The Control Systems Analyze of the Romanian Refinery Gases Desulphurization Plants

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Abstract: - The paper presents the control aspects concerning Romanian gases desulphurization plants. The paper has been divided into four parts. First part presents the structure of the Romanian gases desulphurization plants. The second part contains the steady-state and dynamical process modeling. For the steady-state modeling, the authors have tested two simulation programs, respectively UniSim and PRO II program. Using the industrial data, they have also validated the thermodynamic model and mathematical model associated to UniSim program. The third part is dedicated to analysis of the Romanian control system for the absorption column. In the last part, the authors have analyzed and developed the hierarchically control structure for the Romanian gases desulphurization plants.

Key-Words: - absorption, modeling, UniSim, industrial, control, hierarchical, identification

1 Introduction
Within Romania 50 % of crude oil comes from abroad resources. Because the external crude oil contains 1-2% sulfur, the oil products contain sulfur compounds too. The refining processes converts the sulfur into hydrogen sulfide, the most important acid component of the refinery gases. These gases are used to gas fuel for the burners. The hydrogen sulfide concentration (2-4%) in the fuel gas determines the usage of the tubular heaters and generates SO₂ as combustion byproduct. In this context, the Romanian refineries have implemented Amine Treating Units which consists in the absorption of the hydrogen sulfide using an aqueous solution of the diethanolamine. The increase of the economic performances of the Amine Treating Units may be obtained using the advanced control systems.

In the last period, the authors have studied the hydrogen sulfide absorption process [1] and they have studied the control systems used into Jibissa (Syria) desulphurization plant [2, 3, 4]. The present paper is focused to the problems of the Romanian control systems to the Amine Treating Units.

2 The Romanian desulphurization plants
Because the crude contains hydrogen sulfide, the Amine Treating Unit belongs to the integrated structure of the Romanian refineries. The Romanian refinery gases desulphurization processes have the following objectives: quality objective, financial objective and environment objective. Usually, for the hydrogen sulfide absorption is used a solution of the diethanolamine (DEA). Because the refinery gases are used on to combustion within the refinery’s furnaces, the performances of the desulphurization plant is strictly related to the level of the emissions of the hydrogen sulfide. The process structure, presented in figure 1, consists in two columns: one absorption column and one stripping column (absorbent regeneration column). The feed flow contains the following components: methane, ethane, propane, butane, pentane, hydrogen, carbon-monoxide, carbon-dioxide and hydrogen sulfide. Because the absorber feed flow is a sum of the output flows of some refinery units, the feed flow rate and the feed flow composition have important variations.

Within the 2009 years, the authors have selected the most representative operating data associated at Romanian refinery gases desulphurization plant.
Table 1 presents the feed characteristics for then operating days and the operating medium point of the industrial plant. The operating parameters of the absorption column are presented in table 2.

### 3 The steady-state process model

The process model represents the most important element to design the structure and the algorithm of the process control system. The steady-state process model is used to study the input-output characteristics, to determine the sensibility of the process and to design the structure of the control system.

For the steady-state modeling, the authors have utilized the UniSim and the PRO II simulation program. The process model is de-composite into six sub-systems: the absorber column C3; the distillation column C4; two flash vessels; one heat exchangers and one flash valve.

The absorber column has 8 theoretical stages and the stripping column is modeled with 12 theoretical stages. The specifications of the stripping column are: condenser temperature seated at 90°C and the hydrogen sulfide fraction in the rich DEA seated at 0.0004 molar fractions.

The UniSim simulation diagram is presented in figure 2. The authors have selected the Amine Package thermodynamic model with Li-Mather thermodynamic model for aqueous amine solutions [5].

