CHEMICAL ENGINEERING TRANSACTIONS
VOL. 51, 2016

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Tichun Wang, Hongyang Zhang, Lei Tian

ISBN 978-88-95608-43-3; **ISSN** 2283-9216
DOI: 10.3303/CET1651035

Silver Ore-dressing Model and Performance Analysis Based on ANFIS

Ping Huang[a], Ji Ge[b], Zaipeng Duan*[a], Jingjing Xu[a]

[a]College of Environment and Resources, Fuzhou University, No. 2 Xueyuan Road, Minhou County , Fuzhou, Fujian, China
[b]College of Resources and Environmental Engineering, Jilin Institute of Chemical Technology, No.45, Chengde street, Longtan District, Jilin, Jilin, China
duanzaipeng@163.com

1. Introduction

The aim of mineral ore-dressing technology research and ore-dressing production technology management is to improve the utilization rate of resources, reduce environmental pollution and costs, and improve efficiency and get higher profits.

The main purpose of the mineral ore-dressing is the pursuit of higher resource recovery, in order to make maximum use of resources. Ore recovery rate is determined by analyzing ore, concentrate grade is calculated, and ore dressing recovery rate of high and low, the concentrate grade is related.Arhada Lead and Zinc concentrator, for example, analyze the influence on ore-dressing recovery rate, find what factors influencing the ore-dressing recovery rate of the larger, get the effect and correlation of general law, to guide the reasonable control of mineral ore-dressing technology research and Industrial production control, determine the beneficiation technology in the economic indicators plays an important role. Therefore, it is very necessary to explore analysis correlation between grade and ore-dressing recovery rate.

In this paper, by integrating a total of 6 months of daily report from Arhada Lead and Zinc concentrator, 484 sets of data, based on controlling screening of these data and eliminating abnormal data, carrying out based on the mathematical relations between common 11 kinds of a metadata model of data statistics, correlation analysis and statistical test, through the comparison of all kinds of models, silver ore-dressing recovery rate and concentrate grade is established the unprocessed ore grade optimal data model.

2. The recovery rate model of silver mineral ore-dressing

Arhada Lead and Zinc ore-dressing plant silver ore grade and ore dressing recovery rate correlation curve regression analysis, modeling results are shown in Table 1 below.

The adaptive fuzzy inference system (ANFIS) of Arhada Lead and Zinc ore-dressing plant silver ore grade and ore dressing recovery rate correlation curve regression analysis. Importing 484 sets of data by sliver rate of recover and sliver grade to ANFIS edit, it would generate ANFIS automatically by Grid partition. After 500 times, training of the model of ANFIS would be got. The adaptive fuzzy inference structure diagram, the recovery rate of silver after training, see Figure 1, Figure 2.

From the training output of silver recovery rate relations in Figure 2, It can be seen that with the increase of silver ore grade, the silver recovery rate tended to decrease. When silver ore grade exceeds 26 g/t, the recovery rate of silver showed a trend of fluctuation. Because the original design of the beneficiation process of silver ore grade design is about 20 g/t, due to the limitation of the beneficiation process design, with the increase of silver ore grade and silver recovery rate has shown a decreasing trend. Initial membership function and membership function after training, comparison of model output and original output and training error, see Figure 3, Figure 4.

Please cite this article as: Huang P., Ge J., Duan Z.P., Xu J.J., 2016, Silver ore-dressing model and performance analysis based on anfis, Chemical Engineering Transactions, 51, 205-210 DOI:10.3303/CET1651035

Table 1: Based on the raw data the overview and parameter estimation table of silver mineral ore-dressing rate of recover model

Model review and the parameter estimates Dependent variable: silver rat of recover									
Equation	Overview of model					Parameter estimation			
	R^2	F	d_{f1}	d_{f2}	Sig.	Constant	b_1	b_2	b_3
Liner	0.060	30.496	1	476	0.000	71.469	-0.267		
Logarithmic curve	0.101	53.258	1	476	0.000	96.466	-9.989		
Quadratic curve	0.123	66.619	1	476	0.000	53.266	262.940		
Cubic curve	0.140	38.815	2	475	0.000	85.849	-1.222	0.014	
Blend curve	0.152	28.398	3	474	0.000	99.331	-2.496	0.049	0.000
Power function curve	0.057	28.584	1	476	0.000	71.029	0.996		
S-curve	0.094	49.621	1	476	0.000	104.471	-0.154		
Growth curve	0.115	61.696	1	476	0.000	3.982	4.052		
Exponential curve	0.057	28.584	1	476	0.000	4.263	-0.004		
Logistic curve	0.057	28.584	1	476	0.000	71.029	-0.004		
Independent variable: silver raw ore grade									

