Prospects for future mining of steep iron-ore deposits in the context of Kryvbas

Anatolii Dryzhenko

Doctor of Engineering Science, professor
Professor of Open-cast Mining Department
SHEI "National Mining University", Dnipropetrovsk, Ukraine
E-mail: ipgpnmu@mail.ru

Oleksandr Shustov

Candidate of Engineering Science
Teaching Fellow of Open-cast Mining Department
SHEI "National Mining University", Dnipropetrovsk, Ukraine
E-mail: fishboy1986@mail.ru

Andrii Adamchuk

Master of Mining
Post-graduate student of Open-cast Mining Department
SHEI "National Mining University", Dnipropetrovsk, Ukraine
E-mail: a.a.adamchuk@mail.ru

Abstract
A problem of mining of platform-like steep and synclinal iron-ore deposits with inside overburden rock dumps was considered. Expedient production concepts for typical deposits of Kryvy Rih iron-ore basin were demonstrated. Rational parameters to mine iron-ore deposits with inside overburden rock dumps were substantiated. Basic indices concerning deepening and continuous mining for iron-ore open pits were provided. Dependence of level depth with temporary dumps within advance zone on ore deposit thickness was determined. Poltava MPIW was taken as an example to prove both economic and environmental efficiency of the proposed decisions.
Key words: OPEN-CAST MINING, IRON-ORE DEPOSITS, INSIDE OVERBURDEN ROCK DUMPING, MINED OUT AREA, WORKING ZONE PARAMETERS

Introduction

Long-term practice of iron-ore open pits operation in Kryvbas shows that it is rather expedient to mine them one by one when mined-out area of previous open pit is used to stockpile overburden rocks of active one. In this context, relative closeness of open-pit fields as well as developed railroad network would make it possible to achieve high efficiency of open-pit mining as land would not be disturbed by outside dumps. Complete refilling of mined-out open pits and availability of soil layer at the level of undisturbed land would help to resoil considerable territories which today is surface disturbed by deep cuts, high dumps, and tailing pounds. At the same time, the lessons learned may be used effectively while prospective deposits mining. First, one should be geared to synclinal ones where deposit outbreak takes place under shallow overburden. The deposits are similar to Sklevatskoe magnetite, Inhuletskoe, Petrovskoe, Artemovskoe, Zelenorechenskoe and other deposits. Such deposits are characterized by the fact that value of plunge of axis of fold is within 15 – 20° [1].

Main part

Intensive formation of mined-out area to provide minimum continuous overburden rock mining is possible in terms of lateral primary mining of producing level as well as primary axis development with displacement of advance bench along synclinal flanks towards opposite edge of open pit (Fig. 1). The key criterion to determine mining parameters is to enable complete stockpiling of overburden rocks within mined-out area and its preparation for agricultural reclamation. Mined-out area within edge of open pit may be used for upper floor of constant dump at ground level of 60 – 100 m higher [2].

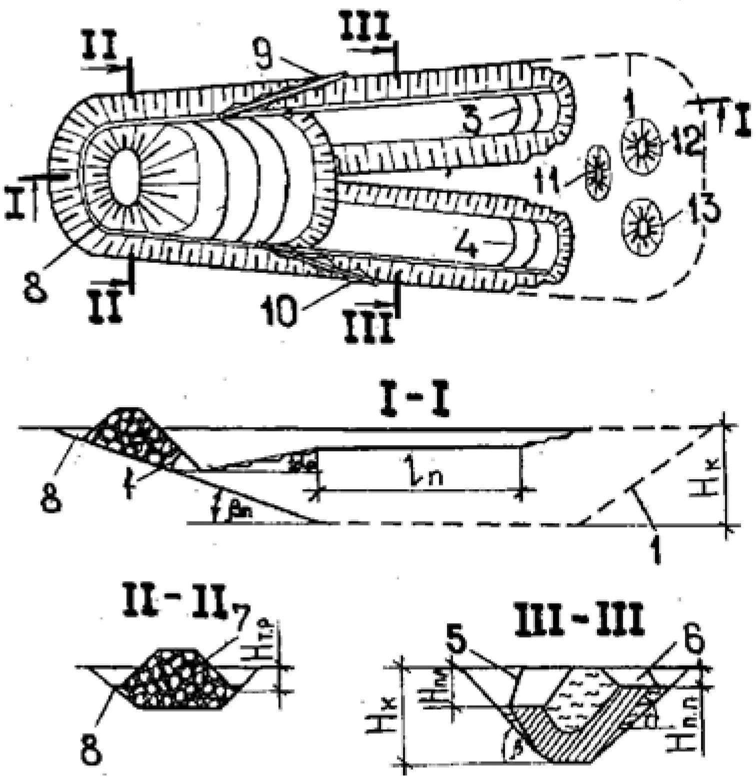

Figure 1. Analytical model for calculating parameters to mine synclinal iron-ore deposits with inside dumps

