Modeling and Simulation of a System to Control the Water Level in a Vase Accumulator

Alexandre da S. Rufino, Iana da S. Lobato and Charles L. S. de Melo

***Abstract*— Overhead drums have two different functions: minimize the effects of disturbances from the debutanizer over the other parts of the system and to separate, by decantation, the water that comes from the steam used during the process. Besides, in order to preserve the quality of products, the water accumulated needs to be removed from the system by drainage. When this situation occurs in vessels containing liquefied petroleum gas, LPG, in high pressure, to drain the water becomes a delicated operation due to the risk of leakage. Thus, an automatic system capable of controlling the level of water between a minimum safe level and a maximum level that doesn't compromise the specifications of the products is shown as the object of study in this paper.**

***Index Terms*—— controle valve, level control, PID controllers.**

I. Introduction

THE oil extracted from nature is composed of hydrocarbons, and more light formed by small molecules such as ethane whose formula is C_2H_6 and heavier containing up to 70 carbon atoms[1]. Thus, fractions of commercial value that can be obtained from the crude oil are shown in Table 1.

TABLE I
COMMERCIAL EXTRACTED FRACTIONS OF OIL.

Amount Carbons	Products
1 to 4	Gases
5 to 10	Naphtha
10 to 16	Kerosene
14 to 20	Diesel
20 to 50	Lubricants
20 to 70	Fuel Oil
Over 70	Asphalt

So, for the crude oil or oil unprocessed, be transformed into fuel or inputs for industry, need to go through physical and chemical processes called refining processes. As the various components of crude oil have different sizes, weights and boiling temperatures initially they can be easily separated by physical atmospheric distillation process, which is the main unit operation used for this purpose. So after the distillation follows each fraction to be processed differently according to their needs and among these, the lighter fractions or top products composed of gas and naphtha, are taken to the stabilizer tower [2].

As in the standard configuration of a fractionation system exemplified in Fig. 1, the product leaving the top of the tower, LPG, is cooled and condensed by through a heat exchanger, P_{02}, and brought to a V_{02} accumulator vessel for containing LPG, takes the pressure from the top of the column located between 6 and 11 kgf/cm^2. Part of these hydrocarbons condensate is pumped back to the tower through B_{02}, forming the top reflux flow which is used to control the temperature of the stabilizer. Since the other party is sent by pump B_{03} needed for chemical treatments and subsequent storage. In the same top vessel V_{02}, also accumulated residual water from the vapors used for heating and grinding and water in the oil itself in processing.

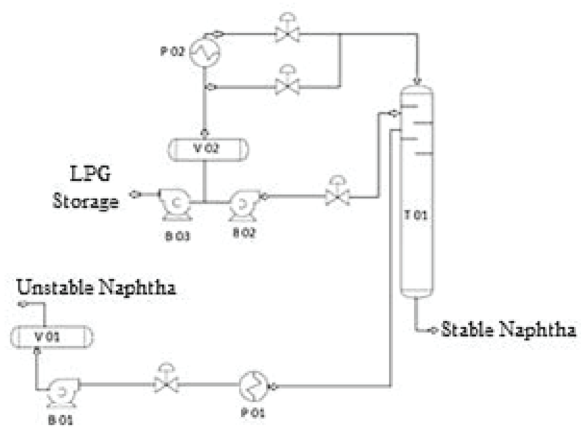

Fig. 1. System of debutanization

Then, according to this architecture water vessel is deposited by settling in the lower part producing a hydrocarbon-water interface level during the process. When this level reaches a threshold that varies according to the geometry of the accumulator vessel, LPG passes out of the vessel carrying water in their composition, which let out of specification for commercialization.

