

ESTIMATION OF GAS HOLDUP AND INPUT POWER IN FROTH FLOTATION USING ARTIFICIAL NEURAL NETWORK

B. Shahbazi^{1,*}, B. Rezai², S. Chehreh Chelgani¹, S. M. J. Koleini³ and M. Noaparast⁴

* bzshahbazi@yahoo.com

Received: July 2014

Accepted: February 2015

¹ Department of Mining Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran.

² Department of Mining Engineering, Amirkabir University of Technology, Tehran, Iran.

³ Department of Mining Engineering, Tarbiat Modares University, Tehran, Iran.

⁴ Department of Mining Engineering, University of Tehran, Tehran, Iran.

Abstract: Multivariable regression and artificial neural network procedures were used to modeling of the input power and gas holdup of flotation. The stepwise nonlinear equations have shown greater accuracy than linear ones where they can predict input power, and gas holdup with the correlation coefficients of 0.79 thereby 0.51 in the linear, and $R^2=0.88$ versus 0.52 in the non linear, respectively. For increasing accuracy of predictions, Feed-forward artificial neural network (FANN) was applied. FANNs with 2-2-5-5, and 2-2-3-2-2 arrangements, were capable to estimating of the input power and gas holdup, respectively. They were achieved quite satisfactory correlations of 0.96 in testing stage for input power prediction, and 0.64 for gas holdup prediction.

Keywords: Flotation; Input Power; Gas Holdup; Regression; Artificial Neural Network

1. INTRODUCTION

Gas dispersion properties include bubble size (d_{32}), gas holdup (ϵ_g , %), while bubble surface area flux (S_b), and input power (P) which are effective parameters related to flotation performance. During the last 10 years, some investigations have been carried out to measure these parameters in mechanical flotation cells [1-7]. The gas holdup as a function of broad groups of chemical, operational, and machine variables presents in froth flotation [8-12]. The gas holdup is related to bubble size (a function of frother characteristics, concentration, solids coverage, and air flow rate), slurry flow rate, and solids content. It also defines the bubble flow density (or the bubble surface area flux), which is related to flotation kinetics [13]; Therefore, determination of the gas holdup for diagnosing, and controlling a flotation cell during the operation should be fruitful.

Based on an operating aspect, the impeller rotational speed (N_s) provides an opportunity to control the specific input power (P) to the flotation cell slurry, and impeller tip speed. Recent studies have highlighted the important influence of local turbulent energy dissipation (ϵ)

on the both frequency of bubble-particle collision, and stability efficiency of the particle-bubble aggregate [14-16]. Because there is difficulty in establishing the exact spatial average of local energy dissipation for a given turbulent mixing system, the mean energy dissipation ($\bar{\epsilon}$) in a flotation cell containing mass (M) of slurry is determined by the equation below [17]:

$$\bar{\epsilon} = \frac{P}{M} \quad (1)$$

Typical mean energy dissipation values in industrial flotation cells change from 1.0 to 5.0 W/kg, depending upon the cell size, installed motor power, transmission losses, and slurry density [18]. It is well recognized that energy dissipation is a local function, and also the maximum value near the impeller may be higher than the mean energy dissipation across the entire cell (10–20 times higher) [19].

It is thought useful to develop empirical models to estimate gas dispersion factors in different conditions because of poor understanding of gas dispersion phenomena, and difficulty in measuring them in flotation cells. In other words, these models could be used readily for applications such as cell comparison,

selection, new cell installation, scale-up for plant design, cell optimization, circuit modeling, and simulation, etc. Using the laboratory data, computing techniques have been applied to many aspects of mineral processing that were mentioned in the references [20-25].

The aim of the present work is prediction of gas holdup (ϵ_g , %), and input power (P,W) according to effective variables on froth flotation (Impeller peripheral speed (N_s , m/s), superficial gas velocity (J_g , cm/s), and pulp density (P_d , %) using experimental data obtained at a laboratory scale. The multivariable regression, and feed forward artificial neural network (FANN) were used for those estimations.

