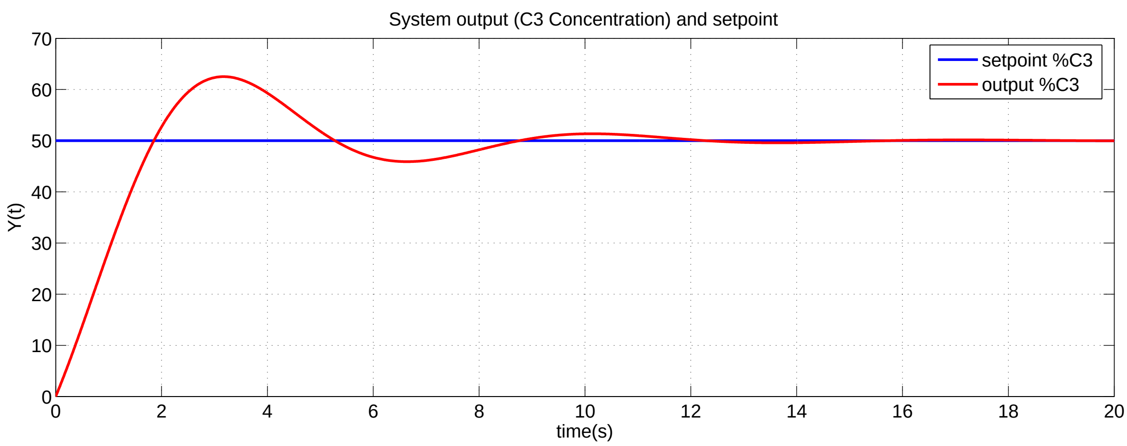

Figure 5. System Output Response for Initial PID Gains

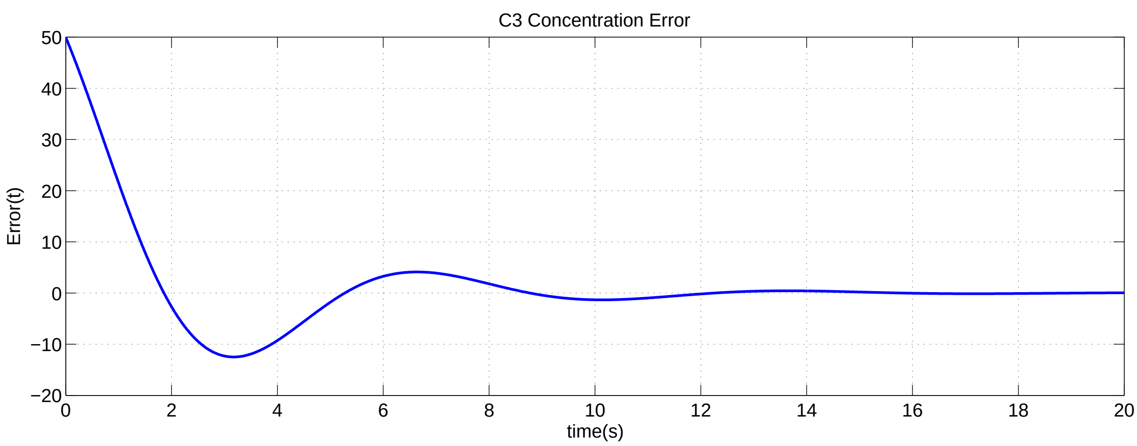

Figure 6. C3 Concentration Error for Initial PID Gains

Figure 7 presents the system output response for optimal values of the PID gains. Regarding the setpoint tracking, the system response shows an overshoot of 2.96% and a settling time value of 3 s.

Figure 8 shows the variation of C_3 concentration error values for K_p, K_i, and K_d obtained by mathematical optimization. The IAE value for this metric was 44.2.