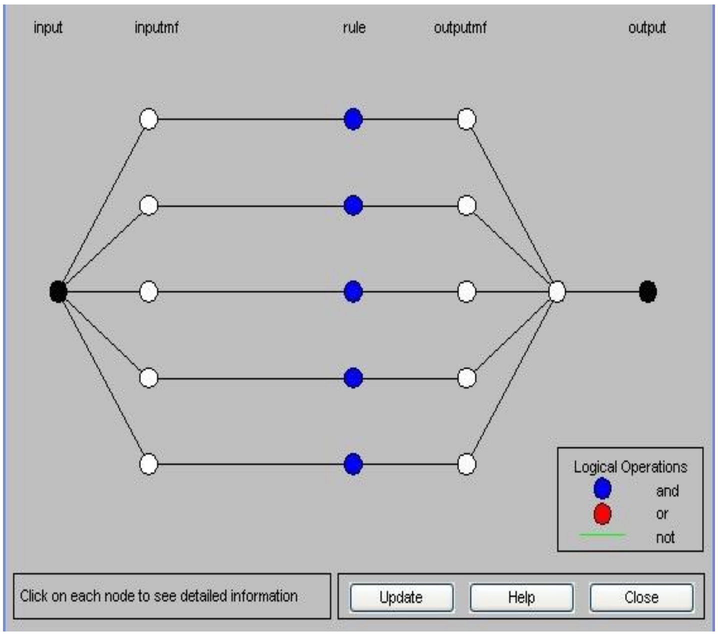


Figure 1: The adaptive fuzzy inference structure diagram

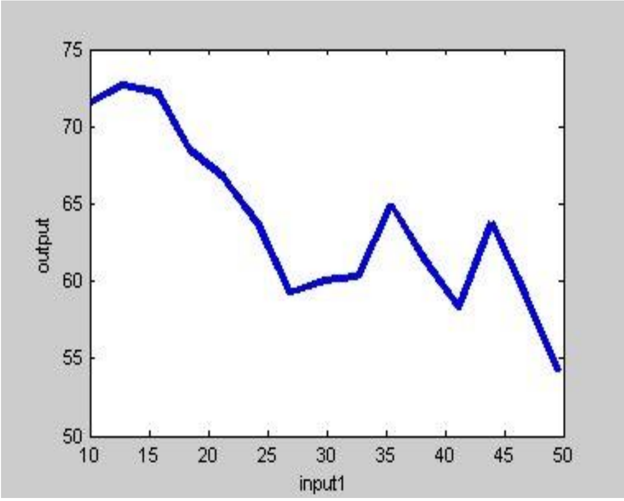
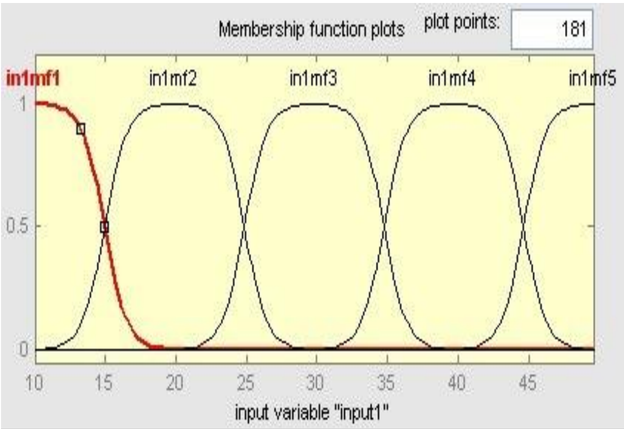
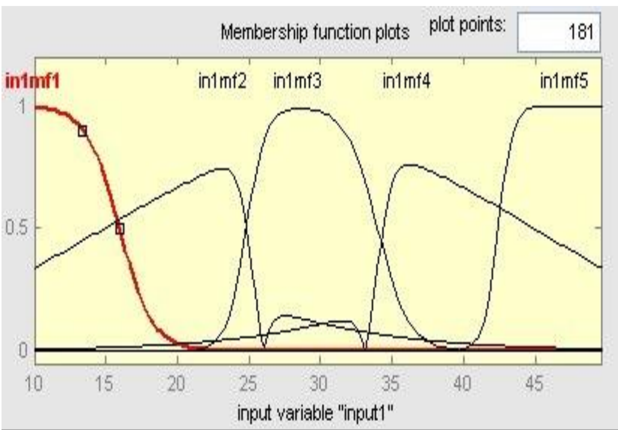