1 - lines of open-pit field; 2 - working benches within deepening zone; 3 and 4 - working benches within advance zone in terms of left and right wings; 5 and 6 - lines of temporary dump within advance zone in terms of left and right wings; 7 - permanent inside dump within deepening zone; 8 are residual trenches for open-pit transport; 9 and 10 - conveyors within left and right wings; 11 and 13 - temporary dumps of black soil, soft overburden rocks, and hard overburden rocks

It was determined that in terms of open pit deepening down to 100 m, mined-out area with steep floor at the edge cannot receive the whole amount of overburden rock even if height of surface dump is 60 m. When deepening angle of axis is 15° then further lowering of pit bottom at the depth of more than 150 m enables complete stockpiling of overburden rocks within mined-out area. That is impossible for δ = 20 – 30° (Table 1); thus, certain portion of overburden rocks (mainly soft ones) should be temporarily stockpiled within undisturbed area of open-pit field. Amount of such rocks is from 10 to 36 mln m^3; they will be subsequently reexcavated to mined-out area in the process of hydrotechnical reclamation of disturbed surface.

When deepening angle of axis is 20° (for the whole range of considered thicknesses of deposit series under mining) the mined-out area within edge lines of deepening zone can receive overburden rocks in full measure. When deepening angle of axis is 30° then it is expedient to stockpile from 52 to 58 m^3 of overburden rocks within intermediate level of advance zone. As subsequent mining (in terms of final depth) is characterized by horizontal advance only, then length of area for temporary stockpiling within advance zone ℓ_a (m) is determined on conditions of economic stockpiling of current rock amount within permanent dump. Reexcavation of previously stockpiled overburden rocks is also involved. Taking into consideration output data from Table 1 it is possible to say that if H_a increases, starting from 100 m depth amount of residual overburden rocks within advance zone decreases by 20 to 25 % in reliance on every subsequent 50 m. The length of intermediate level for temporary stockpiling of the amount is within 830 m on every wing of deposit under mining. If single-direction mining of open pit takes place, then length of temporary dump is no less than 1660 m.

Table 1. Parameters for iron-ore deposit mining with inside dump of overburden rocks

Description	Index					
Type of open-pit field	1	3	6	2	4	5
Positions of the deposits	synclinal			steep		
Annual ore output, million cubic meters	2.6	6.8	12.4	4.0	6.0	9.0
Horizontal thickness of ore zone, m	370	875	1300	200	300	800
Rate of deepening of mining operations, m/year	11.0	7.7	5.8	14.9	16.7	17.6
Length of deepening zone if α_w = 19°, b_{tr} = 40 m: δ = 15°	3040	3040	3040	–	–	–
δ = 20°	2540	2540	2540	–	–	–
δ = 30°	2040	2040	2040	–	–	–
if β = 40°, b_{tr} = 40 m: α_w = 19°	–	–	–	2100	2100	2100
α_w = 30°	–	–	–	1500	1500	1500
Amount of overburden rocks within deepening zone, million cubic meters: δ = 15°	180.6	226.0	271.0	–	–	–
δ = 20°	150.5	188.3	225.8	–	–	–
δ = 30°	119.8	149.8	179.7	–	–	–
α_w = 19°	–	–	–	323.3	300.7	219.7
α_w = 30°	–	–	–	225.9	215.5	163.7
Capacity of inside dump within deepening zone, million cubic meters: δ = 15°	202.2	287.1	369.7	–	–	–
δ = 20°	129.8	181.7	283.6	–	–	–
δ = 30°	67.4	94.4	121.6	–	–	–

$\beta = 40°$	–	–	–	421.8	448.4	613.5
Required capacity of inside dump in the process of advance zone progress, million cubic meters	–	–	–	618.1	562.8	417.2

Note: b_{tr} is width of residual trench bottom, m; α_w is angle of working area slope, degrees; β is angle of unworking area slope, degrees; δ is longitudinal angle of iron ore layer, degrees

In contrast to synclinal deposits, mining of steep ones is characterized by lower productive capacity and higher average opening coefficient. Such open pits as # 3 AMKR, # 1 CMPIW, Hannivka NorthMPIW, SMPIW and others have much worse economic performance. Skew angles of their edges are no less than 30 to 36°. Under such conditions, inside dump at intermediate level within advance zone requires complete overburden rock excavation on bottom layer of deposit as well as formation of spoil-pile wall with desired length (Fig. 2).

