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A Suggested Improvement to The Plant Recovery Formula: A Case Study for Elazig Ferrochrome Plant

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The plant recovery is widely used for an assessment of plant performance in mineral and metal processing plants. It has been formulized as a uniform function in the form of a ratio of output to input. In this study, plant recovery formula in an exponential form was developed based on exponential distribution. First of all, plant recovery in the exponential form was shown with the establishment of probability density functions, based on the parameters of assays in feed, concentrate (or mineral) and tailing (or slag) depending on assay in feed. Characteristic parameters and probability density functions of exponential distribution were adapted for the plant recovery formula. The plant recovery in the exponential form was determined by using the data over a 1-month period in Elazig ferrochrome plant-B in Turkey. Only the lowest assays in feed were picked from the data obtained over a 11 month period and re-analyzed to determine the changes existing the recovery. Significant difference was not observed with both calculations performed the suggested recovery formula. As a result of this study, it is shown that plant recovery based on the exponential distribution can be used effectively to determine whether under control of the process or not.

Key Words: Plant recovery, Ferrochrome, Mineral processing, Metallurgical process.

INTRODUCTION

Performance assessment in a mineral processing or metallurgical process plants and control of the operation using the evaluated results are rather important. Plant performance is assessed by calculating the assays in feed (f), concentrate (c) and tailing (t). Plant recovery is formulated as[1]:

$$R = \frac{c}{f} \times \frac{(f - t)}{(c - t)} \times 100\ \% \tag{1}$$

Plant recoveries obtained from eqn. 1 are discrete, *i.e.* only give results related to definite time frame of operation and it is not sufficient to make any decision related to plant. Therefore, if it is reformulated using assays according to exponential distribution, effective decisions could be made about the plant performance.

Formulization of the plant recovery using the exponential distribution: The probability density function of exponential distribution is shown graphically in Fig. 1 for the possible values of assays in the feed, when assays in feed are distributed as the form of exponential. If mean assays of tailing and concentrate is drawn over Fig. 1, two states of probability according to mean assay of feed are established as the probabilities of $P(\bar{c} \geq \bar{f})$ and $P(\bar{t} \leq \bar{f})$, as seen in Fig. 2. The curve could be separated as two proportions of the distribution from the line $\bar{f}$.

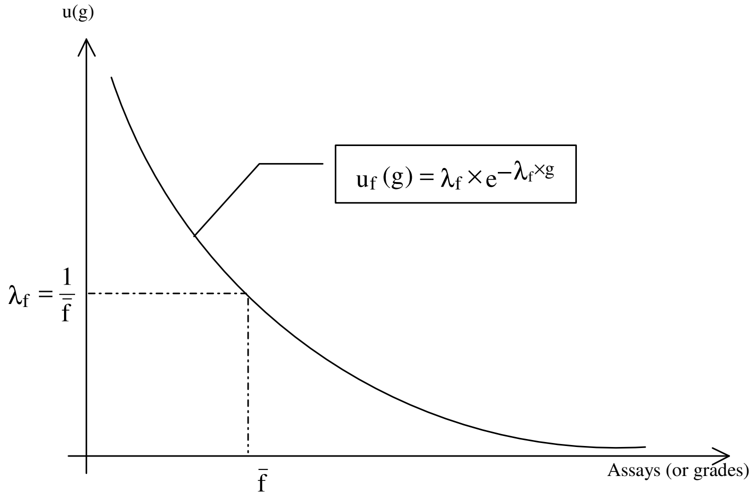

Fig. 1. Curve of exponential distribution

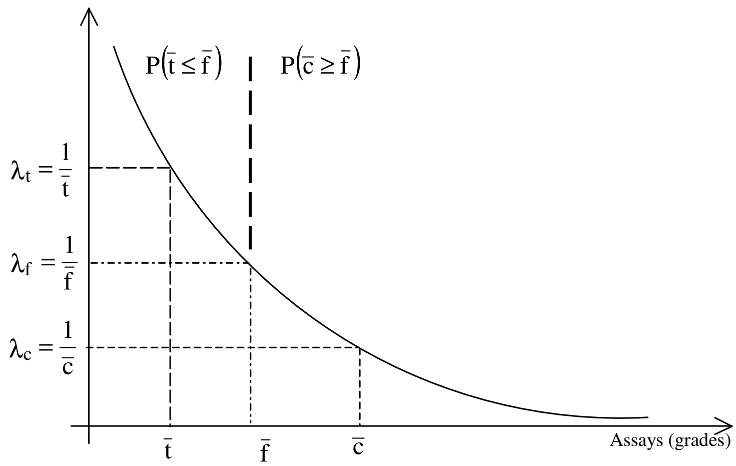

Fig. 2. Determination of two states of the probability

The first proportion of the distribution which is below mean assay of feed is given by $P(\bar{t} \leq \bar{f})$. Curve of the exponential distribution is drawn for any values of assays in feed and then the probability density function depending on mean assays of tailing and feed could be written as given in Fig. 3.

