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COMPARATIVE ANALYSIS OF FOREIGN AND DOMESTIC EXPERIENCE IN APPLYING CYCLICAL-AND-CONTINUOUS TECHNOLOGY AT OPEN-PIT MINING ENTERPRISES

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Abstract. *This paper reviews foreign and domestic research and industrial experience with in-pit crushing and conveying (IPCC) systems, which open-pit mining operations use to reduce haulage costs. It examines the economic efficiency, energy efficiency and fields of application of IPCC. Particular attention is given to Uzbekistan's experience and its international significance, especially the work carried out at the Muruntau open pit of the Navoi Mining and Metallurgical Company (NMMC). The paper also provides a table comparing IPCC with the conventional truck-and-shovel system. It is shown that the advantage of IPCC over truck haulage becomes evident at depths of about 300 m and more, and that the joint optimisation of semi-mobile IPCC and truck-and-shovel systems is a promising direction for further research.*

Аннотация. *Ушбу мақолада очиқ усулда фойдали қазилмаларни қазиб олувчи корхоналарда ташиш харажатларини камайтириш мақсадида қўлланиладиган карьер ичида майдалаш ва конвейер билан ташиш (In-Pit Crushing and Conveying – IPCC) тизимининг хорижий ва маҳаллий илмий-амалий тажрибалари таҳлил қилинган. IPCC нинг иқтисодий самарадорлиги, энергия самарадорлиги ва қўлланиш соҳалари кўриб чиқилган. Ўзбекистон тажрибаси, хусусан, Навоий кон-металлургия комбинати (НКМК) Мурунтов карьерида олиб борилган ишларнинг халқаро аҳамияти алоҳида таҳлил қилинган. Анъанавий автомобиль-экскаватор тизими билан қиёсий жадвал келтирилган. IPCC нинг автомобиль транспортига нисбатан афзаллиги тахминан 300 м ва ундан чуқур карьерларда яққол намоён бўлиши, ярим кўчма IPCC ва автомобиль-экскаватор тизимларини биргаликда оптималлаштириш истиқболли йўналиш экани кўрсатилган.*

Аннотация. *В статье проанализирован зарубежный и отечественный научно-практический опыт применения циклично-поточной технологии с внутрикарьерным дроблением и конвейерным транспортом (In-Pit Crushing and Conveying – IPCC). Эта технология применяется на предприятиях, разрабатывающих месторождения полезных ископаемых открытым способом, для снижения затрат на транспортирование горной массы. Рассмотрены экономическая и энергетическая эффективность IPCC, а также области её применения. Отдельно проанализирован опыт Узбекистана, в частности международное значение работ, выполненных на карьере Мурунтау Навоийского горно-металлургического комбината (НГМК). Приведена сравнительная таблица IPCC и традиционной экскаваторно-автомобильной системы. Показано, что преимущество IPCC перед автомобильным транспортом проявляется на глубине около 300 м и более, а совместная оптимизация полустационарных систем IPCC и экскаваторно-автомобильных комплексов является перспективным направлением дальнейших исследований.*

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Keywords: *open-pit mining, cyclical-and-continuous technology, IPCC, conveyor transport, in-pit crushing, Muruntau, belt conveyor, high-angle conveyor.*

Калит сўзлар: *очиқ кончилик ишлари, даврий-узлуксиз технология, IPCC, конвейер транспорти, карьер ичида майдалаш, Мурунтов, лентали конвейер, юқори қияликли конвейер.*

Ключевые слова: *открытые горные работы, циклично-поточная технология, IPCC, конвейерный транспорт, внутрикарьерное дробление, Мурунтау, ленточный конвейер, крутонаклонный конвейер.*

