Production Quality, Value and Revenue in Polish Copper Mines

Jerzy Malewski 1

1 Wrocław University Science and Technology, Faculty of Geoengineering, Mining and Geology, Na Grobli 15, Wrocław, 50-421 Poland
E-mail address: jerzy.malewski@pwr.edu.pl

Abstract. Polish copper ore deposits, located in the Legnica-Głogów Copper District (LGOM) documented an area of over 200 km², at a depth of 600-1400 meters. The estimated resources equal to 22.7 million tonnes of copper (proven and probable), or 44.4 million t (measured and indicated), or 8.7 million t (inferred), at the criterion of profitability at a cost less than 50 cents per ton of ore. Organization of production takes place in the combine of mining and metallurgy (KGHM). Ore is extracted in three mines: Lubin, Polkowice-Sieroszowice and Rudna. The total production of these mines is about 31 million tonnes/year of ore, from which it receives a 576000 t/y of copper, 1152 t/y of silver, 1066 kg/y of gold, and certain amounts of Pb, Zn, Se, Re, Ni, SO4, H2SO4. The quality (grading) of the ore in exploited deposits is varied, affecting the quality and quantity of produced concentrates, what influence on its market value. The paper presents a brief description of ore deposit and estimates mines revenues and production profit. Calculations show that at today's (June 2016) metal prices each of the mine can expect the following net smelter revenue: Lubin ~41, P-S ~70, Rudna ~75 $/t of ore. But estimated cost production differs less, i.e.: 45, 56 and 65$/t of ore respectively, because of mining depth.

1. Introduction
Polish copper mining is well known in the world because of its share in the global metals market. Ranks 8 in Cu production and 1 in the production of silver. The annual revenue is 20 billion US$, at the production cost of 1.89 $/lb. Company mined in Poland 31 million tonnes of copper ore and produces 576 thousand tons of copper, 1256 t of silver, 153 000 oz of gold. Operation is carried out in the area of 200 km², with employs 18,000 workers, [1].

In Polish company, copper production is organized as a mining and smelting company, which is functionally divided into mining, ore beneficiation, and smelting divisions. The divisions settle their mutual accounts according to the volume and quality of the main product, but not financially. Consequently, it is interesting to determine what maximum revenue can be achieved by the individual mine (ore extraction + beneficiation plant) from mining production considering the processing costs and the price on the global market of non-ferrous metals. For this purpose, it will be used NSR formula built on relationships between the quality of ore, quality and yield of the concentrates, processing costs, and metal prices in the open market.

2. Mining conditions
The deposit is a type of sedimentary rocks. Starts from the vicinity of Legnica at a depth of approx. 500 m and extends to the north-west sinking to a depth of 1,200 m and more. (Figure 1) The ore consists of three lithological type of rocks: sandstone, carbonate and shale – having different petrographic and
mineralogical properties influenced on the ore benefication process. The average copper content in the bed is in the range 1.0-2.0%. Main minerals are: chalcocite (Cu₂S), bornite (Cu₅FeS₄) and chalcopyrite (CuFeS₂) and rarer covellin (CuS). Cu resources estimated at 22.7 million tons (Proven & Probable), 44.4 million tonnes. (Measured & Indicated) and 8.7 million tons (Inferred). These reserves provide mining production for the next 30-40 years, [1].

Each of mine manages some deposits: Lubin (Lubin, Małomice); Polkowice (Polkowice, Sieroszowice, 50% Deep Głogów); Rudna (Rudna% 50% Deep Głogów). Mining operations is progressing towards Glogow, and therefore its depth now exceeds 1200 m. (Figure 1). Table 1 shows typical thickness of the layers and its mineralization of Cu in the mines.

Figure 1. Geology of mining district, [2], blue line – target level of mining

Table 1. Mines parameters influenced on the company economy

|                | LUBIN    | POLKOWICE | RUDNA    |
|----------------|----------|-----------|----------|
| Cu, %          | Proven₁  | In ore*   | Proven₁  | In ore*   | Proven₁  | In ore*   |
|                | 1.05     | 0.91      | 1.7-1.9  | 1.79      | 1.6      | 1.77      |
| Ag, g/t        | 51       |           | 35-48    |           | 41-51    |           |
| Au, g/t        |          | 0.012²    |          | 0.036²    |          | 0.0094²  |
| Mine output, mln t/y | 7       |           | 11       |           | 12       |           |
| Exploit. deep, m | 680-890 |           | 600-1200 |           | 920-1200 |           |

¹Nikon Report, ²Monografia KGHM [3] *Concentrator feed (Investor presentation [4])

Deposits quality (mineral grading) varies. Shallower resources have poor copper mineralization, deeper - better. Cu mineralization is dependent on the type of rock. Shale has the best mineralization (4-16% Cu), much worse have carbonate and sandstone rocks (0.5-1.5% Cu). Every mine runs exploitation deposits in various fields for more than ten branches with different mining capacity, so there is a possibility of averaging of ore to keep the needed average grade of the ore for enrichment.