II. Level Control System

The level of control is one of the most important in the Industrial units for being present in virtually all of them, for many problems of control units and conducted operation changes or failures in the level of mesh adjustment and for

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Alexandre da Silva Rufino, Universidade do Estado do Amazonas (UEA), Manaus, Amazonas, Brazil, adsr.eng@uea.edu.br.
Iana da Silveira Lobato, Universidade do Estado do Amazonas (UEA), Manaus, Amazonas, Brazil, iana.s.lobato@gmail.com.
Charles Luiz Silva de Melo, Universidade do Estado do Amazonas (UEA), Manaus, Amazonas, Brazil, charles.melo@yahoo.com.br.

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being responsible for the mass balance of plants [3]. This is because to maintain a level of a tank or vessel constant is necessary that the mass flow rate of entry, M_e, is equal to the output, M_s. So when there is a change in the input flow, the output should be monitored. Thus, for a system whose control variable is the level of a container has as study beginning the mass balance shown below, where the example system is a reactor where the output flow, F_{out}, is based on the level tank, h, and varies according to the input flow, F_{in}, and is engaged in the correlation between the level or height and the water withdrawals.

For the system of Fig. 2:

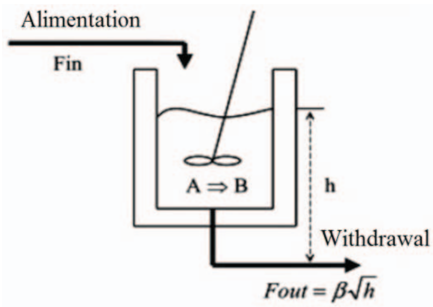

Fig. 2. Representations of a reactor

The mass balance is given by:

$$\text{Mass}_{accum.}/\text{time} = \text{Mass}_{input}/\text{time} - \text{Mass}_{output}/\text{time} \quad (1)$$

For the proposed system, which is considered the liquid density, ρ, constant input and output:

$$(\rho hA)/dt = \rho F_{in} - \rho F_{out} \quad (2)$$

Where A is the area of the tank at the time *t*. In terms of the dependent time, which describes the relationship over time tank level behavior resulting equation is:

$$A\,[dh(t)/dt] = \rho F_{in} - \rho F_{out} \quad (3)$$

And, the disclosed system the output flow is:

$$F_{out} = \beta\sqrt{h} \quad (4)$$

Being β the coefficient of discharge of the tank.

After this, it's possible to start a study of a structure of a control system to such a situation [4]. This level control system, when translated in the block diagram has the structure of Fig. 3.

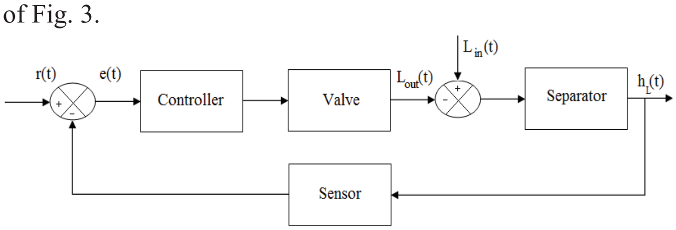

Fig. 3. Block Diagram of a Control System

III. Dimensioning of the Control Valve

The system for level control as shown in Fig. 3 comprises: controller, valve and sensor separator vessel, in which case study is presented as a level differential pressure transmitter. Therefore, to design the automatic controller, it is necessary that the transfer function representing the process vessel and understood by the control valve, in addition to the sensor transfer function used in the feedback. For this, the first step taken is the sizing and selection of control valve to be used, as shown below in Fig. 4:

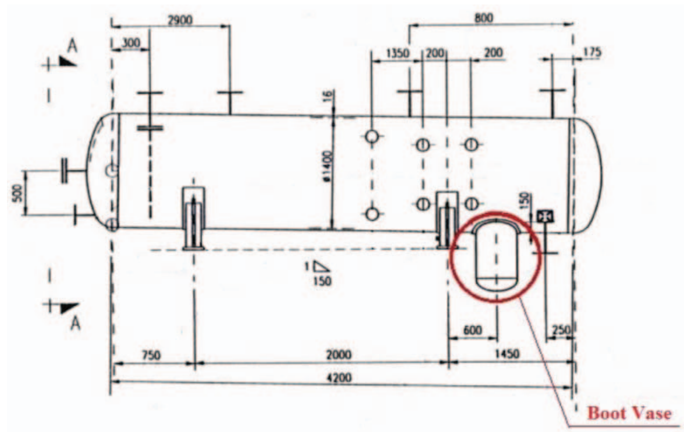

Fig. 4. Accumulator vase top

The water incorporated into the LPG stream to settle, by decanting, in boot of it, detailed in Fig. 5 being the 8A and 8B the directions taken to the level transmitter, the indications 7A and 7B takes the level of the display and the indication 4, the nozzle outlet water.

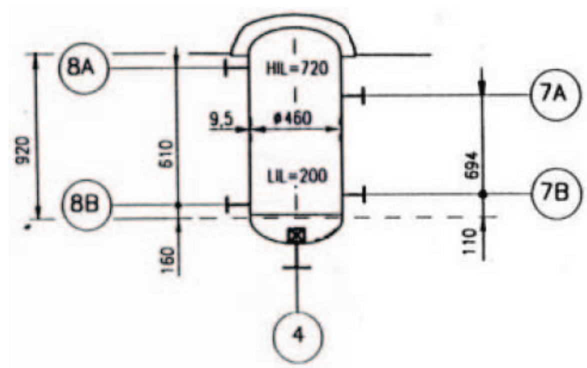

Fig. 5. Boot of the Accumulator Vase

So to know the flow of water entering the vase, it is first calculated the volume of the boot. This, according to reference [1] is considered a vertical cylinder with a spherical wedge bottom, then its volume is given by:

$$\text{Total}_{Volume} = Cylinder_{Volume} + \text{Wedge}_{Volume} \quad (5)$$

$$T_v = (\pi R^2 h) + (1/6 \,.\, \pi h' (3A^2 + h'_2))$$

Where R is the radius of the boot, h its lenght, A the height of the boot and the h' is the height of the wedge.

$T_v = 230^2\pi \cdot 920 + 1/6 \cdot 80\pi (3 \cdot 230^2 + 80^2)$

$T_v = 0{,}15980m^3$

As known volume container, knowing that the number of drainages of the boot for an 8 hour shift, it is possible to determine the water flow at the entrance in accordance with:

$$Q = D_N \cdot (T_v / t) \tag{6}$$

Where: Q is the flow, D_N the number of drainages, T_v the total volume of the boot and t the time.

Thus, knowing that for a shift 8 hours minimum time in which the boot is drained is 1, it has the minimum flow in accordance with (6):

$Q_{min} = 0{,}019975m^3/h$

For normal flow, in turn, we used a $D_N = 3$.

$Q_{normal} = 0{,}059927m^3/h$

And for maximum flow, $D_N = 8$.

$Q_{max} = 0{,}015980m^3/h$

According reference [5], for sizing a control valve is required, firstly, to know the fluid and the pipe working conditions where it will be installed. So the initial information is contained in Table 2. Where P_1 is the pressure upstream of the valve to be the vase's operating pressure, P_2 is the pressure to the valve downstream, considered null by this discharge into a channel, and G_f, P_c and P_v are fluid data obtained by testing lab.

