Longwall panel width optimization

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ABSTRACT: The article discusses the issues encountered by mining companies in Russia when extracting coal through the use of fully mechanized longwalls. The article presents the results of an analysis of coal mining operations in the world's largest coal producers (USA, Australia, and Russia). As a result of the analysis, it has been determined that longwall panel width depends on a range of geological and engineering factors, such as average annual production, panel length, working height, depth of cover, etc. Using the cases of several Australian mines, the authors examine the influence of longwall panel dimensions on water inflows in the longwall face and mine faces taking into account the influence of overburden pressure and fracture density. The issue of massive water inflows at the thick-seam coal mine named after V. D. Yalevsky in the Kuznetsk Basin is considered. The results of mathematical modeling and economic evaluation for different longwall panel dimensions presented in the article make it possible to determine the range of optimal longwall panel dimensions with due consideration of working heights.

1 INTRODUCTION

When facing volatility and tough competition in the global coal market, one of the key issues for coal mining companies is to reduce their production costs. The main cost-reducing method in underground coal mining is to deploy a fully mechanized longwall system, which delivers excellent results in terms of productivity and economic performance if there are no mining constraints. However, as the main coal-mining regions in Russia are characterized by complicated geological settings, it negatively influences equipment performance indicators. This is why searching for optimal engineering solutions for the effective use of advanced equipment is an important practical task for Russian mines. The longwall method is the most popular method of underground coal mining in Russia. Such parameters of longwalls as panel width and length have a significant impact on productivity and safety. It should be noted that Russia has not yet accumulated any experience in using longwall faces with a length of more than 400 m (only one mine has been operating with a panel width of 400 m since 2017), which makes analyzing the experience accumulated by the top coal-producing countries of particular interest.

2 LITERATURE REVIEW

One of the global coal mining leaders is the United States of America in terms of not only production indicators but also the state of technology used in mining operations. When analyzing data on American longwall mining operations over the last 35 years, it can be noted

that over this period the share of panels with widths ranging from 122 to 183 m decreased from 81% in 1984 to 5% in 2018, with a large share taken by panels having a width over 305 m (Figure 1). It should be stressed that there is a common upward trend in panel width seen in all the top coal-mining countries and the number of longwalls being operated in the U.S. almost halved over the same period due to the use of state-of-the-art equipment in favourable geological settings and an increased concentration of production.

If we look at how longwall panel width influenced average annual production in U.S. coal mines over a period from 2013 to 2018 (Figure 2), it becomes obvious that longwalls with panel widths exceeding 400 m are characterized by the highest production rates in each of the years analyzed (Fiscor, 2014-2019).

It should be kept in mind that the choice of longwall panel dimensions depends on geological settings and engineering parameters, such as working height and depth of cover.

Based on the analysis of data on U.S. mines operating in 2018, it can be argued that, as a rule, thick coal seams are mined using panel widths of up to 350 m, whereas medium-thick seams are mined using bigger panel widths.

The influence of the depth of cover on the choice of panel width is the following: the greater the depth, the less likely the use of panel widths exceeding 300–350 m.

Each of the above factors influencing the choice of panel width is, in its turn, influenced by overburden pressure and face ventilation conditions.

At the same time, panel dimensions are undoubtedly interrelated, which makes it necessary to find the optimal panel length when determining the optimal panel width. This requirement is based on the fact that geological data on the block of the seam being mined is unevenly distributed. In 2018, panels with widths ranging from 350 to 400 m had the biggest length

Figure 1. Shares of U.S. mines active in 1984, 1993, and 2018 based on longwall panel width.

Figure 2. The dependence of average annual production on longwall panel width at U.S. mines for years 2013 to 2018.

Figure 3. The dependence of average and maximum panel lengths on panel width in the U.S. in 2018.

(about 7 km) along with the biggest average length (Figure 3). Based on these figures, it can be assumed that an increase in panel length sets the stage for an increase in panel width.

Under ideal geological settings, i.e. when the coal seam is flat-lying and free of such geologic structures as faults and joints, the methane content is low, and water inflows are regular as mining operations are conducted far enough from river valleys or lake basins or other sources of massive water inflows, an increase in panel dimensions undoubtedly leads to an increase in equipment utilization efficiency and a growth in the concentration of production at minimum cost. However, when geological settings are not ideal, the feasibility of increasing panel length should be studied from an economic perspective. The main questions arising in this process are: what restrictions are there on increasing panel dimensions and how much do these restrictions affect the productivity indicators of one or another mining sequence?

The positive results of increasing panel dimensions (a decrease in the number of assembly and disassembly operations in the mine, a decrease in the unit cost of panel preparation, an increase in face productivity, more regular methane emissions, and a decrease in coal loss due to chain pillars) in real-life geological settings should be considered along with negative consequences (an increase in absolute methane emissions from the seam being mined into the working area, an increase in methane emissions from adjacent seams into the mined-out areas, an increase in the length of assembly and disassembly operations in the working area, an increase in initial capital costs due to the cost of equipment, an increase in the variability of geological settings within one panel, as well as an increase in loads on load-bearing elements and, as a result, a bigger influence of overburden pressure).

