Annual production enhancement at deep mining

Nataliia Shvaher[1*], *Tetiana* Komisarenko[1], *Serhii* Chukharev[2], and *Svitlana* Panova[3]

[1]Kryvyi Rih National University, Department of Labor Protection and Civil Security, 11 Matusevycha St., 50027 Kryvyi Rih, Ukraine
[2]Kryvyi Rih National University, Department of Underground Mining of Mineral Deposit, 11 Matusevycha St., 50027 Kryvyi Rih, Ukraine
[3]Kryvyi Rih National University, Department of Ecology, 11 Matusevycha St., 50027 Kryvyi Rih, Ukraine

Abstract. The article aims at determining possible annual production considering mining and technical capabilities of the underground mine. Deepening of mining operations at Kryvyi Rih iron ore basin reduces considerably annual production of the useful mineral which results in increased mining costs. To maintain annual production, it is reasonable to build the second stage of opening the depth of which depends on production volumes. When determining the optimal depth of the first stage opening, it is necessary to apply a complex research method including the graphoanalytical one for determining the underground mine's annual production and the industrial one for adjusting the methods considering technical conditions of the enterprise. It has been determined that annual production is influenced not only by mining and geological but also by mining and technical conditions. It has been proved that annual production of an underground mine decreases in direct proportion to the increased depth of mining. The speed of skips in the shaft is greatly impacted by the length of the main opening and its operating life. With the increase of the shaft operating life the skip speed decreases from 12 to 6 – 8 m/s. When designing the flowchart of further opening of underlying levels, it is necessary to consider both mining capabilities and technical conditions of the shaft and headgear, mining depth and the main opening operating life as well as the strategy of the mining enterprise. Consideration of the above mentioned factors enables maintaining the required annual production when mining iron ores at great depths. Under conditions of Kryvyi Rih iron ore basin, it has been determined reasonable to apply the main vertical shaft flowchart when mining reserves to the depth of 1650 m.

1 Introduction

Kryvyi Rih iron ore basin accounts for 10 bn t of ferruginous quartzite mined by open-pit and underground methods. Nearly 1.1 bn t is made by rich ores with the useful mineral component of over 60% which is mined by the underground method. When mining underground to the depth of up to 1115 m, the designed annual production of underground

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[*] Corresponding author: knu.shwager@gmail.com

mines made 4 – 8 mln t [1 – 3].

Underground mining of iron ores has deteriorated mining-geological and mining-technical conditions resulting in 2 – 3-fold decrease of annual production and 1.5 – 2.5-fold increase of mining costs. Currently, iron ore is mined at the depth of over 1300 m by traditional mining systems: bulk caving and open stoping. Ore drawing is performed by obsolete equipment (slusher or vibrofeeder), then ore is transported in cars to the shaft and by 50t-skips to the surface [4 – 6].

The process chain of the kind has not only decreased capacity of Kryvyi Rih iron ore basin underground mines to 1.5 – 2.5 mln t but also increased the injury and occupational disease rates [7 – 10]. Mining enterprises are making efforts to eliminate the above mentioned drawbacks by purchasing import mobile equipment, installing powerful hoisting machines, improving mining systems, enhancing labour conditions, etc. However, the mine production capacity of 4 mln t/year has not yet been reached.

It should be noted that with small production volumes of 1.5 – 2.5 mln tpa, marketable products make 1.2 – 2.0 mln t, waste rocks account for 0.3 – 0.5 mln t. The latter are stockpiled in external dumps or caving zones and aggravate the regional environment.

2 Methods

Leading scientists are constantly solving problems of increasing annual production and decreasing mining costs through development of innovative highly efficient technologies, complex mining of useful mineral deposits, enhancement of mining systems and increase of the useful mineral content in the mined ore mass.

Thus, to increase output of marketable products there are suggested open stope systems [11 – 14]. This will enable increase of marketable product volumes by 5 – 10%. However, considering mining and geological conditions, this system cannot be 100% applicable, so on the whole the amount of marketable products at the underground mine is 2 – 5% larger.

When applying bulk caving, [15 – 18] suggest application of underground magnetic separation to increase production volumes by 15 %. However, this technology cannot be widely applied as there are 5 – 9 mineralogical and technological types of ore in the massif on average [19 – 21] and this will lead to frequent change of settings of the technological concentration equipment.
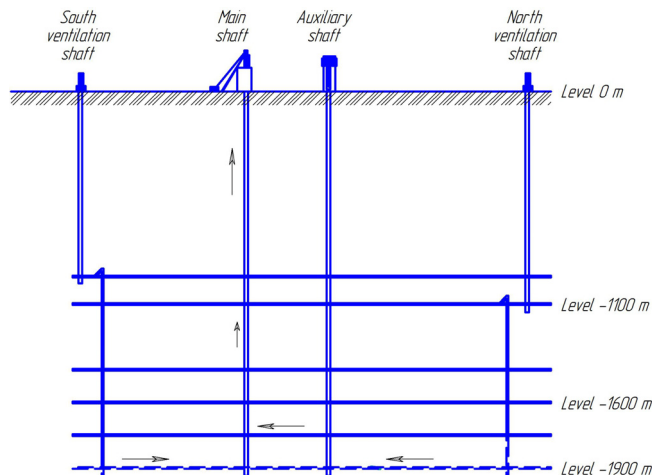

Fig. 1. The basic diagram of opening the Kryvyi Rih iron ore basin deposit by the main shaft to the final depth.