The PRO II simulation diagram is presented in figure 3. For this simulation program, the authors have selected the Amines package, the Chemdist algorithm for solving the mathematical model of the absorber and fractionation column [6].
Table 1 The feed composition

| Day | Feed flow rate [Nm³/h] | Feed temperature [°C] | Component | CH_4 | C_2H_6 | C_3H_8 | i-C_4H_10 | n-C_4H_10 | i-C_5H_12 | n-C_5H_12 | H_2 | CO | CO_2 | H_2S |
|-----|------------------------|------------------------|-----------|------|--------|--------|-----------|-----------|-----------|--------|----|------|------|
| 1   | 17635                  | 40.0                   | CH_4      | 0.2428 | 0.3658 | 0.1904 | 0.0222    | 0.0111    | 0.0007    | 0.0212    | 0.1219 | 0.0050 | 0.0017 | 0.0171 |
| 2   | 16210                  | 42.0                   | C_2H_6    | 0.2755 | 0.4020 | 0.1470 | 0.0195    | 0.0113    | 0.0007    | 0.0165    | 0.0966 | 0.0051 | 0.0020 | 0.0236 |
| 3   | 17060                  | 43.0                   | C_3H_8    | 0.2288 | 0.3339 | 0.1989 | 0.0731    | 0.0112    | 0.0005    | 0.0162    | 0.0954 | 0.0051 | 0.0018 | 0.0233 |
| 4   | 18150                  | 47.0                   | i-C_4H_10 | 0.2541 | 0.3219 | 0.2713 | 0.0658    | 0.0213    | 0.0009    | 0.0243    | 0.0344 | 0.0068 | 0.0020 | 0.0263 |
| 5   | 18300                  | 44.0                   | n-C_4H_10 | 0.2189 | 0.3037 | 0.2141 | 0.0715    | 0.0113    | 0.0009    | 0.0223    | 0.0856 | 0.0068 | 0.0017 | 0.0296 |
| 6   | 17900                  | 41.0                   | i-C_5H_12 | 0.2125 | 0.1423 | 0.1420 | 0.0174    | 0.0133    | 0.0009    | 0.0388    | 0.0991 | 0.0072 | 0.0017 | 0.0255 |
| 7   | 15150                  | 49.0                   | n-C_5H_12 | 0.2196 | 0.1433 | 0.2876 | 0.1620    | 0.1208    | 0.0017    | 0.0137    | 0.0236 | 0.0072 | 0.0019 | 0.0279 |
| 8   | 17500                  | 52.0                   | H_2       | 0.2168 | 0.1381 | 0.2894 | 0.1625    | 0.1208    | 0.0011    | 0.0163    | 0.0202 | 0.0096 | 0.0019 | 0.0316 |
| 9   | 17130                  | 42.0                   | CO        | 0.2366 | 0.2992 | 0.2906 | 0.1649    | 0.1208    | 0.0007    | 0.0182    | 0.0202 | 0.0097 | 0.0026 | 0.0284 |
| 10  | 16060                  | 44.0                   | CO_2      | 0.2843 | 0.2204 | 0.2906 | 0.1510    | 0.1208    | 0.0008    | 0.0165    | 0.0204 | 0.0071 | 0.0019 | 0.0268 |
|     | 17109                  | 44.4                   | H_2S      | 0.2755 | 0.2843 | 0.2906 | 0.1510    | 0.1208    | 0.0008    | 0.0165    | 0.0204 | 0.0071 | 0.0019 | 0.0268 |