Figure 2 : The recovery rate of silver after training

Therefore, recommended Arhada Lead and Zinc ore-dressing plant is necessary for effective improvement of the relevant part of the sorting and recovery of silver, in order to facilitate the recovery of silver, and avoid the loss of silver resources and waste. Finally with the increase of silver ore grade and silver recovery rate in a certain extent also with corresponding increase, to silver resources recovery and utilization can be achieved.



(a)



(b)

Figure 3: Initial membership function and membership function after training

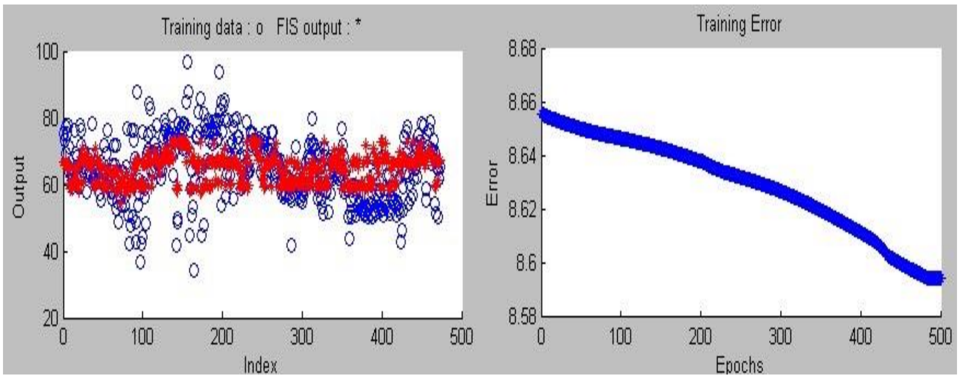


Figure 4: Comparison of model output and original output and training error

3. The grade model of silver concentrates

The modeling results are presented in Table 2 through conducting fitting analysis of correlation between the grade of silver raw ores and the grade of sliver concentrates in Arhada Lead and Zinc Mine.

Table 2: The grade model of silver concentrate review and the parameter estimates which are based on the original data

Model review and the parameter estimates									
Dependent variable: grade of silver concentrates									
Equation	The model review					The parameter estimates			
	R^2	F	d_{f1}	d_{f2}	Sig.	Constant	b_1	b_2	b_3
Liner	0.155	87.226	1	476	0.000	1.265	8.199		
Logarithmic curve	0.129	70.197	1	476	0.000	785.063	216.113		
Inverse curve	0.111	59.435	1	476	0.000	1.680	-4.786		
Quadratic curve	0.187	54.739	2	475	0.000	1.440	-3.429	0.165	
Cubic curve	0.254	53.823	3	474	0.000	828.100	54.373	-1.421	0.012
Blend curve	0.126	68.442	1	476	0.000	1.298	1.005		
Power function curve	0.114	61.377	1	476	0.000	966.893	0.130		
S-curve	0.107	56.795	1	476	0.000	7.417	-2.992		
Growth curve	0.126	68.442	1	476	0.000	7.168	0.005		
Exponential curve	0.126	68.442	1	476	0.000	1.298	0.005		
Logistic curve	0.126	68.442	1	476	0.000	0.001	0.995		
Independent variable: silver raw ore grade									