Nevertheless, it should be noted that increase of the depth of the first stage of opening to 1500 – 1700 m will inevitably result in decreased annual production due to longer periods for ore mass hoisting and increased loads on constructive elements of the headgear, Fig. 1. All these factors may affect negatively mining costs and worker safety [22 – 27].

Thus, it is necessary to substantiate the maximum depth of the first stage of opening that will provide high mine production and safe labour conditions.

3 Results and discussion

When determining annual production of the underground mine, the formula characterizing only mining capacity of the enterprise is used:

$$A = S \cdot V_s \cdot \gamma \cdot \frac{1-P}{1-R} \cdot 10^{-6} \text{ mln t/year,} \tag{1}$$

where S is the total horizontal operational area of the deposit, m^2; V_s is the average annual decrease of stoping, m/year; γ is the specific weight, t/m^3; P, R are extraction values with relation to ore losses and dilution at underground mining, fraction units.

It should be noted that annual production according to formula (1) is not impacted by the mining depth. That is why, when determining annual production of the underground mine at great depths, the mining depth, as well as the current condition and prospects of the mining enterprise's performance should be taken into consideration.

So, the underground mine's annual production by hoisting capacities per main rock shaft equipped with two balanced skips is determined by the expression:

$$A_h = \frac{60 \cdot T \cdot Q \cdot k_n \cdot t_d}{t} \cdot \frac{1-P}{1-R} \cdot 10^{-6} \text{ mln t/year,} \tag{2}$$

where T is the time of the hoister work during a year period, days; Q is the skip capacity, t; $k_n = 0.85 – 0.90$ is the skip fill factor, fraction units; t_d is the hoister work time during a day (considering idle and maintenance time), hours; t is the time of one hoister's cycle, min.

The time of one hoister's cycle for loading, unloading and hoisting is determined by the formula:

$$t = t_{n.p} + t_p + t_{p.t} \text{ min,} \tag{3}$$

where $t_{n.p} = 1 – 3$ is the time for loading (unloading) a skip, min.; t_p is the time of the skip moving along the shaft, min.; $t_{p.t} = 1 – 2$ is the time for placing the skip for loading (unloading) and reaching the required speed, min.

The time of the skip movement along the shaft is determined by the formula:

$$t_p = H / (v \cdot 60) \text{ min,} \tag{4}$$

where H is the height of hoisting in the shaft (accepted equal to the depth of mining according to the norms of the technological design for the first stage of opening), m; v is the skip speed in the shaft, m/s. The skip speed depends on the technical condition of the shaft.

Analysis of the project design documentation and Kryvbas mining enterprises' practice enables the conclusion that when mining deposits below 1100 m, the skip speed decreases by 3 – 7% every 10 years of shaft operation.

Calculations of annual production of the underground mine depending on mining systems applied are given in Figs. 2 and 3.

Fig. 2 shows that when mining reserves by the bulk caving system, increased depths of the first stage of opening from 1200 to 1900 m results in decreased annual production of the

underground mine from 7.5 to 1.0 mln tpa, mine annual production by mining capacity at that being 5.5 mln t and the current average production making 1.8 mln t. The diagrams in Fig. 2 demonstrate that to maintain the current production at the level of 1.8 mln t, it is necessary to build the second stage of opening (further mining by sub-vertical shafts) below 1600 m.
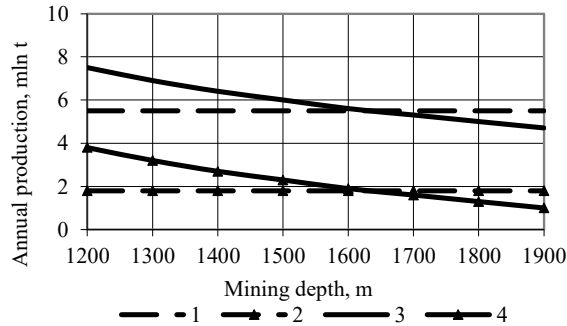