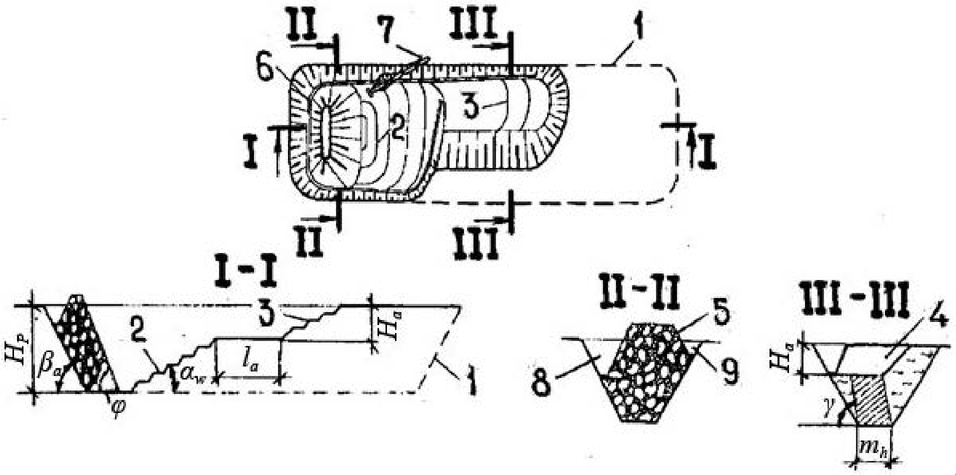

Figure 2. Scheme for calculating parameters of platform-like steep deposits with inside dump of overburden rocks

1 - lines of open-pit field; 2 and 3 -working benches within zones of deepening and advance; 4 - 5 are lines to locate inside dumps within zones of deepening and advance; 6 are railway tracks; 7 -conveyor hoist; 8 and 9 - residual trenches for transport

Receiving capacity of mined-out area within deepening zone $W_{mo.a}$ (cubic meters) is determined as follows

$$W_{mo.a} = \frac{0{,}3H_a b_{tr}}{K_{f.d}}\left[2m_h + 3H_P ctg\beta - 1{,}5(H_{b.l} + H_{h.l})\cdot(ctg\beta + ctg\varphi) - 4b_{tr} - h_d ctg\varphi\right] \quad (1)$$

where $H_{b.l}$ and $H_{h.l}$ are depthes of residual trench from bottom layer and hanging layer of ore deposit, m; h_d is height of inside dump above ground level, m. H_P is depth of open pit, m; m_h is horizontal thickness of iron ore layer, m; φ is angle of inside dump inclination, degrees; $K_{f.d}$ is fragmentation index of inside dump.

Overburden rock amount within deepening zone $W_{or.a}$ (cubic meters) is

$$W_{or.a} = 0.34H_P(B_f L_s + m_h b_{tr} + \sqrt{m_h b_{tr} BL_s} - 0.5m_h(L_n + b_{tr})(H_P - H_o) \quad (2)$$

where B_f is width of open-pit field in terms of surface, m; L_s is length of deepening zone over the surface, m; $L_s = b_{tr} + H_P(ctg\beta + ctg\alpha_w)$; H_o is thickness of overburden, m.

Receiving capacity of mined-out area at the level of temporary dumping within advance zone $W_{d.a}$ (cubic meters) is calculated as follows

$$W_{d.a} = 0{,}3H_a \ell_a\left[m_h + (H_P - H_a)(ctg\beta - ctg\gamma) + 0.5\,H_a(ctg\beta + ctg\alpha_w)\right] \quad (3)$$

where γ is horizontal angle of iron ore layer

Length of temporary dumping level within advance zone is identified if current overburden rock amount from advance zone is stockpiled; in terms of mined-out edge of deepening zone it can be done taking into account reexcavation of previously stockpiled overburden rocks. Assumption of output data from Table 1 makes it possible to say that length of intermediate level for the amount stockpiling is from 3.5 (if m_h = =200 m) to 0.7 km (if m_h = 1200 m).