Table 2 The operation parameters of the absorption column

<table>
<thead>
<tr>
<th>Day</th>
<th>Top pressure absorber column [bar]</th>
<th>Top temperature absorber column [°C]</th>
<th>Lean DEA flow rate [m³/h]</th>
<th>Lean DEA temperature [°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11.9</td>
<td>39.0</td>
<td>42.6</td>
<td>36.0</td>
</tr>
<tr>
<td>2</td>
<td>12.0</td>
<td>41.0</td>
<td>44.1</td>
<td>34.0</td>
</tr>
<tr>
<td>3</td>
<td>12.2</td>
<td>42.0</td>
<td>43.5</td>
<td>31.0</td>
</tr>
<tr>
<td>4</td>
<td>12.6</td>
<td>38.0</td>
<td>45.0</td>
<td>33.0</td>
</tr>
<tr>
<td>5</td>
<td>11.8</td>
<td>41.0</td>
<td>45.0</td>
<td>35.0</td>
</tr>
<tr>
<td>6</td>
<td>11.9</td>
<td>40.0</td>
<td>44.4</td>
<td>35.0</td>
</tr>
<tr>
<td>7</td>
<td>12.3</td>
<td>46.0</td>
<td>42.0</td>
<td>31.0</td>
</tr>
<tr>
<td>8</td>
<td>12.5</td>
<td>49.0</td>
<td>45.0</td>
<td>36.0</td>
</tr>
<tr>
<td>9</td>
<td>12.2</td>
<td>40.0</td>
<td>43.8</td>
<td>36.0</td>
</tr>
<tr>
<td>10</td>
<td>12.2</td>
<td>41.0</td>
<td>42.0</td>
<td>33.0</td>
</tr>
<tr>
<td>Medium point</td>
<td>12.1</td>
<td>41.7</td>
<td>43.7</td>
<td>34.2</td>
</tr>
</tbody>
</table>

Fig. 3 The PRO II simulation diagram.

Using the UniSim and PRO II simulation programs, the authors have simulated the desulphurization plant for each operated day presented in table 1. The comparative results are presented in figure 4 and 5. The analysis of the numerical results has permitted the authors to formulate the next conclusions:

a) The concentration of the hydrogen sulfide and the concentration of the carbon dioxide have been determined by the laboratory chromatography analyses. This technique has generated some errors, because the flow rates, temperatures and pressures data are recorded by the DCS and the laboratory chromatography results are manually recorded.
b) The UniSim simulation results are better in rapport to PRO II simulation results. That conclusion has obtained by comparison of the simulation results with the industrial data. The differences between UniSim and PRO II results are reported to different thermodynamic model and different mathematical model of the absorber column and stripping column.

c) Evidentially of the numerical results, the authors have considered that the UniSim mathematical model has been validated.

Fig. 4 Concentration of the hydrogen sulfide: a) industrial data; b) UniSim model; c) PRO II model.

Fig. 5 Concentration of the carbon dioxide: a) industrial data; b) UniSim model; c) PRO II model.

4. Dynamic process identification

The dynamic model will be used to determine the transfer functions of the disturbance-output channel and the manipulated variable-output channel of the process. In this moment, the authors develop the dynamical model of the Romanian refinery desulphurization plant. The results will be used to dynamical identification of the input-output process channels.

For the identification of the first order dynamical systems, the authors have developed a mathematically algorithm [7]. Let the mathematically model of the first order system

\[ a\Delta y + \Delta y = b\Delta i. \]  

(1)

The analytically solution of the mathematically model (1) is

\[ \Delta y(t) = b\Delta i \left( 1 - e^{-\frac{1}{a}t} \right). \]  

(2)

The gain factor \( b \) may be calculated using the steady-state regime. For to calculate the constant time factor \( a \), the authors have proposed to use a square sum function

\[ F(a) = \sum_{j=1}^{m} \left[ \Delta y_j - b\Delta u \left( 1 - e^{-\frac{1}{a}t_j} \right) \right]^2, \]  

(3)

where \( t_j \) and \( y_j \) represent the experimental data of the system.

The minimum of the function (3) is obtained using the condition

\[ \frac{dF}{da} = 0. \]  

(4)

The concrete expression of the (4) has the form

\[ \frac{dF}{da} = \frac{2b\Delta i}{a^2} \sum_{j=1}^{m} t_j \Delta y_j e^{-\frac{1}{a}t_j} - \frac{2b^2\Delta i^2}{a^2} \sum_{j=1}^{m} t_j e^{-\frac{1}{a}t_j} + \frac{2b^2\Delta i^3}{a^2} \sum_{j=1}^{m} t_j e^{-\frac{2}{a}t_j} = 0. \]  

(5)