An example of a mine characterized by negative results of an increase in panel dimensions is the mine named after V. D. Yalovsky (the Kuznetsk Basin). The section of coal seam No. 52 being mined is affected by the Srednyaya Salanda River valley causing massive water inflows into the longwall face and the mine faces. As a rule, when there are massive water inflows, it is recommended that reserves should be mined in a bottom-up sequence to prevent water from flooding the faces (Chemezov, 2019). However, an increase in panel dimensions has resulted in the fact that the geological and geometrical characteristics of the coal seam within one panel are so different on the up-dip and down-dip sides that the extraction sequence has to be changed. When mining in a top-down sequence, there is a sharp drop in face productivity.

It is considered that the main reason causing massive water inflows is an increase in panel dimensions. For example, in a report on one of the Australian mines dated October 29, 2008 (Gale, 2008), the author analyzes the effect of changes in panel width on water inflows into working areas. Using computer modelling tools, the author shows that with an increase in panel width, there is a bigger zone of distressed strata, which causes stress redistribution and, as a consequence, a growing zone of high rock pressure resulting in extra fracturing. An

increase in fracture density entails an increase in water inflows at the face ends. However, such a parameter as the depth of cover should also be taken into account. At shallow depths, the influence of these processes is especially great, since the river valley, as a rule, is impacted by mining operations even if there are impermeable layers. However, with an increase in the depth of cover, the impact of mining operations on the layers located closer to the surface diminishes, which suggests that there is such a depth of cover at which an increase in panel dimensions does not have a significant impact on water inflows into the longwall face and the mine faces.

According to the results of studies conducted at another Australian mine in 2015 (Skorulis& Minchin, 2015), the impact of longwall mining operations can be graphically represented in the following way (Figure 4):

The dimensions of each zone are calculated individually for each kind of geological settings and each set of panel dimensions. The results of calculations make it possible to predict, to some degree, the intensity of water inflows into longwall faces, which, in turn, enables engineers to take precautions against water inflows and tackle the issue of a drop in face productivity.

3 MATERIALS AND METHODS

In order to find the optimal panel width, mathematical modelling and economic evaluation of the dependence between panel width and performance indicators were carried out. In the model, the total unit costs for the main items as well as the net present value (NPV) were taken into account. A range of panel widths from 200 to 450 m with a step of 50 m was analyzed. The model was built using the parameters of geological settings at the mine named after V. D. Yalevsky (SUEK-Kuzbass).

Mathematical modelling and economic evaluation were carried out taking into account the following cost items: unit production costs, unit development costs, total unit costs. As the next step, the price for coal as of the moment of modelling was taken to calculate the income based on different production volumes, which was later discounted.

Figure 4. Zones of disturbance and hydrogeological effects following longwall mining (Skorulis& Minchin, 2015).

Figure 5. Changes in NPV over time depending on longwall panel width.

4 RESULTS

As a result of mathematical modelling and economic evaluation, unit development costs and unit production costs were calculated for each panel width option, based on which the net present value for the most cost-effective options was found (Figure 5).

5 DISCUSSION

Assuming that the calculation error associated with the inaccuracy of the initial data and other factors is 10%, the optimal panel width ranges from 300 to 450 m. This is a range within which the total unit costs are at a minimum.

After calculating the net present value for this range of longwall panel widths and analysing its change over time, it becomes clear that a panel width of 400 m is the optimal one, since it results in the highest net present value over the shortest period possible (Figure 5). However, a panel width of 450 m could also be an optimal solution but for the fact that there are dimension limits, which, when exceeded, result in an increase in coal loss.

6 CONCLUSION

The analysis of longwall mining practices in the top coal-producing countries has revealed that there is a global upward trend in longwall panel dimensions, with panel widths reaching 400 to 500 m and panel lengths reaching 6 to 8 km, which is a result of utilizing reliable high-performance equipment. However, there is a range of factors limiting the use of such panels. Among them are significant methane emissions, and limited panel length. The main factors limiting panel length are the limited size of the area being mined, the presence of faults and joints, as well as complex geometry and geological settings accompanied by massive water inflows. It has also been revealed that longwall panel dimensions are interrelated: an increase in panel length sets the stage for an increase in panel width. In addition, longwall panel width is greatly affected by working height, since an increase in panel width results in an increase of coal volume within the panel and, consequently, a decrease in unit development costs. The results of mathematical modelling and economic evaluation show that using longwall panels with widths bigger than 400 m in thick coal seams is impractical, which is also confirmed by the fact that no such panels are used in the top coal-producing countries.

Further research will be conducted with the view to solving the issue currently relevant to Russian mines, which is finding optimal longwall panel dimensions in mines characterized by complex seam geometry and geological settings and influenced by massive water inflows.

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