TABLE II
OPERATING SYSTEM DATA

G_f	0,986
P_c	224,9kgf/cm^2
P_v	0,14kgf/cm^2
P_1	10,1kgf/cm^2
P_2	0kgf/cm^2
D	460mm
μ	0,52cP

Then it is performed the calculation of the primary flow coefficients that will serve as a basis for the calculations continuity. For this is used (7), assigning initially $F_R = 1$ and $F_P = 1$

$$F_c = \frac{Q}{N_1 \times F_P \times F_R}\sqrt{\frac{G_f}{\Delta P}} \tag{7}$$

Then, calculating the F_c to the minimum, normal and maximum flow rates specified previously we have:

• For the minimum flow:

$F_{Cmin} = 0{,}007285GPM$

• For the normal flow:

$F_{Cnormal} = 0{,}0218586GPM$

• For the maximum flow:

$F_{Cmax} = 0{,}058287GPM$

So initially choosing one globe valve, single port and air-to-open, has $FL = 0{,}9$ and $FD = 0{,}46$. And, to calculate the next parameter, F_F is used in Eq. 8.

$$F_F = 0{,}96 - 0{,}28\sqrt{\frac{P_v}{P_c}} \tag{8}$$

That by replacing the values in Table 2, we have:

$$F_F = 0{,}96 - 0{,}28\sqrt{\frac{0{,}14}{224{,}9}}$$

$F_F = 0{,}953$

In the next step, the critical flow check for the operating region of the valve according to Eq. 9 is performed.

$$\Delta P_{max} = F_L^2 \cdot (P_1 - F_F \cdot P_V) \tag{9}$$

$$\Delta P_{max} = 0{,}9^2 \cdot (9{,}904716 - 0{,}953 \cdot 0{,}14)$$

$$\Delta P_{max} = 7{,}9147kgf / cm^2$$

To be confirmed critical flow situation, the new C_V is calculated according to Eq. 10.

$$C_V = \frac{Q}{N_1 \times F_L}\sqrt{\frac{G_f}{\Delta P_{max}}} \tag{10}$$

Thus, again by calculating the C_{Vi} for normal flow, we have:

$$C_{Vi} = \frac{0{,}059927}{0{,}865 \times 0{,}9}\sqrt{\frac{0{,}986}{7{,}9147}}$$

$C_{Vi} = 0{,}0271697GPM$

Then, for calculating the Reynolds number Eq. 11 is used.

$$R_{ev} = \frac{N_4 \cdot F_D \cdot Q}{v \cdot \sqrt{F_L \cdot C_{Vi}}} \cdot \left(\frac{F_L^2 \cdot C^2 Vi}{N_2 \cdot D^4} + 1\right)^{\frac{1}{4}} \tag{11}$$

$$R_{ev} = \frac{76000 \cdot 0{,}46 \cdot 0{,}059927}{0{,}52738 \cdot \sqrt{0{,}9 \cdot 0{,}0271697}} \cdot \left(\frac{0{,}9^2 \cdot 0{,}0271697^2}{890 \cdot 2^4} + 1\right)^{\frac{1}{4}}$$

$R_{ev} = 25404{,}26$

Finally, as Rev> 10000, the flow coefficient to be used is already computed, or for selecting valve C_V= 0,0271697GPM.

Having possession of dimensioned C_V, other factors for the selection of control valve are described in Table 3. First was chosen globe valve because, [1], this is more rugged construction supporting higher temperatures and pressures . In relation to trick-ment class to [6], Class IV sealing is sufficient for applications that require security, but do not deal with abrasive fluids. Further, as to the inherent characteristic of the linear it is the most suitable because the pressure loss is constant and occurs in most of the valve. Then, for checking the valve's operating conditions are used the guidelines of the [7] standard that dictates the equations for control valve sizing.

TABLE III
GENERAL CHARACTERISTICS OF THE VALVE DESIRED CONTROL

Type	Simple thirst
leakage class	IV
flow direction	air-to-open
inherent characteristic	linear
type guide	cage
actuator type	diaphragm
dimension	2”300#

Further, as to the inherent characteristic of the linear it is the most appropriate since the fall pressure is constant and occurs frequently in the valve. And to the direction of air flow, it was determined air-to-open, because it is preferable for the valve to close to prevent discharge of LPG to the environment in the event of failure. Finally, as gauge, it was determined a second valve "since this is the dimension of the outlet pipe of the vessel, avoiding the use of pipe extensions and reductions in installation thereof. So after getting all the relevant features, the selected valve was F_c = 0 to 11, the highest value nearest to the calculated with all the attributes described in Table 4 present in the manufacturers catalog Mansoneilan®, from 21100 series.

