SCADA-System for Zeolite Suspension Production Using Multivariable Crisp Logic Controller

A. I. Kayashev
Ufa state petroleum technical university
Sterlitamak branch
Sterlitamak, Russia
e-mail: kayashev.ai@rambler.ru

E. A. Muravyova
Ufa state petroleum technical university
Sterlitamak branch
Sterlitamak, Russia
e-mail: muraveva_ea@rambler.ru

R. F. Gabitov
Ufa state petroleum technical university
Sterlitamak branch
Sterlitamak, Russia
e-mail: gabitoff@yandex.ru

Abstract[1]

The paper is devoted to the creation of SCADA-system for zeolite suspension production on Ishimbay specialized chemical factory of catalysts using multivariable crisp logic controller. Two control stages are suggested to use: approximate and fine control. It has been shown that the control method suggested allows to improve control characteristics of the zeolite suspension production process.

1. Introduction

An object for automation is a crude pre-conditioning department of catalysts production on Ishimbay specialized chemical factory of catalysts, designed for catalysts production on the basis of catalytic cracking of different types of fluid. The production is comprised of the following production installations:

1. zeolite suspension production;
2. HNO_3 dilution and sodium silicate solution;
3. production of silica hydrosol and pulp.

Among them installations 1 and 2 are of the most considerable importance for efficiency of the crude preparation department. The said processes are entirely similar therefore it is adequate to consider their automation as exemplified by zeolite suspension installation since it differs in more complicated control algorithm due to three interrelated components involved in the process as well as in non-linear pH relation to the amount of material.

2. The concept

In the technology of suspending from Na-Y or H-Y zeolite types (zeolite based on sodium and hydrogen respectively) formed is a finely divided suspension refered to as zeolite pulp employed in order to increase rate of ion exchange processes and to simplify both transport and mixing of materials. Fine division is provided by prolonged stirring of components in a tank with a stirrer as well as by liquid circulation by means of a pump. The preset component ratio is effected by water flowmeter provided inside the tank. The process flowchart of zeolite suspention installation is shown in Fig. 1.

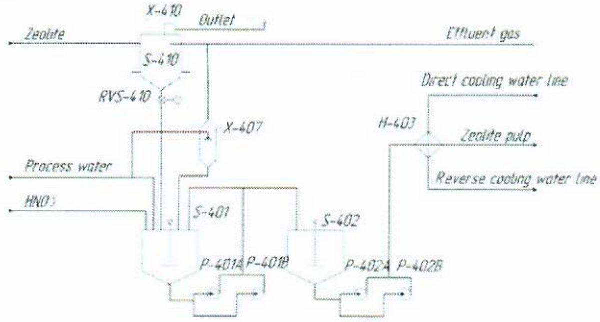

Fig 1. Process flowchart of zeolite suspension department

Zeolite weight in the tank S-410 is controlled by means of automated control system (ACS) provided with a weight sensor. The pH value is controlled by feeding the tank with HNO_3 solution. For the product supply to the

[1] **Proceedings of the 12th international workshop on computer science and information technologies CSIT'2010, Moscow – Saint-Petersburg, Russia, 2010**

downstream process stages to be continuos the final pulp is charged into storage tank S-402.

The control goal in the installation under consideration is the manipulation of the HNO_3 solution supply valve to feed tank S-401 in order to reduce the controlled value i. e. the pH value of the zeolite pulp down to six. This controlling object has the folowing features: the HNO_3 supply valve is of a dicrete operation (it can operate in two stable positions: either open or shut off), the control process due to the closed-loop tank volume and irreversability of component supply is a one-way process.

As the ACS functions it generates the information as to the weight of zeolite supplied, to the volume of the process water fed and HNO3 solution supplied as well as to the pH value of the zeolite pulp in the tank. The relation of the zeolite pulp amount in tank S-401 to the volume of HNO_3 solution supplied is expressed by the following formulae:

For the acid medium:

$$pH = \\ = -\log\left(\frac{[HNO_3]-[NaOH]+\sqrt{([HNO_3]-[NaOH])^2+4\cdot 10^{14}}}{2}\right). \quad (1)$$

For the alkaline medium:

$$pH = 14 + \\ + \log\left(\frac{[NaOH]-[HNO_3]+\sqrt{([NaOH]-[HNO_3])^2+4\cdot 10^{14}}}{2}\right), \quad (2)$$

where $[HNO_3]$ and [NaOH] is concentration of nitric acid and of sodium hydroxide in the tank, g-mol/l respectively. The diagram of the pH value function of the acid solution weight is shown in Fig. 2.