2. EXPERIMENTAL PROCEDURE

All flotation experiments were carried out in a laboratory Denver flotation cell. An impeller diameter of 0.07 m was used for agitation in a cell with a square section of 0.12 and 0.1 m height. The type of impeller was a Rushton turbine with 8 paddles, and a stator was used around the rotor. All tests were done without any baffling in the flotation cell. MIBC (methyl iso-butyl carbinol), and Quartz particles (solid density of 2.65 g.cm⁻³ and particle size of -500) were used for flotation experiments. Concentration of the frother was 22.4 ppm.

3. RESULTS AND DISCUSSION

3. 1. Gas Hold Up

The gas holdup (ϵ_g , %) was measured using a device similar Jameson and Allum [26]. According to Fig. 1, it consisted of a 50 milliliter volume cylinder with a plunger attached to a central rod. The plunger had an O-ring for an air tight fitting when it moved inside the cylinder. The plunger drew into the cylinder, encapsulating a volume of aerated pulp in the space between the cylinder and plunger.

The pulp-air mixture encapsulated between the cylinder, and plunger was emptied into a measuring cylinder at which point the air escaped into the atmosphere. The volume of the space between the cylinders was determined by water

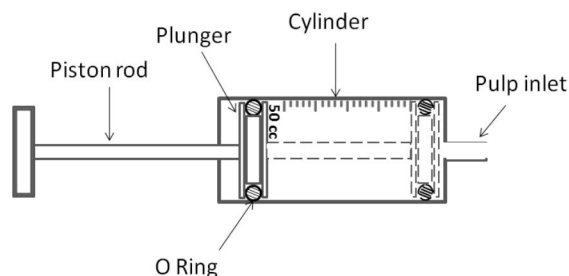


Fig. 1. Schematic of a device for measuring gas holdup

calibration. By calculating the difference between the measured volume of slurry, and the calibrated volume of water, the volume of air in the aerated pulp was obtained, finally ϵ_g was the volume fraction of air in each sample.

For $2.93 < N_s < 6.12$ m/s, $0.32 < J_g < 0.94$ cm/s, and $0 < P_d < 15.6$ %, gas holdup was obtained $3.04 < \epsilon_g < 22\%$.

3. 2. Input Power

For calculating net power consumption, at first equipment power consumption was determined without pulp. Then, flotation cell was filled with pulp and power consumption was measured again. Net power consumption was calculated by reducing these two measured powers.

For $1.83 < N_s < 6.12$ m/s, and $0 < P_d < 40$ % input power was achieved $0.05 < P < 52.58$ W. In mechanical flotation cells, power intensity of 1 to 2 kW.m⁻³ is common [27]. Thus, an impeller peripheral speed of $2.93 < N_s < 3.66$ (impeller diameter of 0.07 m and impeller speed of 800 to 1000 rpm) is suitable for the flotation process.

3. 3. FANN Procedure

Few years, artificial neural networks (ANNs), and particularly feed forward artificial neural networks (FANNs) have been extensively studied in academia as process models, and are increasingly being used in industry [28]. Neural networks of multi-layer perceptron (MLP) type are often used as black-box models of systems where the underlying relations are poorly known or extremely complex [29]. The main advantages

of neural network over conventional regression analysis are: free of linear supposition, large degrees of freedom, and more effectively deal with non-linear functional forms [30].

A Feed forward neural network of multi-layer perceptron type can be used as a nonlinear

black-box model in data-mining tasks, and typically consists of an input layer, hidden layers with sigmoid activation functions, and an output layer with linear activation function. Each node in the input layer is linked to all the nodes in the hidden layer using weighted connections. Similar connections exist between hidden, and output layer as also between nodes of hidden layers [31]. The number of nodes in the layers is adjustable parameters, whose magnitudes are governed by issues such as the desired prediction accuracy, and generalization performance of the FANN model. FANN is one of the most popular, and well documented neural network models, which has a good software support. In this study, two FANN models have been developed for predictions of gas holdup (ϵ_g , %), and input power (P, W).