3. Processing and smelting

Production in KGHM Polska Miedź S.A. is a fully integrated production process, in which the end product of one stage is the feed to another stage. Ore mined from Lubin, Rudna and Polkowice-Sieroszowice mines processed in three separate concentrators, products of which is a feed to metallurgical plants of smelting and refinery: Legnica, Głogów I and Głogów II.

Management Production takes place in the context of the entire company. Thus, sale of concentrates in KGHM is a symbolic term, since the exchange of goods among its own mills and mines held by. qualitative-quantitative criterions, not financial. The company in its reports shows general data revenue
and production costs. But it’s very interesting to know how the revenues and expenses are distributed to individual mines and what income these mines can expect in the context of current metal prices. Estimation of that data is the subject of this work.

4. Mine profit assessment

Mine profit $Z$ is the cost $K$ subjected from revenue (Net Smelting Return) i.e.

$$ Z = NSR - K $$

(1)

The NSR formula determines how much income can be obtained from the sales of the main product at a given stage of production taking into account its current quality and the processing costs at subsequent operations to the final level of quality acceptable in the open market. It is commonly known as following expression:

$$ NSR = \sum_i (\beta_i \cdot \delta_i \cdot p_i) - (MC + DC) - P + B \cdot \gamma_1, $$

(2)

$$ MC = \sum_i (\mu_i \cdot RC_i) + TC $$

(3)

where: $NSR$ – net smelter return measured in $ per 1 ton (Mg) of ore; $\beta_i$ - share of $i$-component (metal) in the main product (concentrate); $\delta_i$ - payable part of metal in concentrate; $\mu_i = \beta_i \cdot \delta_i$ - payable amount of $i$-metal; $p_i$ - price of the $i$-component in the open market; $MC$- metallurgical charge in $ per 1 Mg of concentrate; $TC$ – concentrate treatment (smelting) charge; $RC_i$ - refining charge of $i$-metal; $DC$ - delivery ex-recipient charge; $P$ - penalties for the presence of harmful components (according to contract terms); $B$ - bonuses for the presence of desirable components (according to contract terms); $\gamma_1 = 1$ - yield of the concentrate in the feed (ore); where $\gamma_2$ - yield of tailings, and $\gamma_0 = 1$ - amount (unit) of feed (ore). Formula (2) may additionally introduce costs of chemical analyses of quality testing, and other contractual limitations.

4.2. Yield of concentrate

In the optimization analyses the basic problem is to identify the relationship between the efficiency of beneficiation operations (recovery, $\varepsilon$) and the concentration of the enriched minerals. In the case of complex ores, the producer may be interested in any one component (metal, mineral), but not each one is the subject of beneficiation even though it will be recovered in subsequent smelting operations. This is precisely the case that will be considered in this work on the example of copper production technology at the polish mines of KGHM Polska Miedź S.A., [5].

For the qualitative and quantitative calculations of the yield of the main component (Cu) depending on the efficiency of the beneficiation operations we use the following relationship, [6]:

$$ \gamma_i = \frac{\alpha}{\beta} \left[ 1 - \left( \frac{\beta - \alpha}{\beta_{\text{max}} - \alpha} \right)^A \right], \alpha \leq \beta \leq \beta_{\text{max}} $$

(4)

where: $\gamma_i$ - concentrate yield; $A = f(\pi, z, t)$ is a function of current values of the operation parameters $\{\pi\}$, environmental variables $\{z\}$ and duration of the beneficiation operation $t$; $\beta_{\text{max}}$ – limit of the metal (Cu) content in processed minerals; $\alpha, \beta$ – actual Cu content in ore and concentrator’s product.
4.3 Payments and deductions

Typical formulas for payable part of a metal in formula (2,3) are as follows [7]

\[
\delta_{Cu} = (\beta_{Cu} -1\%) / \beta_{Cu} ; \quad \delta_{Ag} = (\beta_{Ag} - 30) / \beta_{Ag} ; \quad \delta_{Au} = (\beta_{Au} - 1) / \beta_{Au}
\]

\[(5)\]

where \(\beta_{Cu}, \beta_{Ag}, \beta_{Au}\) are the actual, standard (24%) grade of concentrate; \(\delta\) - the percentage deducted from the payable amount.

The smelting \(TC\) and refinery \(RC\) charge will depend strictly on the amount of Cu in concentrate. In this case certain heuristic models of those relationships is proposed, as presented in Fig. 2b. This is energy dependence relationship extracting amount \(\beta\) metallic Cu by smelting 1 Mg of concentrate. The model in general form may be of the type (Fig. 2b):

\[
\frac{TC}{TC^*} = C \cdot \left(\frac{\beta}{\beta^*}\right)^{-k} + D,
\]

\[(6)\]

where: \(TC, TC^*\) – actual or standard treatment costs, \(\beta, \beta^*\) - actual and standard (24%) grade of concentrate; \(C\) – variable and \(D\) – constant share in cost formula, respectively; \(k\) – curve form factor determined experimentally by iteration in a way similar to how it was described in the case of formula (3). Note: if \(\beta=\beta^*\) then from formula (5) we have \(C+D=1\).