According to the technical data of this valve, you can see that it is a good choice because work in an opening range of about 30% for the normal flow of input and about 60% for maximal flow, which for [6] are within the optimal range of 20% to 80%.

IV. PLANT MODELING

Having scaled the control valve for this application, the vessel and valve assembly, which forms the studied plant may already be patterned. For that were allies two studies modeling, one developed for petroleum presented in [1] and a complementary consolidated already provided presented in [9] as follows.

A. Model for the vase-valve set

According to Reference [1], for modeling biphasic separator vessels to perform mass balances for each phase separately. However, as in the studied system control is applied only to the water level, only its mass balance is achieved, which is given by Eq.12:

$$\frac{dM_L(t)}{dt} = [L_{in}(t) - L_{out}(t)]\rho_L \quad (12)$$

In this analysis the mass balance of the hydrocarbon is despised because it is considered that the pressure control of this vessel is fast enough to maintain a constant working pressure of this vessel. Furthermore, the acid decanted water is considered an incompressible fluid, so that the given relationship is true in Eq.13:

$$\frac{dM_L(t)}{dt} = \rho_L \frac{dV_L(t)}{dt} \quad (13)$$

The vessel region in which water is stored, the boot is in the form of a vertical cylinder with a spherical wedge bottom, but by the volume of the wedge is minimum and is below the outlets of both the display as the level transmitter, its volume becomes negligible. Then the volume corresponds to Eq.14:

$$V_L(t) = \frac{\pi D^4}{4} h(t) \quad (14)$$

So, deriving (14) and substituting in 4.2 it has:

$$\frac{dh(t)}{dt} = \frac{4[L_{in}(t) - L_{out}(t)]}{\pi D^2} \quad (15)$$

The control valve is responsible for handling the output flow of the vessel, then second [1] its equation is given by:

$$L_{out}(t) = 2,4 \cdot 10^{-4} \cdot X_L(t) \cdot C_V \sqrt{\frac{P_1(t) - P_2}{G_f}} \quad (16)$$

Setting the Eq. 17 for the given model [8], which considers the pressure of the liquid column exercised, Eq.17 is obtained:

$$L_{out}(t) = 2,4 \cdot 10^{-4} \cdot X_L(t) \cdot C_V \sqrt{\frac{P_1(t) + \rho_L g h(t) \cdot 10^{-5} - P_2}{G_f}} \quad (17)$$

It is a constant working pressure of P_1 vessel. Linearizing the Eq. 17. And the input and output flows being the same. By applying the Laplace reducing the constants, we obtain the transfer function , which describes the system:

$$H(s) = \frac{K1}{\tau \cdot s + 1} Q_{in}(s) - \frac{K2}{\tau \cdot s + 1} X_L(s) \quad (18)$$

That, as in the Reference [8], it is represented by the diagram block of Fig. 5.

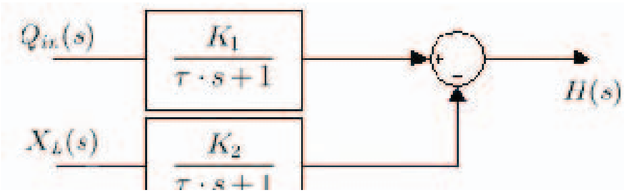

Fig. 5. Block diagram of the studied plant

So for the transfer function represented in Eq. 18 acquire the characteristics of the studied system, it needs to determine the values of K_1 constant K_2 and τ. Therefore, it is determined as operation point a level of 50% of the vessel boot. So if $K_1 = 1/C2$ and knowing that,

$$C_2 = \frac{1{,}2 \cdot 10^{-9} \cdot \rho_L g \cdot C_V}{G_f}\left(\frac{P_1(t) + \rho_L gh(t) \cdot 10^{-5} - P_2}{G_f}\right)^{\frac{-1}{2}}$$

Substituting the values from Table 2, we have $C_2 = 1{,}28779 \cdot 10^{-9}$, then $K_1 = 776{,}5239 \cdot 10^6$.