3. 4. Regression

By a least square mathematical method, inter correlations between input, and output variables were calculated (table 1). From the mentioned results it can be concluded that the worthy relationships are for impeller speed with positive

effect on both power, and gas holdup. In addition, the increase of gas velocity rates have negative effect on input power, and in contrary term, have positive effect on gas holdup. The results show that there is no significant correlation between pulp density and gas holdup.

The stepwise variable selection procedure was used to prepare regression equations. The best linear, and non linear multivariable equations between the froth flotation operational conditions with input power (P, W), and gas holdup (ϵ_g , %) can be presented as the following equations:

$$P(\text{wat}) = -34.137 + 11.775N_s - 12.969J_g + 0.164P_d^2 \quad R^2 = 0.79 \quad (2)$$

$$P(\text{wat}) = 7.809 - 6.824N_s + 1.718N_s^2 + 293.254P_d - 70.134P_d^2 + 5.493P_d^3 - 0.141P_d^4 - 6.748J_g \quad R^2 = 0.88 \quad (3)$$

$$\epsilon_g(\%) = -7.285 + 3.282 N_s + 5.961 J_g \quad R^2 = 0.51 \quad (4)$$

$$\epsilon_g(\%) = -12.634 + 3.288 N_s + 43.729 J_g - 76.673J_g^2 + 45.548J_g^3 \quad R^2 = 0.52 \quad (5)$$

The distribution of difference between power,

Table 1. Inter- item correlation matrix for input, and output variables

Parameters	Input power (wat)	Impeller peripheral speed (m/s)	Pulp density (%)	Gas velocity (cm/s)	Gas holdup (%)
Input power (wat)	1	0.85	0.06	-0.28	0.30
Impeller peripheral speed (m/s)	0.85	1	-0.02	-0.05	0.64
Pulp density (%)	0.06	-0.02	1	0.05	-0.07
Gas velocity (cm/s)	-0.28	-0.05	0.05	1	0.28
Gas holdup (%)	0.30	0.64	-0.07	0.28	1

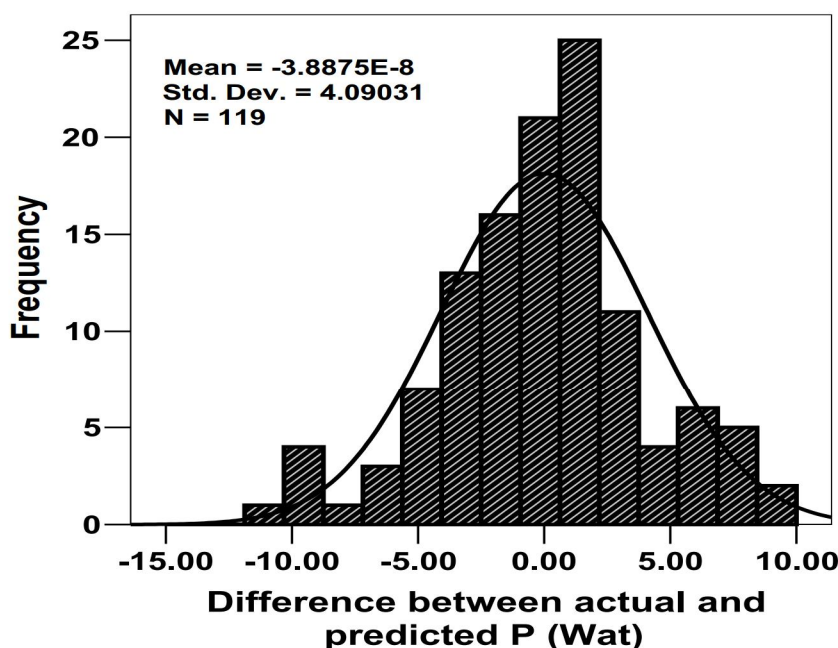


Fig. 2. Distribution of the difference between measured power values and estimated power values obtained from multivariate regression Eq. (2)

and gas holdup predicted from Eq. (3), and (5) with actual determined amounts of them according to their frequency are shown in Fig. 2, and 3, respectively.