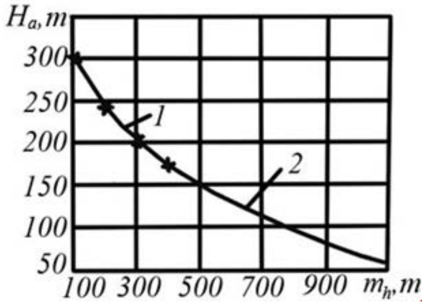

Figure 3. Graph of dependence of depth of level with temporary dump within advance zone H_a on thickness of ore deposits: 1 is area of inside dumps with relative height of ground level; 2 is area of overburden rock stockpiling at ground level

Figure 3 explains that while mining strata series which horizontal thickness is up to 300 – 450 m it is expedient to locate inside dumping level at 150-200 m; permanent inside dump should be formed with 60 to 100m relative height of ground level. It is rather efficient to apply railway transport at every mining stage if depth varies from 150 to 200 m. However, its operation involves certain limitations concerning intensity of working zone of open pit formation. In this context its productive capacity is of prime importance. Table 1 shows that if mining takes place in the period of deepening zone formation, then mining operations deepen considerably; in terms of open pits of 2nd, 4th, and 5th types it is from 14.9 to 17.6 meters per annum. Even upon availability of motor vehicles such intensification of mining operation is hardly achieved.

Table 2 demonstrates that while operating open pits of 2nd, 4th, and 5th types, planned advance of mining within deepening zone (when rate is 10 meters per annum) involves the necessity to displace upper benches for extra productivity increase by 12.5, 40, and 43.3 % respectively.

To normalize mining operations it is proposed to put into operation additional benches with their displacement in the line of course of ore towards oppo-site edge of open pit. Parameters of advance zone should provide increase in efficiency of ore mining in the context of allowable rate of mining deepening. In this case, deepening rate D_r (m/y) and advance intensity T_a (m/y) are determined as follows

$$D_r = \frac{H_d A_{od}}{P_d}, \text{ m/year; } T_a = \frac{A_o - A_{od}}{m_h H_c} \quad (4)$$

where H_d is depth of deepening zone, m; A_o and A_{od} are annual output of ore mining both in open pit and deepening zone, cubic meters; P_d are reserves of mineral within deepening zone, cubic meters; H_c is current depth of open pit, m.

Table 2. Basic indices of deepening and continuous mining system for iron-ore open pits

Description	Index					
Type of open pit	1	2	3	4	5	6
Volume of deepening zone, mln cubic meters:	98.5	244.0	636.8	437.2	758.3	2450.7
– ore	50.0	99.6	430.9	165.6	281.9	1571.0
– overburden rocks	48.5	144.4	227.9	271.6	476.4	879.7
– overburden of them	11.5	47.5	104.3	93.3	166.0	380.6
Share of overburden hard rock within upper part of deepening zone, mln cubic meters: – if current depth of open pit is, m:						
H_1=100	28.2	58.0	66.7	96.4	97.7	187.4
H_2 = 150	6.7	25.5	39.6	57.3	80.8	150.4
H_3 = 200	–	–	21.7	10.7	52.4	102.5
H_4 = 250	–	–	–	–	30.2	70.3
Deepening rate of open pit with specified productivity, m/y	11.0	14.9	7.7	16.7	17.6	5.8
Annual output of open pit if deepening rate is 10 m/y, mln cubic meters	–	3.5	–	3.6	5.1	–

Annual ore output within advance zone, mln cubic meters	–	0.5	–	2.4	3.9	–
Expenses connected with overburden hard rock displacement, UAH, mln $H_1 – \ell_{mv}$ = 1.5 km; $C_{tr.mv}$ = 0.6 UAH/m³km	25.38/13.54	52.2/27.84	60.3/32.02	86.76/46.27	87.93/46.90	132.66/70.75
$H_2 – \ell_{rt}$ = 4 km; $C_{tr.rt}$ = 0.12 UAH/m³km ℓ_{mv} = 2.25 km; ℓ_{rt} = 6 km;	9.04/4.82	34.43/18.36	53.06/28.51	77.36/41.26	109.08/58.18	203.31/108.43
$H_3 – \ell_{mv}$ = 3.8 km; ℓ_{rt} = 8 km	–	–	39.06/20.83	19.26/10.27	92.52/49.34	184.5/98.4
$H_4 – \ell_{mv}$ = 3.75 km; ℓ_{rt} = 10 km	–	–	–	–	67.95/36.24	158.18/84.36
Period of ore mining within deepening zone if D_r = 10 m/y, years	25.5	47	60	46	55	138

Note: numerator contains data for motor vehicles; denominator contains data for railway transport

Open pits of 3rd and 6th types are mined with 7.7 and 5.8 m/y deepening rates; that makes it possible to form their working zone without advance of upper benches. In each case, rock mass mining within deepening zones of the open pits is rather considerable being from 46 to 60 years. Open pits of 6th type are unique according to their reserves and occurrence mode. Long-term formation of mined-out area within their lines postpones the solution of inside dumping problem up to 138 years.