After, to the calculus of C_1, we have:

$$C_1 = 2{,}4 \cdot 10^{-4} \cdot C_V \sqrt{\frac{P_1(t) + \rho_L gh(t) \cdot 10^{-5} - P_2}{G_f}}$$

Substituting the values from Table 2, we have $C_1 = 26{,}5191 \cdot 10^{-3}$. Then, knowing that $K_2 = C_1/C_2$, it has to be $K_2 = 20{,}5927 \cdot 10^6$. Finally, the last parameter is given by $\tau = \pi D^2/4C_2$, then $\tau = 129{,}05 \cdot 10^6$. Then, the transfer function at the end of numeric parameters is:

$$H(s) = \frac{776{,}5239 \cdot 10^6}{129{,}05 \cdot 10^6 \cdot s + 1} Q_{in}(s) - \frac{20{,}5927 \cdot 10^6}{129{,}05 \cdot 10^6 \cdot s + 1} X_L(s) \quad (19)$$

B. Model for the level transmitter

Transmitters, and the interface between the process and the control system, whose function is to convert the sensor signal into a control signal [9]. Thus, for the differential pressure transmitter in question, the 4 to 20mA signal should be proportional to the level of the vessel ranges from 0 to 100%. So your gain is given by:

$$K_{LT} = \frac{20\text{mA} - 4\text{mA}}{100\% - 0\%} \quad (20)$$

Thus,

$K_{LT} = 0{,}16$ [mA/%]

The transmitter's dynamic response is generally faster than the process control valve and thereby the transmitter is considered only a gain in system function [9].

C. Modeling of the I/P Converter

Similarly the transmitters according [9], the converters can be represented only by a gain, since their response is much faster than the valve and of the plant. So for the drive gain it has:

$$K_{IP} = \frac{15\text{psi} - 3\text{psi}}{20\text{mA} - 4\text{mA}} \quad (21)$$

Thus,

$K_{IP} = 0{,}75$ [psi/mA]

D. Characteristic of the modeled plant

In possession of the transfer of functions and their characteristic parameters, you can simulate plant behavior using the Simulink® environment. To this is mounted scheme shown in Fig.6:

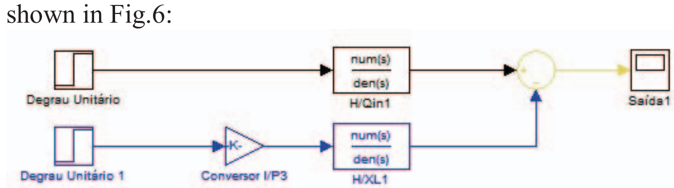

Fig. 6. Simulation scheme studied plant

Then, by applying a unit step entries for Q_{in} and X_L, is obtained the curve depicted in Fig. 7. From there, you can see that the plant has the characteristics of an unstable system integrator open loop and that despite the negative characteristic corresponding to the portion of the control valve, the portion corresponding to the input flow overlaps causing the vessel level indefinitely increase with time.

To unite all elements of the system modeled under closed loop without a controller, as in the Fig. 8 scheme, the system response is given in Fig. 9. For this Q_{in} simulation is considered a noise whatsoever, since it is not being considered a measure disorder, while the setpoint is given by an amplitude step 30 to represent the desired level of 30%.