The nitric acid concentration in the tank is related to the m_p mass of the pulp supplied into V_0 volume by the following function [4]:

$$[HNO_3] = \frac{m_p \cdot k}{0.063\cdot\left(V_0 + \frac{m_p}{\rho_p}\right)}; \quad (3)$$

where k is concentration of the acid in the solution, %;

ρ – solution density, kg/l.

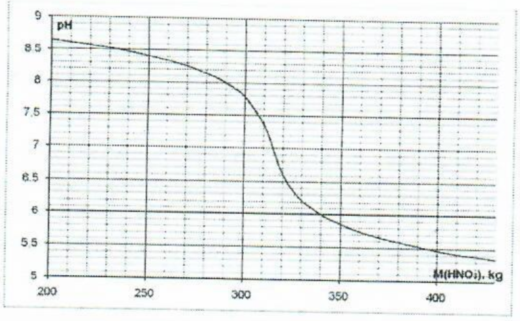

Fig 2. The pH value function of the acid solution amount

As it follows from (2) the pH value is influenced by the amount of solution, by acid concentration in the solution, by the solution density and by the tank liquid volume. Since the solution volume used for acidification is by 2 orders of magnitude less then that of the liquid acidified, we can ignore the variation in the liquid volume followed by acid addition hence the density value needed to calculate the solution volume can also be ignored. Then formula (2) looks like:

$$[HNO_3] = \frac{m_p \cdot k}{0.063\cdot V_0}. \quad (4)$$

By substitution of (4) in (1) and (2) we obtain:

For the acid medium:

$$pH = -\log\left(\frac{\frac{m_p\cdot k}{0.063\cdot V_0}-[NaOH]+\sqrt{\left(\frac{m_p\cdot k}{0.063\cdot V_0}-[NaOH]\right)^2+4\cdot 10^{14}}}{2}\right). \quad (5)$$

For the alkaline medium:

$$pH = 14+\log\left(\frac{[NaOH]-\frac{m_p\cdot k}{0.063\cdot V_0}+\sqrt{\left([NaOH]-\frac{m_p\cdot k}{0.063\cdot V_0}\right)^2+4\cdot 10^{14}}}{2}\right) \quad (6)$$

Practical significance of formulae (5) and (6) lies in calculation of acid amount needed in order to reduce the zeolite pulp pH value from initial one down to the required.

3. Control methods suggested

In the existing systems the pH value control in the tank is effected by sending discrete signal to the valve when the current value of value controlled is out of match with the preset value. A drawback of such a solution is necessity to account the pH-meter signal time lag due to time outlay for stirring and uniform acid distribution throughout the entire tank volume. The control quality doesn't increase even in cases of replacement of the relay drive valve with the servo drive valve. Thus it has been suggested to control the pH value in tank S-401 via two stages:

1. Approximate control: ignoring errors and ACS element's sluggishness the acid supply valve with discrete output is open till the moment when the zeolite pulp pH value decreases from (7–9) down to the value ranging within (6.3–6.4).

2. Fine control using feedback. At this stage the most reasonable is batchwise supply of preset acid doze in the tank, time delay for stirring and acidity measurement using pH-meter. Stirring duration must be sufficient for the solution to be uniformly distributed all throughout the entire tank volume.

At the stage of the approximate control of solution supply to the tank there is no need to take into consideration lagging in the installation reaction, which makes it possible for the relay controller to be used. It's algorithm is expressed by the following production rule:

If $m_s < m_{s\,pr}$, THEN valve open, ELSE valve shut off,

where m_s and $m_{s\,pr}$ are current and preset value of amount of the acid doze supplied into the tank respectively.

The main control action at the stage of fine control is the choice of the $m_{s\,pr}$ value which determines to which value acidity will be reduced after a consequent acid addition. Application of P-, PI- PID-controllers for the above mentioned purposes gives rise to a number of problems among which the main problems are such as irreversibility of pH value reduction which eliminates use of the I-component; discrete nature of the process which leads to the discontinuous changing of the D-component; whereas the P-component is unacceptable due to the law non-linearity of the pH value variation depending on the concentration. Therefore it is particularly reasonable to preset several different nitric acid doze values which will be selected based on the condition under which the current pH value falls into this or another interval by means of the crisp logical controller (CLC). The above mentioned control concept [1, 2, 3] allows to minimize the program code, it doesn't require complicated mathematical calculations and lends itself to be readily adjustable. CLC output variable is a doze value of the acid supplied, calculated following formula (4).

Value of both intervals and dozes can be obtained from experts. Thus the controller behavior is similiar to that of a human-operator at nitric acid addition into the closed-loop tank in order to attain the preset pH value: successive approximation to the preset value occurs with the control action being reduced according to the logarithmic law. It will allow to approach the pH preset value with the algorithm adequately simple at the maximum rate and without overshoot.