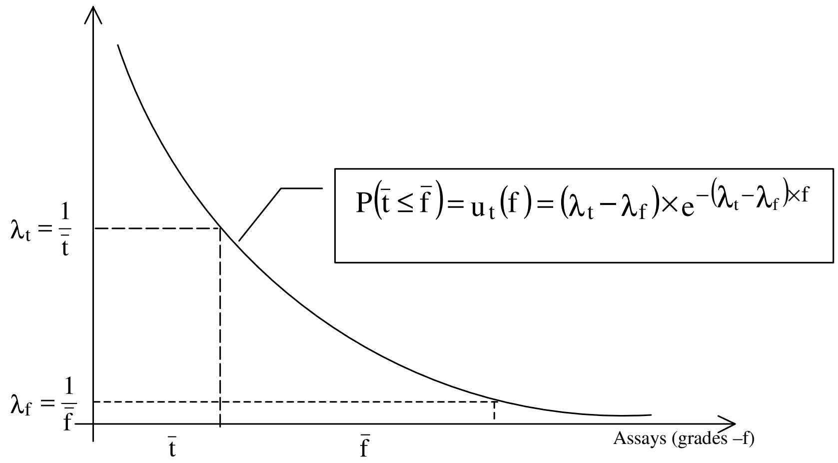

Fig. 3. Tailing proportion of the distribution

The second proportion of the distribution which is above mean assay in feed is given by $P(\bar{c} \ge \bar{f})$. Curve of the exponential distribution is drawn for any values of assays in feed and then the probability density function depending on mean assays of concentrate and feed could be written as given in Fig. 4.

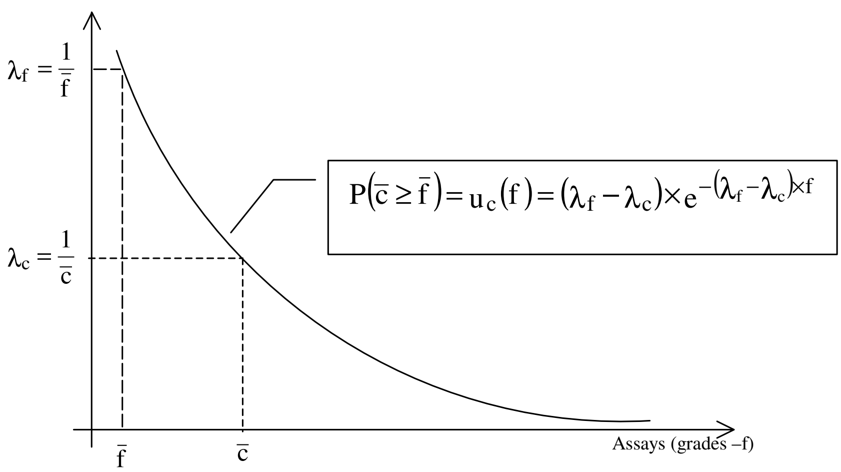

Fig. 4. Concentrate proportion of the distribution

Relationships between components of two-dimensional continuous random variable are particularly important in probability and statistical analysis[2]. This random variable (Fig. 2) shows the two portions, which is indicative of the probability of assay in feed, f, in this study. The portions represent a two-dimensional continuous random variable having assays in tailing and concentrate as components. In this case, the probability of mean assay in tailing, $\bar{t}$, being less than assay in feed is given by:

$$P(\bar{t} \leq \bar{f}) = \int_0^f u_t(f)df \tag{2}$$

where, u_t (f) is the probability density function of assay in tailing portion.

Probability of mean grade in concentrate, $\bar{c}$, being greater than grade in feed is given by:

$$P(\bar{c} \geq \bar{f}) = \int_f^\infty u_c(f)df \tag{3}$$

where, u_c (f) is the probability density function of assay in concentrate portion.