When the coefficient of fitting degree, R^2 equals to 0.254, it means that the preselected model has a big difference from the real model. Through observation of silver concentrate grade and silver ore grade diagram, we can see that the relationship of silver concentrate grade and silver ore grade is relatively more concentrated. Thus, the method of fuzzy clustering can be applied for finding out the clustering center in the relation. Through using the command of find cluster to open the graphical fuzzy clustering tool-MATLAB, importing the 484 groups of data formed by the silver concentrates and silver raw ores into it, selecting the subtractive calculation method, importing corresponding parameters into it and then choosing the Start button, the clustering center of the silver concentrates and the silver raw ores can be found. The clustering center is presented in Figure 5. The coordinate value of the clustering center is (x=23.2, y=1445).

It is better that the mineral ore-dressing flow sheet and the flotation reagent can be controlled to get a relatively accurate silver concentrate grade in the silver ore-dressing recovery. And then the silver resources can be realized an efficient utilization if the recovery rate can be increased to an extreme on this basis. Thus, after clustering the silver concentrate model into a clustering center through adopting the method of fuzzy clustering, This point corresponds to the quality of the concentrate grade is the optimal target value The target value of the silver concentrates obtained from the fuzzy clustering analysis is 1445 g/t. Thus, the mineral ore-dressing flow sheet and the reagent adopted in the flotation had better be controlled in making the silver concentrate grade fluctuate around 1445 g/t. And then on this basis, through increasing the recovery rate of silver to an extreme to realize efficient recovery and utilization of silver resources, the ore-dressing plant can get the maximum economic benefits.

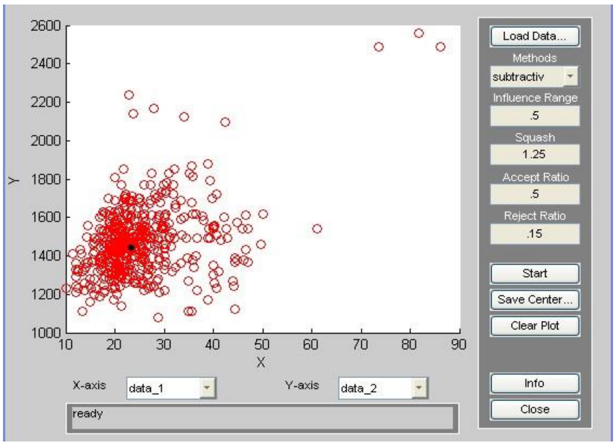


Figure 5: The clustering result of the relation between the silver concentrate grade and the silver raw ore grade

4. Analysis of the Model of Silver's Ore-dressing Recovery Rate

As is shown in Table 3, the optimal model of silver's ore-dressing recovery rate can be built by checking and screening the original data set, removing the abnormal ones, calculating the standard deviation and at last with the regression analysis.

Table 3: Summary of the Optimal Model of Silver's Ore-dressing Recovery Rate and Parameter Estimation

Equation	Model Review					Parameter Estimation			
	R^2	F	d_{f1}	d_{f2}	Sig.	Constant	b_1	b_2	b_3
Cubic Curve Mode	0.8125	236.87	3	164	0.000	115.03	-4.2269	0.1017	-0.0008

Table 3 indicates that the optimal model of silver's ore-dressing recovery rate is as follows:

(1)

Where y—silver's ore-dressing recovery rate, %;
x—raw silver grade, g/t.
The results of goodness-of-fit test of the model: R^2=0.8125, Sig=0.
Based on selected silver's grade in the original data set, the data is evenly divided into 12 groups from 0 to 48 with the gap of 0.4 between each group, followed by elimination of abnormal data. The fuzzy clustering center points for each data group can be obtained with every data group analyzed in the means of fuzzy clustering. Finally, with the regression analysis of the data set composed of fuzzy clustering center points in each group, the optimal model of silver's ore-dressing recovery rate will be built.
The optimal model of silver's ore-dressing recovery rate is as follows:

(2)

Where y—silver's ore-dressing recovery rate, %;
x—raw silver grade, g/t.
The results of goodness-of-fit test of the model: R^2=0.918, Sig=0.
The index of judging fitting degree of the built model is the coefficient of determination R^2. The closer R^2 is to 1, the higher the fitting degree is. R^2 of the two kinds of models built by curve fitting and ANFIS is 0.8125, 0.918 respectively. It shows that there is indeed high correlation and close connection between lead recovery rate and raw lead grade. From the two ways of modeling above, it can be concluded that the R^2 value in ANFIS model is bigger than that of curve fitting model. It shows that the fitting degree of the ANFIS model is better

than that of the curve fitting model. Therefore, ANFIS modeling is more advantageous and representative than the curve fitting model.

