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# ARTIFICIAL INTELLIGENCE TECHNIQUES APPLIED IN A SIMULATED OIL DISTILLATION SYSTEM

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***Abstract.*** *In this work Artificial Intelligence techniques are applied for a simulated oil distillation system. The chosen system was a debutanizer column. At this process, the feed comes to the column is segmented by heating. The lightest components become steams, by forming the LPG (Liquefied Petroleum Gas). The others components continue liquid and they are being often called C5+. In the composition of the LPG, ideally, we have only propanes and butanes, but, in practice, there are contaminant, as, for example, pentanes. The ideal LPG to be used do not must have in its composition more than 3% of pentane. The objective of this work is to control pentane amount in LPG, by means of a intelligent determination of the sets points (SP) for PID controllers that are present in originalcolumn instrumentation. A Mamdani fuzzy system is designed to set values of these SP's with base in the desired quantity of pentane. The designed fuzzy system disposes of two inputs (error and error variance), and one output (SP of the reflux flow controller). The results of this work show the fuzzy controller efficiency in the dynamic generation of set points applied in regulatory control of a gas process plant.*

***Keywords****: fuzzy system, system oil distillation, intelligence techniques*

## 1. INTRODUCTION

The *fuzzy* logic is actually one of well-succeeded technologies for development of sophisticated processes control systems (Dutta, 1993, Castro, 1995, Lee, 1990). These systems are called fuzzy controllers and have their origin with the E. H. Mamdani (Mamdani, 1976) researches, based on theories proposed by L. Zadeh (Zadeh, 1965). These controllers have founded space in many learning, research and development institutions around the world, being today an important application of fuzzy set theory (Sandra, 1999). A great appeal of fuzzy technology in control is the possibility to operate with uncertainties and imprecisions. It can consider an uncertainty on definition of input and output variables (Abreu and Ribeiro, 1999).

The success of the fuzzy controllers lies in the necessity of acting on areas where decisions must be made from an imprecise and vacant information set. In this type of controller are used logical rules to describe, through a computational routine, the human experience and intuition to control a process. The fuzzy logic expresses operational laws of a control system by linguistic terms instead of mathematical equations, as occurs in classic methodology, being this its main advantage (Botura et all, 1999).

The fuzzy controllers are robust and high adaptable, incorporating knowledge that sometimes are not achieved by other systems (Guerra, 1998). They are also versatile, mainly when the physical model is complex and has a hard mathematical representation. In fact, fuzzy controllers are especially useful in non-linear systems and plants with a high level noise (Sandri, 1999). The conventional controllers deal with non-linearities of physical systems by approaching, considering the systems simply linear, linear in parts, or describing them by extensive lookup tables that try to map the process inputs and outputs.

At complex industrial plants, as petrochemical processes, non-linear control techniques have been introduced, at automation scale level, between regulatory control and supervisory system. This way, the regulatory control loops that are considered reliable by industry is maintained, and more sophisticated techniques operates in optimization level and in the set points generation to regulatory control. This strategy is termed as advanced control. It have presented excellent results on natural gas processing plants where are usually applied predictive control techniques (Cavalcanti, 2007).

In this work, the fuzzy controller will be used to adjust the molar fraction of i-pentane in LPG (Liquefied Petroleum Gas) composition. This adjust will be made generating set points to one of PID controllers present on gas processing plant. In industry, this problem is usually solved by predictive control strategies. However, an intelligent control strategy can be applied. This work investigates the efficiency of fuzzy controllers on set points generation.

## 2. DEBUTANIZER COLUMN

At natural gas processing plants the debutanizer column is responsible for LPG production. The debutanizer receives as feed the NGL (Natural Gas Liquids), consisting normally of C3+. The debutanizer column goal is separate, by distillation, the LPG and C5+. The LPG is the column’s top product and the C5+ is the bottom product.