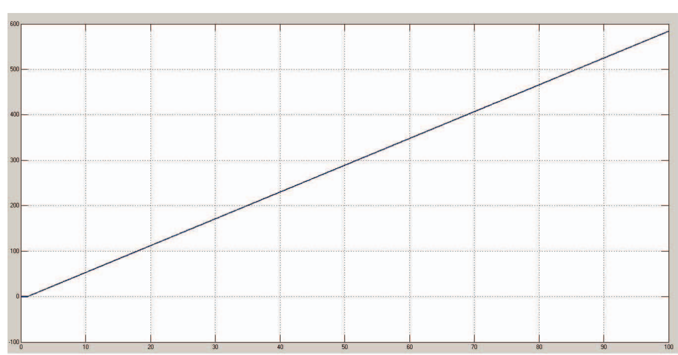

Fig. 7. Plant response to a unit step

According to the system response graph, the closed loop plant assumes a decreasing characteristic due to the action of the control valve is fed back indefinitely. Therefore, this condition is unstable presents the same manner as in open loop.

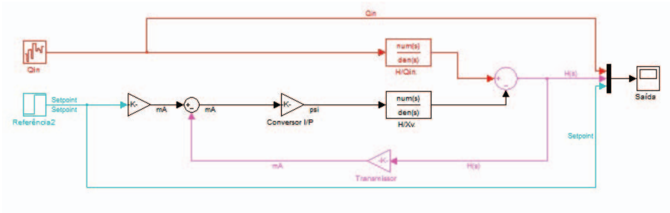

Fig. 8. Plant without closed-loop controler

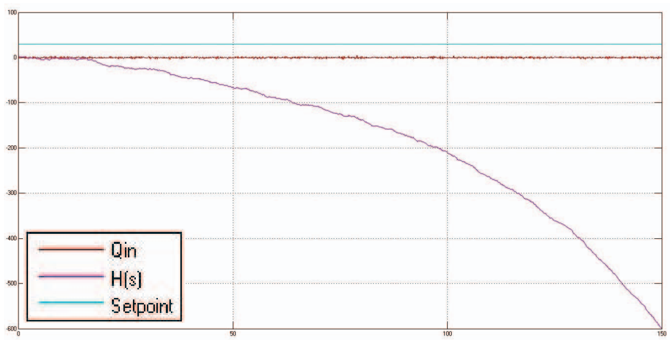

Fig. 9. Response to unit step of the plant without closed-loop controller

V. Controller Design

According to reference [1] and the wide range PID controllers are available in commercial market, with the known type of controller to be used, their design shall be based phase in your tune. However, to tune level control loops there are two options objectives to be achieved. At first, with mostly at the level of mesh has the function disorders of cushioning process, using Net inventory as a vase lung form to absorb the disruption of the process. Second, other level mesh having the function to keep controlled level as close as possible to set point, or have a fairer control as in the case of reactors in which the level of the liquid phase It is a parameter that defines the conversion reached. For the development of PID controller the foundations have been used proposed by Fredman, apud Lobato, 2013, while the available methods in classical literature are sufficient to be obtained the second behavior.

VI. Results and Discussions

Despite the fulfillment of the objectives set initially, some project were adapted for this to be a real plant protected under the company's confidentiality policies and part of their data is in information protection regime. Thus, the valve of choice, for example, was performed from surface data presented in catalogs of manufacturers, since field visits are required to determine the optimum valve for each process. We conducted a simulation reference is given by a range of step 50 to represent a level of 50%, while the input flow to be unknown is given by a white noise. The resulting output is shown in Fig. 6, high amplitude oscillations occur in the first 10 seconds, but this time after the system was stabilized ranging between 47% and 53%. This enables the damping oscillatory behavior disturbance, by allowing for a variation in the level, use is made of the capacitive characteristics of the vessel being achieved the goal of this line.

The fact that this is a real plant makes it difficult to search for similar jobs for comparison purposes and because the process is studied in the oil and gas field of knowledge, most of the references is restricted to scientific production generated by the company and its effective, it is based on their own plans. Within this lack of reference, the study of refining plants is more difficult still available for the works relating to control in oil and gas systems are limited in large part, to operating processes, i.e., extraction wells, the expense of refining processes. This was circumvented by allying the classical literature to recent studies looking at each source a resemblance to the studied plant and combining them.