Taking into account the errors found in [6] the interval of the fine control has been split into terms as follows: "Very big deviation": pH > 6.4; "Big deviation": 6.4 ≥ pH > 6.2; "Medium deviation": 6.2 ≥ pH > 6.1; "Small deviation": 6.1 ≥ pH > 6.05.

Thus, maximum term boundary "Big deviation" matches the pH values of approximate control, whereas the minimal boundary of the term "Small deviation" is the resolution of the pH-meter. But at any rate as the zeolite pulp pH value approximates 6.1, the term width decreases.

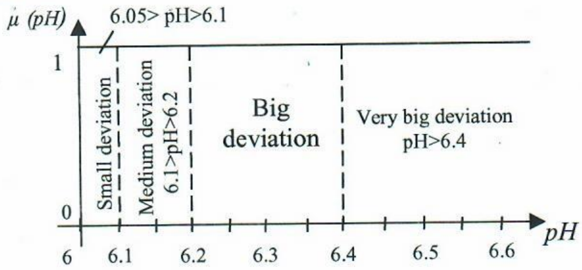

Fig 3. Membership functions of terms of the input linguistic variable of the pH value

The arrangement of membership functions of crisp terms along the numeric axis of the input variable is shown in Fig. 3.

From formula (4) an expression to determine the amount of solution required to reduce the pH value from $pH_{(i+1)}$ down to pH_i has been obtained:

$$m_p = \left(10^{(pH_i-14)} + 10^{-pH_{(i+1)}} - 10^{-pH_i} - 10^{(pH_{(i+1)}-14)}\right)\times \\ \times 0.063 \cdot 20170 \qquad (7)$$

where i = (1–4) is the number of the current term of the input variable.

By substitution of the crisp pH values into (7) corresponding to both top and bottom boundaries of the terms of the output linguistic variable instead of pH; and $pH_{(i+1)}$, the doze values for each term have been obtained. The calculated values must be reduced by a total error of solution weight calculation and maximum leak at valve shut off. The values obtained are entered into Table 1:

Table 1. Doze values of acid supplied in keeping with intervals

Description of a term	Doze value, kg
Very big deviation	11.3
Big deviation	5.4
Medium deviation	2.5
Small deviation	1

Graphic presentation of the output variable which is doze weight of the acid supplied is shown in Fig. 4.

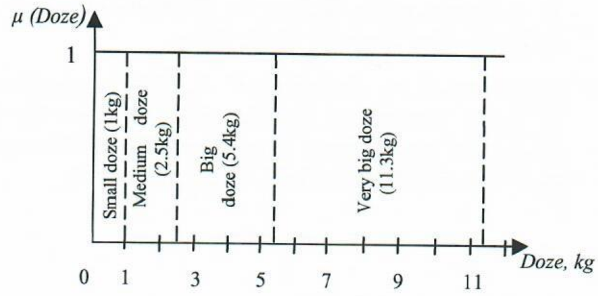

Fig 4. Membership functions of the terms of the output variable

4. Criteria of control evaluation

As the main criterion used to evaluate the solutions entered into the pH control system in tank S-401 the value of control time of the pH value has been accepted when the zeolite pulp is considered ready for transmission to the department of catalyst preconditioning.

In Fig. 5 presented is graphic interface (GI) of the zeolite suspension section in SCADA-system with discrete – logic control of zeolite pulp pH value developed in integrated environment Trace Mode 6. GIs of the other installations of the crude pre-conditioning department for catalyst production are similar.

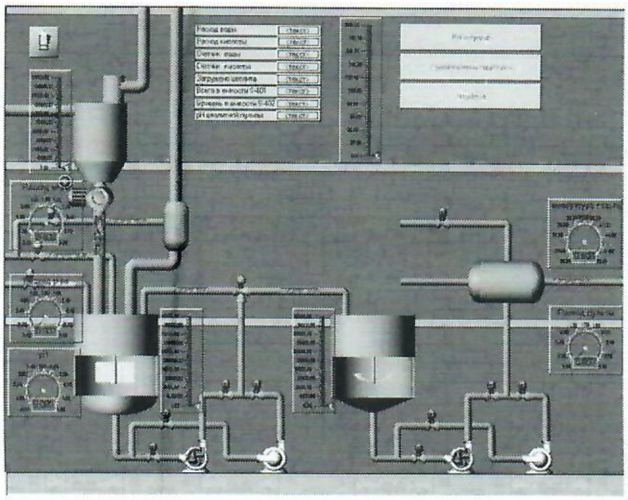

Fig 5. Graphic interface of the zeolite suspending department

The first experiment on the SCADA-system was conducted under conditions of approximate control of the pH value. The value of time as spent on control has been defined by means of the process archive trend (Fig. 6).