Based on the modeling results above, a t-test has been given to the regression coefficient in the prediction model of silver recovery rate. For SPSS model: t_1 = 2.347 > 2.201, indicating that the constant term has practical influence on the forecast of silver recovery rate; t_2 = 2.415 > 2.201, showing the great significance of raw silver grade upon lead recovery rate. For ANFIS model: t_1 = 2.542 > 2.201, indicating that the constant term has practical influence on the forecast of silver recovery rate; t_2 = 2.535 > 2.201, showing the great significance of raw silver grade upon lead recovery rate. As can be seen, the goodness of fit in ANFIS model is better than that of curve fitting.

Therefore, it is more realistic to predict silver's ore-dressing recovery rate with ANFIS fitting function ($y = 0.018x^2-1.765x+95.58$). This result shows that the model can be used for the forecast of silver's ore-dressing recovery rate for ore-dressing plants.

5. Conclusion

On the basis of statistical analyses of silver samples' grade frequency in various mining areas of Arhada lead and zinc mine, A model for geologic reserves and average grade can be built through modeling work such as data smoothing, reserves integration and reserves regression. By regression analyses and statistical tests, and comparisons between various models, Adaptive-Network-Based Fuzzy Inference System (ANFIS) is employed to build a model for raw silver grade, ore-dressing recovery rate and concentrate grade. It is considered, by analyzing the model, that ANFIS model is more applicable to the establishment of the silver-dressing model than curve fitting model. Silver-dressing recovery rate is closely related to the raw ore grade and the concentrate grade, of which the raw ore grade is most relevant, followed by the concentrate grade. This is why the raw ore grade should be reduced and controlled in searches and practice of ore-dressing. For the certain silver concentrate grade, ore-dressing recovery rate increases as the raw ore grade increases: ore-dressing recovery rate and the raw ore grade are positively correlated; for a certain raw silver grade, ore-dressing recovery rate decreased, ore dressing recovery rate and selected ore grade is negative correlation.

Acknowledgments

This research is supported by the China Postdoctoral Science Foundation (2016M592895XB). Special thanks to Xilinguole league Shandong Gold Arhada Mining Co., Ltd., which provided much research material and support during the research crew worked at the mine, and the discussion and suggestion also improved the study.

Reference

Cosenza B., Galluzzo M., 2011, Adaptive Type-2 Fuzzy Logic Control of Non-Linear Processes, Chemical Engineering Transactions, 2011: 235-240, DOI: 10.3303/CET1124040

Meng X.Y., Gui X.Y., Yu Z.M., 2008, Study on application of drill cutting weight andits gas desorption index in forecasting coal and gas outburst, Mining Research and Development 28 (2), 75 (in Chinese), DOI: 10.3969/j.issn.1005-2763.2008.06.001

Mitri H.S., 2007, Assessment of horizontal pillar burst in deep hard rock mines, International Journal of Risk Assessment and Management 7 (5), 695–707, DOI: 10.1504/IJRAM.2007.014094

Nie B.S., 2003. Present situation and progress trend of prediction technology of coal and gas outburst, China Safety Science Journal 13 (6), 40–43 (in Chinese), DOI: 10.16265/j.cnki.issn1003-3033.2016.01.002

Rocscience Inc., 2007. Online Help Manual: Phase 2 v6.0 – Finite Element Analysis for Excavations and Slopes.

Yin G.Z., Li X.Q., Zhao, H.B, Li X.S., Li G.S., 2010. Insitu experimental study on the relation of drilling cuttings weight to ground pressure and gas pressure, Journal of University of Science and Technology Beijing 32 (1), 1–7 (in Chinese), DOI: 10.13374/j.issn2095-9389.2016.03.002