Introduction. Improving the efficiency of open-pit mining remains one of the major challenges facing the modern mining industry. According to statistical data, haulage costs account for 45–60 % of total costs in open-pit mines [1]. The increasing depth of open pits, increasingly stringent environmental requirements and energy shortages are prompting the industry to replace conventional diesel-powered haul trucks with more efficient alternatives. Many large ore pits already operate at depths of 600 m or more, and their design depths reach 800–1000 m [2]. As pits deepen, haul truck productivity declines sharply: at the Muruntau open pit, as mining deepened from 100 m to 400 m, the productivity of 40-t and 110-t haul trucks decreased by factors of 2.0 and 2.9, respectively [3]. Cyclical-and-continuous technology (CCT; Russian ЦПТ), known internationally as in-pit crushing and conveying (IPCC), is recognised as a fundamental solution to this problem. In this technology, haul trucks transport the rock only to an in-pit crushing and transfer station, and the rest of the haulage is performed by continuous conveyor transport [2]. However, experience with CCT implementation has been uneven. According to V.I. Galkin and E.E. Sheshko, although Russia has a large number of deep open pits, CCT has been adopted at only 10 % of mining enterprises, and in the first years of operating combined transport the design performance indicators were not always achieved [2].

IPCC technology was first applied in Germany in 1956 [4]. In deep open pits, truck-conveyor transport has been shown to reduce the number of haul trucks by a factor of 2–3, energy consumption by a factor of 1.5–2 and specific operating costs by a factor of 1.2–2.6 compared with truck haulage [5]. The aim of this paper is to systematically analyse leading foreign and domestic research on IPCC and to assess the international significance of Uzbekistan's experience.

Research methods. The study is a review. Publications on IPCC technology, the transition depth from truck-and-shovel haulage to IPCC and the experience of the Muruntau open pit were selected from peer-reviewed journals, monographs, conference proceedings and dissertations published mainly in 2011–2024. Foreign and domestic sources were compared using common indicators: share of haulage costs, type of energy, valuable operating time, NPV and initial capital cost.

Results. ***Review of foreign research.*** S.P. Reshetnyak (1998) developed and substantiated schemes of cyclical-and-continuous technology using mobile in-pit crushing and transfer complexes. Researchers from various countries have made a significant contribution to the theoretical foundations of IPCC systems. Among them, a team led by Professor M. Osanloo of Amirkabir University of Technology (Iran) proposed a heuristic approach to solving the time and location problem of IPCC systems [1]. Their study is widely cited in research on determining the optimal location of in-pit crusher and conveyor systems.

V.L. Yakovlev and co-authors at the Institute of Mining of the Ural Branch of the Russian Academy of Sciences studied the efficiency of IPCC in terms of energy consumption and capital costs and showed that the economic advantage of conveyor systems becomes more pronounced as pit depth increases [3, 5]. D. Liu and Y. Pourrahimian (University of Alberta, Canada) used integer linear programming (ILP) to develop a long-term production scheduling model for a semi-mobile IPCC (SMIPCC) system with a high-angle conveyor [6]. C. Drebenstedt (TU Bergakademie

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Freiberg, Germany) and co-authors classified the IPCC systems operated in 1956–2015 by continent and commodity type [4]. M. Dean and co-authors (Australia) developed a methodology for the selection and planning of fully mobile IPCC (FMIPCC) systems [7]. Among recent studies, L. Findlay and R. Dimitrakopoulos (McGill University, Canada) developed a stochastic integer programming (SIP) model for planning SMIPCC systems that accounts for geological uncertainty [8]. Other studies have addressed conveyor exit strategies in open-pit mines [9], production planning and scheduling under IPCC mining systems [10], the valuable operating time of truck-and-shovel versus in-pit conveyor systems [11] and the choice of the optimum transportation system between truck haulage and SMIPCC in production scheduling [12].

Transition depth from the truck-and-shovel system to IPCC. As pit depth increases, the efficiency of the truck-and-shovel system declines. V.I. Galkin and E.E. Sheshko found that, at pit depths exceeding 300 m, the difference in haulage costs increases sharply, and they noted that under such conditions high-angle conveyor transport is more efficient [2].