Fig. 2. Dependence of the underground mine annual production on the mining depth when applying the bulk caving system: 1 – by mining capacities; 2 – current production; 3, 4 – skip speed in the shaft: maximum (12 m/s) and current (8 m/s) respectively.
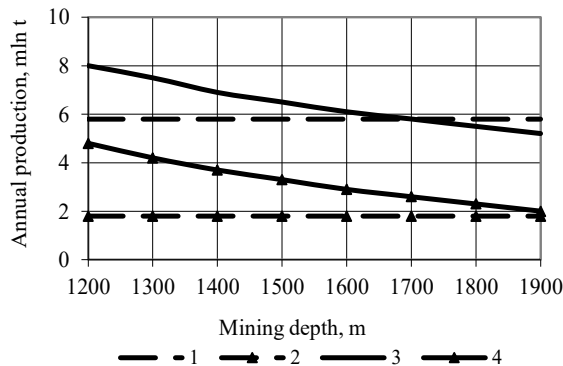

Fig. 3. Dependence of the underground mine annual production on the mining depth when applying the filling system: 1 – by mining capacities; 2 – current production; 3, 4 – skip speed in the shaft: maximum (12 m/s) and current (8 m/s) respectively.

Also, annual production may be increased at the expense of the increased skip speed in the shaft from 8 to 12 m/s. However, this will result in increased capital expenditures.

The rough value of capital expenditures is determined by the formula:

$$K = 0.1 \cdot Q^{0.77} \text{ ccu/t,} \tag{5}$$

where Q is the balance ore reserves, mln t.

Considering the fact that there is still about 150 mln t within the boundaries of the deposit, according to formula (5) total unit costs make about 4.7 conditional currency units (ccu) per ton when mining by sub-vertical shafts. In case of reconstructing the main shaft when deepening it to 1900 m, unit costs will grow by 1.2 ccu/t when putting each level into operation. Thus, total unit costs when mining the deposit by main shaft to the depth of 1900 m with the skip speed of 12 m/s make 9.5 ccu/t which is by 4.8 ccu/t greater than at building the second stage of opening.

Application of the room-and-pillar system with consolidating backfill enables mining enterprises to mine reserves up to the depth of 1900 m by one main shaft with the same annual production (see Fig. 1). It should be noted that according to data of mining enterprises mining costs of 1 ton of ore will increase by 2.5 – 3.0 ccu.

However, this requires additional alienation of land, extra technological chains, sequence of mining operations and clear work organization. .

The following flowcharts of opening on the second stage are possible for Kryvbas conditions: by a sub-vertical shaft with skip transportation of ore; by inclined spiral ramps with ore haulage by powerful trucks; by an inclined sub-vertical shaft with a conveyer.

Aggregate economic indicators by variants of opening and mining with the help of the second stage of opening are given in Table 1.

Table 1. Aggregate economic indicators by opening flowcharts.

Indicators	Sub-vertical shaft	Spiral ramp	Inclined sub-vertical shaft
Proven reserves, mln t	150.0	150.0	150.0
Annual production, mln t	2.0 – 4.0	2.0 – 8.0	2.0 – 12.0
Expenditures on reconstruction of underground complex, mln ccu	0.85	0.69	0.77
Expenditures on building underground complex, mln ccu	1.56	1.73	1.62
Expenditures on additional workings, mln ccu	0.05	0.06	0.09
Total capital expenditures, mln ccu	2.46	2.48	2.48
Total unit costs, ccu/t	0.0164	0.0165	0.0165
Operating costs per year (to the second opening stage), mln ccu/t	0.058	0.065	0.047
Total, annual expenditures, ccu/t	0.07444	0.0815	0.0635

As is seen from Table 1, the most efficient is the flowchart of opening by a vertical shaft to the depth of 1600 m and by an inclined sub-vertical shaft. The flowchart provides minimum unit costs of 0.0635 ccu/t with annual production of the underground mine of 2.0 to 12.0 mln t. But, as is seen from the practice of opening the deposits of Kryvyi Rih iron ore basin at Artem-1 underground mine, labour conditions of conveyer workers are greatly deteriorated.

Considering leading foreign practices, reserves of Kryvyi Rih iron ore basin below 1600 m are reasonable to be mined by using opening by a vertical shaft up to the depth of 1600 m and by an inclined spiral ramp applying import mobile equipment. According to calculations, the greatest expenses under this flowchart fall to the share of exploitation due to servicing the mobile equipment as compared with the national equipment.

The research conducted results in the following flowchart of opening the deposit applying the second opening stage (Fig. 4).

The flowchart involves the following: the vertical shafts are deepened along with mining the underlying levels up to the depth that provides the required annual production of the underground mine according to formula (1). The lower opening is conducted by the second opening stage.

Ore mass from deep levels is hoisted by underground trucks from breakage faces on the spiral ramp to the loading point at the -1600 m level. At the spiral ramp mouth a loading point is established for re-loading ore from trucks into cars and further transporting to the main shaft.