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1 At the time being Treatment Charge (TC) in long term prognoses for 2016 is equal to 97$/DMT and Refining Charge - 215 $/DMT of payable metal. For precious metals RCs states as 0.6 $/troy or 0.01926 $/DMT of payable silver, and 8$/troy or 0.25680 $/DMT of payable gold. Plats McGraw Hill Finance, 26 Jan 2016

2 Copper: Some smelters will pay for as much as 40% of contained copper while at some other smelters is considered deleterious. Gold: Deduct 0.03 to 0.07 troy ounce per dry tonne and pay for 95% of the remaining gold at market value. Silver: Deduct 0.5 to 2.0 troy ounce per dry tonne and pay for 95% of the remaining silver at market value [8]
The same formula is used for RC\textsubscript{Cu} refining deduction, for parameter of $k=1$. In our case $\beta^*=24\%$, $C=0.65$, $D=0.35$, $k_{TC}=2$, $k_{RC}=1$. were assumed as well as from recent concentrates market we have: TC*=97 \$/t conc, RC(Cu)=214 \$/t Cu. Figure 2b presents the result of TC/RC vs Cu content in concentrate.

4.4 Mine revenue and profit performance
To estimate mining revenue, it will be used industrial data of metal content in the operation streams throughout the copper production cycle. Input data for calculation are presented in Table 2. Figure 3 shows the results for calculations for a practical scope of metal grading in ore and concentrate. Penalties ($P$) for undesirable components and bonuses ($B$) for desirable ones are neglected.

Table 2. The data adopted for calculations [3, 5] and the results of NSR optimization

| Metal | Mine | Concentrator | Market 1.06, 2016 |
|-------|------|--------------|-------------------|
| Cu%*  | LUBIN| 0.9%         | 17                |
| Ag,g/t*|     | 62           | 810               |
| Au,g/t*|     | 0.012        | 0.28              |
|       | POLKOWICE |          | TC                |
| Cu%*  |     | 1.67         | 25                |
| Ag,g/t*|     | 32           | 410               |
| Au,g/t*|     | 0036         | 0.49              |
|       | RUDNA| 1.78         | 27                |
| Cu%*  |     | 1.78         | 27                |
| Ag,g/t*|     | 49           | 650               |
| Au,g/t*|     | 0.009        | 0.039             |

*Operating data

To assess how that mine conditions, affect the profitability of production at individual mines we need to estimate the cost of production. Unfortunately, we have only general data concerning the whole company KGHM Polska Miedz SA. It has been provided some approximations of this forecast distributes the overall cost of the individual mines in proportion to their extraction and the mining depth are presented in the last column of Table 3.

Table 3. Rough estimation of cost production distribution relying on data [4, 5]

| Operations | Mine | Lubin | Polkowice | Rudna | KGHM PM |
|------------|------|-------|-----------|-------|---------|
| Capacity, mln t | 8    | 11    | 12        | 31    |         |
| Depth assumed, m | 700  | 950   | 1100      | 944   |         |
| Mining, $/t ore | 32.3 | 43.9  | 50.8      | 43.6  |         |
| Processing, $/t ore | 6.2  | 8.4   | 9.8       | 8.38  |         |
| Metallurgy, $/t ore | 5.6  | 7.7   | 8.9       | 7.6   |         |
| Administration, $/t ore | 2.9  | 4.0   | 4.6       | 3.96  |         |
| K=Mining+Proc+Adm, $/t ore | 41.50| 56.32 | 65.22     | 63.54 |         |
| Relative mining cost | 0.74 | 1.01  | 1.17      | 1.00  |         |
| Relative production cost | 0.70 | 0.89  | 1.03      | 1.00  |         |
| NSR , $/t ore | 45.9 | 69.4  | 75.9      | 65.9  |         |
| Profit Z=NSR-K | 4.40 | 13.08 | 10.68     | 9.9   |         |
This is the average cost for the entire KGHM Polska Miedz SA. Spreading these costs by capacity and differentiating it by the depth of exploitation we got the results as in Table 3.

5. Final results and discussion
After the results of the estimation of revenues and production costs (Table 3) we see that the probable costs of production in Lubin Polkowice and Rudna mines distributed in proportions of 0.7: 0.89: 1.03 relative to the average of KGHM. Gross profit of all mines is positive and equals to 4.4: 13.08: 10.68, $/t respectively, with the company average 9.9 $/t of ore. This means that with the current relatively low prices of metals, mines are profitable and the differences between them are not as large as in the case of its NSRs.

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