Open-pit mining practice shows that mining of long steep deposits is of the most intensive nature in the context of sites with the thickest deposits specified by minimum opening coefficient, considerable dimensions of working zone in a plan as well as projected depth of basic open pit. The sites of open pit with thinner deposits differ in higher opening coefficients. The tendency to decrease the total amount of overburden rock mining under the conditions lies in the fact of accelerating advance of horizontal mining operations in the line of the deposit occurrence in terms of poor intensity of deepening of bottom of open-pit. Projected mining depth within the sites is much less to compare basic open pit. Longer open-pit field makes it possible to use highly economical railway transport for rock mass. Railway tracks on both frontal edges of open pit help supply trains at rather considerable depth within deepening zone. Sequence of advance area mining is determined within central part of open-pit field and a part located far from deepening zone in accordance with value of opening coefficient being economic for mining operations. In this context, benches of 1st and 2nd orders are open form deepening zone. Temporary inside dump is formed at bottoms of average-order benches at the distance being no less than $\ell_{n.1}$ (m) from projected one determined as follows

$$\ell_{b.1} = h_2\left(\frac{b_b}{h_b} + ctg\alpha_b\right) + 2\sqrt{h_d b_b ctg\varphi_d} + b_s \quad (5)$$

where h_2 is height of benches of 2nd order, m; b_b is width of bench, m; h_b is height of bench, m; α_b and φ_d are slope angles of bench and primary inside dump, degrees; h_d is height of primary inside dump, m; b_s is width of safety area between bottom edge of primary dump and bottom of central part of open-pit field, m.

After that working front of mining operations and dumping ones is advanced horizontally from deepening zone to opposite edge of open pit; transport communications are located at upper unfilled areas of edges within central and remote parts of open-pit field. While forming worked-out area within bottoms of benches of 2nd order inside dump together with overburden rocks excavated in the process of open-cut of walls of open pit is displaced from its primary location to stationary one within deepening zone. Reexcavation of temporary inside dump is performed with the help of transport communications of basic open pit.

Open pit of 5th type (PoltMPIW) is taken as an example to determine that height of average order is 170 to 180 m. It is not planned to deepen achieved depth within remote part down to finite value at the edge of open-pit field while mining. Then it is intended to mine central part at the depth of 320 m. 60 mln cubic meters of overburden rocks will be placed in temporary inside dump. Annual output of internal dumping is from 4 to 5 m³. Width of bench (60 m), height of benches (15 m), slope angle of bench (75°), slope angle of dump (36°), height of temporary internal dump (45 m), and width of safety area between lower edge of dump and working bench (45 m) are those output data to calculate dumping parameters for temporary inside dump. Then length of bottom of level to locate temporary dump will be 1510 m.

In the context of PMPIW the technique of internal dumping has been industrially implemented since 1993. Within western edge poor ferruginous quartzites from –135 and –75 m levels were stockpiled in inside dump with – 150 m bottom grade (Fig. 3). Up to the year of 2000 almost 9 mln cubic meters of overburden rocks from central part of the open pit were stockpiled in temporary inside dump with –105 m bottom grade. Inside dumping made it possible to shorten the distance of overburden rock transportation using motor vehicles by 1.2 – 2.5 km; in terms of railway transport the distance was shortened by 5 km. 6 hectares of arable land was been disturbed by outside dumps. Annual economic effect exceeded UAH 6.5 mln.

Figure 4. Technique for PMPIW open pit mining with temporary inside overburden rock stockpiling within central part of open-pit field

Conclusions

In each case of control of overburden rock excavation can be achieved at the expense of increase in slope angles of highwalls. It is possible to increase slope angles of frontal spoil banks by means of their surcharging with the help of temporary inside dumps. Parameters of advance zone as well as volume of temporary dumping in it are determined by means of feasibility analysis depending upon transport type. Amount of reexcavation of temporary dumps depends heavily on lumpiness of overburden rocks and intensity of their use as by-product mineral raw materials. Environmental directivity of mining technique with minimum disturbance of land surface and its pollution is the key criterion of inside dumping within deep open pits.

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