Assuming that assays in concentrate and tailing are independent random variables. Therefore, the probabilities of two independent variables are multiplied[3,4]. Hence the plant recovery, R, for the possible values of assay in feed is:

$$R(f) = P(\bar{t} \leq \bar{f}) \cdot P(\bar{c} \geq \bar{f}) \tag{4}$$

Probability density functions are put into eqn. 4.

$$R(f) = \int_0^f u_t(f)df \cdot \int_f^\infty u_c(f)df \tag{5}$$

or

$$R(f) = \int_0^f u_t(f) \cdot \left[\int_f^\infty u_c(f)df\right]df \tag{6}$$

Input and output variables (such as feed, concentrate and tailing) in plant recovery formulation are expressed with only one parameter, which is the mean. In this case, it complies with the exponential distribution having one parameter probability density function. First of all, $\bar{f}$, $\bar{t}$ and $\bar{c}$ and mean assays in feed, tailing and concentrate, then assay rates in feed, tailing and concentrate per unit assay should be calculated:

$$\lambda_f = \frac{1}{\bar{f}} \tag{7}$$

$$\lambda_t = \frac{1}{\bar{t}} \tag{8}$$

$$\lambda_c = \frac{1}{\bar{c}} \tag{9}$$

If probability density functions based on exponential distribution are set according to the assays in feed:

$$u_c(f) = (\lambda_f - \lambda_c) \cdot e^{-(\lambda_f - \lambda_c) \cdot f} \tag{10}$$

$$u_t(f) = (\lambda_t - \lambda_f)\cdot e^{-(\lambda_t - \lambda_f)\cdot f} \quad (11)$$

Since the assays in concentrate and tailing should theoretically be $\infty \geq \bar{c} \geq$ and $0 \leq \bar{t} \leq f$, respectively, probability density functions of concentrate and tailing are integrated as in eqn. 12. In this case, the following equation is integrated by assays in feed (f) as element df and the recovery for the possible values of assays in feed is derived as:

$$R(f) = \int_0^f (\lambda_t - \lambda_f)\cdot e^{-(\lambda_t - \lambda_f)\cdot f}\left(\int_f^\infty (\lambda_f - \lambda_c)\cdot e^{-(\lambda_f - \lambda_c)\cdot f} df\right) df \quad (12)$$

$$R(f) = \frac{(\lambda_t - \lambda_f)}{(\lambda_t - \lambda_c)} - \frac{(\lambda_t - \lambda_f)}{(\lambda_t - \lambda_c)}\cdot e^{-(\lambda_t - \lambda_c)\cdot f} \quad (13)$$

The assays are put into eqn. 13 instead of the rates, eqn. 15 is obtained:

$$R(f) = \frac{\frac{1}{\bar{t}} - \frac{1}{\bar{f}}}{\frac{1}{\bar{t}} - \frac{1}{\bar{c}}} - \frac{\frac{1}{\bar{t}} - \frac{1}{\bar{f}}}{\frac{1}{\bar{t}} - \frac{1}{\bar{c}}}\cdot e^{-(\frac{1}{\bar{t}} - \frac{1}{\bar{c}})\cdot f} \quad (14)$$

$$R(f) = \frac{\bar{c}\cdot(\bar{f} - \bar{t})}{\bar{f}\cdot(\bar{c} - \bar{t})} - \frac{\bar{c}\cdot(\bar{f} - \bar{t})}{\bar{f}\cdot(\bar{c} - \bar{t})}\cdot e^{-(\frac{\bar{c}+\bar{t}}{\bar{t}\cdot\bar{c}})\cdot f} \quad (15)$$

If the grade (f) theoretically goes to infinity in eqn. 15, the recovery becomes:

$$R(f \to \infty) = \frac{\bar{c}\cdot(\bar{f} - \bar{t})}{f\cdot(\bar{c} - \bar{t})} \quad (16)$$

Case study: Determination of minimum production capacity of a ferrochrome plant: In this study, Elazig ferrochrome plant-B in Turkey was investigated. This plant was established in 1989 with a high carbon ferrochrome production capacity of 100,000 tons per year. There are two arc furnaces with a power of 30 MWA each[5]. The assays for this plant over a 1 month period was tabulated (Table-1). The assays in feed, tailing and ferrochrome, obtained from the ferrochrome plant over a 1 month period, were placed into eqns. 7-9 and 13.

TABLE-1
MEANS OF OBSERVATION VALUES OVER ONE MONTH PERIOD

Items	Mean assays (Cr %)	
	1 month period	11 month period
Feed (chromite ore)	30.83	27.63
Ferrochrome	64.40	63.66
Slag (or tailing)	2.46	2.29

$$\lambda_f = \frac{1}{\bar{f}} = \frac{1}{30.83} = 0.032436$$

$$\lambda_c = \frac{1}{\bar{c}} = \frac{1}{64.40} = 0.015528$$

$$\lambda_t = \frac{1}{\bar{t}} = \frac{1}{2.46} = 0.406386$$

$$R(f) = \frac{(0.406386 - 0.032436)}{(0.406386 - 0.015528)} - \frac{(0.406386 - 0.032436)}{(0.406386 - 0.015528)} \cdot e^{-(0.406386-0.015528)\cdot f} \quad (17)$$

Equation 17 is plotted for the possible values of assays in the feed (Fig. 5). It can be seen that the plant recovery in one month period does not change for feeds containing 13 % Cr and higher. However, the plant recovery for feeds containing metallic chrome being less than 10 % Cr decreases rapidly.