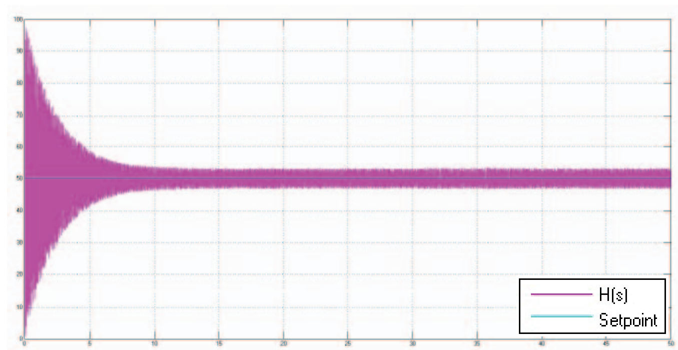

Fig. 10. System response to tune proposed by Friedman (1994).

This project has distinction of being molded to the physical implementation, then seeks to solve the problem given theme in the most practical way possible. For this we used manual techniques and standards rather than academic studies in their implementation. We attempted to maintain a close relationship between the projected elements and available. The control valve, for example, was represented according to type, model and manufacturer, while the controller was chosen for the PID to be the most common algorithm among commercial drivers. And the model was carried out in the most practical way found, disregarding relevant details in theoretical studies.

Thus, with this Project as a basis you can:

- Determine the commercial driver being used;
- Implement designed control in real plant;
- Make studies comparing different control strategies, especially ON-OFF, since the flow is small and this is presented as simple control and cost;
- Conduct studies comparing PID tuning current methods to control specific level;
- Study the use of other control valves, as this is the most costly part of the project and the part involving project cost was not taken into account.

Anyway, as this project is a preliminary study, all the elements set can be optimized through specific studies, which generates a considerable number of these jobs to be performed.

VII. Conclusion

The design of an automatic control system occurs when you want to provide safety to the operator, preventing it perform dangerous activities or harmful to their health and to be exposed to hostile environment. Therefore, targeting these benefits, this study presents the automatic level control design for a vessel that needs constant drainage, but containing pressurized LPG, which adds risk to this simple activity. Translating the features required for its development, this control design was divided into four specific objectives were: scale a control valve for the system model the process being controlled valve formed by the vessel assembly and finally designing a PID controller for the system. Each of these steps was developed and described evidencing compliance with the proposed objectives and culminating in the design of a level control containing all the basics: Controller, Actuator, Plant and Measuring Element, which is not required for project already be sized and installed in the vessel under study.

Thus, according to the organization of this work was first scaled control valve using the specific ISA manual for this purpose. In dimensioning the valve, calculations were made for testing as a critical flow conditions, cavitation, work opening and precise characteristics were valve construction as leakage class, type of actuator and direction of airflow to be ensured valve efficiency in the middle where it should operate. Having the control valve was possible to follow for system modeling to be controlled, which also included a vertical cylindrical vessel with constant pressure.

In the modeling stage, the region of interest of the vessel is one in which water accumulates, ie the boot. This was considered an independent vessel to simplify their mathematical modeling. Other features of this model are that the operating pressure of the vase is kept constant as in [1], pressure losses are negligible in the pipe and the valve downstream pressure is zero in this discharge on a channel at atmospheric pressure.

Finally, the controller is designed. By presenting a large number of possibilities for implementation and for ensuring control of the system, even if it is not a great control, it was determined that the driver used would be the PID from the start. And despite its variations as parallel or series, in this work the PID used was academic, since from it there are conversion rules for all other types. As for the line were considered two desirable behaviors to the level of control: disturbance attenuation and rejection of disturbances. Although the first to be of most interest in this case, it was considered useful to have the second to even notice the difference in behavior of the system resulting from the two different types of tuning.

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