The advantages of the variant are the following: increased annual production of the underground mine; fast putting into operation of mining levels below -1600 m; decreased length of workings; decreased capital and operating costs for the second stage of opening.
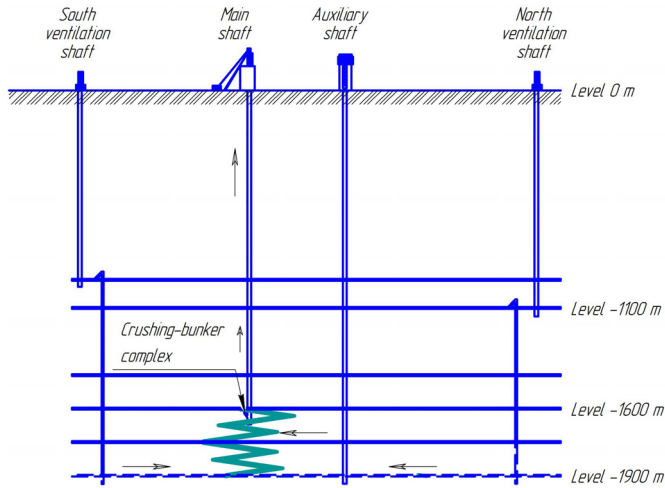
Fig. 4. The diagram of opening Kryvyi Rih iron ore basin deposits with the spiral ramp below the depth of 1600 m.

The disadvantage of the flowchart is dependence of the mine annual production on hoisting capacities of the main vertical shaft.

At Kryvyi Rih iron ore basin, to increase annual production, it is reasonable to combine underground mines into a single transportation system, Fig. 5.
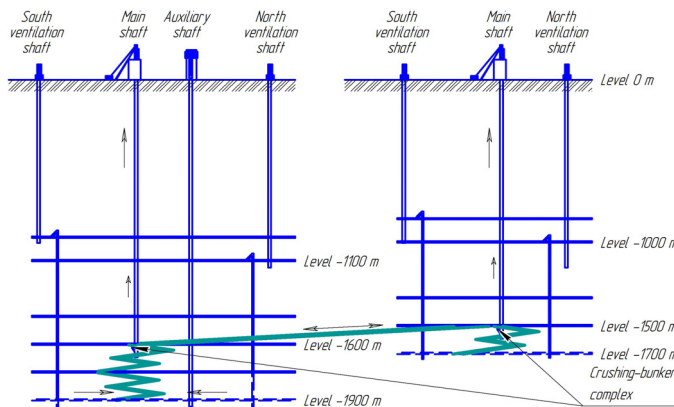

Fig. 5. The diagram of opening Kryvyi Rih iron ore basin deposits with combining mine fields and driving a spiral ramp below the depth of 1600 m and a single transport working.

Application of the method enables doubled annual production within the mine field and further development of underlying levels. Also, this will enable preserving employment, decreasing expenditures on building the second opening stage and providing distribution of the mined ore mass according to the useful component content.

At the depth of 1600 m main shafts are connected with the working for electric transport that will enable simultaneous quality grading of ore from the two underground mines.

The advantage of the flowchart presented in Fig. 5 is the fact that it is reasonable to apply a single transport working to hauling not only ore mass but also waste rocks. This will enable using only one shaft for hoisting waste rock, thus using efficiently the shaft capacity for hoisting waste rock of one mine field and then using the shaft for hoisting waste rock for hoisting ore of the other underground mine.

The disadvantages of the flowchart are considerable capital investment for purchasing mobile equipment; additional operating costs for maintaining the loading point working; complexity of ventilating the second stage of opening; necessary maintenance of the concentration level (-1600 m); clear organization of mining operations.

Efficiency of the presented scientific results depends on their implementation in projects on developing systems of forecasting and providing reliability of current mining enterprises or those being designed or their subdivisions. It should be noted that practical implementation of the suggested scientific results provides for mainly development of information technologies and software according to the presented methods. This enables significant reduction of expenditures on implementation as the software is characterized by: rather low costs for its porting and adapting to new production conditions; high degree of reliability provided by powerful means of testing and adjustment at early stages of development. The cost of modernization of functional capabilities of the given system of forecasting and providing objects' reliability is rather low as it will only require the current software upgrade.

4 Conclusions

The research conducted enables determining the fact that annual production of the underground mine impacts significantly the choice of an opening flowchart when mining reserves at great deaths. If underground mine annual production does not exceed 2 mln t, opening is performed to the depth of 1900 m. At that, it should be taken into account that operating costs for maintaining the shaft and headgear increase. That is why, not only technical but also economic components should be considered when determining annual production of an underground mine.

Combination of underground mine fields will considerably facilitate growth of economic indicators at the expense of increased annual production and distribution of the mined ore mass according to the useful component content.

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