When the debutanizer column is heated, the lightest components become steams, by forming the top product. However, a small part of the heaviest components can be also evaporated, mainly the pentane. To assure the LPG quality, its total composition must have no more than 3% of pentane. In another way, if the column is cooled in excess, the lightest products cannot be evaporated at all and a part of them would be removed with the bottom product. Hence, we have a product out of the quality specifications and an economical loss, since he C5+ has lower prices in market than LPG.

In this work, the debutanizer column dynamic was simulated by the HYSYS software. This software is a rigorous chemical processes simulator.

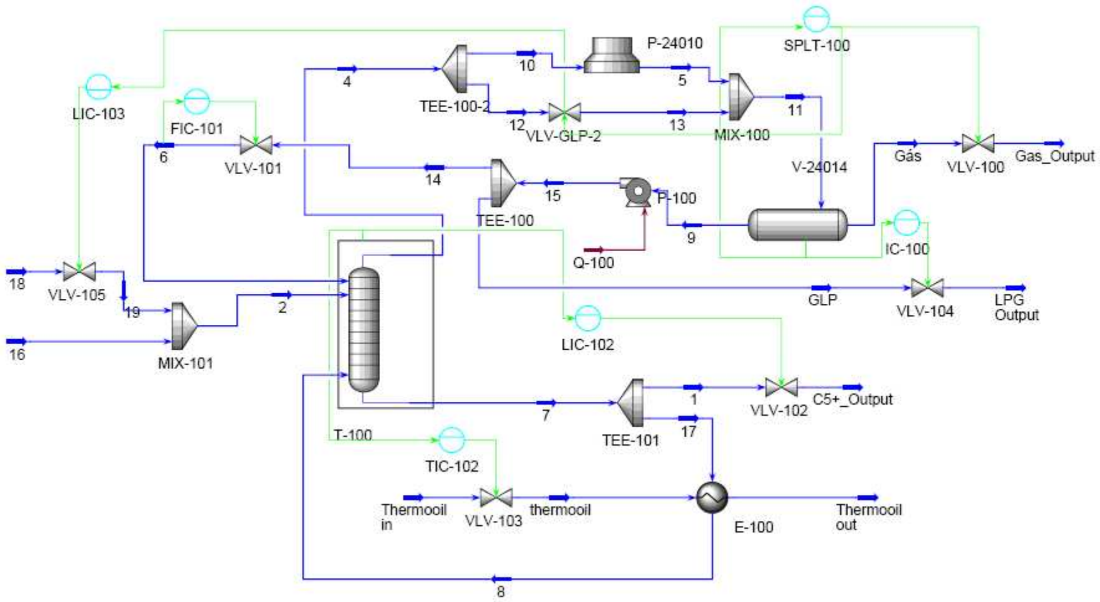


Figure 1. Simulated debutanizer column.

A schematic diagram of the simulated debutanizer column is shown in Fig. 1. In line 2 we have the feed top stream, which is the mixture of the products in lines 16 and 18. The line 16 carries NGL (C3+), the bottom product of an ideal deethanizer column, while the line 18 carries an ethane controlled flow rate. This way, it turns possible simulate different feed conditions. In the debutanizer column, a part of the bottom product that leaves the column flows to the C5+ production and the other part flows through the reboiler E-100, taking part in the heating process and returning to column. The thermal oil flow rate in E-100 is controlled by TIC-102. On the other hand, the top product flows to a reflux drum, before that the top product can flow through the air cooler P-24010. The top product flow rate, that flows through the air-cooler or goes into reflux drum, depends on split ranger pressure controller (SPLT-100) action on bypass valve VLV-GLP-2. From reflux drum, a LPG part can be streamed to LPG output line to be commercialized and the other part returns to the debutanizer column through a reflux line (line 14). This reflux process is controlled by FIC-101, which operates the reflux valve VLV-101, increasing or decreasing the LPG flow rate that comes from the reflux drum. Depending on the pressure inside of the reflux drum and the temperature column, a LPG amount can flows to gas output line to be burned, this process is called flare.