M. Shamsi and M. Nehring [13] analysed five scenarios to determine the optimal transition depth between a truck-and-shovel (TS) system and an SMIPCC system. The analysis showed that the second scenario, with transition at a depth of 335 m, provides the lowest cumulative discounted cost. In this case, the cumulative discounted cost was 17.6 % lower than in the pure TS scenario and 10.7 % lower than in the pure SMIPCC scenario.

Domestic experience: the Muruntau open pit and NMMC. The most significant research and practical contribution to IPCC implementation in Uzbekistan was made by specialists of the Navoi Mining and Metallurgical Company (NMMC), including K.S. Sanakulov, F.Ya. Umarov and P.A. Shemetov. Research conducted at the Muruntau open pit, one of the largest open-pit gold mines in Central Asia, has been recognised in international scientific publications, including Springer Nature's Journal of Mining Science, and on the Rudmet platform [14].

Since 2007, pilot industrial operation at the Muruntau open pit has confirmed the efficiency of the high-angle conveyor. Based on these successful results, a project of high-angle conveyor transport with a capacity of 3500 t/h was developed. In March 2011, the "CCT-ore" complex with the KNK-270 high-angle conveyor was commissioned. The inclined section of KNK-270 has an angle of 37°, the belt speed is 3.15 m/s, the technical capacity is 3500 t/h, the lift height is 270 m, and the total length is 960 m, of which 483 m is inclined [2]. The complex shortened the haul distance by 3.5 km and the lift height by 285–320 m. As a result, the productivity of the in-pit haulage fleet increased by 30 %, the annual mileage of haul trucks decreased by 30.4 %, the number of haul trucks, drivers and repairmen by 27.2 %, and the consumption of fuel and lubricants by 37 %. Combining the flows of ore, low-grade ore and waste rock increased the productivity of the KNK complex by a further 20 % [15, 16]. This experience was analysed in a separate paper by Yakovlev and co-authors [3]. T.J. Annakulov also developed a scheme for mining the upper layer in open-pit operations using fully mobile IPCC (FMIPCC) technology and established that the annual productivity of FMIPCC depends on the block length [17].

Comparative analysis of IPCC and conventional systems. The main technical and economic indicators of the truck-and-shovel (TS) and IPCC systems are given in Table 1 (based on data from [5, 6, 8]).

Table 1

Main technical and economic indicators of the truck-and-shovel and IPCC systems

No.	Indicator	Truck-and-shovel (conventional)	IPCC
1.	Share of haulage costs	45–60 %	15–30 %
2.	Type of fuel (energy)	Diesel fuel (high CO_2 emissions)	Electricity (30–40 %)
3.	Valuable operating time	Average	More than 95 % (conveyor)

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4.	NPV (net present value) in deep open pits	Decreases	Increases significantly
5.	Initial capital cost	Low (staged)	High (for the entire system)

Discussion. As can be seen from the table, the IPCC system provides a significant economic advantage in deep open pits: according to [2, 13], its advantage over truck haulage becomes evident at depths of about 300 m and more. However, high initial capital costs limit the application of this technology in small and shallow pits. For this reason, researchers are increasingly focusing on semi-mobile IPCC (SMIPCC) systems, which combine the advantages of conveyor transport with greater flexibility.

Conclusion. The literature review made it possible to draw the following main conclusions.

1. IPCC technology is an internationally recognised and scientifically substantiated method of reducing haulage costs in open-pit mining. As open pits deepen, the economic efficiency of IPCC increases.

2. Uzbek scientists have made both practical and scientific contributions to this field.

3. The joint optimisation of SMIPCC and truck-and-shovel systems has been identified as a promising research direction.

In summary, comprehensive research on developing IPCC technology and adapting it to national conditions will further enhance the competitiveness of Uzbekistan's mining industry. With regard to substantiating the conditions for the transition to IPCC, domestic studies have not yet developed a methodology that determines the boundaries of CCT application (depth, haul distance, annual output) dynamically as mining operations develop. In foreign studies, this problem is solved using discounted cost criteria and dynamic models. The scientific novelty of this study lies in the comparison of foreign and domestic IPCC experience using a single set of indicators, taking into account the conditions under which each result was obtained.

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