Line 1 displays the current value of the pH control value. Line 2 corresponds to the value of the variable "Solution supply" according to witch the valve is controlled. Line 3 shows acid flow rate to be supplied to the tank. Control time in such mode was 180 min.

The second experiment was conducted under control conditions using CLC (Fig. 7). During the whole procedure the control time was 92 min., which is less as compared with the first case by 88 min. or 47 per cent.

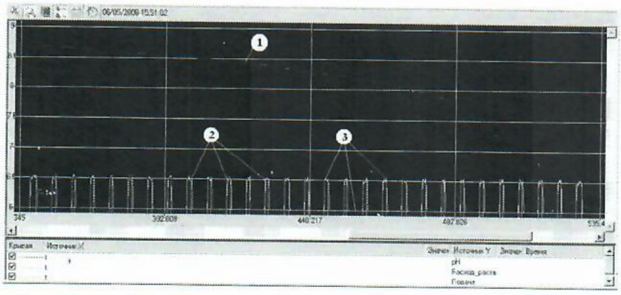

Fig 6. Zeolite suspending in the approximate control mode

Finally the third experement was conducted in CLC control mode the correction being made for the complimentary nitric acid flowrate as caused by the finite time of valve open/shut off.

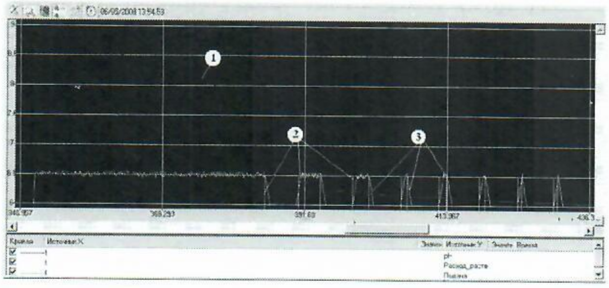

Fig 7. Process trends in CLC control mode

The control time in this mode was 84 min., i.e. in comparison with the first case it decreased by 96 min. or by 72 per cent.

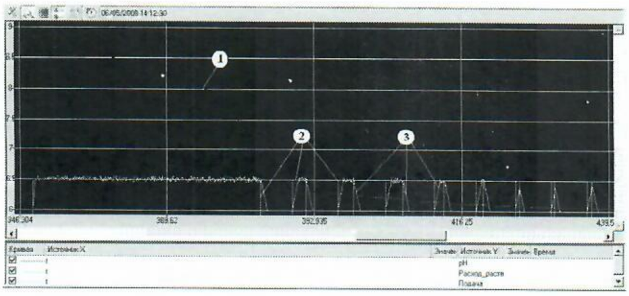

Fig 8. Crips logic control with correction for the valve technical state

5. Conclusions

Thus, from the analysis of the results of the experiment conducted it follows that the most considerable reduction from 180 down to 84 min. (by 96 min. or by 72 per cent) in the transition process time of the logic control of the zeolite pulp pH value occurs while taking into account nitric acid supply valve performance. In this case economic benefit from CLC implementation amounted to 4.6 million roubles per annum. Such increasing of zeolite production technical-and-economic indices is only feasible with the appropriate increase in efficiency of both previous and subsequent production stages of the final product downstream the process operations.

References

1. Kruglov V. V., Dli M. I. Intellectual information systems: Computer support of the systems of fuzzy logic and of fuzzy inference. M.: Publishing Phismath literature, 2002. 256 p.
2. Leonenkov A. V. Fuzzy modeling in MATLAB and fuzzyTECH. Spb: Piterburg, 2005. 736p.
3. Shtobva S. D. Designing of fuzzy systems using MATLAB tools. M.: Hot line-Telecom, 2007. 288 p.:il.
4. Muravyova E. A., Baimanov I. F., Kayasheva G. A. "The fuzzy system of pH value control in electrolyte in chlorine manufacture via the electrolysis route". In: *Automation, telemetry and communication in oil industry*. 2008. № 1. pp. 10–13.
5. Methods of classic and up-to-date automatic control theory: Textbook in 5 v.; 2nd edition, V3: synthesis of the automatic control system controllers / Edited by K. A. Upkov and N. D. Egupov. M.: Publishing house of MSTU after Bauman, 2004. 616 p.
6. Muravyova E. A., Kayasheva G. A. "The peculiarities of fuzzy controllers on the base of the fuzzy production rules system using functions of Boolean logic". In: CSIT'2008. 2008. Vol. 2. pp. 45-47.