## 3. FUZZY SYSTEM

A fuzzy system can be divided in three stages: fuzzification, knowledge base and defuzzification. In the fuzzification stage, the real values of the variables are mapped in memberships functions called $\mu_A(x)$, the membership of the variable *x* on the membership function *A*. This way, a element can belongs to a set with a membership function in the interval [*0,1*], where the value *0* denotes a complete exclusion (not membership), the value *1* denotes complete membership (totally member) and the values between *0* and *1* denotes intermediates membership functions defined to the object related to the set. So, there is the possibility of a determined element belongs to a set with a value called membership grade (Zadeh, 1965).

The knowledge base is divided in database system and rule base. The database system defines the membership functions, which receive labels that translate in words some meaning to the modeled physical phenomenon. The rule base defines a set of rules by logical operators, establishing relationships between input and output values.

The controller final stage, called defuzzification, gets the resulting values from the fuzzification stage to produce a control action by using the incorporated decision logic in the inference structure of the knowledge base. These values are mapped in a numerical output which will be used by a control action in the real world.

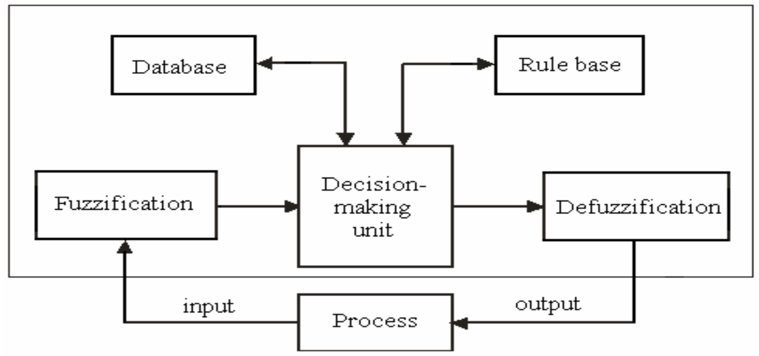


Figure 2. Fuzzy controller diagram.

**4. PROPOSED CONTROL SYSTEM**

At natural gas processing plants the debutanizer column is responsible for separate the LPG (top product) and natural petrol or C5+ (bottom product). The LPG has a more valuable commercial price than C5+ and the control of its composition is assured by the joint action of some controllers that compounds the column instrumentation, mainly the reflux flow rate and bottom temperature controllers. These controllers joint action turns possible to achieve faster responses about the composition of LPG produced, while the natural petrol quality is assured simultaneously.

The objective of this research is optimizing only the LPG composition control, without deep concern about the natural petrol. In this work is presented a fuzzy system able to generate set points dynamically to the FIC-101 controller based on i-pentane molar fraction in LPG composition. The pentane in LPG is composed by the sum of fractions of i-pentane and n-pentane. Both present the same change tendency in function of the operation conditions. However, i-pentane molar fraction is present in a higher quantity in LPG, as shown in simulation presented in Fig. 3. Therefore, only i-pentane molar fraction control was chosen.

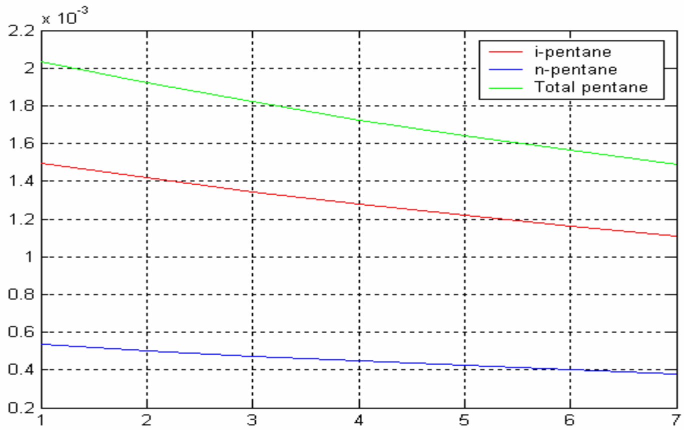


Figure 3. Molar fractions of i-pentane, n-pentane and total pentane in LPG

The Mamdani model was the base of the fuzzy system projected. The system was developed in a C++ programming environment. The error and change in error, as indicated above, are the inputs of the fuzzy system.

$$e = ref - v\_ip \quad (1)$$

$$\text{var}\_e = e - e\_ant \quad (2)$$

Where *ref* is the desired i-pentane molar fraction, *v_ip* is i-pentane molar fraction in the LPG composition, *e* is the error, *e_ant* is the previous error and *var_e* is the change in error.

The designed system uses the Bell-shaped membership function. Its membership grades are given by the following equation:

$$\mu_A(x) = \frac{1}{1 + \left| \frac{x - c}{a} \right|^{2b}} \tag{3}$$

Where *a*, *b* and *c* are parameters of the membership function.

The fuzzy system presents in its output an increment value to the FIC-101 set point, featuring as a fuzzy PI controller (Shaw e Simões, 1999).

Table 1 shows the fuzzy system rules.

Table 1. Rule base.

<table>
<tr><th colspan="7">CHANGE IN ERROR</th></tr>
<tr><th rowspan="6">ERROR</th><th></th><th>Negative Big</th><th>Negative</th><th>Zero</th><th>Positive</th><th>Positive Big</th></tr>
<tr><th>Negative Big</th><td>Increase</td><td>Small Increase</td><td>Increase</td><td>Small Decrease</td><td>Decrease</td></tr>
<tr><th>Negative</th><td>Increase</td><td>Small Increase</td><td>Hold</td><td>Small Decrease</td><td>Decrease</td></tr>
<tr><th>Zero</th><td>Increase</td><td>Hold</td><td>Hold</td><td>Hold</td><td>Decrease</td></tr>
<tr><th>Positive</th><td>Large Increase</td><td>Increase</td><td>Hold</td><td>Decrease</td><td>Large Decrease</td></tr>
<tr><th>Positive Big</th><td>Large Increase</td><td>Increase</td><td>Small Decrease</td><td>Decrease</td><td>Large Decrease</td></tr>
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## 5. RESULTS

Figure 4 shows the debutanizer column behavior in terms of i-pentane presence in LPG and the generation of set points to PID FIC-101 by the fuzzy system. In this way, the objective is increase the i-pentane molar fraction in the composition of LPG produced. We can verify that the fuzzy system developed was able to achieve dynamically i-pentane molar fraction values very close to the reference value.

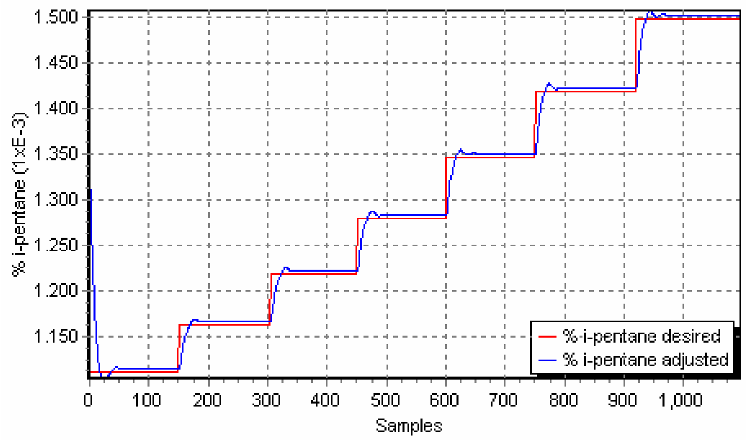


Figure 4. I-pentane molar fraction adjusted.

With the aim of quickly achieve the desired value of i-pentane molar fraction, the fuzzy system produces set points over or under necessary, but when the molar fraction comes closer to the desired value, the fuzzy system comes back to the values that yield an amount of i-pentane close enough to the desired value.

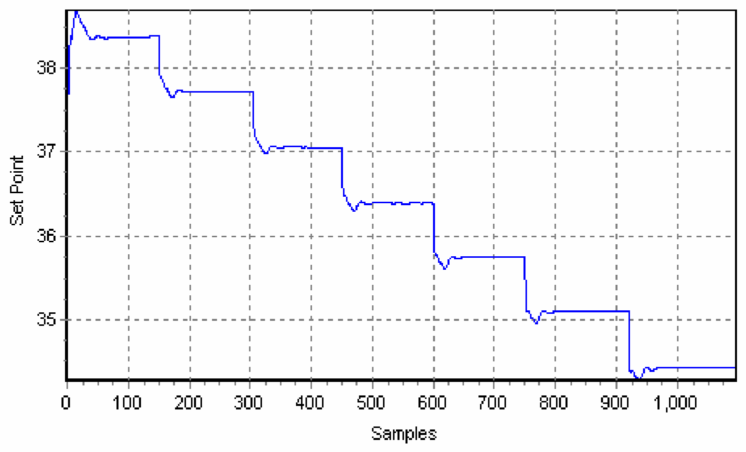


Figure 5. *Set point* generated by fuzzy system.

The following graphics show the debutanizer column and the fuzzy system behaviors in case the molar fractions are adjusted in decreasing values. Likewise in the case presented before, the fuzzy system worked well, generating suitables *set points*. However, the plant has a different dynamic due to the decreasing changes in the operation condition. Note that the production of set points is not as smooth as in the first case, oscillations have higher amplitudes. Therefore, i-pentane molar fraction in composition of LPG reaches slower the steady state for each change of reference.

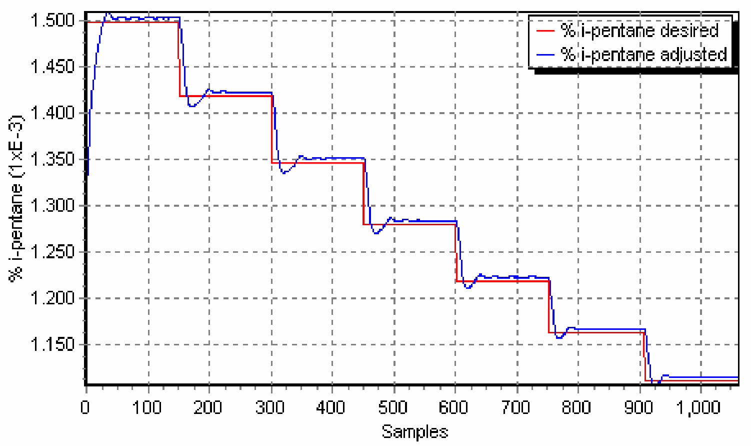


Figure 6. I-pentane molar fraction adjusted.

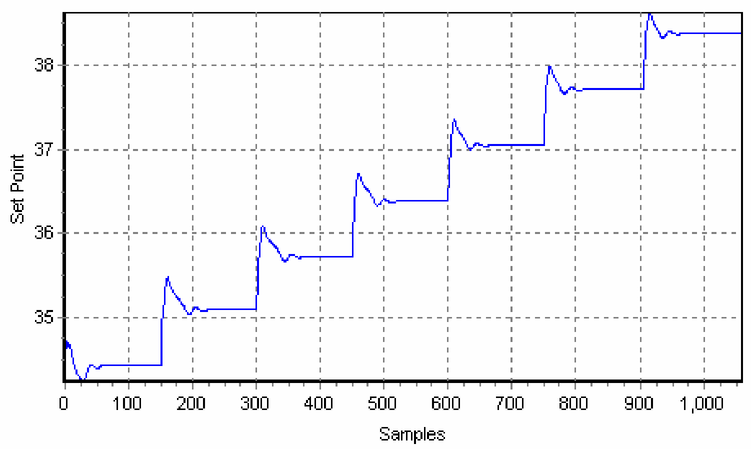


Figure 7. *Set point* generated by fuzzy system.