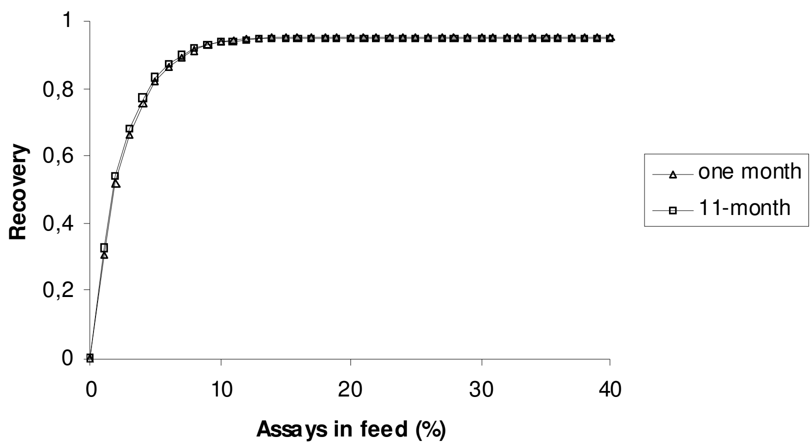

Fig. 5. Recoveries *versus* assays in feed

In order to investigate the mentioned above, the lowest assays in feed were collected over a 11 month period (Table-2). The lowest assays in feed per day were observed to be at 27.30 and 28 %. The lowest assays in feed of this plant over a 11 month period was tabulated (Table-2). The mean assays in feed, ferrochrome and slag, obtained from the ferrochrome plant over a 11 month period, were placed into eqns. 7-9 and 13.

$$\lambda_f = \frac{1}{\bar{f}} = \frac{1}{27.63} = 0.036197$$

$$\lambda_c = \frac{1}{\bar{c}} = \frac{1}{63.66} = 0.015709$$

$$\lambda_t = \frac{1}{t} = \frac{1}{2.29} = 0.435878$$

$$R(f) = \frac{(0.435878 - 0.036197)}{(0.435878 - 0.015709)} - \frac{(0.435878 - 0.036197)}{(0.435878 - 0.015709)} \cdot e^{-(0.435878 - 0.015709)\cdot f} \quad (18)$$

TABLE-2
DAILY ASSAYS OF MINIMUM OBSERVATION VALUES
OVER A ELEVEN MONTHS PERIOD

Days	Assays (Cr %)		
	Feed	Ferrochrome	Slag
1	27.70	62.28	2.51
2	27.67	62.30	1.64
3	27.67	62.04	1.68
4	27.95	61.37	1.56
5	27.55	64.92	2.79
6	27.48	64.35	1.37
7	28.00	64.21	1.98
8	27.44	63.10	1.71
9	27.38	62.20	2.33
10	27.54	63.80	2.53
11	27.30	64.70	3.69
12	27.37	64.14	2.69
13	27.76	65.15	2.94
14	27.95	65.64	2.69

Equation 18 is shown graphically in Fig. 5 for the possible values of assays in the feed. Although daily assays in feed decreases by 3.2 % (Table-1), considerable change is not observed in recovery (Fig. 5). Significant difference was not observed with both calculations performed the suggested recovery formula. The plant is under control. As a result, plant performance could be assessed better using the suggested recovery formula.

Conclusion

In this study, the plant recovery based on definitions and equations of the exponential distribution was developed for improving its use in an easily applicable manner to the mineral and metallurgical processing plants or experimental studies in laboratory. It is shown that this improved plant recovery could be used in the determination of minimum assays in feed of the plant at a required recovery. It is also possible to estimate the accepted recovery at any assay in the feed.

The case study for the implementation of recovery formula was conducted using the historical data over the 1 month period collected from Elazig Ferrochrome plant-B. It was determined that the recovery obtained through the consideration of the lowest assays collected from the plant over the 11 month period was very close to the recovery estimated with the suggested recovery formula and the plant was operated under control. In conclusion, it could be suggested that this improved recovery formula could be used as an efficient tool for the assessment of plant performance or experimental studies in laboratory.

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