3. 5. FANN Results

According to the Eqs. (2), and (4), the selected variables were determined as the best variables for the predictions of P , and ϵ_g . Therefore these variables were chosen as inputs to FANN for the improvement of estimations.

If certain preprocessing steps (normalizing processes) were performed on the network inputs and targets, neural network training can be made

more efficient; therefore, before training, it is often useful to scale the inputs, and targets because they always fall within a specified range. For ANN work, all input, and output data were scaled using the following model:

$$N_p = (A_p - \text{mean}A_{ps}) / \text{std}A_p \quad (6)$$

Where, A_p is actual parameter, $\text{mean}A_{ps}$ is mean of actual parameters, $\text{std}A_p$ is standard deviation of actual parameter and N_p is normalized parameter (input). The mean, and standard deviation of input, and output variables for pre-processing are given in Table 2. After determining the number of input variables by

Table 2. Pre-processing parameters for ANN

Variable	Minimum	Maximum	Mean	Std. Deviation
Impeller peripheral speed (m/s)	2.93	6.12	4.58	0.84
Pulp density (%)	0	15.6	8.09	6.25
Gas velocity (cm/s)	0.11	0.94	0.46	0.22
Gas holdup (%)	2.8	19.8	10.48	4.16
Input power (wat)	2.01	38.19	15.22	11.72

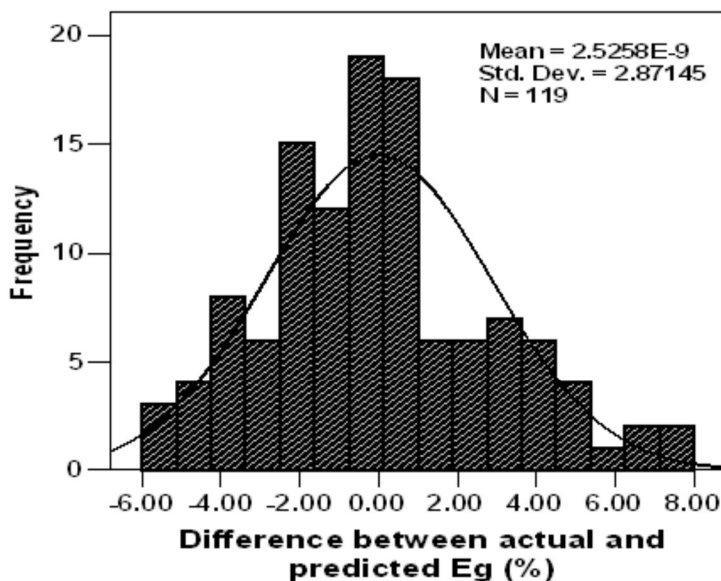


Fig. 3. Distribution of the difference between measured gas holdup values and estimated gas holdup values obtained from multivariate regression Eq. (3)

statistical means, the most appropriate architecture for the network was determined. From the total dataset (119 laboratory experiments) were used for the input power and gas holdup predictions by FANN, 100 samples were input for training, and 19 sets were used for testing the network. The training process was

Several FANNs were created, trained, and tested to achieve a suitable FANN topology, which is able to predict accurate values of outputs. The number of neurons in the hidden layers was obtained by the trial and error method so that the error between the desired, and estimated outputs was minimized. The 2-5-5-5,