A last test was accomplished to confirm the fuzzy system efficiency; with the references values of i-pentane molar fraction being determined randomically. As shown in Fig. 8 and Fig. 9, the fuzzy system presented a great behavior, achieving good adjusts to the i-pentane molar fraction for all references, including the intervals where was necessary a significant increase in the set point value.

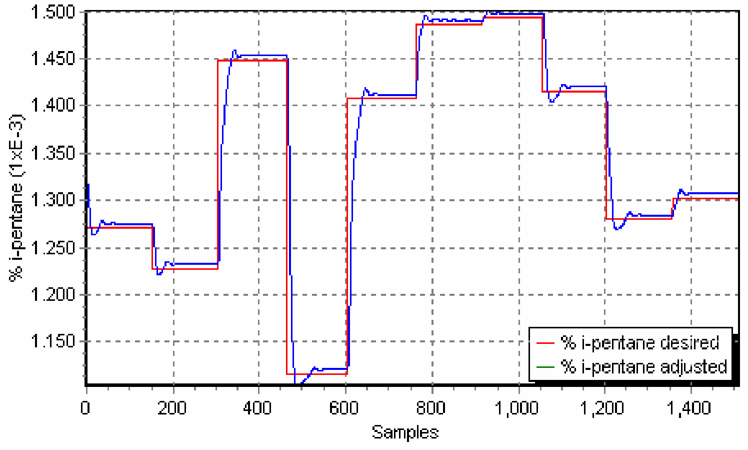


Figure 8. I-pentane molar fraction adjusted.

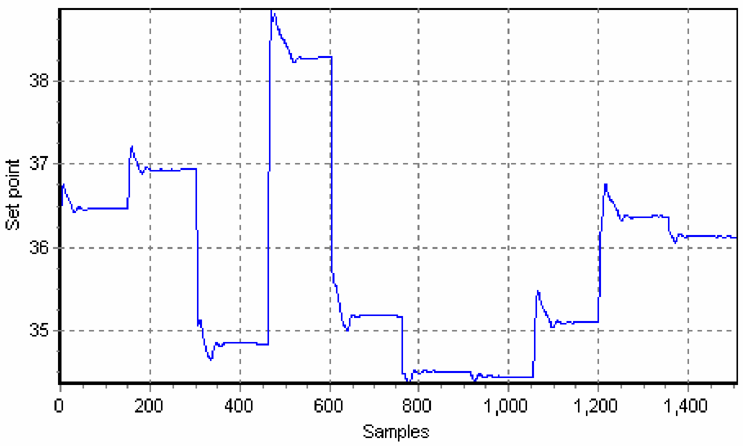


Figure 9. *Set point* generated by fuzzy system.

## 6. CONCLUSIONS

It is possible to note the existence of a small error when the process is in steady state. This error observed can be related with the debutanizer column non-linearities, since the used system to control the plant was a fuzzy system with a structure called fuzzy PI. In addition to that the membership functions were adjusted based on experiments, so efforts to achieve a better adjust is an alternative that must be considered. In this way, the error in steady state can be reduced. However, the mainly objective of this work was demonstrating the potential and the utility of fuzzy system in advanced control, producing *set points* for regulatory control of a debutanizer column. Therefore, the results obtained were satisfactory and leaved open the possibility of also use inferential techniques with the fuzzy system and promote an expansion in the system generating simultaneously set points for FIC-101 and TIC-102.

## 7. ACKNOWLEDGEMENTS


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