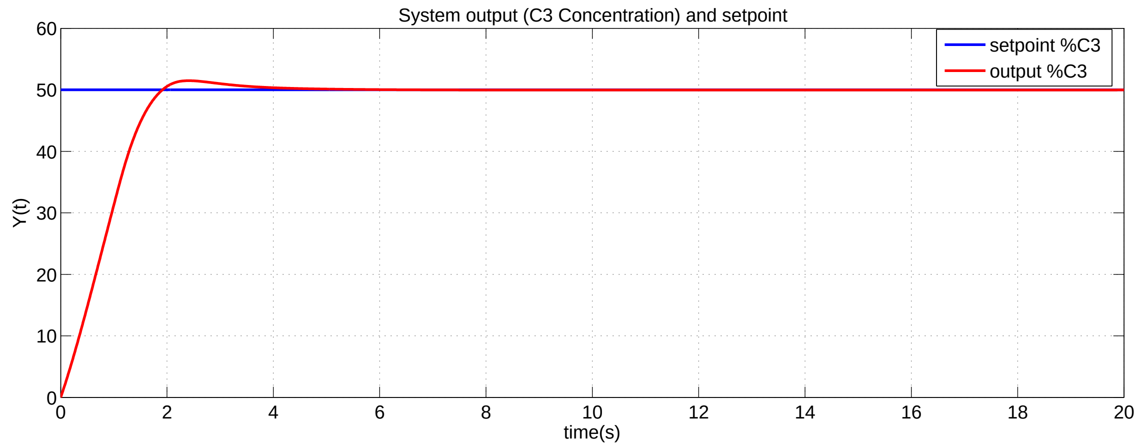

Figure 7. System Output Response for Optimal PID Gains

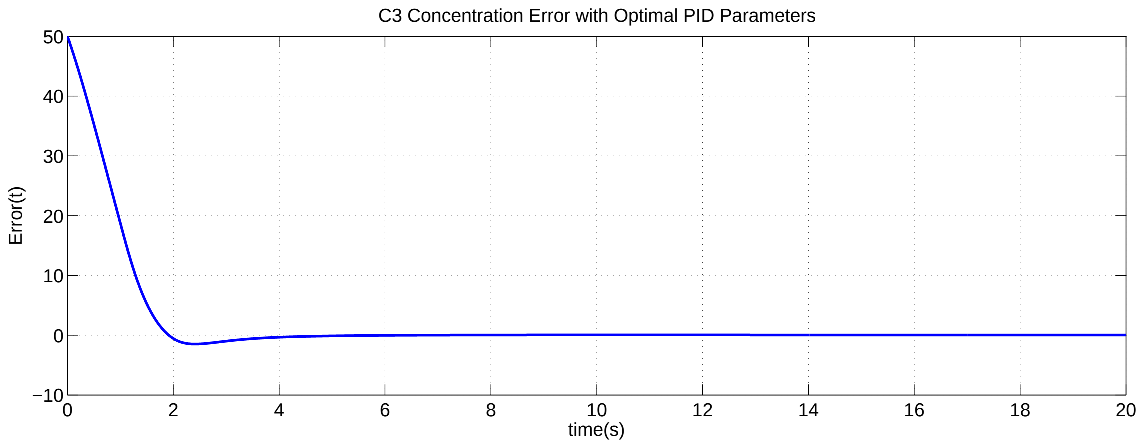

Figure 8. C3 Concentration Error for Optimal PID Gains

In comparison with the values of K_p, K_i, and K_d previously used and the optimal values proposed in this work, a considerable reduction in relation to the chosen metric is seen. Besides that, the overshoot values decreased from 25% to 2.96%. Table 4 compares the results obtained from original and optmized gains.

The objective of controlling the composition (% of C3 and C4) of the LPG exiting the top of the tower is to maintain the gas within the specifications, and thereby avoid losses by reprocessing it. The smaller the concentration error related to a predetermined value (set point), the higher the assurance of having a quality product at the end of the process.

Table 1. Trial and error method: PID Gains

	K_p	K_i	K_d
Upper Bound	10	10	10
Nominal value	1	1	0
Lower Bound	0	0	0

Table 2. Optimization Objective and Method

Objective	Minimize IAE
Method	*Pattern search*

Table 3. Optimal PID Gains and respective IAE value

$K_p^\star$	$K_i^\star$	$K_d^\star$	IAE
9.95	0.62	4.61	44.12

Table 4. Comparison between optimal and original gains regarding criteria results

	IAE	M_p	t_s
Originals Gains	84.03	25%	36.41 s
Optmal Gains	44.12	2.96%	3 s

4. CONCLUSION

The presented paper proposed the implementation of a new control strategy in debutanizer plant of LPG. The change consists in optimizing the values of the PID controller gains in order to manage the concentration of C_3 in LPG coming out from the debutanizer tower.

Moreover, a graphical user interface for optimization problem management (op-GUI), together with MATLAB algorithm was used to facilitate the optimization problem setup and define the optimal configuration parameters.

The simulation results showed that the proposed technological solution can be implemented in a real plant, so the goals can be achieved. The risk of an incorrect LPG framework classification decreases, reducing the costs of gas reprocessing. Consequently, the quality of the final product increases and the price for the end consumer may decrease.

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6. RESPONSIBILITY NOTICE

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