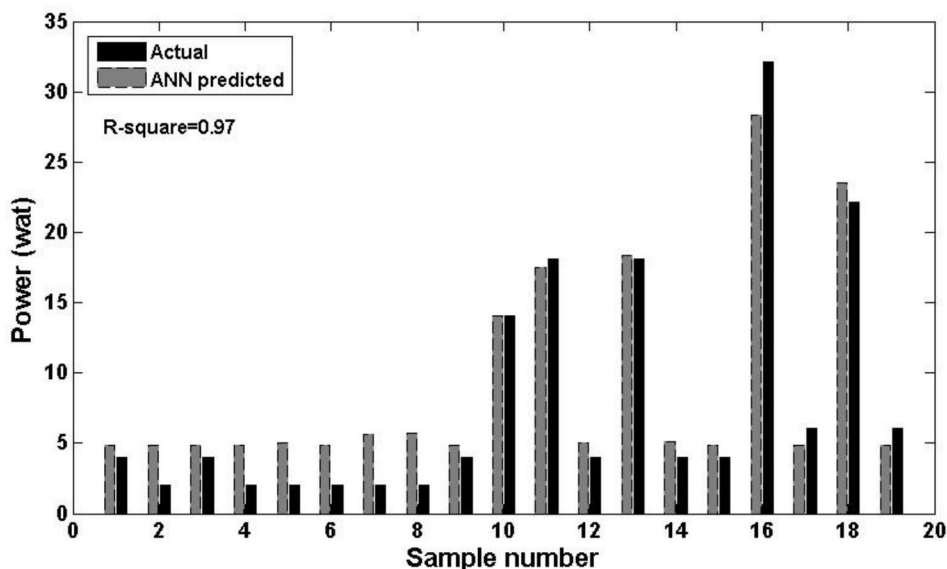


Fig. 4. Comparison between measured power values and estimated power values obtained from ANN stopped after 3000 epochs. and 2-2-3-2-2 FANN models adequately

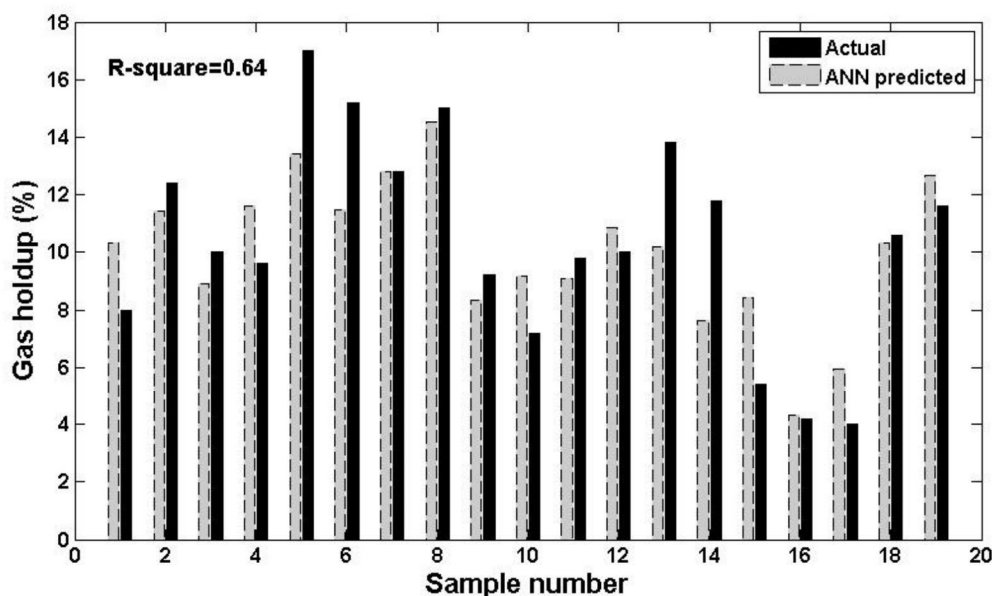


Fig. 5. Comparison between measured gas holdup values and estimated gas holdup values obtained from ANN

recognized the effects of different operational conditions on the outputs, and usefully predicted both input power, and gas holdup, respectively. Figs 4 and 5 show the relationship between estimated variables by FANN model from testing phase and their determined value by the laboratory methods. The testing sets, which actually test how good the models are, show that the models can estimate input power, and gas holdup quite satisfactorily. The correlation coefficient (R^2) values for testing sets are 0.96 and 0.64 for input power, and gas holdup predictions, respectively. Upon comparison with the regression results, the FANN models were shown to have greater accuracy in predicting values from the same inputs.

4. CONCLUSION

Predicting input power, and gas holdup using regression, and artificial neural network is put forward. 119 laboratory data sets were used for the prediction operations. The input-correlations between operational conditions with input power, and gas holdup show that with the increase of gas velocity rates both input power, and gas holdup values increase remarkably. Through the

modeling data, the correlation coefficients between the prediction value, and the laboratory value of input power, and gas holdup were 0.88, and 0.52 for the non linear regression, where they can predict them with greater accuracy than linear ones with $R^2=0.79$, and 0.51. Using the FANN method for the modeling and predicting were achieved $R^2=0.96$, and 0.64 for input power, and gas holdup, respectively. The results showed that laboratory operational conditions can be used as predictors of input power, and gas holdup successfully, and can create accurate models. As a comparison between equations, and FANN models, it was found that the performances of FANN models are better than regression models. Therefore, it can be effectively used in estimations of input power, and gas holdup.

5. ACKNOWLEDGMENT

Authors are grateful to Islamic Azad University, Amirkabir University of Technology, Tarbiat Modares University and Tehran University for their contribution on this research.

NOMENCLATURE

A_p	Actual parameter
N_p	Normalized parameter
$stdA_p$	Standard deviation of actual parameter
A_{ps}	Mean of actual parameters
N_s	Peripheral speed
ϵ_g	Local energy dissipation
d_{32}	Sauter mean diameter
P	Input power
ϵ_g	Gas holdup
J_g	Superficial gas velocity
P_d	Pulp density
$\bar{\epsilon}$	Mean energy dissipation
M	Liquid mass
S_b	Bubble surface area flux
ρ	Fluid density

REFERENCES

- James, A., Finch, A., Jan, E. and Nasset, A., "Claudio, Role of Frother on Bubble Production and Behaviour in Flotation". A., Miner Eng, 2008, 21, 949-957.
- Nasset, J. E., Hernandez-Aguilar, J. R., A. Claudio, Gomez, C. O. and Finch, J. A., "Some Gas Dispersion Characteristics of Mechanical Flotation Machines". Miner Eng, 2006, 19, 807-815.
- Finch, J. A., Xiao, J., Hardie, C. and Gomez, C. O., "Gas Dispersion Properties: Bubble Surface Area Flux and Gas Holdup". Miner Eng, 2000, 13, 365-372.
- Hernandez-Aguilar, J. R., Rao, S. R. and Finch, J. A., "Testing the k-Sb Relationship at the Microscale". Miner Eng, 2005, 18, 591-598.
- Duan, J., Fornasiero, D. and Ralston, J., "Calculation of the Flotation Rate Constant of Chalcopyrite Particles in An Ore". Int J Miner Process, 2003, 72, 227-237.
- Heiskanen, K., "On the Relationship Between Flotation Rate and Bubble Surface Area Flux". Miner Eng, 2000, 13, 141-149.
- Kracht, W., Vallebuona, G. and Casali, A., "Rate Constant Modeling for Batch Flotation as a Function of Gas Dispersion Properties". Miner Eng, 2005, 18, 1067-1076.
- Klimpel, R. R., Dhansen, R. and Fee, B. S., "Selection of Flotation Reagents for Improved Sulphide Mineral Flotation". In: Mular, A.L., Anderson, M.A. Eds, Design and Installation of Concentration and Dewatering Circuit, Chap 26, 1986.
- Shahbazi, B., Rezai, B., Koleini, S. M. Javad and Noaparast, M., "The study of influence of bubble surface area flux on flotation rate constant of coal particles", Geosciences Scientific Quarterly Journal, 2014, in press.
- Shahbazi, B. and Rezai, B., "The effect of dimensionless parameters and bubble surface area flux on flotation rate constant", Journal of Dispersion Science and Technology, 2014, in press.
- Shahbazi, B., Rezai, B., Koleini, S.M. Javad and Noaparast, M., "The effect of bubble surface area flux on flotation efficiency of pyrite particles", Iran. J. Chem. Chem. Eng., 2013, 32, 109-118.
- Shahbazi, B., Rezai, B., Koleini, S.M. Javad and Noaparast, M., "The effect of dimensionless parameters on coal flotation", International Journal of Coal Preparation and Utilization, 2012, 32, 157-168.
- Gorain, B. K., Franzidis, J. P. and Manlapig, E. V., "Studies on Impeller Type, Impeller Speed and Air Flow Rate in an Industrial: Scale Flotation Cell". Part 4: Effect of bubble surface area flux on flotation kinetics. Miner Eng, 1997, 10, 367-379.
- Pyke, B., "Bubble-Particle Capture in Turbulent Flotation Systems". PhD Thesis, University of South Australia, Australia, 2003.
- Pyke, B. and Fornasiero, D., Ralston, J., "Bubble-Particle Capture in Turbulent Flotation Systems". J Colloid Interf Sci, 2003, 265, 141-151.
- Bloom, F. and Heindel, T. J., "On the Structure of Collision and Detachment Frequencies in Flotation Models". Chem Eng Sci, 2002, 57, 2467-2473.
- Schubert, H., "The Role of Turbulence in Mineral Processing Unit Operations". In: Sastry, Fuerstenau, K., M.C. (Eds.). Challenges in Mineral Processing, SME Inc., Littleton, 1989.
- Deglon, D. A., Egya-mensah, D. and Franzidis, J. P., "Review of Hydrodynamics and Gas

- Dispersion in Flotation Cells on South African Platinum Concentrators". *Miner Eng*, 2000, 13, 235-244.
19. Schubert, H., "On the Turbulence-Controlled Microprocesses in Flotation Machines". *Int J Miner Process*, 1999, 56, 257-276.
 20. Chehreh Chelgani, S. and Jorjani, E., "Artificial Neural Network Prediction of Al_2O_3 Leaching Recovery in the Bayer Process at the Jajarm Alumina Plant (Iran)". *Hydrometallurgy*, 2009, 97, 105-110.
 21. Cilek, E. C., "Application of Neural Networks to Predict Locked Cycle Flotation Test Results". *Miner Eng*, 2002, 15, 1095-1104.
 22. Chehreh Chelgani, S., Shahbazi, B. and Rezai, B., "Estimation of Froth Flotation Recovery and Collision Probability Based on Operational Parameters Using an Artificial Neural Network". *Int J Min Met Mater*, 2010, 5, 526-534.
 23. Jorjani, E., Asadollahi Poorali, H., Sam, A., Chehreh Chelgani, S., Mesroghli, Sh. and Shayestehfar, M. R., "Prediction of Coal Response to Froth Flotation Based on Coal Analysis Using Regression and Artificial Neural Network". *Miner Eng*, 2009, 22, 970-976.
 24. Jameson, G. J. and Allum, P., "A Survey of Bubble Sizes in Industrial Flotation Cells". report prepared for AMIRA limited, 1984.
 25. Khoshjavan, S., Heidary M., and Rezai B., "Estimation of coal swelling index based on chemical properties of coal using artificial neural networks", *Iranian Journal of Materials Science & Engineering*, 2010, 7, 1-11.
 26. Deglon, D. A., "The Effect of Agitation on the Flotation of Platinum Ores". *Miner Eng*, 2005, 18, 839-844.
 27. Ungar, L. H., Hartman, E. J., Keeler, J. D. and Martin, G. D., "Process Modelling and Control Using Neural Networks" *American Institute of Chemical Engineers Symposium Series*, 1996, 92, 57-66.
 28. Liang, Y. C., Feng, D. P., Lee, H. P., Lim, S. P. and Lee, K. H., "Successive Approximation Training Algorithm for Feed Forward Neural Networks". *Neurocomputing*, 2002, 42, 311-322.
 29. Farshad, F. F., Garber, J. D. and Lorde, J. N., "Predicting Temperature Profiles in Producing Oil Wells Using Artificial Neural Networks". *Eng. Comput*, 2000, 17, 735-753.
 30. Patel, S. U., Kumar, B. J., Badhe, Y. P., Sharma, B. K., Saha, S., Biswas, S., Chaudhury, A., Tambe, S. S. and Kulkarni, B. D., "Estimation of Gross Calorific Value of Coals Using Artificial Neural Networks". *Fuel*, 2007, 86, 334-344.
 31. Demuth, H. and Beale, M., "Neural Network Toolbox for use with MATLAB". *Handbook*, 2002.