By using the notations

\[ \begin{aligned}
    s_1 &= \sum_{j=1}^{m} t_j \Delta y_j e^{-\frac{1}{a}t_j} \\
    s_2 &= \sum_{j=1}^{m} t_j e^{-\frac{1}{a}t_j} \\
    s_3 &= \sum_{j=1}^{m} t_j e^{-\frac{2}{a}t_j} \\
    c_1 &= 2b\Delta u \\
    c_2 &= 2b^2\Delta i^2
\end{aligned} \]  

(6)

the relation (5) will have a new form

\[ g(a) = c_1 s_1 \frac{1}{a} - c_2 s_2 \frac{1}{a^2} + c_2 s_3 \frac{1}{a^2} = 0. \]  

(7)
In conclusion, for identifying the time constant of the first order dynamically model is necessary to solve the non-linear equation (7).

5. The Romanian control systems analyze

The most important control system is associated to absorber column [3]. The authors have studied the absorption control structure and they have identified the next representative control structures of the Romanian gases desulphurization plant, figure 6:

- The classically control structure;
- The structure based on the rapport control;
- The acid gas concentration control structure.

The classically control structures are characterized by the flow control system associated to the absorbent flow, the pressure control system and the bottom column level control system. The efficiency of this control structure is very small, because the major disturbance of the process (the feed gases flow rate) has important variations and the consequence is that the concentration of the hydrogen sulfide is variable.

![Fig. 6 The Romanian absorption control systems:](image)

a) the structure based on the rapport control;

b) the acid gas concentration control system.

The ratio control structures are better structures in rapport to classically structures, figure 6-a. The constant maintain of the concentration of the hydrogen sulfide into treating gas in relation to feed flow rate is the major advantage of this structure. The numerical value of the flow ratio has been difficult to determinate because the composition of the feed is variable.

The acid gas concentration control system is a Romanian control structure also, figure 6-b. The structure uses a hydrogen sulfide transducer for the

acid gas concentration control system. In this case, for the any variation of the feed flow rate or the feed composition, the control structure maintains the composition of the hydrogen sulfide at the specified value. The acid gas concentration feedback control system has an important inertia because the transport and mass transfer phenomena causes delay time into process.

6. The study of the hierarchical control system structures

The authors have studied the hierarchical control structures for the desulphurization plants [1, 3]. The conclusions of the study are the next:

a) The advanced control system for the desulphurization plant has a hierarchical structure with minimum two levels. First level of the hierarchical control system contains the basis control and the upper level realizes the feed forward control or the optimal control function.

b) The most important element of the control system structure is the value of the high limit of the hydrogen sulfide concentration into treated gas. For a small value of the hydrogen sulfide concentration the upper level of the hierarchical structure has the optimal control function, because the DEA flow rate will have great values and the financial cost is bigger [4]. If the hydrogen sulfide concentration limit is high, the upper level of the hierarchical structure will contains a model predictive controller.

c) The statically characteristic of the hydrogen sulfide concentration into treated gas versus DEA flow rate selects the function of the second level of the hierarchical structure. If this characteristic has a discontinuous point, the optimal control structure is recommendable [2, 4]. If the discontinuous point misses within of the characteristic, that is recommendable to implementing a concentration control system based to a model predictive controller.

Used the mathematical model validated above, the authors have studied the statically characteristics for a Romanian desulphurization plant. Figure 7 shows the dependence between the hydrogen sulfide concentrations versus DEA flow rate.
Because the hydrogen sulfide concentrations varies for a large domain of the DEA flow rate, the upper level of the hierarchical control system will contain a concentration controller based on the predictive model algorithm, figure 8.

Fig. 8. The hierarchical control structure for the Romanian desulphurization plant

7. Conclusion
The paper reflects the author’s researches in the chemical process control. The focus of the paper is the Romanian control gases desulphurization plants. The authors have analyzed the structure of the desulphurization plants. For the steady-state process modeling, the authors have tested two simulation programs: the UniSim and the PRO II simulation program. Using the industrial data, they have validated the thermodynamic model and mathematical model associated to UniSim program. The authors have analyzed the absorption control structure of the Romanian desulphurization plants. To increases the technical and economical performances of the desulphurization plants, the authors have developed a hierarchical control system.

References: