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Kazalo

Foreword

This year marks the 90th anniversary of the first professional mining event “jump over the leather” and 94 years since the Department of geotechnology and mining of the Faculty of Natural Sciences and Engineering of the University of Ljubljana has been providing skilled mining and geotechnological engineers not only to Slovenia, but also to several other mining countries of the EU and the rest of the world. Today Mining and Geotechnology Engineering is not recognized as a very important discipline in Slovenia, even though the Mining Engineering study was initiated in 1919, the same year as the founding of the University of Ljubljana.

Most people in mining agree that we have a lot of work to do and the topic is debated ad nauseam at professional conferences, gatherings, etc. We all talk ourselves into a state of despair and then go back to doing nothing about it. However, there are many people right now working at addressing the problems, performing studies, and determining how to get out of the hole we have found ourselves in. This is of course necessary – we need proper prioritization and plans to address the problem.

French writer and pioneering aviator Antoine de Saint-Exupéry said “A goal without a plan is just a wish”. Sometimes, though, one wonders if we should not at least start by just getting on with the job. He also said “What saves a man is to take a step. Then another one. It is always the same step, but you have to take it”. If we don’t start walking, we are not likely to ever be at any other place than where we are today.

This edition of the RMZ – Materials and geoenvironment journal covers a wide variety of subjects from mining and geotechnology areas. The nature of the papers covers a wide spectrum, from fundamental research to almost common-sense mining application. There should be something of interest for just about everyone.

In the end, I would like to thank all the authors of the articles who have kindly responded to our request and thus honoured an important jubilee of 90 years since our first professional mining event “jump over the leather”. Special thanks also go to the editors of this edition who have spent a lot of their precious time and energy on its realization, and last but not least, to the editorial board of RMZ – Materials and geoenvironment journal, who have included our collection of articles into their program.

Assist. Prof., Jože Kortnik, PhD,
Guest Editor

Uvodna beseda

Leto 2013 zaznamuje 90. obletnico izvedbe prve strokovne prireditve „Skok čez kožo“ in 94-letnico organiziranega izobraževanja rudarskih in geotehnoloških inženirjev na Oddelku za geotehnologijo in rudarstvo Naravoslovnotehniške fakultete Univerze v Ljubljani ne samo za domače potrebe, ampak tudi za potrebe republik nekdanje države, drugih evropskih držav in sveta. Rudarstvo in geotehnologija danes v Sloveniji ni prepoznana kot zelo pomembna gospodarska panoga, kljub dejstvu, da je bil študij rudarskega inženirstva ustanovljen leta 1919, to je istega leta, kot je bila ustanovljena Univerza v Ljubljani.

Večina rudarskih kolegov se bo strinjala, da je pred nami še veliko trdega dela, strokovnih izzivov ter žolčnih razprav o stanju v domačem rudarstvu na naših strokovnih konferencah, srečanjih itd. Vse te (dostikrat brezplodne) razprave nas postopoma silijo v obup, ko pa se vrnemo v domača strokovna okolja, pa ne storimo dosti za spremembo stanja. Kakor koli že, veliko rudarskih kolegov prav v tem trenutku išče rešitve za različne strokovne izzive, izvaja študije in se odloča o načinu izhoda podjetij iz gospodarske krize, v kateri se sedaj nahaja panoga. Danes je, kot še nikoli doslej, nujno potrebno poznati prioritete in imeti izdelan načrt za rešitev problema.

Francoski pisatelj in letalski pionir Antoine de Saint--Exupéry je izjavil: „Doseči cilj brez načrta je samo pobožna želja.“ Kljub vsemu pa nekateri še vedno naivno mislijo, da lahko pot do cilja že s samim začetkom iskanja nekako tudi najdejo. Prav tako je izjavil: „Kaj nam preprečuje narediti prvi korak. Nato naslednji. Koraki so vedno enaki, vendar jih je treba narediti.“ Šele ko začnemo hojo, se bomo znašli na drugem kraju, kot smo danes.

Tokratna jubilejna številka revije RMZ – Materiali in geookolje obsega številne teme s področja rudarstva in geotehnologije. Vsebine člankov se dotikajo tem vse od temeljnih rudarskih raziskav do številnih aplikativnih rudarskih projektov. To zagotavlja, da lahko v tej številki revije vsakdo najde kakšno zanimivo strokovno temo tudi zase.

Ob koncu se želim zahvaliti vsem avtorjem in soavtorjem člankov, ki so se prijazno odzvali našemu vabilu in s tem počastili pomemben jubilej ob 90. obletnici izvedbe prvega „Skoka čez kožo“. Posebno zahvalo namenjam tudi vsem urednikom te številke revije, za njihov dragocen čas in vloženo energijo pri pripravi revije in ne nazadnje tudi članom uredniškega odbora RMZ – Materiali in geookolje, ki so zbirko naših člankov vključili v svoj program. S tem smo vsi skupaj izrazili spoštovanje do jubileja in nadaljujemo pot v svetlejšo prihodnost. SREČNO!

Doc. dr. Jože Kortnik,
gostujoči urednik

Original scientific paper

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Situation analysis and assessment of investment starting points for opening and exploitation of Brnica Mine

Analiza stanja in ocena investicijskih izhodišč za odpiranje del in pridobivanje premoga v rudniku Brnica

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Abstract

The Faculty of Natural Sciences and Engineering in Ljubljana has conducted extensive research for assessment of reserves as well as technical and economic factors influencing the feasibility of opening a part of unexploited seam in the former Hrastnik mine between the height points +50 and –60 in the central section of the mine; the seam was named Brnica. Coal reserves in the Brnica area amount to at least 6.25 Mt (according to estimates, at least 2.5 Mt to 4 Mt of coal could be released from the mine after additional exploration), and it would be reasonable to extract them to supply the Trbovlje Thermal Power Plant (TET) which is about to remain without the cost-competitive domestic energy feedstock already in mid-2013.

The planned quantity of coal production would amount to 310 000 t per year in the period from 2014 to 2033, the total excavation amount would be 6.25 Mt of coal with average heating value of 12.10 GJ/t. The planned selling price of coal would remain constant throughout the entire period of operation of the mine, i.e. 2.60 EUR/GJ.

The economic valuation of the project was conducted by using three methods for valuation of investment projects: the net present value (NPV), internal rate of return (IRR) and the payback time method (PBT).

The present article presents the fundamental conditions for the opening and exploitation of the Brnica brown coal mine.

Key words: energy industry, coal reserves, heating value of coal, investment project economics, opening of a coal mine

Izvleček

Naravoslovnotehniška fakulteta iz Ljubljane je izdelala obsežne raziskave za oceno zalog in tehnično-ekonomskih vplivnih dejavnikov izvedljivosti odpiranja dela še neizkoriščenega sloja bivše jame Hrastnik med kotama +50 in –60 v centralnem delu jame; sloj je dobil ime Brnica. Zaloge premoga, ki se nahajajo v območju Brnice, so najmanj 6,25 Mt (ocena je, da bi se po raziskavah iz jame sprostilo vsaj še 2,5 Mt do 4 Mt premoga), zato ga je smiselno kopati za potrebe Termoelektrarne Trbovlje (TET), ki je že sredi leta 2013 ostala brez cenovno konkurenčnega domačega energenta.

Načrtovana količina izkopa premoga bi bila v obdobju od 2013 do 2034 310 000 t, skupaj bi se izkopalo 6,25 Mt premoga povprečne kurilne vrednosti 12,10 GJ/t. Načrtovana prodajna cena premoga bi bila v celotnem obdobje delovanja rudnika konstantna, in sicer 2,60 EUR/GJ.

Ekonomičnost projekta smo ugotavljali s tremi metodami vrednotenja investicijskih projektov, in sicer z neto sedanjo vrednostjo (NPV), interno stopnjo donosnosti (IRR) in metodo dobe vračila (PBT).

V tem članku so predstavljeni temeljni pogoji za odpiranje del in proces odkopavanja v rudniku rjavega premoga Brnica.

Ključne besede: energetika, zaloge premoga, kurilna vrednost premoga, ekonomika investicijskega projekta, odpiranje rudnika

Introduction

By adopting the Act Regulating *Gradual Closure of the Trbovlje-Hrastnik Mine (hereinafter: RTH*[1], the Republic of Slovenia has made a decision to close coal mines in the Zasavje region until and including the year 2015. RTH *supplies coal exclusively to the Trbovlje Thermal Power Plant (hereinafter: TET).* The operational life of TET is gradually being extending by eliminating the restrictions by means of technological modernisations prescribed in the laws and regulations of the EU and related to emissions into the atmosphere. TET is planning to produce electricity with the existing installations until 2017, when more stringent requirements of environmental protection will come into force. TET is an important energy location for Slovenia[2], a decision on its comprehensive modernisation has not been made yet. Such decision could be largely and or even crucially related to the possibility of further production of coal in the Zasavje region and its coal for the power plant at the price reasonable for the power plant.

In the second half of 2013, TET is about to remain without cost-competitive domestic coal from RTH. The price of coal from RTH is a little less than 3 EUR/GJ, and the current offers for imported coal in world markets exceed the price of 4 EUR/GJ. Further operation of TET and its supply of cost-competitive coals, which are crucial for the existence of TET, led us to study the possibilities of opening and excavation of the remaining coal reserves in the Zasavje region.

The potential excavation reserves of RTH (Expert report on reserves as at 31 December 2002) amount to 53 Mt of balance sheet reserves, including 24 Mt of excavation reserves at the average heating value of 11 MJ/kg.

The Brnica Mine

In the future, it will be necessary to change the attitudes towards domestic energy sources in electricity production and to thoroughly consider all the steps that will bring important decisions. The fundamental goal of Slovenian electricity sector is the maximum self-sufficiency in power supply and exploitation of synergy effects by upgrading the balanced structure of energy sources in Slovenia (1/3 hydropower, 1/3 nuclear power, 1/3 thermal power). Long-term conservation of coal extraction in the Zasavje region[3] is important for the diversification of energy sources, especially for electricity production. Being a domestic energy source, coal significantly reduces the risk of power supply failure. It would be reasonable to use the remaining coal reserves in the Zasavje region in relation to the investment in TET which is an important energy location for our country and will have to be preserved in the future. Continuation of coal mining in the Zasavje region and the planned opening of the Brnica Mine and operation of TET has strong support from local communities in the region. All investments in new energy facilities in both Slovenia and Europe are contributing to higher energy, environmental and economic efficiency.

The Brnica Mine represents the excavation potential of an unexploited section of the seam in the Hrastnik mine which operated under the company Rudnik Trbovlje-Hrastnik, d. o. o. It is evident from the study "Options for Coal Mining Operations in the Brnica Area"[4] that coal reserves of sufficient quality amount to at least 6.25 Mt. According to estimates, coal reserves in the Brnica area could be even greater: at least 2.5 Mt to 4 Mt of coal could be released from the mine after additional exploration [5]. The reserves can be excavated in a commercially acceptable manner under the following conditions:

- with the entry of one or several strategic partners in the company TET. In this way, it would be possible to provide investment funds for the reconstruction of the thermal power plant as well as exploration and opening works in the mine;
- the company Brnica Mine would be established as a limited liability company and would not have any relation with RTH;
- the sale of coal to TET or TEŠ is guaranteed[3] for the next 20 years or more, at prices at least 25 % lower than the supply from competitive global coal suppliers;
- the company Rudnik Trbovlje-Hrastnik, d. o. o., is conducting the mine closure until 2015 (the costs of facility closure pursuant

to the RTH Act must be separated between RTH and, if necessary, the new company). The company RTH preliminary carries out all activities and obligations arising from "Permit for cessation of exploitation" No. 354-15-27/2003 and 354-15-6/2004, of 19 January 2005;
- the state, which is a 100 % owner of the property of RTH, assesses the facilities necessary for opening and excavation, and offers them for sale by public tender to the "new company", to which it also grants an excavation concession;
- the company RTH offers for sale to the "new company" its equipment that will no longer be needed after excavation;
- strategic investors make an investment in the "new company" in the form of construction of investment mine facilities, in the amount of approximately EUR 6 million. Capital works would be started in 2013, and then continued and finalised in 2014. In the year 2015, the first floor is prepared and then excavated by the end of the year;
- the new company is established in 2013 and its first revenue is realised in 2014;
- the company Brnica will be mainly employed manufacturing mine workers, for all the other services that are necessary for the smooth operation of the mine will benefit from synergies with Premogovnik Velenje;
- production workers, who would remain in open unemployment after the finished closure of RTH, would get employment. In the long term, at least 80 direct mining jobs are ensured in Trbovlje, while maintaining all jobs in the energy sector.

In March 2012, the management team of the company RTH calculated the effects of opening of the Brnica Mine with respect to the realisation of the programme of closure of RTH for the years 2013 and 2014. Savings in funds from the HR and social programme would amount to the total of EUR 4.25 million, which also means a significant relief for the budget of the Government of the Republic of Slovenia for the years 2013 and 2014[6].

Legal and regulatory framework

Immediately after its establishment, the company Rudnik Brnica d. o. o. organises all activities and procedures for obtaining a concession for the exploration and extraction of brown coal in the Brnica area. In obtaining the concession, it will be necessary to consider any potential conflicts that might arise here due to the procedures related to the closure of RTH [1]. A part of surface and mine facilities could be used for the activities of the newly established company. For this purpose, the company RTH has, with the objective of restructuring of the company, acquired a "Legal memorandum - Legal assessment of the possibility of potential obligation for repayment of received state aids upon the decision to proceed with coal mining activity", prepared by the law firm Odvetniška družba Kavčič, Rogl in Bračun, o. p., d. o. o., in September 2011. The findings in the decision are entirely related to the likelihood of a claim from EU to return the funds received from the state aid for the case of continuation of the activities of RTH and if it was another company. In both cases, the operation can be continued. The decision on the selection of the legal form of the new company will be made by the potential investors.

Activities and procedures for obtaining a concession for the exploration and extraction of brown coal in the Brnica area were prepared in the form of a legal memorandum, again by the law firm Odvetniška družba Kavčič, Rogl in Bračun, o. p., d. o. o., in March 2012. The text shows that based on the legal order in our country, an exploration permit can be obtained. In this analogy, the following documents issued by the Government of the Republic of Slovenia reasonably apply:
- The Concession Contract No. 354–14–187/01, of 27 November 2011, Government of the Republic of Slovenia, Minister of Environment and Spatial Planning, mag. Janez Kopač.
- Annex No. 2 to the Concession Contract No. 354–14–187/01, of 18 December 2011, Government of the Republic of Slovenia, Minister of Economy, mag. Mitja Gaspari.
- Permit for cessation of exploitation No. 354 – 15–27/2003 and 354–15– 6/2004, issued on 19 January 2005 by mag. Roman Čerenak, under the authorisation No. 350 – 06–20/01 issued on 18 October 2004 by the Minister of Environment and Spatial Planning.

Research and analysis of domestic and global coal market

According to BRG (German Federal Institute for Geosciences and Natural Resources) data[7] from 2009, the structure of global energy reserves that are still available consists of 24.2 % of oil, 17.6 % of gas, 4.3 % of uranium and thorium and 53.8 % of all categories of coal. Coal is the only resource among the fossil fuels that will remain in the energy market the longest, due to the large volume of reserves around the world. At the end of 2009, world proven reserves amounted to 729 Gt. At the current extent of exploitation and status of investigated global coal reserves, the availability should be sufficient for the next 200 years. Table 1 shows the prices of energy coal by months for the past twenty years.

The history of trends of coal prices in the global energy market shows that coal prices were relatively low and stable from 1992 to 2004; after this period, they increased sharply in 2008 and dropped to the price level of the year 2004 in 2009. In the last three years, they have been rising again. The coal price forecast is shown in Figure 1.

All projections and forecasts of energy coal prices indicate that they will also gradually increase in the next three years, up to 125 USD/t in 2013. This means that in forthcoming years, the prices of imported coal in Slovenia (including transport costs on site Trbovlje) will amount to more than 4 EUR/GJ.

Another important element in the use of coal are allowances for emissions of carbon dioxide into the atmosphere; for the emissions above the limit permitted in Slovenia, they will have to be purchased in the open market in the EU. The prices of allowances for CO_2 emissions are shown in Figure 2.

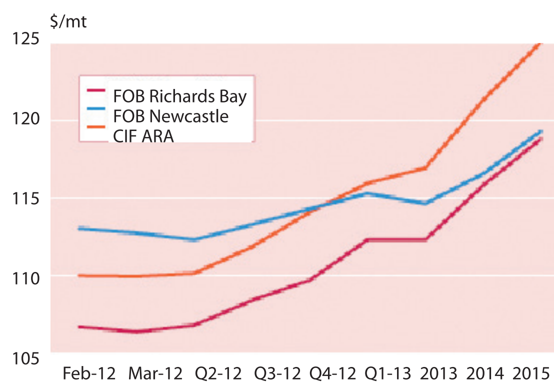
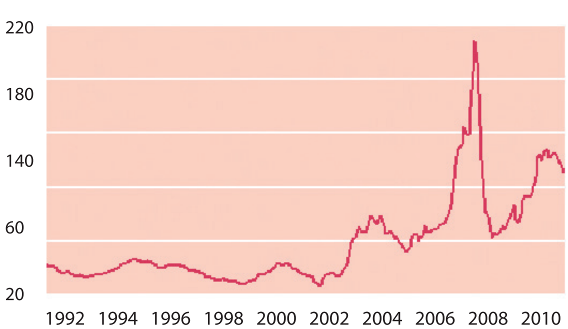


Figure 1: *Coal price forecast for the period 2012–2015*[9].

Table 1: *Overview of trends in world prices of energy coal for the period from 1992 until and including 2011*[8]



ICR Steam Coal Marker Price 1992 – December 2011 (Spot CIF Price, NW Europe, $/mt basis 6,000 kCal/kg NAR)

	1992	1993	1994	1995	1996	1997	1998	1999	2000
January	42,18	34,55	34,55	42,89	43,60	41,72	35,74	29,97	30,15
February	41,66	34,51	33,99	43,38	43,52	41,01	35,39	29,66	30,30
March	40,59	33,66	35,19	43,94	42,07	41,11	32,40	29,94	33,85
April	40,57	34,45	35,23	45,10	41,03	40,82	32,24	29,22	34,81
May	40,29	34,32	36,18	45,87	39,77	39,93	31,83	29,21	34,39
June	39,69	33,11	36,26	45,75	39,49	39,12	31,52	27,84	35,13
July	37,45	32,35	37,04	45,37	39,86	38,11	31,27	26,65	36,16
August	36,45	32,40	37,51	44,96	40,31	37,75	30,43	26,68	36,20
September	35,30	32,87	38,31	44,77	40,98	37,34	30,29	27,26	37,01
October	35,87	33,53	38,93	43,85	41,09	36,98	31,46	29,17	39,56
November	36,11	34,04	40,77	44,10	41,62	36,76	30,97	29,53	41,73
December	36,16	34,32	42,22	44,01	41,67	36,38	30,49	30,39	43,07

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
January	41,94	34,10	36,45	67,70	70,55	54,26	68,50	130,87	78,30	86,13	124,18
February	41,08	33,10	35,49	69,94	64,41	60,62	68,87	144,70	72,00	75,40	119,38
March	41,99	33,25	33,64	66,38	66,14	64,60	72,31	139,63	61,56	73,31	125,99
April	42,98	32,75	33,09	66,23	67,00	63,75	71,69	138,69	66,25	79,38	128,25
May	42,40	28,70	34,21	67,35	65,16	60,05	72,14	158,65	63,70	89,50	122,52
June	41,41	28,60	37,13	73,86	60,91	62,64	77,10	185,00	66,31	93,63	122,80
July	39,87	27,00	39,67	77,87	62,80	62,57	78,69	208,88	67,33	92,78	123,80
August	38,22	25,98	42,67	76,52	59,16	71,02	86,60	192,65	71,50	92,66	124,78
September	37,91	30,23	47,55	74,12	58,20	65,61	95,75	170,50	68,19	92,63	123,44
October	36,00	34,28	58,80	72,10	54,90	66,19	116,25	120,00	73,30	99,98	117,58
November	35,12	34,34	61,33	77,77	52,06	67,60	128,40	92,63	77,36	107,07	114,58
December	34,50	35,01	62,02	77,06	52,24	68,10	129,62	81,25	79,70	122,38	111,27

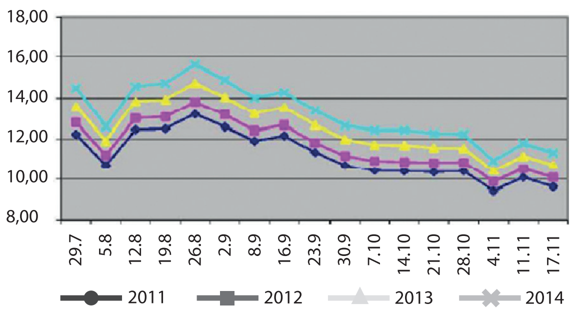


Figure 2: *Futures market - prices of allowances for CO_2 emissions for the period 2011 – 2014 (EU ETS – EUR/t CO_2)[10].*

Figure 2 shows projections of prices for CO_2 allowances, which are supposed to range from approx. 10 EUR/t to 12 EUR/t in the years until 2014. According to the Figure 2, the prices of allowances are gradually falling; the most likely cause of this is certainly the nuclear disaster in Japan which has strongly stirred the thinking about energy scenarios around the world.

Macro-economic aspects of coal mining in the Republic of Slovenia

Coal mining in Slovenia is related to two power generation locations in the Šaleška dolina valley and in the Zasavje region. There are further potential or strategic coal reserves in Prekmurje. In the Šaleška dolina valley, these locations are the Velenje Coal Mine (PV) and the Šoštanj Thermal Power Plant (TEŠ). In Zasavje, the locations are the Trbovlje-Hrastnik Mine (RTH) and the Trbovlje Thermal Power Plant (TET).
In the Šaleška dolina valley[11], the national and economic importance of PV and TEŠ in view of the participation of these two companies in the broader reproduction chain of the Slovenian economy is enormous. The companies' elimination from the reproduction chain, i.e. in the event of closure of PV followed by TEŠ, would affect the main macroeconomic indicators of the Slovenian economy as a whole (GDP, industrial production, employment, foreign trade balance, price stability, etc.) and economic indicators in terms of the partial components of the Slovenian economy, i.e. industries that are related to PV and TEŠ both indirectly and directly. In this area, we can expect the impact on business performance, production, consumption of fixed capital, number of employees in companies in most industries. Long-term plans of PV and TEŠ represent a reliable link in the electricity production chain in the Republic of Slovenia, as in the long-term (until 2054) they ensure 1/3 of domestically produced electricity.
RTH and TET are two companies that are strongly connected to the local and regional environment; their elimination from the reproduction chain would have a strong impact on the local and regional economy, but significantly less impact on macroeconomic indicators of the Slovenian economy than PV and TEŠ. TET is a strategic energy location for Slovenia that will continue to be counted on in the future[11]. With potential options for the extension of exploitation of the remaining coal reserves in the Zasavje region in connection with their use in TET, negative demographic trends in the region would be greatly alleviated.
Coal reserves in Prekmurje represent, considering the modest reserves of fossil energy sources in our country, a strategic reserve of Slovenia[11].

The project for exploration and opening of the Brnica area

Based on the reference points in the study "Opportunities for coal mining activities in the Brnica area"[4], the Trbovlje-Hrastnik Mine prepared a mining project for exploration and opening of the Brnica area titled "Opening of the Brnica Mine"[12]. The following is a brief description of required opening and exploration works.

Necessary infrastructure and capital facilities

Opening of the Brnica area is relatively simple and can be done entirely from the existing facilities at the horizon "Zvezno obzorje" in the Hrastnik mine. Both in the mine and on the surface, the entire system necessary for the smooth operation of the mine is set up. The existing surface and mine facilities that would be necessary for excavation of the Brnica mine are in a very good condition and could be used without major maintenance throughout the entire period of exploitation. In the mining project for the opening of the Brnica mine, all significant items relating to the intended exploitation of coal in the Brnica area have been treated in sufficient detail. Figure 3 shows a three-dimensional presentation of the coal seam scheduled for excavation and the necessary facilities to access to the seam from the level of the horizon “Zvezno obzorje” of the Hrastnik mine.

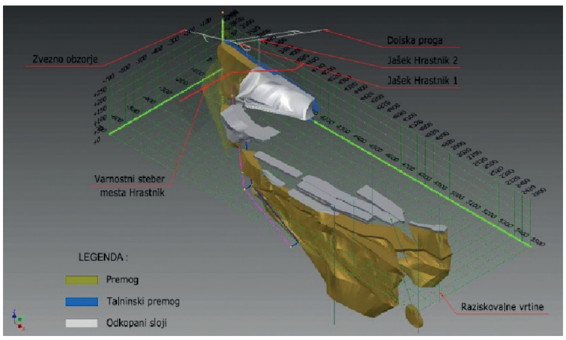


Figure 3: *Opening facilities and seam disposition*[12].

Operation and excavation of the Brnica mine requires only the mine facilities. Design solutions for the opening have been prepared, i.e. the concepts of ventilation, water pumping, transport of coal, material, equipment, and people, as well as other logistics necessary for the extraction process. Mine facilities are constructed in total length of 3089 m. The scheduled opening facilities, which must be constructed up to the height point 30 and at this height point, include:

— conveyor slope, h. p. 240/170/30
Point of application of the conveyor slope h. p. 240/170/30 is planned at the horizon “Zvezno obzorje”. The length of the slope will be L = 857 m, and the minimum clearance gauge must be S = 15 m^2. A trough belt conveyor measuring 800 mm to 1 000 mm in width will be installed in the slope. The conveyor slope will be supported with TH arch support and lined with reinforced mesh and sprayed concrete.

— supply slope, h. p. 240/170/30
Point of application of the supply slope h. p. 240/170/30 is planned at the horizon “Zvezno obzorje”. The length of the slope will be L = 797 m, and the minimum clearance gauge must be S = 15 m^2. In the slope, a suspension track for the transport of materials to individual open floors. The supply slope will be supported with TH arch support and lined with reinforced mesh and sprayed concrete.

— cross-cuts at h. p. 170, h. p. 100 and h. p. 30
Connections between the conveyor slope and the supply slope will be made by means of three cross-cuts. The first cross-cut is made at the h. p. 170, the second one at the h. p. 100 and the third one at the h. p. 30. The total length of all three cross-cuts is 160 m. The cross-cuts will be supported with TH arch support, reinforced mesh and sprayed concrete, and the minimum clearance gauge must be S = 12 m^2.

— pumping station at h. p. 30
The total length of mine roadways will be L = 75 m, clearance gauge S = 20 m^2; two pumps with the capacity Q = 5m^3/min and pumping height H_{man} = 350 m will be installed in the pumping station.
Roadway support in the pumping station will be made of poured concrete.

— water gates at h. p. 25
The total length of water gates will be L = 90 m, with clearance gauge S = 15 m^2. Water gates must accumulate an water inflow 8 h; the anticipated water inflow is 4 m^3/min.
Roadway support in the water gates will be made of poured concrete.
The total length of opening facilities up to the height point 30 and at this height point amounts to 2025 m.
For the opening of the mine below the height point 30, the construction of the following mine facilities is planned (at the time of opening the Brnica mine below the height point 30, preparation works and excavation of the floor at the height point 50 will be in progress):

— conveyor slope, h. p. 30/–60
Point of application of the conveyor slope h. p. 30/–60 is planned at the height point 30. The length of the slope will be L = 377 m, and the minimum clearance gauge must be S = 15 m^2. A rubber trough belt conveyor measuring 800 mm to 1 000 mm in width will be installed in the slope. The slope will be supported with TH arch support and lined with reinforced mesh and sprayed concrete.

— supply slope, h. p. 30/–60
Point of application of the supply slope h. p. 30/–60 is planned at the height point 30. The length of the slope will be L = 377 m, and the minimum clearance gauge must be S = 15 m^2. In the slope, a suspension track for the transport of materials to individual floors will be installed (the first floor is planned at the height point 50). The supply slope will be supported with TH arch support and lined with reinforced mesh and sprayed concrete.

— cross-cut at h. p. –60
A connection between the conveyor slope and the supply slope will be made by means of a cross-cut at the height point –60. The planned length of the cross-cut is 45 m, and the minimum clearance gauge is S = 12 m^2. The cross-cut will be supported with TH arch support, reinforced mesh and sprayed concrete.

— pumping station at h. p. –60
The total length of mine roadways will be L = 75 m, clearance gauge S = 20 m^2; two pumps with the capacity Q = 5 m^3/min and pumping height H_{man} = 350 m will be installed in the pumping station. Roadway support in the pumping station will be made of poured concrete.

— water gates at h. p. –65
The total length of water gates will be L = 90 m, with clearance gauge S = 15 m^2. Water gates must accumulate an water inflow 8 h; the anticipated water inflow is 4 m^3/min. Roadway support in the water gates will be made of poured concrete.
The total length of opening facilities below the height point 30 amounts to 1 064 m.

Preparatory works

After conducting exploration works, it will be possible to begin placing the excavation fields in the seam[13], in a manner that will ensure maximum yield of the seam and thus minimum excavation loss. Mining fields must allow excavation according to the principles of the longwall mining method with sublevel caving. Preparatory facilities will be mainly used for a very short time; it is important for them to be cost-optimal and provide functionality during the preparation and excavation without major additional maintenance activities. Mining fields must be ventilated with flow mode, even separately if necessary. The conveyor track must be constructed with the fewest possible refraction points, possibly in more favourable geomechanical conditions. In the event of the need for tilting the coal faces, they should be tilted from the supply side to the conveyor track and with a downward slope in the direction of the coal face advance.
Given that all preparatory facilities will be entirely constructed in coal, the construction of these facilities will be carried out mechanically, by means of advance loading machines and continuous conveyance of excavated material. The mine facilities will be supported by steel arch supports, either open or closed, in combination with bolts if necessary. The siding will be made of mesh - either iron or nylon - or timber. In case of danger of spontaneous combustion of coal, insulation lining will have to be made. Progress in the construction of such facilities is 4–12 m/d, depending on the geomechanical conditions, construction technology and organisation of work.

The coal mining process

Depending on the location, shape and thickness of the seam as well as the characteristics of hanging wall and footline, it will be reasonable to use the highly productive longwall mining method with sublevel caving. The length and the width of the excavation floors will have to be maximum, depending on the dimensions of the seam, and the heights of excavation will be able to amount to up to 15 m and will depend on geomechanical and hydrological characteristics of the hanging wall seams. When sizing the floors, it is also necessary to consider the impacts of the excavation on the surface.
The technology of coal face excavation by using the longwall mining method with sublevel caving consists of two separate stages: In the first stage, the mine facilities are constructed and coal is excavated from the footline, followed by the stage of pouring of coal from the hanging wall section of the coal face. Depending on the geomechanical properties, an adequate number of shifts of the conveyor and arch support is made, followed by the stage of exploitation

from the hanging wall section. During footline formation, there is a consecutive sequence of cutting the upper cut with the shearer, supporting the excavated space, cutting the lower cut and shifting the conveyor and hydraulic support. At the same time, intersections on the supply and conveyance side must be constructed. Extraction of coal from the hanging wall consists of pouring of coal in front of the sections or through openings in the shields of the hydraulic support. If necessary, crushing and crumbling of coal by blasting can also be performed. If the coal face is 45 m wide and 15 m high, the excavation loss amounts to 10 % and the volume mass of coal is 1.45 t/m^3, then approximately 680 t of coal is produced from one 80 cm deep cut. Depending on the organisation of work, an average of up to 6 cuts can be carried out daily.

For the process of excavation, it will be sensible to use technical solutions provided in the mining project for the implementation of works: "Mining method in the Trbovlje-Hrastnik Mine"[14].

Drainage

All the water from the excavation floor as well as other mine facilities will be gravitationally channelled to the height point 30 and height point –60, where two pumping stations will be located. From the pumping stations, the water will be pumped in pressure pipelines to the horizon "Zvezno obzorje"; the pressure pipelines will be installed on the conveyor slope.

It is necessary to drill drainage holes in the limestone at the height points 30 and –60, and pump as much water from the limestone to maintain the level of groundwater in the limestone always at least 10 m below the level of the floor in the process of excavation. The expected inflow of water in the mine amounts to 4 m^3/min.

Ventilation

The required volume of ventilation in one excavation floor is 480 m^3/min. Fresh air inflow will be entering the mine from the surface down the Barbara slope to the level of the horizon "Zvezno obzorje", and then in the direction of the conveyor slope to the excavation floor. The used air will be led along the conveyor slope to the horizon "Zvezno obzorje", to the Javor hanging wall and further to the Javor fan station.

Transport of coal, materials and people

Coal will be transported from the floor in the direction of the conveyor slope, to the horizon "Zvezno obzorje" and to the separation site. From the floor to the separation site, 5 conveyor belts with automatic control mode would be installed for coal transport.

Materials and people would be transported from the surface to the floor by means of a suspension diesel engine. The length of the entire transportation route will be between 2 500 m and 3 000 m.

Measures to ensure the safety

When opening a mine or excavation field of the Brnica area, it is necessary to consider the measures listed in general projects taken from RTH and also the provisions of the mining project for opening works, general instructions and prescribed measures for safe work.

Environmental impacts

The implementation of preparatory, opening and excavation works in the mine will have a certain impact on the environment; first of all, the level of groundwater in the rock mass will decrease, and influences in different forms will also be reflected on the surface. The decreasing level of groundwater will also result in potential emptying of caverns in the rock mass. This can lead to instability of the ground on the surface in the form of small slips or wrinkling. Other major changes on the surface due to lowering of groundwater are not expected.

According to the experience of excavation in RTH, the settlements resulting from the excavation within the caving area will amount to a few meters and to several 10 cm in the influence area. Such changes on the surface could affect the change in terrain, increasing the possibility of migration of rainwater towards the coal face, a decrease in stability can be expected in the lower part of southern and south-eastern area. The possibility of erosion will also be increased, especially in the steep part of the surface where crumbling of rocks can occur.

The implemented technological processes of direct rehabilitation of cracks and other impacts of mining on the surface will, in addition to providing safe excavation in the mine, influence an improved appearance of the surface; they will ensure safe movement of workers, machinery and transport equipment and represent the basis for the implementation of primary recultivation of the area. Recultivation works will prevent any excessive and prohibited negative impacts on the environment.

Rehabilitation, recultivation and spatial planning

According to the assessment and experience from RTH, there will be no facilities on the surface endangered by the impacts of exploitation in the mining area (area with concession). At the very edge of the area, there are two potentially affected objects, but do not represent a significant amount of purchase cost. The settling of the area will be handled promptly, according to the existing regime in RTH. In order to improve appearance and prevent erosion, grass is sown on temporarily rehabilitated surfaces.

Economic evaluation of investments

Methods for the evaluation of investments

For the economic evaluation of the project, we selected three methods of evaluation of investment projects according to Runge[15] and the NSW project[16], namely the net present value method (NPV), internal rate of return method (IRR) and the payback period method (PBT).

The net present value method of the project estimates the economic success of the investment project in the light of future returns of invested assets and means the sum of the values obtained by discounting the net inflows of the project at a certain selected discount rate to their present value. The required rate of return for the calculation of the cash flow was calculated on the basis of the weighted average cost of ordinary shareholders capital (WACC). The cost of ordinary capital is calculated according to the capital assets pricing method (CAMP). The model rests on the premise that the investor requires a higher return on investment at a higher level of risk.

The internal rate of return method represents the real interest rate for the money that has been or will be bound up over the lifetime of the investment. This is the interest rate at which the net present value of an investment is equal to 0. The method is usually used as an additional judgement in deciding on the choice of one of two competing projects.

Payback period method of the investment is the time necessary for income to cover the full amount of the investment costs. PBT unlike NPV and IRR is not a dynamic method because it does not take into account the time value of money. PBT in this form only serves as the comparative method.

Basis for the evaluation of the Brnica project

As a starting point for the calculations we took into account the assumptions of the study "Opportunities for coal mining activities in the Brnica area"[4], assumptions of the study "Preparation of a business model and options for its application in establishing and organising a mining company"[11], the mining project "Opening of the Brnica Mine"[12] and the Decree on mining concession fee and funds for rehabilitation[17]. The basic assumptions underlying the projections of financial statements presented below are summarised in the following points:

- the owners provide share capital amounting to EUR 4.5 million in 2013 and an additional amount of 1.5 million in 2014;
- in 2013, the purchase of buildings, mine facilities and equipment from RTH is made in the value of EUR 3 million;
- in 2013, an investment in the preparation of the exploitation is planned in the amount of EUR 7.3 million, followed by EUR 0.64 in 2014 and approximately EUR 0.51 million in the years from 2015 to 2020. Throughout the period of operation of the mine, further investments in equipment are planned in the total amount of EUR 18.7 million;
- the remaining value of fixed assets at the end of the year 2034 is estimated at EUR 2.15 million;
- all assets from depreciation and amortisation will be written off during the period of operation of the mine. In all cases the linear

depreciation method was used, the annual depreciation rate will be 6.67 % until 2020. In case of equipment purchased by the year 2025 the annual depreciation rate of 10 % or 12 % were taken. For purchases from 2026 onwards the annual depreciation rates of 11 % until 2033 and 50 % after 2033 were used;

— the average number of employees in the direct production will be 67 or 54 during the first and last year of the mine respectively, and 80 in the periods in between. The expected 20 % absence from work will be compensated by hiring additional labour, costs were accrued among the costs of production services;
— cost of upgrade services (Commerce, Finance and Accounting, Design Engineering and other management or administrative work within the general activities) are evaluated at an average of EUR 625 000 per year and are disclosed in the company's non-production costs as expenses of the period;
— the planned quantity of coal production will be 26 000 t in the first year, 24 000 t in the last years and 310 000 t per year in the period from 2014 to 2033. In the period from 2013 to 2034, the total of 6.25 Mt of coal with average heating value of 12.10 GJ/t will be excavated;
— the sales will amount to 26 000 t in the first year, 300 000 t per year in the period from 2014 to 2033, and 224 000 t in 2034;
— the planned selling price of coal should remain constant throughout the entire period of operation of the mine, i.e. 2.60 EUR/GJ;
— From 2014 to 2033, coal stocks will increase by 10 000 t per year, and in the final year 2034, the disposal of all stocks together with current annual production is expected. The unit value of coal in stock is evaluated according to the production costs method;
— the interest rate for long-term and short-term loans received amounts to 6 % p. a. The same rate is also taken into account when discounting cash flows to calculate the net present value of the entire project;
— the interest rate on short-term deposits is 1.5 % p. a.;
— Value Added Tax (VAT) is not included in the projections of financial statements, as it has a neutral impact on the cash flows;
— furthermore, the corporate income tax (corporate income tax) is not calculated in the projections, as it is expected that the Company will, in accordance with the predicted amendment of Article 55.a of the Corporate Income Tax Act (ZDDPO-2), be able to claim deductions for investments (i.e. 40 % of the amount invested or up to the amount of the tax base), which will make the basis for corporate income tax in a given tax period equal to zero.

The entire project is evaluated on the basis of fixed prices for April 2012. A summary evaluation of the investment project Brnica for the entire operational life of the project is shown in Table 2.

At a 6 % discount rate, the net present value of cash flow is positive and amounts to EUR 3 216 551. The invested funds are reimbursed after 15.4 years. The internal rate of return amounts to 8.6 %, which means that at this interest rate, the investment expenditure would equal the returns.

As the final value of the project, we considered only the value of the balance of deposits at the end of 2034, less EUR 4 million for precautionary reasons.

In the years 2035 and 2036, the Company with its own sources of funding carries out a rehabilitation of the mining area, disposes of fixed assets, the residual value of which is estimated at EUR 2.15 million and settles all of its obligations. After carrying out a technical inspection of the performed rehabilitation, the Ministry notifies the Eco Fund which makes a calculation of the funds reserved for the rehabilitation; based on the final decision of the Ministry to terminate the rights and obligations of the concessionaire, these funds are returned to the concessionaire's bank account. It is estimated that after the final liquidation of the company, approximately EUR 18.2 million would remain for the owners.

Table 2: *A summary evaluation of the project "Brnica"* [11]

in EUR			Rudnik Brnica d. o. o.
	Cash flow	**Discount rate**	**Present value**
2013	(7555 370)	0.94	(7 127 708)
2014	435 500	0.89	387 593
2015	813 600	0.84	683 114
2016	623 700	0.79	494 029
2017	223 700	0.75	167 162
2018	(3076 300)	0.70	(2 168 670)
2019	(76 300)	0.67	(50 744)
2020	223 700	0.63	140 352
2021	1 312 300	0.59	776 748
2022	1 347 600	0.56	752 493
2023	1 347 600	0.53	709 899
2024	1 347 600	0.50	669 716
2025	1 247 600	0.47	584 924
2026	347 600	0.44	153 744
2027	847 600	0.42	353 674
2028	1 347 600	0.39	530 478
2029	1 347 600	0.37	500 451
2030	1 347 600	0.35	472 123
2031	1 347 600	0.33	445 399
2032	1 447 600	0.31	451 369
2033	1 487 600	0.29	437 586
2034	1 983 780	0.28	550 509
Final value	11 900 000	0.28	3 302 311
Present value			**3 216 551**
Initial investment			0
Net present value			**3 216 551**
Weighted average capital cost			6.0 %
Internal rate of return			8.6 %
Modified internal rate of return			7.4 %
Payback period			15.4 years

Conclusion

Mining is related to electricity production in TET. We believe that opening of the Brnica Mine and establishment of the company is a realistic, if not even necessary, option for provision of coal at a competitive price of 2.6 EUR/GJ for further operation of TET. Imported coal could continue to be purchased by TET at a price of more than 4 EUR/GJ, but the thermal power plant would most likely not be able to handle such costs. The investment in the opening works in the mine is relatively small. An assumption for the operation of the new mine is based on the annual production of 310 000 t of coal in 20 years or the total excavation of 6 250 000 t of coal. The economic evaluation of the project was conducted by using three methods for valuation of investment projects; all considered criteria have resulted in a positive assessment of the investment performance. The jobs that could be preserved in this way in the mining and energy industry would substantially improve the negative demographic trends in the otherwise heavily worn-out Zasavje region.

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Monitoring of high safety pillars stability in quarry Lipica II – EL beam displacement sensors

Merilni nadzor stabilnosti visokih varnostnih stebrov v kamnolomu Lipica II. – palični merilniki deformacij EL

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Abstract

Underground excavation of natural stone in Lipica II quarry is carried out using the modified room-and-pillar mining method. In order to support and ensure the stability of underground chambers high safety pillars are used. These pillars are made of surrounding stone and therefore intersected by discontinuities. The discontinuities represent high risk to stability of underground facilities and work itself. To monitor stress and strain parameters in pillars we use 2D WV stressmeters (VW – vibrating wire) inside the safety pillars and EL beam sensors on the surface of pillars. In this paper we will present procedures of wedges deformation monitoring in safety pillars with EL beam sensors in the underground natural stone quarry Lipica II.

Key words: EL (electronic level) beam sensor, natural stone, high safety pillar, room and pillar mining method

Izvleček

Podzemno pridobivanje blokov naravnega kamna v kamnolomu Lipica II poteka po modificirani komorno-stebrni odkopni metodi. Za podpiranje in zagotavljanje stabilnosti podzemnih prostorov se uporablja samonosilno naravno podporje v obliki visokih varnostnih stebrov. Visoke varnostne stebre sekajo naravne razpoke, ki pomenijo nevarnost pri zagotavljanju stabilnosti podzemnih prostorov in nevarnost pri obratovanju podzemnih delovišč. Za spremljavo napetostnih in deformacijskih parametrov se izvaja merilni nadzor dogajanja na in v varnostnem stebru. Poleg uporabe napetostnih merilnih celic v notranjosti varnostnih stebrov se za spremljavo v podzemnih kamnolomih uporabljajo elektronski palični merilniki deformacij. V prispevku bodo predstavljeni postopki spremljave deformacij klinov v visokih varnostnih stebrih in rezultati spremljave deformacij s paličnimi merilniki deformacij EL visokih varnostnih stebrov pri podzemnem pridobivanju blokov naravnega kamna v kamnolomu Lipica II.

Ključne besede: palični merilnik EL, naravni kamen, visoki varnostni steber, komorno-stebrna odkopna metoda

Introduction

Proper monitoring of safety pillars and rock masses can help a mining engineer recognize when the probability of a failure is higer than usual. This pre-failure warning can help the mining engineer in many ways. Not only do safety pillar failures wreak havoc on current production, they are able to seriously damage machine equipment, and in the worst casese, injure workers too close to the point of failure. The objective of safety pillars monitoring is to detect, before failure, possible instabilitities to allow the mining engineer to take appropriate remedial masures. The main concer and main purpose of monitoring is the protection of workers and equipment.

In analysis of special phenomena such as failure of structures, pillar wedge stability, etc. requires deformation measurement with specific instruments of high accuracy[2]. This paper demonstrates two types of measuring instruments, EL beam or tiltmeter and 3 screw open fissures displacement meter. Several types of sensitive tiltmeters have been developed to measure and observe ground deformations[3, 14]. A tiltmeter gives the rotation of a line segment fixed in the rock about a chosen horizontal axis perpendicular to the local gravity vector. An 3 screw dyke-displacement meter measures the change in distance between three points (screws) on the rock which are a finite triangle distance apart[9]. Both instruments enabled the detection od small deformations that cannot be detected and measured by ordinary surveying instruments. These instruments were used to study the movement of ceiling/roof and walls in underground structures of quarry Lipica. Two tiltmeters and several 3 screws open fissures displacement meters were used in the rock deformations monitoring in quarry Lipica II.

The underground quarry Lipica is situated near village Lipica, at 5.5 km to the southeast of Sežana. In the Lipica II. quarry, the underground excavation blocks of natural stone runs for more than 12 years. One of the important advantages of the underground mining operations is do not affect on the surface above. For the purposes of safe and stable excavation of natural stone in underground structures is required a good knowledge of rock properties in safety pillars, primary geomechanical conditions in the overburden and discountinuity orientations in the deposition. In addition, during the excavation also monitoring of stress conditions in the safety pillars and ceiling. In the context of in-situ measurements and control of the Room-and-Pillar mining method using stress measurements (2D WV stressmeter device) and deformation measurements (EL beam gauge and 3 screw open fissures displacement meters) in the sefety pillars, such as on the ceiling of large open underground spaces. In 2010 we started to use the vertical EL beam gauges with the task of monitoring the wedges movements or the major open cracks at the surface area of high safety pillars.

In situ stresses measurements in quarry Lipica II

All rock masses contain discontinuities such as bedding planes, joints, shear zones and faults. At shallow depth as underground structures in quarry Lipica II, where stresses are low, failure of the intact rock material is minimal and the behaviour of the rock mass is controlled by sliding on the discontinuities. In order to analyse the stability of this system of individual rock blocks, it is necessary to understand the factors that control the shear strength of the discontinuities which separate the blocks.

The weight of the vertical column of rock at a depth *h* is the product of the depth and the unit weight of the overlying rock mass. Vertical stress σ_v is estimated from the simple relationship

$$\sigma_v = \gamma \cdot h \qquad (1)$$

where

γ ... the unit weight of the overlying rock (typically about 0.027 MN/m^3)

h ... the depth below surface.

The horizontal stresses acting on an element of rock at a depth z below the surface are much more difficult to estimate than the vertical stresses. Normally, the ratio of the average horizontal stress to the vertical stress is denoted by the letter k such that:

$$\sigma_h = k \cdot \sigma_v = k \cdot \gamma \cdot h \quad (2)$$

k ... the average horizontal stress to the vertical stress.

In-situ measurements of horizontal stresses at mining sites around the world show that the ratio k tends to be high at shallow depth and that it decreases at depth (Brown and Hoek, 1978, Herget, 1988)[1, 6]. Sheorey (1994)[12] developed an elasto-static thermal stress model of the rock. This model considers curvature of the crust and variation of elastic constants, density and thermal expansion coefficients through the crust and mantle. A simplified equation which can be used for estimating the horizontal to vertical stress ratio k is (Figure 1, left):

$$k = 0.25 + 7 \cdot E_h \cdot \left(0.001 + \frac{1}{h}\right) \quad (3)$$

E_h ... the average deformation modulus of the upper part of the earth's crust measured in a horizontal direction (typically in range from 10–100 GPa).

Horizontal direction of the average deformation modulus measurement is important particularly in layered sedimentary rocks, in which the deformation modulus may be significantly different in different directions. A plot of this equation is given in Figure 1 for a range of deformation moduli. The curves relating k with depth below surface h are similar to those published by Brown and Hoek (1978)[1], Herget (1988)[6] and others for measured in situ stresses. Hence equation 3 is considered to provide a reasonable basis for estimating the value of k.

With the background of previous stress measuring studies in literature, Brown and Hoek (1978)[1] have tabulated in Table 1 a wide range of stress measurement data for depth h = 0–100 m.

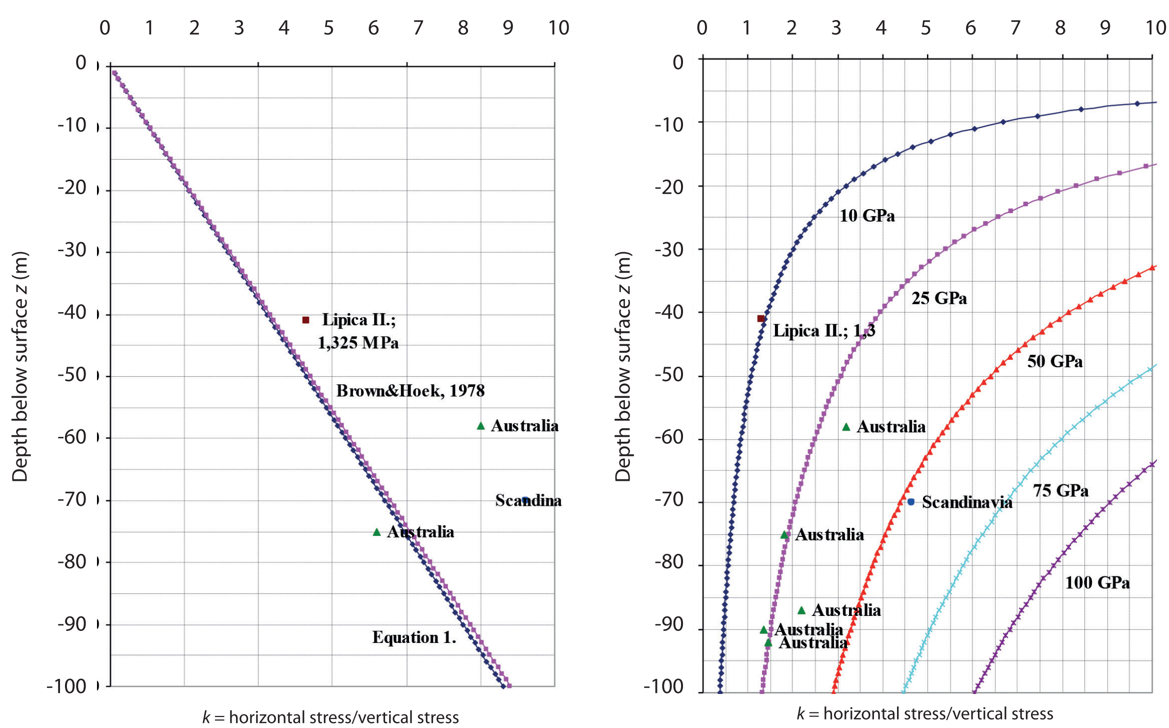

Figure 1: *Ratio of horizontal to vertical stress for different deformation moduli base upon Sheorey's equation (Sheorey, 1994)[12] (left) and calculated vertical stress (Brown and Hoek, 1978)[1] (right) with measured parameters in the quarry Lipica II. and the world.*

Table 1: *In situ stress meassurement data (Brown and Hoek, 1978)*[1]

No.	Location	Rock type	Depth h/m	σ_v/MPa	$k = \sigma_h / \sigma_v$	Ref.
Australia						
1	Kanmantoo, SA	Black garnet mica schist	58	2.50	3.30	[15]
2	Mount Charlotte mine, WA	Dolerite	92	11.20	1.45	[15]
3	Durkin mine, Kambalda, WA	Serpentine	87	7.40	2.20	[15]
4	Dolphin mine, Kings Is., Tas.	Marble and skarn	75	1.80	1.80	[15]
5	Cethana, Tas.	Quartzite conglomerate	90	14.00	1.35	[15]
Scandinavia						
6	Bidjovagge mine, N. Norway	Pre-Cambrian rocks	70	2.80	4.64	[10]
Slovenia						
7	Lipica II.	Limestone	41	1.32	1.30	[9]

In Figure 1 (right), the vertical stress, σ_v is plotted against depth h, while Figure 1 (left) shows a plot of $k = \sigma_h / \sigma_v$ against depth h. Figure 1 (right) shows that measured vertical stresses generally follow the trend given by the simple relationship;

$$\sigma_v = 0{,}927 \cdot h \tag{4}$$

At shallow depths (0–100 m), there is considerable scatter in the observed values.

Discontinuities in quarry Lipica II

Discontinuities (open craks) appearing in the quarry Lipica II. have rough walls and in space variable dip, which is a favorable property regarding the stability of randomly generated wedges. Cracks are mostly empty or filled with heavy mouldabe reddish-brown clay (Figure 2). The thickness of clay fillers varies from thin clay trush to few inches thick clay layer. Cracks walls are mostly lined with red calcite incrustation, which is also advantageous feature of the stability of cracks. In cases where cracks have no incrustation, they are wavy to the rough, which means that the unevenness of the cracks surface increases the shear strength of the cracks. Spacing between the cracks is 1–5 m. This means that the choice of GSI index less than 50 is not appropriate, since this is applicable in the case of smooth cracks filled with clay. Geomechanical parameters of Lipica limestone are reduced by Hoek analysis[7].

The index GSI (Geological Strength Index) was determined on the basis of engineering-geological mapping of cracks and is 55 ± 5[5]. For GSI = 55 ± 5 is characterized by a block structure with three rock fracture systems and with good merged blocks, whereas the walls of the crack to the flat smooth, with a moist surface. Cracks are closed or open. Open cracks are filled with a compact infill or coarser primary rock particles.

Geotechnical properties of cracks were accurately determined by reverse analysis of the quarry Lipica II. underground structures. Robertson's test of the samples with a crack-free clay showed values of the angle of internal friction φ = 26°, cohesion c = 21 kPa at 100 kPa load and angle of internal friction φ = 16°, cohesion c = 50 kPa at 160 kPa load.

Laboratory and "in-situ" tests have shown the following geomechanical properties of the intact limestone Lipica:

Deposit of natural stone in quarry Lipica is a strong tectonic disrupted with at least seven leading towards discontinuity (casting), which cause the danger of underground mining. The

Figure 2: *Open fissures in underground structures of quarry Lipica II.*

cracks link together and form in the ceiling and the side of the underground spaces of the dangerous rocky wedge. Precisely because of this, in order to ensure stability and safe working conditions we implement in-situ monitoring and controling devices. In addition to the stress gauges also use EL beams gauges for rock wedge movement and deformation monitoring.

E (modulus of elasticity)	14–37 GPa
σ_u (uniaxial compressive strength)	94–220 MPa (170 MPa)
γ (weight)	26.3–26.8 kN/m^3
ν (poisson's ratio)	0.33–0.36 (0.15–0.30)
T (tensile strength)	3.8–6.14 MPa
φ (angle of internal friction)	52–54°
c (cohesion)	46.6 MPa
c_{res} (residual cohesion)	11.5 MPa
m (Hoek-Brown parameter)	10.4

El beam gauges

The use of the EL beam gauges (also tiltmeter) is an extremely broad, since they used to measure vertical movements, declination or movements on dams, observation of the stability and covergences of banks areas, observation of the tunnels stability, observe of the structures around exploitations areas, etc. EL beam sensors monitor differential movement and rotation in structures. Two types of sensors are used – horizontal and vertical type. Horizontal beam sensors monitor settlement and heave. Vertical beam sensors monitor lateral displacement and deformation.

Table 2: *Technical characteristics of EL beam gauge manufacturer Slope Indicator*[13]

<table>
<tr><th></th><th>Horizontal</th><th>Vertical</th></tr>
<tr><td>Measurement range</td><td colspan="2">± 40', (± 11 mm/m)</td></tr>
<tr><td>Accuracy</td><td colspan="2">± 0.1 mm/m</td></tr>
<tr><td>Operating temperature</td><td colspan="2">–20 to +50 °C</td></tr>
<tr><td>Weight</td><td>210 g</td><td>890 g</td></tr>
</table>

The beam sensor consists of an electrolytic tilt sensor attached to a rigid metal beam. The tilt sensor is a precision bubble-level that is sensed electrically as a resistance bridge. The bridge circuit outputs a voltage proportional to the tilt of the sensor. The beam, which is typically one to two meters long, is mounted on anchor bolts that are set into the structure. Movement of the structure changes the tilt of the beam and the output of the sensor. The voltage reading from the sensor is converted to a tilt reading in mm per meter. Displacements are then calculated by subtracting the initial tilt reading from the current reading and multiplying by the gauge length of the sensor (the distance between anchors). When sensors are linked end to end, displacement values can be accumulated from anchor to anchor to provide a profile of differential movements or settlement.

Figure 3: *Horizontal EL beam gauge*[13].

The metal rods, on which the meters are instaled, are very sensitive on temperature changes, which may be (in the underground mining of natural stone) in winter/summer peroid quite great. Heating and cooling of the air in the underground spaces result of the expansion and contraction of metal roads. It is therefore necessary to take into account in data processing of metal road expansion correction factor.
Calculation of deflection takes place with the help of the following polynomial equations:

$$\frac{mm}{m} = C5 \cdot EL^5 + C4 \cdot EL^4 + C3 \cdot EL^3 + \\ + C2 \cdot EL^2 + C1 \cdot EL + CO \qquad (5)$$

where
EL ... measured voltage value
$C5$ ... $C0$ ... polynomial coefficients

Reading in mm/m it is necessary to multiply with the length of the bars (in our case, 2 m), which comes out (2x–1.961) –3.922 mm[4].

Temperature resistance equation

$$T = \left[\frac{1}{A + B \cdot (\ln R) + C \cdot (\ln R)^3}\right] - 273.2\,°C \qquad (6)$$

where
T ... temperature in °C
$\ln R$ ... natural log of termistor resistance
A ... 1.4051×10^{-3}
B ... 2.369×10^{-4}
C ... 1.019×10^{-7}

EL beams in quarry Lipica II

Two EL beams we have built in safety pillar (VS3) at level 359 on the open cracks, both located on the corners of the high safety pillar. Discontinuities with the direction 120°/60° and 110°/75° are open and filled with clay. Both discontinuities cross-cut the safety pillar. In the case of additional compressive load of safety pillar, there could appear a deformation and slip a stone wedge from safety pillar. For a Visual check on the safety pillar also installed a glass seals. Dangerous rock wedges on the security pillar are stabilized with anchors.
Visual check on the safety pillar also installed a glass seals. Dangerous rock wedges on the security pillar are stabilized with anchors.
Figure 4. shows a map of the rock discontinuities apparing on sealing of underground structures and locations (green circle) of EL beams gauges instalations in quarry Lipica II.

Table 3: *Example of deviation calculation considering calibration test coefficients*[4]

	Polynomial coefficient	EL reading	Value
$C5$	1.642 6E^{-1}	$-0.585\,71^5$	–0.113 225 700 0
$C4$	–1.583 6E^{-2}	$-0.585\,71^4$	–0.001 863 700 2
$C3$	–2.688 1E^{-1}	$-0.585\,71^3$	0.051 012 382 9
$C2$	–7.990 4E^{-2}	$-0.585\,71^2$	–0.027 411 562 9
$C1$	3.509 8	$-0.585\,71^1$	–2.055 724 958 0
$C0$	8.118 5E^{-2}	$-0.585\,71^0$	0.081 185 000 0
		deviation d/(mm/m) =	**–1.961 154 082**

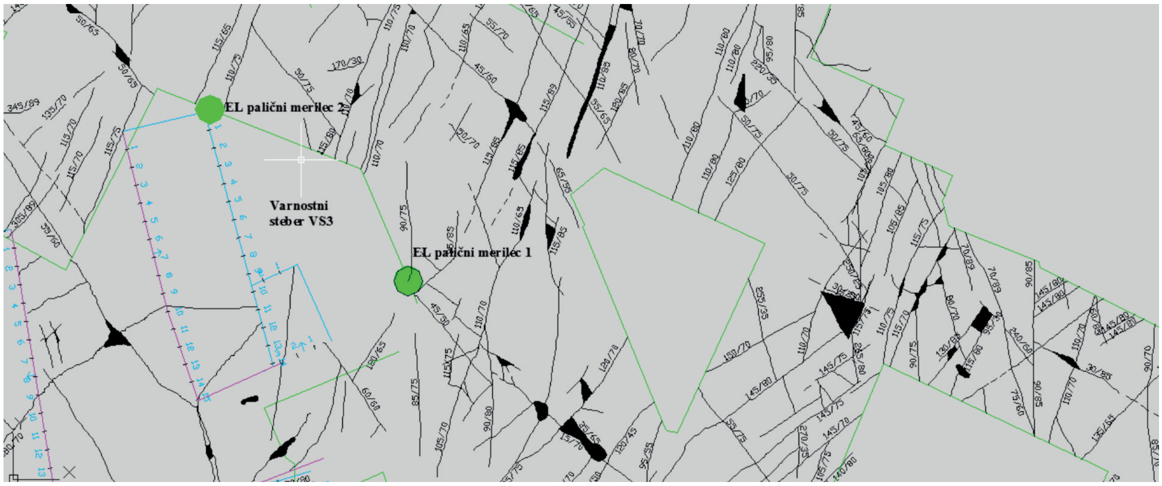

Figure 4: *Map of the rock discontinuita orientations and locations (green circle) of EL beams gauges instalations in quarry Lipica II*[11].

In quarry Lipica II. EL beam meter manufacturer Slope Indicator is used to measure supervisory convergences in one vertical plane in hight safety pillar VS03 (Figure 5). A bar gauge is installed through the cracks, so that there is one screw on the part of the anchor windlass for anchor, such as flexible wedge screw for stable work.

Figure 5: *EL beam gauge on the high safety pillar VS3.*

According to practical experience, the best indicators of developments are movements in pillar corners. For that reasons we decided to monitor the developments on the safety pillar corner, where the sliding surfaces of the main crack are driving out.

From Figure 6, we can see that in the summer time period El beam rod is stretching in the winter time period EL beam rod is shrinkage.

Figure 6: *Vertical EL beam gauge instalation on the high safety pillar VS3.*

The metal rod, on which there is displacement meter is sensitive to changes in temperature, which may be in the underground extraction during the winter/summer relatively large (ΔT/°C in period from 2004/2010 9.24°C / 12.2°C / 14.07°C / 10.52°C / 12.19°C / 14.7°C / 13.55°C). During heating and cooling of air in underground structures leads to expansion and contraction of metal rods. Therefore, the data processing necessary to consider correction factor of metal rods. In the time period October 2010/March 2012 absolute max. measured displacement was 0.08 mm, which does not threaten the stability of the heigh safety pillar VS3.

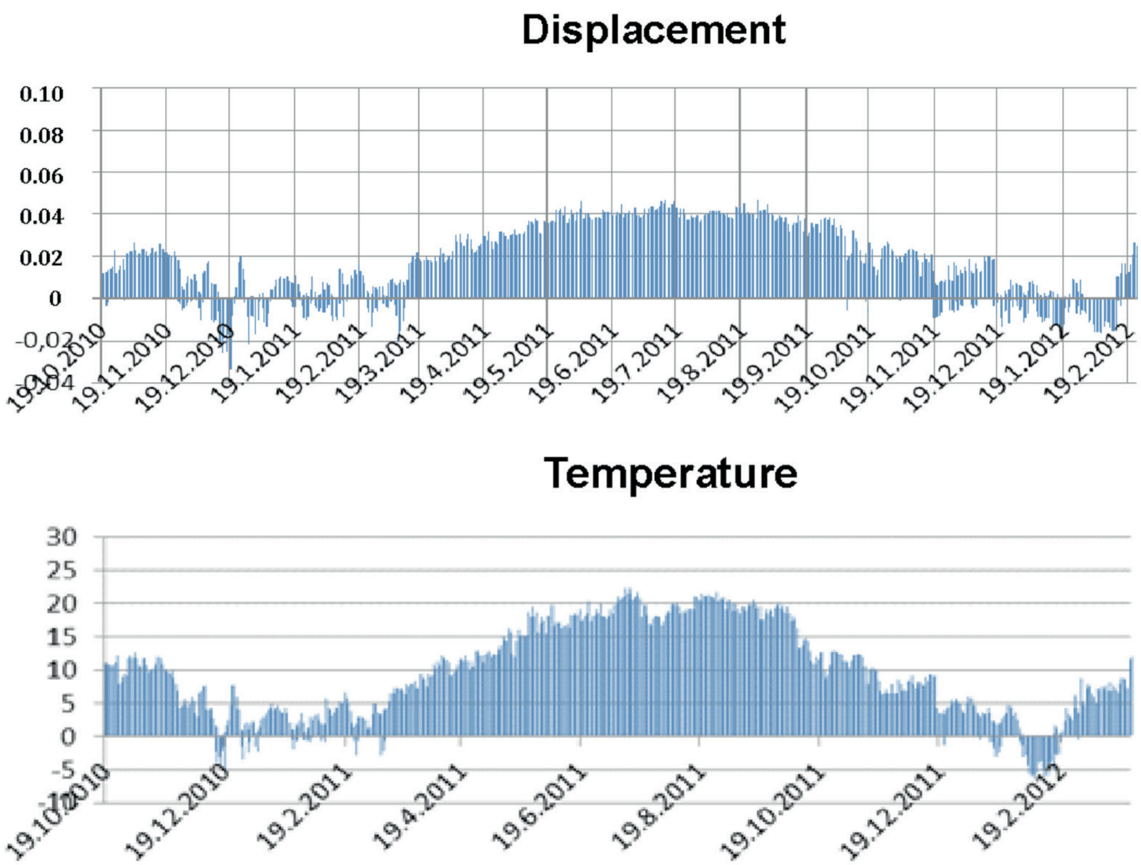

Figure 7: *Diagram of the measured EL beam true deflections/movements in mm (above) and temperature in °C (below) in the time period October 2010/March 2012.*

Conclusion

Mining engineers have to work with the limitations of available technology. The strength and deformation characteristics of the rock and the discontinuities play a major role in determinating suitability as well as the reinforcement and support requirements in underground excavation of natural stone. Efforts to overcome these limitations have resulted in use of the EL beam gauges in quarry Lipica II.

In order to maintain a stable underground structures and the provision of safety and health at work, it is provided constantly monitoring of high safety pillars in quarry Lipica II.. Even small changes in strain-stress state in the vicinity of underground structures can mean a potential risk of the wedge failure, if it is not stabilized properly with anchors. EL beam gauges have so far proved to be a reliable tool for high safety pillar stability monitoring. The advantage of these meters is also that in case of gauge failure, we can easily check the operation of the instrument, supply power cable, etc. and in case of any failure also easily replace or repair (in comparison with VW stressmeter gauge, it is cemented in the borehole and replacement is not possible). An important role is played also the relatively lower price of the EL beam instrument.

Constant monitoring of instability wedges in the pillars hips or in the ceiling of the underground spaces with EL beam gauges will provide more information for the planning of the final dimensions of the new high safety pillars. The experience and results of measurements that are currently passing, we can use in the development and/or modifications of existing monitoring systems and to ensure even greater safety in the underground excavation of natural stone.

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New methods for modern technology for the evaluation of spatial parameters of underground structures

Nove metode za sodobne tehnologije ocenjevanja prostorskih parametrov podzemnih objektov

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Abstract

The process of acquiring geometric data within geosciences is usually limited by predetermined observation points, anthropogenous or naturally exposed visible objects. With the classical geodetic methods for measuring the underground construction's location of observed points are being determined systematically or on spots where manifestations of natural or anthropogenic influences are expected according to professional interpretations. Activities in rocks cannot be entirely predicted. At the same time the problem is often in insufficient accuracy and inadequate plans after implemented activities or excavations, which are often a reference or in null condition for further management with the construction.

The solution for comprehensive three-dimensional measurement with high metric accuracy is 3D terrestrial laser scanning technology. The direct result of such data capture is condensed to be a crowd of spatially located points – a point cloud, which describes the accurate shape of the complex engineering object building with some primary data processing. The raster of scanning is definable and adjusted to the demands and can reach also millimetre spans. Monitoring and the analysis of deformations detected on visible watched surfaces is one of the applications of the mentioned technologies. Besides the deformation analyses, a method for 3D registering of the fractures was developed and consequently predicted of optimal excavation progress. The application is introduced with one epoch in the case of underground excavation of Doline with the capture of Fracture Targets (FT) and the simulation of the progress of excavation.

Key words: 3D model, deformation monitoring, terrestrial 3D laser scanning, quarry, fractures

Izvleček

Pri pridobivanju geometrijskih podatkov v geoznanosti smo navadno omejeni na preddoločene opazovane točke ali antropogene ali naravno izpostavljene vidne objekte. Čeprav se lokacija opazovanih točk v podzemnih prostorih s klasičnimi geodetskimi metodami določa sistematično oz. na mestih, kjer se po strokovnih interpretacijah pričakujejo manifestacije naravnih ali antropogenih vplivov, v kamnini točnih dogajanj nikoli ne moremo zagotovo napovedati. Prav tako se pogosto pojavlja problem nezadostne natančnosti in pomanjkljivih načrtov po izvedenih delih oz. izkopih, ki so pogosto osnova za nadaljnje upravljanje objekta.

Rešitev za celovito tridimenzionalno izmero z visoko mersko natančnostjo je tehnologija s 3D terestričnim laserskim skeniranjem. Neposredni rezultat tovrstnega zajema podatkov je zgoščena množica prostorsko lociranih točk – oblak točk, ki z nekaj primarne obdelave opisuje natančno obliko kompleksnega inženirskega objekta. Raster skeniranja je določljiv in prilagojen zahtevam ter lahko dosega tudi do milimetrske razpone.

Ena od metod, ki se nanašajo na omenjeno tehnologijo, je nadzor in analiza deformacij, zaznanih na vidnih opazovanih površinah. Poleg deformacijskih analiz smo razvili metodo za 3D kartiranje razpok in posledično napovedovanja optimalnih napredovanj. Metoda je predstavljena s terminsko izmero podzemnega kopa Doline z zajemom t. i. tarč za razpoke (FT – ang. fracture targets) in simulacijo napredovanja.

Ključne besede: 3D model, nadzor deformacij, terestrično 3D lasersko skeniranje, kamnolom, razpoke

Introduction

The main goal of the project is to set and test methods for inventorying and documentation of underground structures. Methods are also related to monitoring and prediction of deformations. The identification of deformation and impact of fractures on yield in progressions are evaluated qualitatively and quantitatively.

All operations and methods are based on technology TLS (terrestrial 3D laser scanning) in combination with the existing methods. The described methods are tested on cases of volumetric, deformation, fracture mapping and estimation of impact on yield and costs, planning progressions and operational dynamics in the quarry. The focus was on methods for monitoring of deformation on the safety pillars and fracture mapping. Fracture mapping methods were primarily focused on planning of yield.

The methods are verified on the case of the Doline quarry (Marmor Sežana, PLC.) as a user, with MAGELAN skupina Ltd. as a provider of technology and FNSEA as the "know-how".

Methods

Terrestrial 3D laser scanning

TLS is considered to be an effective measuring method of comprehensive spatial data, describing the geometry of the visible objects' surfaces. In a very short time, instrument systematically produces millions of measurements, with a dense crowd of geo-located points as a direct result.[1] Already after a single capture and primary processing (registration in filtration) these "point cloud" data accurately define a high detailed shape of the measured object. With the secondary treatments, the gathered data is useful in many engineering applications.

Instrument characteristics

In order to achieve maximum accuracy with the discussed technology, we chose a pulse based terrestrial 3D laser scanner Leica Scan-station C10 and performed starting with a "null" epoch measurement of Doline quarry (Marmor Sežana PLC).

The pulse based instrument consists of a transmitter/receiver of infrared laser pulses and scanning optics. The distance of measurement is based on the time-of-flight of the laser pulse to travel and reflect from the surface of interest. The location of each point is acquired in a polar coordinate system. The horizontal and vertical angles are modified by the scanning device using an internal system of rotating mirrors.

Compared to conventional surveying methods, a TLS shows a very high data acquisition speed (up to 50 000 points/s). Technical characteristics of the Scan-station C10 supplied by the

Figure 1: *Photo from the field work - 3D terrestrial laser scanner (left), a scheme of scan positions inside the quarry (right).*

[1] Registration: For a complete measurement of the object, more scan positions are usually required. Each scan position has its own coordinate system. Registration means the transformation of all scan positions into a uniform coordinate system.

[2] Filtration: The scanning often covers the surface, some of which is not the subject of interest (mechanization, vegetation, people, etc.). This disturbing object called "noise" should be within the primary treatment to remove. This process is called filtration.

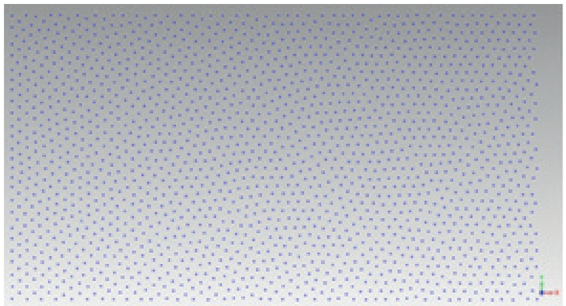
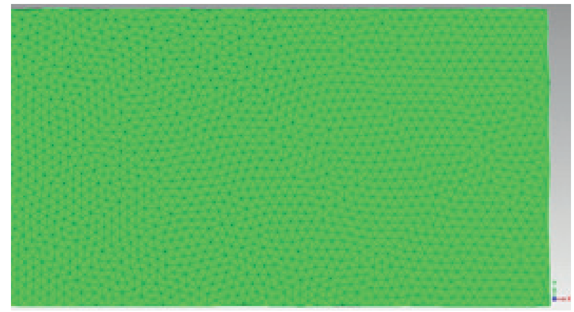

Figure 2: *Schematic illustration of triangulation; point based model (left), surface triangulated model (right).*

manufacturer show high maximum range (up to 250 m for 90 % surface reflectivity) and high point accuracy.
More than 289 million points was measured, which were converted into desired and useful data by computer processing. The basis for all the methods described below is the georeferenced point or surface 3D computer model, generated with the procedure of triangulation (Figure 2).[2]
The methods are related to improvements and additions to the technical documentation, which is currently regulated by the legislation:

Site plans

Site plans are an integral part of the mining technical documentation (floor plans and vertical profiles). After the completion of one-day scanning, our method provided detailed plots of profiles in any direction and in any location. Plansare written in the classical CAD format and are intended for use by all operatively involved professionals, therefore users can individually select plot location of the specified profile.

Fracture mapping

We verified the method for 2D and 3D vectoring of visible fractures in the quarry. The advantage of our method is the fact that in one epoch (1D scanning) all visible fractures on the wall, floor and ceiling can be measured. In the secondary processing of data, measured fractures can be mapped in both 2D and 3D technique. The method provides a comprehensive inventory of visible fractures and represents an effective tool for exploitation planning. As well as site plans, the fracture lines are adjusted in classic CAD form.

In our survey team, we are in the early development of the methods with FT targets (C & C "Fracture Targets") for the measurement of the dip and dip direction of fractures. FT targets are solid slats which are wedged in the unfilled fractures (Figure 3). 3D scanning captures geometric data of wall surfaces as well as the FT surface. Points that hit the FT define the plane from which we get hold of the data of the dip and dip direction of the discontinuity.[3]

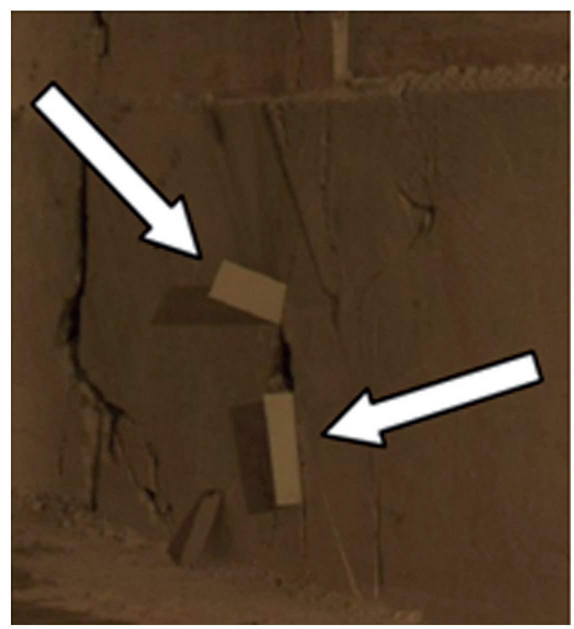

Figure 3: *Photorealistic coloured point cloud, which defines a wall and two FT.*

At the head of progression, where excavations with the method of breaking the block are carried out, there are visible discontinuities. With the TLS semi-automatic and remote sensing, documentation of the geometric properties of visible fractures is possible.

Deformation monitoring

Currently the method of deformation monitoring with TLS is the only method, which provides accurate and comprehensive control of all quarry surfaces. Given the fact, that it is a method of remote sensing, we can identify deformations even on areas with difficult or no access in critical locations such as high walls, ceilings, and dangerous areas. The result of the method is illustrated by numerical and graphical deformation analysis and, in that way contributes to the timely and optimal precaution.[4]

Leveling

The levelling method was used to graphically illustrate the relative and absolute floor level. The raster of measured points reaches up to centimetre ranges. Large utility of such methods is reflected in identifying the locations of water accumulation and controlling of the horizontal progressions.

Codification and dimension analysis

The shape ofthe quarry is measured up to the very smallest detail and presented three-dimensionally. In this way, optimal dimensioning and placement of machines in the quarry can be analysed and pre-planned. A computer model represents a "freeze state" on the day of theepoch measurement. With simple and tailor-made views, the user has direct access to geometric information of the quarry through his personal computer.

Results

3D models, 2D plans

Already with the primary processing of measured data, a point based 3D model of the quarry can be generated. Such models serve as a metric lining for generating site plans and the production of the interactive 3D viewer.

Such plans can be plotted at any location and in any direction (horizontal, vertical, diagonal). The plans are designed for conventional CAD operational planning.

Just like any random selection of the location of transverse and longitudinal profiles, free choice of horizontal/floor plans is possible.

An elevation image is added to the floor plan, which is also one of the products of the TLS method. The elevation image illustrates the levelling data; however the raster of measured points is achieved in centimetre grid ranges. With this data we could identify the locations of water accumulation. The elevation image is also equipped with a colour scale, representing the corresponding absolute or relative elevation.

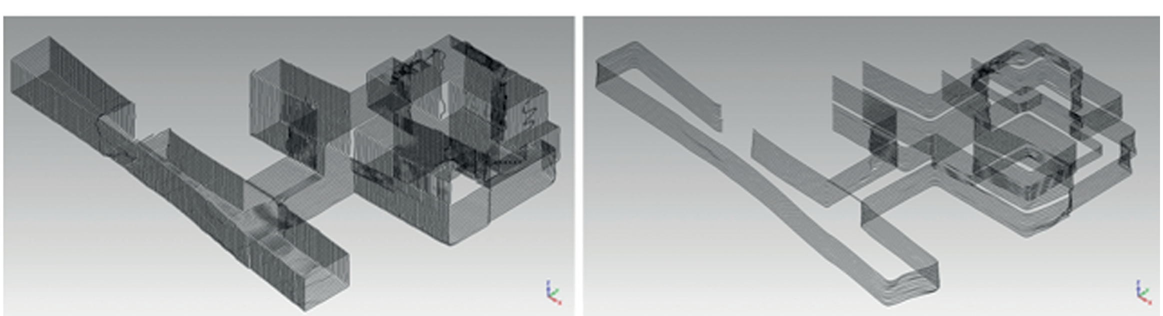

Figure 4: *Vertical and horizontal cross sections, generated from point cloud or 3D model.*

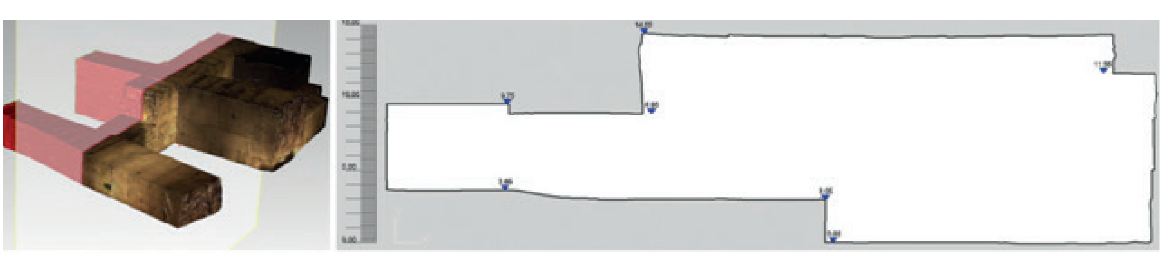

Figure 5: *Location on a selected section of the 3D model (left), CAD plotting profile (right).*

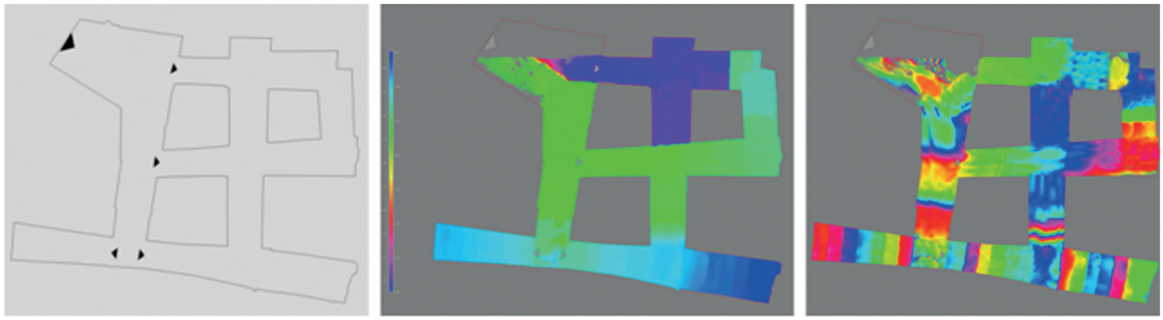

Figure 6: *Site plan of Doline quarry, elevation-coloured view.*

With the process of triangulation, a point model was converted to a surface model format. From the surface model, we obtained the volume data of the quarry, while it also served as a reference surface for the analysis of deformation in future epoch measurements. Figure 7 (left) shows a detailed 3D model of the Doline quarry. Figure 7 (right) shows one of the first and simpler uses – the calculation of the volume of the quarry.

All plansand 3D models are constructed in real dimensions. This meanst hat the geometric condition of the quarry is transferred to a digital format. This way is suitable forreviewing and performing measurements through the personal computer, rather than as field work.[5]

Deformation monitoring

To demonstrate the monitoring of deformation, a "null" epoch measurement and the simulation of the following epoch on the characteristic areas were used. An analysis of the deformation was executed on the case of the wedge slip on the ceiling (Figure 9) and scaled slip on one of

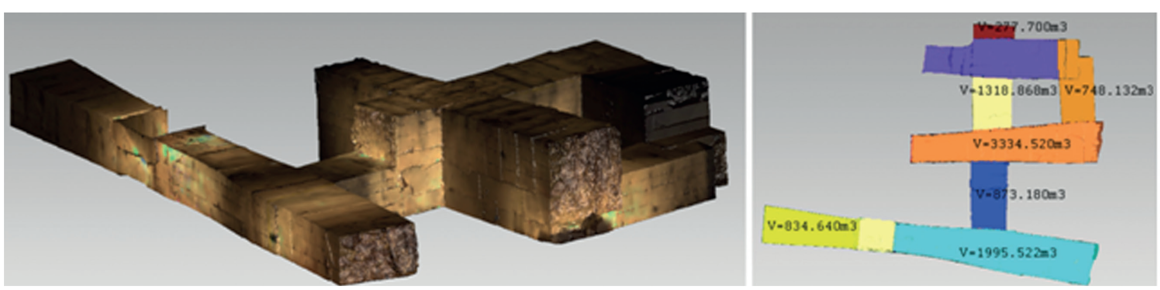

Figure 7: *A 3D computer model of the Doline quarry (left), quarry segmentation of spaces with volume calculations (right).*

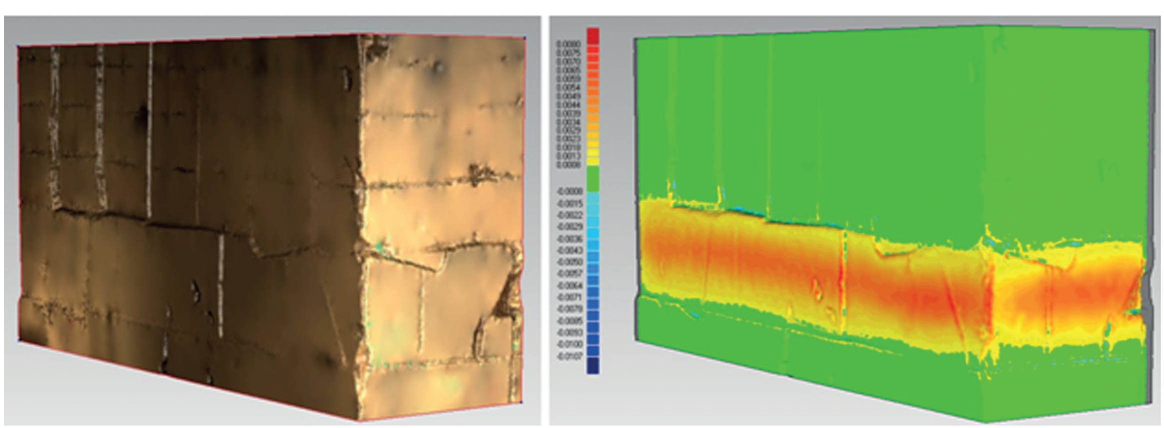

Figure 8: *A 3D model of two sides of the safety support pillar (left), 3D illustration of the analysis of deformations on the pillar walls in the horizontal direction (right).*

the walls, where these kinds of problems have already occurred (Figure 8). An analysis and visualization of deformations on the security pillar was also made with case of simulation of the swelling of rocks (Figure 8).
Since the data acquisition with TLS is performed with an extremely high raster of scanning, it is possible to detect surface deformation in millimetre ranges. Currently, TLS technology represents the only tool for this kind of monitoring and effective complement method for the conventional 2D monitoring of stress states, allowing the analysis of deformations, which are detectedon all visible surfaces through out the monitored object.

The deformation analysis was also performed on a wider area, namely on the longer wall outside the quarry (Figure 11). The discrepancies between the two epochs are demonstrated with colour and numerical analysis.

Fracture mapping

Along with the scanning instrument, the surface of the observed object is also simultaneously photographed with the integrated camera. This method enables the production of orthogonal photosthat represent a metric projection plane for fracture mapping within 2D vector format (Figure 12).

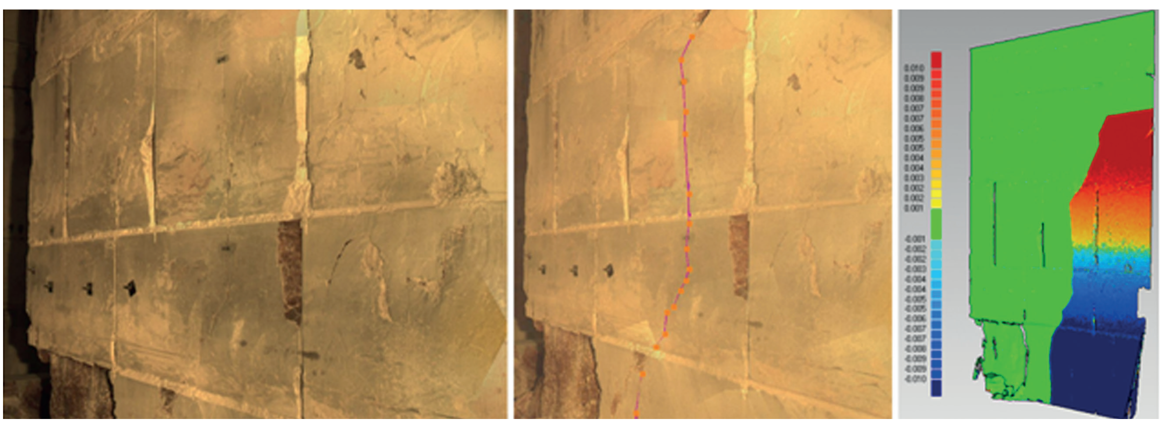

Figure 9: *The support system with safety anchors on the critical region (left), mark of already visible and observed fracture (centre) and illustration of the perception of slipping.*

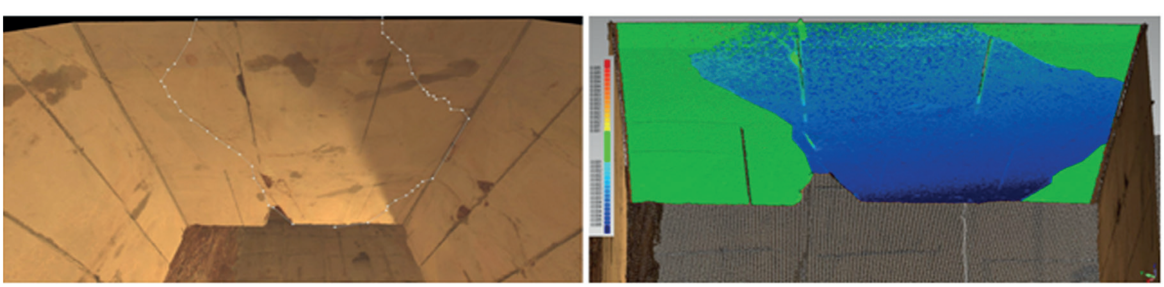

Figure 10: *Outlines of fractures (left) and visualization the perception of the slipping on the ceiling (right).*

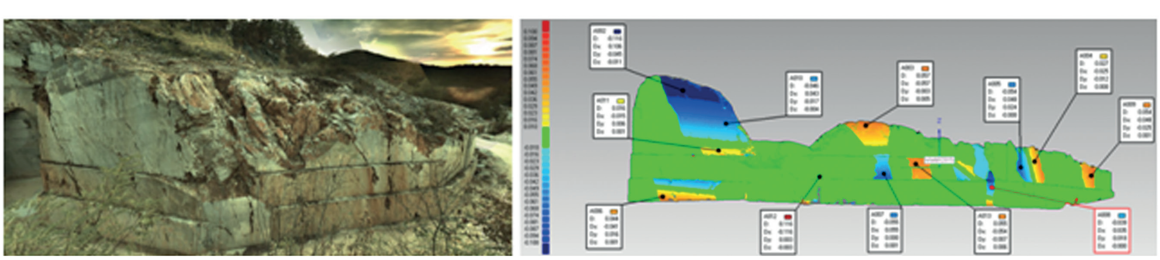

Figure 11: *Photo of the quarry Doline exterior wall of the (left) the deformation analysis of the wall (right).*

The 3D mapping of fractures on the photo-realistic coloured model, which as such represents a projection surface, was also produced. Figure 13 (left) illustrates direct spatial mapping of visible fractures.

Both cases of mapping enable export of the lines in standard CAD formats, allowing the use of date to all of the professionalsin the quarry.

In the field of fracture mapping, we are developing methods for further detecting the strike and dip direction of fractures in which solid slates could be jammed. One of the first results of such methods is demonstrated in Figure 14 (right), where a blue plane is illustrated (the wall), and two smaller planes are generated from points that lie on the situated slates.

Figure 12: *2D mapping of fractures based on orthogonal photos.*

Figure 13: *Fractures as vectors, photograph of situated FT.*

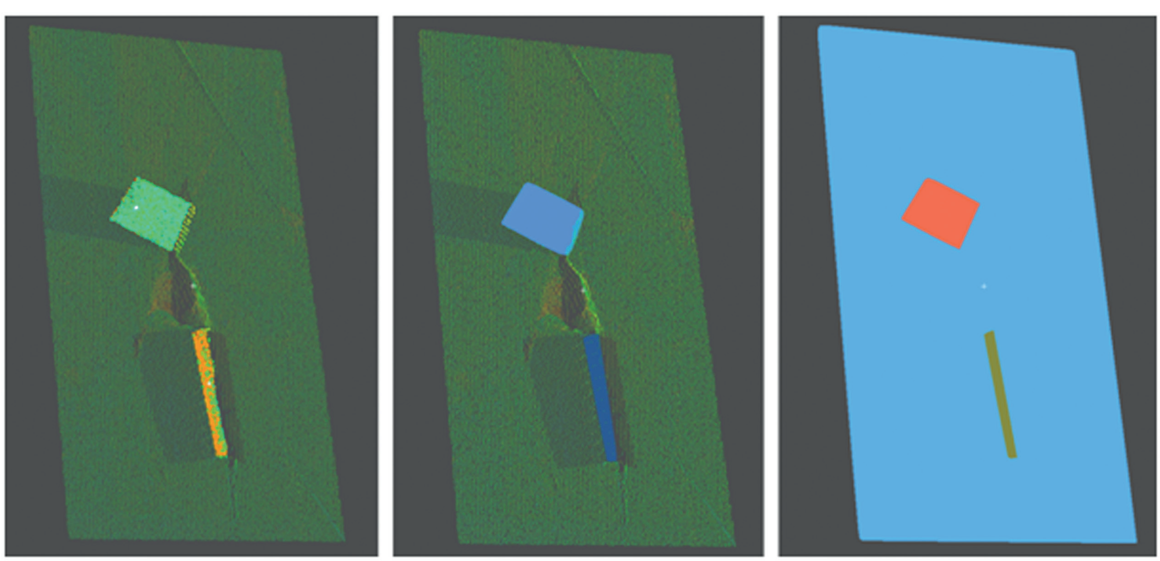

Figure 14: *Scans of walls and two of situated FT (left), modeled planes, which define the dip and dip direction of the fracture (middle), modeled wall and FT planes (right).*

Discussion

As mentioned above, the direct result of the TLS measurements is a photo-realistically coloured point cloud, which defines the spatial model of an object. This model represents an easy and interactive source of geometric information that can be accessed by all the experts (geologists, miners, geo-mechanics, etc.) via personal computer. This type of real-time access to information enables time saving and does not impede the work of the employees and the machines in the quarry.

The great advantage of TLS is also reflected in the non-contact measurements, which enables that the measurements do not influence the status of the observed object. With the non-destructive measuring methods, surfaces which are difficult to reach or dangerous can be measured. Relative distances, which would otherwise be very difficult or even impossible to measure, can be measured as well.

In one day of scanning of the Doline quarry, extensive geological inventory works and geodetic measurements were carried out. In both processes (geological and geodetic), our methods reduced the impact of human error (systematic and random error operator is void). After fieldwork measuring there is no insufficient and inaccurate data. This means that there is no wasting of time or returning to the terrain. The latter could in some cases also be too late, since work processes in the quarry cannot be stopped and wait for a repeated measurements, because of economic reasons.

As the TLS measurements work, processes in the quarry must be stopped or limited, because micro vibrations and dust element adversely affect the outcome of the measurements. Regarding the quality of the end product, measurements are made in very short time. Comparable results cannot be achieved with conventional methods.

Conclusion

The research project evaluated and the tested methods base on TLS. On the basis of the null and the simulation of second epoch measurement, advanced methods were demonstrated. Its demonstrated results can be useful in other engineering objects (e.g. tunnels, excavations, construction pits, hydroelectric stations, landfills, landslides, retaining walls, plants and industrial infrastructures etc.[6]

For example, in tunnelling and building of other underground constructions, the utility of the methods reflects in the possibility of deformation monitoring, measurement of deviations between built and planned, while thickness and regularity of primary and secondary of concrete support system layer could also be measured.[7] In case of these applications, the research continues.

Acknowledgment

Special thanks go to Marmor Sežana, d. d., and Magelan skupina, d. o. o. Despite the fact that the study was not formally or informally funded, they enabled it with unselfish understanding, attention, a lot of voluntary work and engagement of their human resources, as well as their hardware and software. CMSAG as well as FNSEA once again justified its mission - to transmit the theory into the practice, disregarding the fact that the work was performed “pro bono”.

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Odour emissions from the technological processes of coal extraction in Coal Mine Velenje

Emisije vonjav pri tehnoloških postopkih pridobivanja premoga v Premogovniku Velenje

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Abstract

Coal Mine Velenje with production of app 4 Mt of lignite per year is also emitting coal gases and various odours. Occasionally detected odours on the surface of the coal mine area and some of the nearby settlements may also result from the coal mine ventilation system and mined coal deposit on the surface.

In particular Ventilation station Pesje, which is located closer to Velenje, with its emissions represents an occasional locally recognized environmental problem.

On the one hand the legislation, which more and more sharpens and on the other hand the vision and corporate social responsibility dictates that the occurrence of odours Coal Mine Velenje undertakes thoroughly and fundamentally.

The objectives of this research are to develop and implement a robust odour emission monitoring system and collect the necessary data that are necessary to develop an understanding of formation and dispersion of odorous compounds at the process of underground coal excavation and surface coal deposition.

The research activities are divided in three main topics:

— Identification and evaluation of odour sources.
— Monitoring of odour emissions from sources on the surface (using chemical analysis and olfactomety).
— Design and implementation of odour dispersion model.

Key words: odours, coal mine, coal gases, odour dispersion modelling

Izvleček

Premogovnik Velenje s proizvodnjo pribl. 4 Mt lignita letno izpušča v ozračje premogovne pline in različne vonjave. Občasno zaznane neprijetne vonjave na površini pridobivalnega prostora in v nekaterih bližnjih naseljih so lahko tudi posledica prezračevanja podzemnih pridobivalnih prostorov premogovnika Velenje in deponiranja odkopanega premoga na površini. Predvsem ventilatorska postaja Pesje, ki se nahaja bližje Velenju, je s svojimi emisijami občasen lokalno prepoznaven okoljski problem. Po eni strani zakonodaja, ki se bolj in bolj zaostruje, po drugi pa vizija in družbena odgovornost podjetja zahtevajo, da se Premogovnik Velenje pojavljanja vonjav loti temeljito in temeljno.

Glavni cilji temeljnih raziskav področja emisij vonjav pri procesih pridobivanja in deponiranja premoga so pridobitev znanja in zajem podatkov, ki so potrebni za razumevanje pojavljanja vonjav v jami in na površini ter za razvoj in implementacijo merilnega nadzora vonjav za oceno vpliva na okolje.

Raziskave vonjav so razdeljena na tri glavna področja:

— Identifikacija in kvantifikacija virov vonjav (v jami in na površini),
— Merilni nadzor emisij vonjav na površini (z uporabo meritev, kemijske analize in olfaktometrije),
— Modeliranje disperzije vonjav za oceno okoljskega vpliva vonjav.

Kjučne besede: vonjave, premogovnik, premogovni plini, modeliranje disperzije vonjav

Introduction to the problem

The mixtures of gases, which are perceived as odours effect primarily on our olfactory and taste perception of the environment and in the case of unpleasant odours, have a disturbing effect. Despite the fact that odours are usually not toxic (individual toxic gases usually have much lower odour detection threshold (range 10^{-9}) than the mandatory limit values, can significantly affect on quality of life of the surrounding population.

Occasionally detected odours on the surface area of Coal Mine Velenje (CMV) impact and in the nearest settlements are primarily the result of mine ventilation (two surface ventilation stations Pesje and Šoštanj, with total continuous airflow between 21 000 m^3/min and 25 000 m^3/min) and of coal stockpile on the surface (capacity of stockpile is varies between 50 000 t and 800 000 t). Unpleasant odours are to present knowledge the result of detected presence of volatile sulphur compounds (VSC). Emitted VSC are formed and captured between the coal formation processes and are mainly released at the excavation process and other processes of coal crushing, transportation and deposing. VSC are also formed in the mine and the stockpile because of sulphur presence in the coal.

Presence of VSC is detected with gas concentration measurements with gas chromatography and electrochemical sensors from mine air and emission from stockpile samples. With mandatory monthly measurements are controlled known $(CH_3)_2S$ (DMS), H_2S and SO_2. With previous research measurements on the stockpile were also detected COS and CS_2.

Measurements of VSC are particularly exposing DMS concentrations which is countinouosly detected at concentration of more than 1×10^{-6} in air exiting roadways. The odour tresholds of detected VSC (mine and surface) are[1]: SO_2 0.87×10^{-6}; COS 0.055×10^{-6}, CS_2 0.21×10^{-6}; H_2S $0.000\ 41 \times 10^{-6}$; DMS 0.003×10^{-6}.

In analysed one year period from August 2010 to July 2011 the DMS in the air exiting ventilation shafts was detected always except in Pesje pit in August 2010 and in January 2011. The average DMS concentration in Pesje pit was 15.8×10^{-6} and in Preloge pit was 8.5×10^{-6}. Gases H_2S and SO_2 are not detected ($<1 \times 10^{-6}$) in period from August 2010 to July 2011 what is expected under normal operating conditions[2]. Coal stockpile measurements identified DMS, COS, CS_2. The estimated daily emissions of COS and CS_2 for the whole stockpile in the sampling period were 20 g CS_2 and 70 g COS (gas concentration was in range 10^{-9}). The DMS concentrations fell to less than 1×10^{-6} in a few days due to the releasing from freshly loaded coal[3].

The objectives of this research are to develop and implement a robust odour emission monitoring system and collect the necessary data and develop an understanding of formation, dispersion and environmental impact of odorous compounds in the process of underground coal excavation and surface coal deposition.

The research activities are divided in three main topics:

1. Identification and evaluation of odour sources.
2. Monitoring of odour emissions from sources on the surface (using chemical analysis and olfactomety).
3. Design and implementation of odour dispersion modelling to assess environmental impacts due to the emissions of underground coal excavation and surface coal deposition.

Odour perception and measurement

Odour perception

Olfaction, the sense of smell, is the most complex and unique in structure and organization and also the least understood of the five senses. While human olfaction supplies 80 % of flavour sensations during eating, the olfactory system plays a major role as a defense mechanism by creating a natural aversion response to malodours and irritants. Human olfaction is a protective sense, protecting from tainted food and matter, such as rotting vegetables, putrefying meat, and faecal matter. This is accomplished with two main nerves. The olfactory nerve (first cranial nerve) processes the perception of chemical odourants. The trigeminal nerve (fifth cranial nerve) processes the irritation or pungency of chemicals, which may or may not be odourants[4].

As perceived by humans, odours have five basic properties that can be quantified[4]: 1. intensity, 2. degree of offensiveness, 3. character, 4. frequency, and 5. duration. All of which contribute to the neighbour's attitude towards the odour as well as the business generating the odour.

Odour is measurable using scientific methods. Odour testing has evolved over time with changes in terminology, methods, and instrumentation. Odour terminology is linked to standard methods and the instrumentation used in these standard methods. A clear understanding of odour terminology is needed in order to discuss the uses of odour measurements[5].

The objective parameters of perceived odour are[5]:

— Odour Concentration – measured as dilution ratios and reported as detection threshold or recognition thresholds or as dilution-to-threshold (D/T) and sometimes assigned the pseudo-dimension of odour units per cubic meter.
— Odour Intensity – reported as equivalent butanol concentration in 10^{-6}, using a referencing scale of discrete butanol concentrations.
— Odour Persistence – reported as the dose-response function, a relationship of odour concentration and odour intensity.
— Odour Character Descriptors – what the odour smells like using categorical scales and real exemplars (e.g. fruity → citrus → lemon: from a real lemon).

These odour parameters are objective because they are measured using techniques or referencing scales dealing with facts without distortion by personal feelings or prejudices.

Additional measurable, but subjective, parameters of perceived odour are[5]:

— Hedonic Tone – pleasantness vs. unpleasantness.
— Annoyance – interference with comfortable enjoyment of life and property.
— Objectionable – causes a person to avoid or causes physiological effects.
— Strength – word scales like "faint to strong".

These odour parameters are subjective because individuals relying on their interpretation of word scales and relying on their personal feelings, beliefs, memories, experiences, and prejudices to report them[5].

The most common odour parameter determined by odour testing is odour concentration. The characteristic odour concentrations are called "odour tresholds". Odour tresholds are minimal detectable concentrations at specific odour characteristics (detection or recognition). They are usually reported as odour units (OU), defined as the volume of dilution (non-odorous) air divided by the volume of odorous sample air at either detection or recognition. Most often, odour threshold is used to mean detection threshold (DT), which identifies the concentration at which 50 % of a human panel can identify the presence of an odour or odourant without characterizing the stimulus. Detection threshold is the term most frequently used when discussing odour research. The recognition threshold (RT) is the concentration at which 50 % of the human panel can identify the odourant or odour, such as the smell of ammonia or peppermint[1].

Odour measurement methods

Odour is elicited by chemicals in a gas phase which are detected via olfaction producing recognizable smells (cinnamon, lemon) and/or chemesthesis which mediates pungent sensations (tingling, burning, etc) in response to substances such as ammonia[4].

There are a number of factors which affect odour including the volatile compounds themselves, the number of olfactory receptors available to bind them, the degree to which the compounds become solvated for receptor binding, temperature, humidity, and the matrix in which the odour-producing chemicals are embedded. In addition, individual chemicals may interact (chemically). Odours vary in threshold, intensity and hedonic tone[5].

Of particular importance has been the characterization and measurement of key potent odourants responsible for the unpleasant odour associated with specific process. Furthermore, each odourant has a unique odour and odour detection threshold which means that compounds, even if present at the same concentration, may have markedly different odour impacts[6].

Monitoring odours can be accomplished with analytical "chemical" techniques and sensory methods[6]:

Analytical techniques:

— *Chemical analysis* – indirect assessment involving the collection of a sample which, when analysed, will give the concentration of the various chemical species present. This includes wet chemistry, as well as sample collection followed by instrumental analysis by means such as gas chromatography (GC).
— Direct reading instrumental analysis – provides information on the concentration of specific chemical species or their concentrations relative to each other. This includes portable analysers (including portable GCs and GC-MS) and the "electronic nose", as well as colorimetric tubes.

Sensory methods (relating to human response):

— *Olfactometry – a sensory assessment* – which gives an assessment of the physiological response to a particular mixture – strength, quality, characteristics – which provides information on the likely population response. This is obtained by exposing trained individuals to samples of the odorous air, either in the laboratory or in the field.

These are many division of categories for odour measurements techniques and some techniques could fall into more than one. There are a number of different methodologies in use for odour analysis. Selection of a particular method will depend upon: the purpose of the measurement; the frequency of monitoring (once-off, periodic, continous); the location at which the odour is sampled; whether a point source or area (surface) source; the nature and complexity of the emission - a single compound or a complex mixture[6].

Olfactometry measurements (dynamic olfactometry)

Olfactometry uses trained individuals and standardized procedures to measure odour levels. The main advantage of olfactometry is the direct correlation with odour and its use of the human sensitive sense of smell. Olfactometry also has the advantage that it analyses the complete gas mixture so the contribution of each compound is included[7].

Odours are a combination of gases—some in nearly undetectable concentrations. The human nose can sense these gases and gas combinations at extremely low levels. No instrument can match the sensitivity of the human nose. Several techniques have been employed to assist the human nose in determining detection threshold and intensity. The most popular method of odour measurement uses an instrument called the dynamic olfactometer and an odour panel[7].

Olfactometer (dynamic olfactometry) presents three air streams to the trained panellists (standards). One air stream is a mixture of non-odourous air and an extremely small amount of odourous air from a sample. The other two air streams have only non-odourous air. Panelists sniff each air stream and are asked to identify which air stream is different than the other two non-odourous air streams. Initially panelists must guess which air stream is different, because the amount of odourous air added is below the detection threshold[7].

In steps, the amount of odourous air added to one of the air streams is doubled until the panelist correctly detects which air stream is different. The air stream with the odour is randomly changed each time. Figure 1 illustrates the olfactometry measurement process.

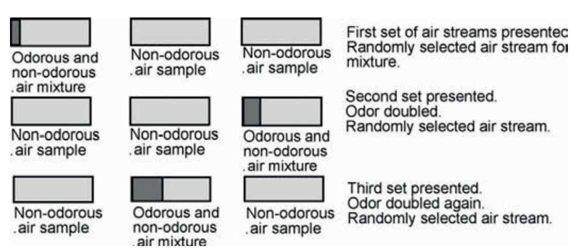

Figure 1: *Olfactometer dilution sequence of sample[7].*

The detection threshold is the non-odorous airflow rate divided by the odorous airflow rate when the panelist correctly recognizes which air stream is different. A panel of eight trained people is significant enough to analyze each odor sample. The panel's average concentration is reported and used for analysis[7]. This statistical approach is called triangular forced-choice method (also EN 13725:2003: Air Quality – Determination of Odour Concentration by Dynamic Olfactometry).

Olfactometers (Figure 2) are not portable and an operator closely controls sample delivery. The dilutionto-threshold ranges are available to be presented at 14 dilutions that represent a range in dilution-to-threshold of 8 to 66.667 (AC'SCENT olfactometer). These units are often used in a laboratory setting by 7 to 10 panelists.

Figure 2: *The AC'SCENT ® International Olfactometer was designed specifically to meet all requirements of the CEN odor testing standard, EN 13725:2003 and ASTM International E679-04.*

Odorous emissions from the processes of underground coal excavation and surface coal deposition

The objectives of this research are to develop and implement a robust odour emission monitoring system and collect the necessary data and develop an understanding of formation, dispersion and environmental impact of odorous compounds in the process of underground coal excavation and surface coal deposition.

Identification and quantification of odour sources

With processes of underground coal excavation the coal gases from coal seam are released on the working sites and instantly diluted with airflow formed by mine ventilation system (two ventilation stations). With mine ventilation system the diluted coal gases are emitted to the surface. In addition from excavation working sites (longwall and roadbuilding) the coal gases are also released (releasing characteristics are different for single gas species) from the coal transportation system (conveyer system is transporting coal on the surface).

Gases are also released from crushed coal on the stockpile (capacity 50 000–800 000 t). On the stockpile excavated coal is daily loaded/unloaded regarding coal production of CMV (10 000–25 000 t/d) and coal consumption of Power plant Šoštanj (up to 15 000 t/d). The stockpile is not covered and is fully exposed to the weather conditions.

The major potential odorous sources detected by humans in the mine and on the surface are to the present knowledge volatile sulphur compounds (VSC) which were detected in the mine and on the surface.

The origin of VSC is coal seam (formated and caught between coal formation) and possible formation of new VSC and transformation of VSC from coal seam, respectively. The released VSC from the coal seam and coal with 1.7 % of sulphur on average[8] are immediately after excavation exposed to the mine air and later atmospheric condition on the coal stockpile. Due to the reactivity and solubility of VSC formation and transformation is possible.

On the CMW (mine atmosphere) gas concentrations are monitored continuously (CH_4, CO_2, CO) with network of gas sensors or periodically (CH_4, CO_2, $(CH_3)_2S$ (DMS), H_2S, O_2, CO, H_2, NO, NO_2, SO_2) with analytical tests by gas chromatography (FID and FPD) and electrochemical sensors in the laboratories.

Measurements of VSC are particularly exposing DMS concentrations. The analysis of gas concentrations of one year periode from August 2010 to July 2011[2] has highlighted DMS concentrations. In air exiting ventilation shafts the DMS was detected always except in Pesje pit in August 2010 and in January 2011. The average DMS concentration in Pesje pit was 15.8×10^{-6} and in Preloge pit was 8.5×10^{-6}. The DMS concentrations up to 10×10^{-6} were periodically detected in air exiting roadway from the main transporation system. Gases H_2S and SO_2 are not detected ($<1 \times 10^{-6}$) in period from August 2010 to July 2011 what is expected under normal operating conditions.

Coal stockpile concentration measurements in 2003 identified DMS, COS and CS_2. The estimated daily emissions of COS and CS_2 for the whole stockpile in the sampling period were 20 g of CS_2 and 70 g of COS (gas concentration was in range 10^{-9}). The DMS concentrations fell to less than 1×10^{-6} in a few days due to the releasing from freshly loaded coal[3].

According to above listed, two ventilation stations (exiting mine air) are presenting point odour sources and coal stockpile is presenting area odour source on the surface of CMV excavation area (Figure 3).

The presented odour sources potentionaly effect few tens of kilometers of underground roadways and on the surface more than 10 km^2 of CMW area and some of nearby settlements. That means very large and diverse environment that's needs understanding regarding potential odorous environmental effect.

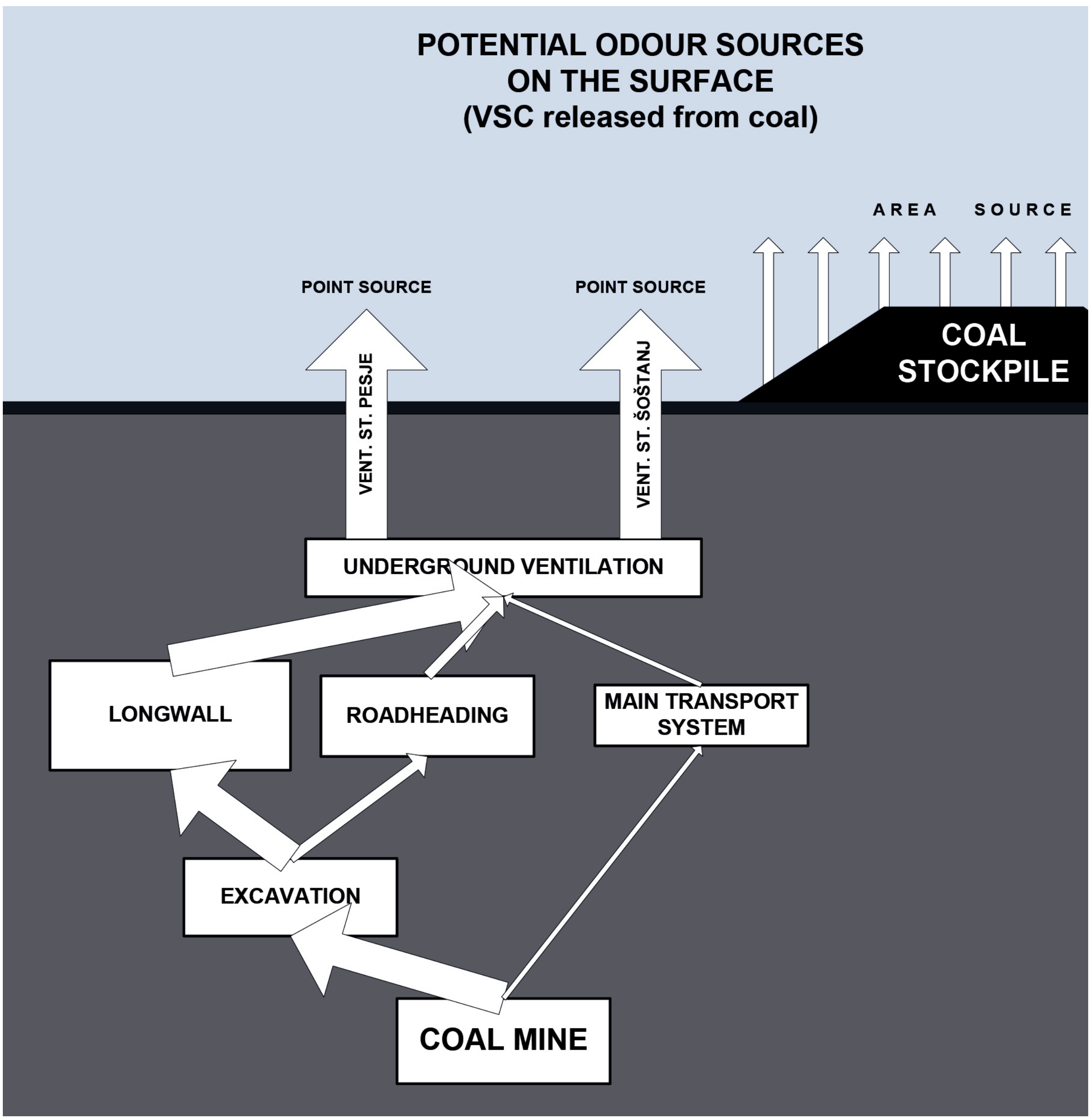

Figure 3: *Schematic presentation of odour sources in CMV.*

The main objectives of identification and quantification of odour sources are (Figure 4):

- Identification of odorous compound in the mine air and on the surface.
- Developing the understandment of main influences on the odour intensity and the correlations between the specific influences in the mine and on the surface.
- Evaluation of odour sources.

Better understanding of VSC presence in mine air is fundamental. The study and analysis of factors that are responsible for the presence (mine and surface) and amount of released individual VSC and correlations between factors are necessary (Figure 4).

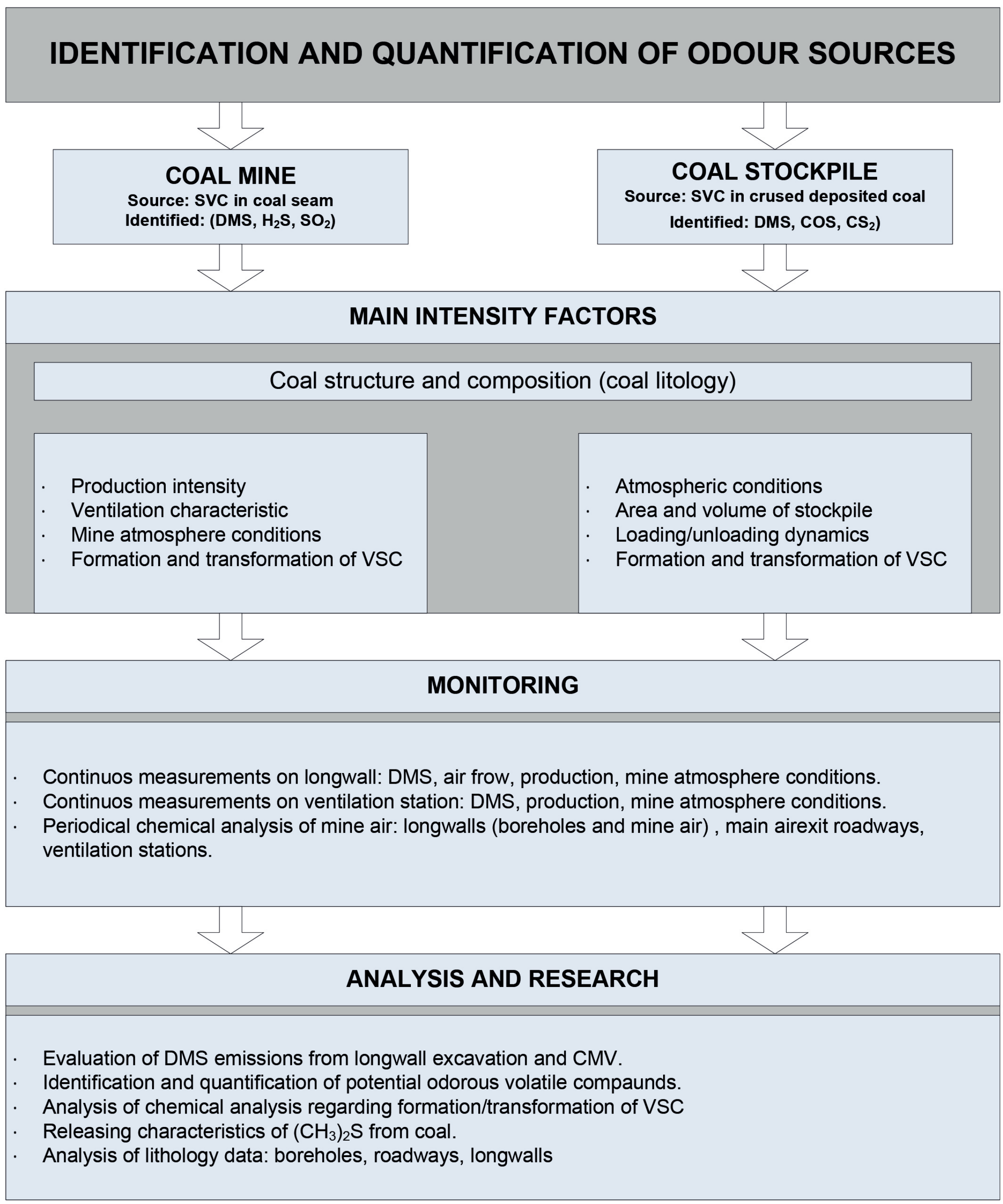

Figure 4: *Main activities of identification and quantification of odour sources.*

From the time of excavation and during transport coal is in contact with mine air. Also coal seam in excavation (longwall or roadbuilding sites) is in constant contact with mine air. Due to the known reactivity of fresh coal and reactivity and solubility of sulphur compounds atmospheric condition the formation and transformation of VSC are possible, respectively[9].

Many studies of Velenje lignite (geo-mechanical, structural geology, coal petrology, isotopic geochemistry, etc) revealed that knowledge about petrographic heterogeneity of lignite is crucial to understand complexity of gas properties and gas behaviour in the course of the mining within the lignite seam of CMV. For example, amounts of from-lignite-released gases depend on petro-chemical characteristics of coal and of technology of advancement and of lignite excavation[8].

Monitoring of odour emissions

On the large CMV area are recognized three main potentional odour sources of two different source types: 2 point sources (ventilation stations) and area source (coal stockpile).

The two types of sources have very different emitting characteristics. The ventilation stations are emitting mine air with known quite constant airflow quantity and gas composition that varies because the "underground influences". However, with the continuous monitoring of airflow and gas composition the averaged emission rates (gas emissions [g/h], odour emissions [OU/h]) can be quite easily estimated. On the other hand, the estimation of emission rates of the emitted odorous volatile compounds by diffusion is very complex due to the constant varying of great number of influences, mainly of releasing characteristics of captured in the coal or later formed volatile compounds, area/volume of stockpile, loading/unloading dynamics and coal manipulation on stockpile, cracks on the stockpile surface, atmospheric conditions, etc... Different emission types demand different sampling technics.

In addition, the large monitoring area demands the optimization of sampling locations that will realistically present odorous emission and odour imissions is very complex.

For odour field monitoring is often used standardized "grid method" according to VDI 3940: Measurement of odour impact by field inspection[10, 11]. Downside of this minimum six months lasting method is that a lot of man and equipment resources is needed for systematically inspection of area devided of squares (ussualy 250 m × 250 m[11]). In case impact evaluation of an anaerobic digestion plant[10] for inspection of approximate area 2 km × 1 km 16 a group panellist was recruted (selected according to EN 13725) and trained to recognise the typical plant emission odours.

The realistic presentation odorous emission and odour imission is also possible with specific characteristic sampling locations when you have good understandment of local weather.

Prior to odour and gas concerations monitoring the analysis of meteorologic data is necessary for detailed understendment of atmospheric characteristic of VCM wider area in all seasons of the year. The analysis and the specifics regarding odour dispersion will help to optimize the sampling location and number of samples.

Dispersion of odours is mainly impacted by topography around the odour source and atmospheric condition.

Differences between traditional dispersion modelling and odour modelling appear in at least three areas: at the source, at the receptor (the nose) and en-route from the source of the odours to the receptor. When conducting odour dispersion modelling, some features that odour sources are different from sources of industrial pollutants have to be taken into account. According to previous researchers, these features may include[12]:

— The odour source is at or near ground level.
— There is insignificant plume rise due to the vertical momentum or lower density of a mass flow of warm gas.
— The source may be of relatively large areal extent.
— The important receptor zone may be relatively close to the source of emissions.
— The difficulty in measuring the odour emission rate.
— The spatial and temporal variability in emission rates.
— The relatively low intensity of emissions.

Usually the at odour monitoring in addition of atmospheric condition the odour concentration and odour intensity are measured for later impact assessment with odour modelling.
In the case of CMW for monitoring of odourous emissions and odour imissions the simultaneous gas concetrations and odour measurement are necessary. With simultaneous measurements the odour compounds/odour data with same base and conditions are acquired which are essential for correlations research between VSC concentrations and odour concentration of ambient air.

From the results of the measured gas concentration data (DMS is only VSC continuously detected at concentrations more than 1×10^{-6}) and from expirence can be assumed that in most situations the individual VSC is only or major infuence odorous compound of detected odour.
The odour matrix of odorous emissions and odour imission from CMV is expected to be far less complexed than at livestock operation regarding of number of odouros compounds. At manure decomposition is produced between

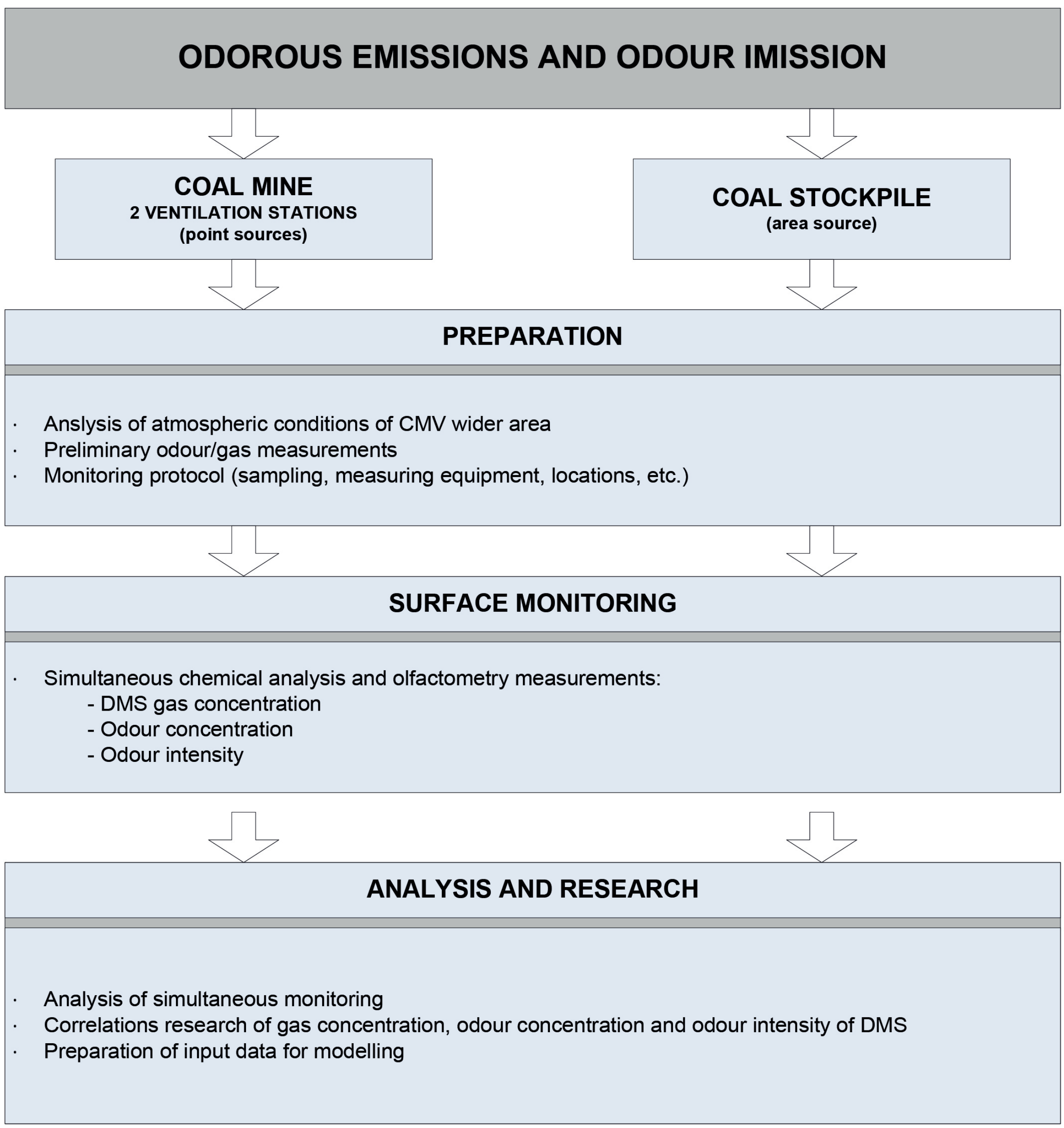

Figure 5: *Main activities of monitoring of odour emissions.*

80 and 200 odouros compounds; 168 have been identified in swine manure[7].

In case of CMV is assumed that major odorous compound is DMS. Therefore the DMS gas/odour interdependence can be potentionally essential base for odour modelling regarding control and validation with DMS dispersion modelling (traditional dispersion modelling) and for odour/DMS monitoring network design based on DMS sensor and enoses, respectively.

The monitoring of odorous emissions part will be focused on (Figure 5):

- Analysis of atmospheric conditions VCM wider area.
- Simultaneous measurements of gas concentration, odour concentration and odour intensity.
- Analysis of simultaneous monitoring.
- Correlations research of gas concentration, odour concentration and odour intensity of DMS.

Design and implementation of odour dispersion model

Dispersion modelling offers means to assess the way in which specific sources influenced by environment are having impact on the same environment.

After odours sources are identified and quantified and impacts of significant influencing factors on the releasing and formation of odorous compounds are known the revealed data are base for odour modelling.

For the assessment of odour impact also the gas concentrations modelling can be aplied, especially if odorous compounds are indentified and quantified. If the correlations between odour concentration and gas concentration of specific species (for example DMS) is known the gas modelling is equivalent and can used for control and validation, respectively.

The modelling of odour emissions and their dispersions will be divided in to two areas: mine and surface.

For the study of influences on mine odour sources the mine ventilation design software will be applied. The test model will be designed in Ventsim Visual. Ventsim Visual is mine ventilation design software with main feature as 3D graphic, simulate paths and concentrations of smoke, dust, or gas for planning or emergency situations, short term and long term planning of ventilation, simulation of gas and aerosol, etc[13]. For this study will be designed simplified test model (regarding to CMV roadway system) to evaluate sources from the longwall working sites and dispersions with airflow in the airexiting roadways and further dispersions all the way to the surface. The simplified model is more appropriate regarding specific correlations study. With the Ventsim Visual the main focus will be dispersion study of gas concentrations

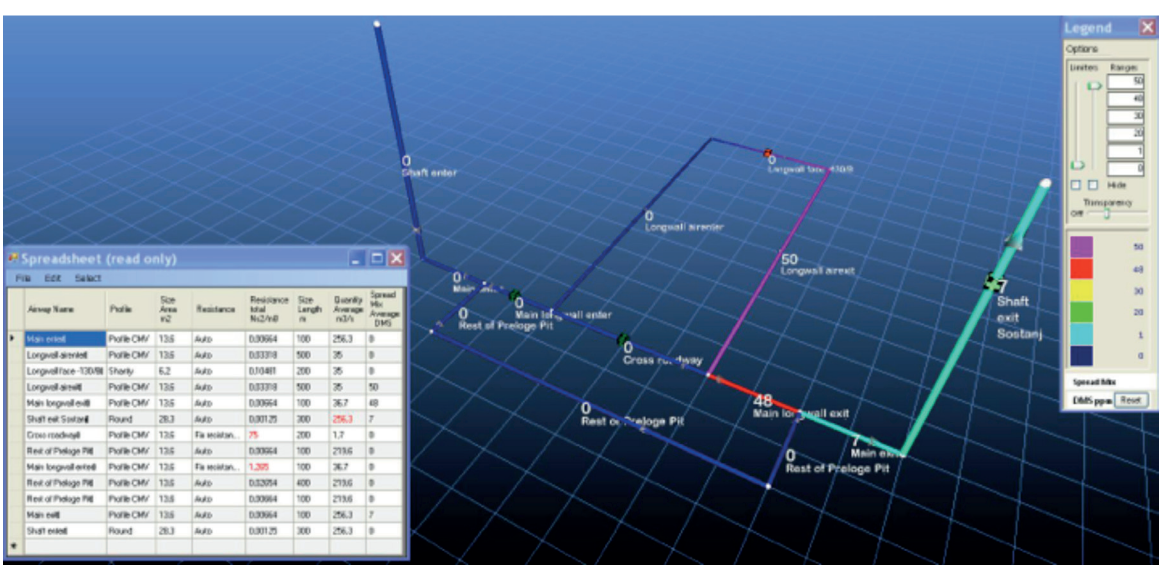

Figure 6: *Example of DMS dispersion modelling for longwall face.*

(no odour option in the software) of specific gas species under the influences of ventilation design and ventilation parameters. Because the dispersion of specific gas compound and odour (odour units – OU/m^3 are actually number of dilutions) in the same environment is similar the dilutions specific gas compound and dilutions of odours are comparable.

The modelling of odour impact on the surface is much more complex process mainly because of the modelling of atmospheric conditions of the wider researched area and because of the challenging quantification of odour sources (especially emission rate of area source – coal stockpile). Accuracy of odour impact assessment is mostly dependent of precision of atmospheric model and precision of odorous sources quantification.

The focus will be on design and implementation of odour dispersion model to assess surface environmental impact due to the emissions of process of underground coal excavation and surface coal deposition. The odour dispersion model will be then tool for study for specific influence factors of atmospheric conditions on the emission rate of odour sources and emission rate of specific odorous compounds.

For the design of odour dispersion model it will be necessary to use the software that is capable of mathematical simulation of atmospheric dispersion and air pollutant dispersion. The CALPUFF modelling system is also used for environmental impact assessment of SO_2, NO_2 and PM_{10} from emission of Thermal Power Plant Šoštanj (www.okolje.info).

CALPUFF has been accepted by the U. S. EPA as a preferred model for regulatory applications from 2003. It consists of three main components: CALMET, CALPUFF and CALPOST. CALMET is a meteorological processor that develops hourly wind and temperature fields in the three-dimensional gridded modelling domain; CALPUFF is a transport and dispersion processor that simulates dispersion and transformation processes of pollutant(s) along the dispersion way; CALPOST is a postprocessor used to process the files from CALPUFF to produce a summary of the simulation results[14].

CALPUFF is a Lagrangian puff dispersion model that is able to simulate the effects of complex meteorological condition in the process of pollutant transport. This model can handle emissions from any types of sources including point, line, area, and volume sources. It could be driven by either complicated three-dimensional meteorological data provided by CALMET for a full run or simple meteorological data from a single weather station.

Conclusions

The presented research plan addresses the problem of occasionally odour pollution of CMV underground coal excavation impact wider area. As the main surface odour sources are recognized: ventilator stations Pesje and Šoštanj and coal stockpile.

The ventilation stations (two point odour sources) are emitting between 21 000 m^3/min and 25 000 m^3/min of mine air. The concentrations of mine gases are time varying (in case of odours, concentrations of VSC) and are mainly dependent of coal seam composition and of technological, vetilation and mine atmosphere parameters.

The coal stockpile is an area odour source with varying in size (area and volume) and varying composition and releasing characteristics of deposited coal.

Gas concentrations measurements in the mine are particularly exposing DMS concetrations that are continuously detected at odour supra-treshold concentrations in airexiting underground roadways. The DMS odour detection treshold is 0.003×10^{-6} and the monitored DMS concentrations are $>1 \times 10^{-6}$.

The emitting point and area odour sources are dispersed according to the atmospheric conditions (also diffusion in calm conditions).

Due to the size and versatility of impact area, the range of influences, varying conditions and the odour science the research plan is divided in three main topics:

1. Identification and evaluation of odour sources;
2. Monitoring of odour emissions from sources on the surface (using simultaneous chemical analysis and olfactomety);
3. Design and implementation of odour dispersion modelling to assess environmental im-

pacts due to the emissions of underground coal excavation and surface coal deposition.

The topics follow the logical sequence of odorous compounds identification, quantifications of odour sources emission rates and development of odour dispersion models for development of an understanding of formation, dispersion and environmental impact of odorous compounds for implementation of technical measures to reduce odour impact and odour monitoring system.

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Review paper

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Mixed municipal solid waste (MSW) treatment in Waste centre Spodnji Stari Grad, Krško

Ravnanje z mešanimi komunalnimi odpadki v Zbirnem centru Spodnji Stari Grad, Krško

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Abstract

The main task of mechanical recycling line is the secretion of useful fractions from mixed municipal waste and thereby reducing the quantities of waste landfilled on the municipal solid waste (MSW) landfills. The capacity of the mechanical recyclin line was 15 t/h of mixed municipal solid waste, which are collected mostly (80 %) in bags. They separate bio-waste (heavy fraction), foil, mixed paper, non-magnetic metal, magnetic metal, PET (polyethilene terephthalate) plastic, hard plastic, composite packaging and waste for substitute fuel. Remnants of sorted waste end up in the press container, secondary raw materials are compressed with horizontal channel baler. After six months of mechanical recycling line operation in a MSW landfill was landfilled only 24 % of the total collected quantities of MSW in Krško municipality or 48 % of the total MSW waste brought into the recycling line. In article will be presented in detail the mode of mechanical recycling line operation and the results of sorting for mixed municipal solid waste in Krško municipality.

Key words: mixed municipal solid waste (MSW), material recovery facility (MRF), waste sorting center, Dolenjska regional waste treatment center (CeROD)

Izvleček

Glavna naloga sortirne linije je izločanje koristnih frakcij iz mešanih komunalnih odpadkov, s tem pa zmanjševanje količin odpadkov, odloženih na komunalna odlagališča. Kapaciteta sortirne linije je 15 t/h mešanih komunalnih odpadkov, ki so v 80 % zbrani v vrečah. Separirajo se biološki odpadki (težka frakcija), folije, mešani papir, nemagnetne kovine, magnetne kovine, PET- (polietilentereftalat) plastika, trda plastika, sestavljena embalaža in odpadki za nadomestna goriva. Preostanki sortiranja končajo v stiskalnem zabojniku, sekundarne surovine pa se stisnejo s horizontalno (kanalno) balirko. Po polletnem obratovanju linije se na odlagališču odlaga še samo 24 % odpadkov od skupne zbrane količine odpadkov v občini Krško oziroma 48 % odpadkov, pripeljanih na sortirno linijo. V članku so podrobneje predstavljeni način in rezultati delovanja sortirne linije za mešane komunalne odpadke v Občini Krško.

Ključne besede: mešani komunalni odpadki, obrat za sortiranje/snovno izločanje, zbirni center za odpadke, Center za ravnanje z odpadki Dolenjske (CeROD)

Introduction

In accordance with the national operational programme of municipal solid waste treatment and taking into account the European guidelines have the greatest emphasis to waste prevention, re-use and recycling and reducing of waste quantities landfilled on the municipal solid waste landfill sites. At the restoration/establishment of the system of municipal solid waste management in the municipality Krško and Posavje region is necessary to take into account the operational waste management programme of Republic of Slovenia and the European Union (EU) and the national legislation in force in the field of waste management. In Slovenia it is necessary in accordance with the current legislation, to organize a separate waste collection at the source and treatment of residual waste prior to disposal, and thus put a small amount of waste as soon as possible.

Table 1 and 2 summarize the objectives of the EU directives related to the municipal solid waste treatment[2, 3, 4].

To achieve the objectives of the EU directives for re-use and recycling of municipal solid waste by 2020 it will be necessary to change the way of municipal waste treatment practices at Slovenia in accordance with good EU and world practices. According to the minimum (waste reduction) scenario, compared to the baseline year 2011 it will be required by 2020:

— reduce the rate of mixed municipal solid waste from 50 % to 36 %,
— increase the share of separately collected waste paper, metal, plastic and glass with 34 % to 47 % (including waste collected outside the operation of public services) and
— consider increasing the amount of separately collected kitchen waste (aprox. 6.5 %).

For purposes of monitoring the environmental objectives of the EU Directives relating to the

Table 1: *The objectives of the EU Directives related to the municipal solid waste treatment*[11]

Targets from EU Directives	Year	Colection targets (in mass fractions, *w*/%)
storage of biodegradable waste on landfill	2006*	reduction of up to 75 % with respect to 1995
	2009*	reduction of up to 50 % with respect to 1995
	2016*	reduction of up to 35 % with respect to 1995
Municipal solid waste (at least for waste paper, metal, plastic and glass) – EU Directive 2008/98/ES	2015	implementation of separate collection
Municipal solid waste (at least for waste paper, metal, plastic and glass) – EU Directive 2008/98/ES	2020	re-use and recycling increased up to 50 % of total municipal solid waste quantity

*Slovenija is in accordance with 5th article of Directive 1999/31/ES postpone the implementation of the objectives for 4 years.

Table 2: *Indicators for assessing achievement of environmental objectives in Slovenia*[11]

	2011	2020	
		Minimum scenario	Feasible scenario
The share of mixed municipal solid waste (%)	50	36	33
The share of separately collected waste fraction (%)	50	64	67
The share of separately collected biowaste (%)	12	12	15
The share of recycled municipal solid waste (%)	45	61	64
The share of landfilled municipal solid waste (%)	47	15	11
The amount of municipal solid wastes (kg per habitant)	428	447	447
The amount of recycling wastes (kg per habitant)	193	271	285
The amount of landfilled municipal solid wastes (kg per habitant)	202	66	49

treatment of municipal solid waste in Slovenia (collected within and outside the public service) were constructed indicators, the values for 2011 and 2020 for the target are shown in the Table 2.

In accordance with the novel ZVO-1B Ur. l. RS, št. 70/2008[5, 10] the waste management must deal with three separate services namely the service for the collection and transportation, service for the waste treatment and service for the waste disposal. In the case of municipal solid waste of Krško the first two jobs, the collection, transportation and the waste treatment with the concession contract is carried out by the company Kostak. Disposal of residual waste by Decree is carried out by a regional community service CeROD on the regional landfill Leskovec at Novo mesto.

Waste treatment in municipality Krško and Kostanjevica

In the municipality Krško and municipality Kostanjevica na Krki (total 15 local communities) in accordance with the Act of waste management in the municipality Krško[1], the company Kostak carried out the collection and disposal of municipal solid waste. In both municipality areas operates 225 public collection points for separate collection of waste.

The quantities of waste fractions collected separately on public collection points and the quantities of waste collected with public services in the municipality Krško and municipality Kostanjevica na Krki in the period 2003 to 2011 are summarized in the following Tables 3 and 4.

Company Kostak transport all mixed and separately collected municipal solid waste into own Waste collection center Spodnji Stari Grad. Waste collection center, which is located near a closed waste landfill Stari Grad, began with operating in 2003. In Table 3 and 4 shows the quantities by public services collected waste and the quantities and shares in both municipalities separately collected fractions of wastes. We can see that the share of separately collected fractions gradually growing and today reaches about 40 % (cf. Figure 1), which approaching the 50 % objective target for Slovenia (cf. Table 2).

From the Table 4 we can see that the amount of waste collected in the municipality of plant growing. The main reason is the active involvement of all citizens in the county held a public waste removal, replacement of bulk tank to the individual, the opening of new businesses, increased purchasing power, clean dumps and operation of the collection center. The increased separate collection of waste also contributes intensive raising awareness through public media by company Kostak.

Table 3: *The quantities of separately collected fractions of wastes (in tonnes) in the municipality Krško[9]*

Year	Bulky waste	Hazardous waste	Paper	Plastic	Glass	Biowaste	Other separated waste fractions*	Total
2003	323	3	61	27	83	1	–	498
2004	349	12	102	64	94	472	–	1 093
2005	623	7	311	98	110	1 067	–	2 216
2006	620	6	315	170	120	1 282	273	2 786
2007	816	11	331	147	136	1 797	457	3 694
2008	576	6	273	175	164	2 048	1 120	4 362
2009	–	12	540	244	181	1 935	1 767	4 698
2010	–	16	603	248	188	2 738	1 962	5 755
2011	–	12	731	299	251	3 208	845	5 346

*Bulky waste from 2009 onwards shown under other separate fractions. Under other separate fractions are listed tin cans, composite packaging, styrofoam, waste grave candles, wood, tires, organic kitchen waste, electric and electronic equipment waste.

Table 4: *The quantities of waste (in tonnes) collected with public services in the municipality Krško, Kostanjevica na Krki*[15]

Year	Krško	Kostanjevica na Krki	Total (t)	Separate collected waste fractions (t)	Share of separate collected waste fractions (mass fractions, w/%)
2003	10 494	–	10 494	498	4.75
2004	10 016	–	10 016	1 093	10.91
2005	12 871	–	12 871	2 216	17.22
2006	14 370	–	14 370	2 786	19.39
2007	15 822	638	16 460	3 694	22.44
2008	11 792	737	12 529	4 362	34.82
2009	12 854	773	13 627	4 698	34.48
2010	12 461	1 102	13 563	5 755	42.43
2011	13 218	796	14 014	5 346	38.15
2012	10 024	752	10 776	–	–

Waste collection center Spodnji Stari Grad collect and sort waste plastic, paper, glass, sheet metal, packaging (carton) and biological, bulky and hazardous waste. Glass does not specially handled and mostly disposed of on an old landfill area. Plastics and sheet metal is sorted, pressed and prepared for further processing. Paper and cardboard they separate on the mechanical recycling line. Biological treatment of waste composting plant in the compost, which is mostly used for the rehabilitation of the collection center areas. The remaining bulky waste are collected in two annual campaigns, hazardous waste in one annual campaign[13]. Since 2007 (closure of local landfill Spodnji Stari Grad), all remainings after municipal waste recycling are unloaded on the ramp into roller tipping containers, waste compress and prepare for transportation on the landfill CeROD in Leskovac at Novo mesto (from the place about 39 km).

The company Kostak in 2011 has carried out waste sorting analysis, although it has been determined the average structure of the waste. Table 5 shows the structure of treated mixed municipal solid waste from municipality Krško and Kostanjevica na Krki, on which data has been estimated revenue that can be achieved from the sale of processed waste fractions[7].

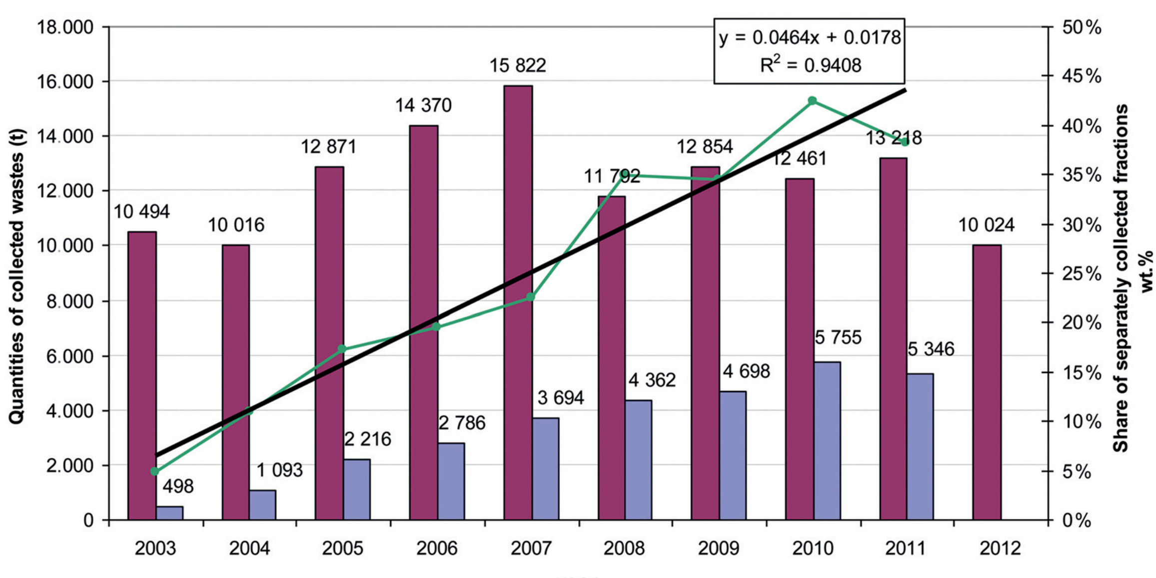

Figure 1: *The quantities and shares of separately collected fractions in both municipalities between 2003/2011.*

Table 5: *Estimated revenue and operating costs from the mechanical treatment of mixed municipal solid waste fractions in Waste collection center Spodnji Stari Grad[7]*

Type of waste	Share after sorting analysis in mass fractions, w/%	Quantity in mass fractions, w/% sorting analysis (t)	Estimated revenue from the sale		
			Estimated quantities (t)	Av. price (EUR/t)	Total (EUR)
Paper and cardboard	9	867	433.5	85	36 847.5
Plastics	23	2 098	1 049.0	60	62 940.0
Metals	5	456	228.0	150	34 200.0
Tetrapac	3	274	137.0		
Tekstil	6	547			
Wood	6	502	251.0	3	753.0
Styrofoam	1	91			
Bio waste	29	2 600			
Glass	9	867	433.5		
Other waste	9	821			
Total	**100**	**9 122**	**2 532.0**		**134 740.5**

The expected total annual cost of waste management in municipality Krško have been estimated to 74.14 EUR/t of waste and 59.37 EUR/t, taking into account the reduction in costs from revenues from the sale of fractions after mechanical recycling. The share of the cost of the mechanical treatment of waste in the total cost of treatment after the investment will amount to approximately 72.75 % or 43.62 EUR/t of waste[7].

In Figures 2 and 3 show the difference in the final composition before (2011) and after mechanical treatment/sorting (2012) of mixed municipal solid waste. We can see that the share of sorted fractions separated after the introduction of mechanical processing/sorting increased by about 1 % (we get new separated fractions like aluminium (ALU) cans, composite packaging (carton), various types of plastics and glass) for 15 % the proportion of organic waste for composting and about 26 % decrease in the proportion of waste for landfilling in CeROD.

In 2012, Waste collection center Spodnji Stari Grad was upgraded with a single stream (binary) mechanical recycling line (opening 17. 8. 2012), is currently one of the most modern recycling facility in Slovenia, which is capable of processing up to 15 t/h (50 000 t per year) of mixed municipal solid waste. Waste recycling will be upgraded in the near future also with a closed biological waste treatment facility.

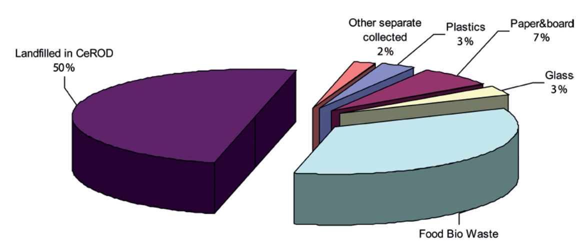

Figure 2: *Average composition of collected MSW before introduction of mechanical treatment (2011) of mixed municipal solid waste.*

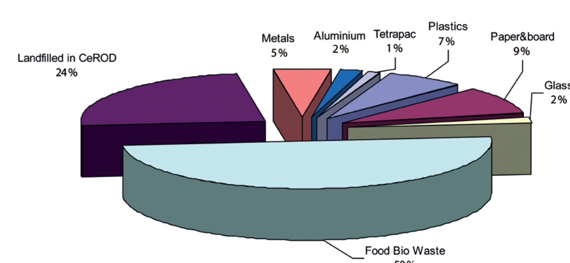

Figure 3: *Average composition of waste residues after introduction of mechanical treatment of MSW[8].*

Binary model of waste material recovery

In Waste collection center Spodnji Stari Grad using a single stream mechanical recycling line for mixed municipal solid waste separation. The separation of one material from a mixture of materials is termed as binary process, as two outputs from the operation[16]. A binary separator receiving a mixed feed of x_0 and y_0. The goal of the unit operation is to separate the x fractions in as pure form as possible and with the greatest total recovery possible.

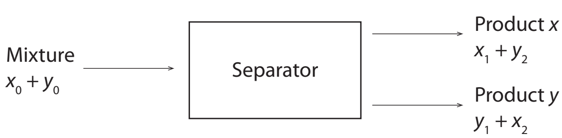

Figure 4: *A binary separator receiving a mixed feed of x_0 and y_0.*

One exit stream will contain the x components or product, the desired material. Separation will not be perfect, there will inevitably be contamination as y_1. A second exit stream, containing mostly the y component or reject (cf. Figure 4.). Note that this stream will also contain some of the component x_1. The recovery of x can be expresed as:[6]

$$R(x_1) = \frac{x_1}{x_0} \cdot 100 \quad (1)$$

where

$R(x_1)$ ... recovery of x in the first output stream

Equation does not take into account purity of the product. If the separation device is not operational, then all the input will pass through. In other words, $x_0 = x_1$ with the result that $R(x_1) = 100$ %. The purity of the product in the extract stream x is defined as:

$$P(x_1) = \frac{x_1}{x_1 + y_1} \cdot 100 \quad (2)$$

There are also difficulties with using purity alone as a descriptor of separator performance. For example, it might be possible to extract a small amount of x in a pure state, but the recovery ($R(x_1)$) will be very small. It is therefore necessary to describe the operation of a materials separation device by incorporating both the recovery and purity. Binary separator efficiency can be determinated as:[14]

$$E(x,y) = \left(\frac{x_1}{x_0}\right) \cdot \left(\frac{y_1}{y_0}\right) \cdot 100 \quad (3)$$

Example for binary separator can be eddy current separator. An eddy current separator is to separate aluminium product from an input stream of material. The feed rate to the separator is 1 500 kg/h. The feed is known to contain 55 kg of aluminium and 1 445 kg of reject. After 1 h of separation a total of 65 kg of material is collected in the product stream. On close inspection it is found that 46 kg of product is aluminium.

Recovery of aluminium product:

$$R(x_1) = \frac{x_1}{x_0} \cdot 100 = \frac{46}{55} \cdot 100 = 83.6\ \% \quad (4)$$

Purity of aluminium product:

$$P(x_1) = \frac{x_1}{x_1 + y_1} \cdot 100$$

$$= \frac{46}{46 + 19} \cdot 100 = 70.8\ \% \quad (5)$$

Efficiency of separator:

$$E(x,y) = \left(\frac{x_1}{x_0}\right) \cdot \left(\frac{y_1}{y_0}\right) \cdot 100$$

$$= \left(\frac{46}{55}\right) \cdot \left(\frac{(1500 - 65) - (55 - 46)}{1445}\right) \cdot 100$$

$$= 82.5\ \% \quad (6)$$

Mechanical treatment of MWS in Krško

Capacity and technology of mechanical recycling line in Waste collection center Spodnji Stari Grad was coordinated on the basis of the average composition of the MSW waste in Krško municipality (cf. Table 5). Mechanical recycling line is designed to have one hour of 15 t mixed municipal waste (50 000 t per year), which are mostly (80 %) collected in plastic bags.

Mechanical recycling line is designed for the separating mixed MSW, bio-waste (heavy fraction), mixed paper, non-magnetic metals, magnetic metals, PET (polyethilene terephthalate) plastic, hard plastics, composite packaging, glass and alternative fuels fractions, etc.

Residual of wastes after recycling process are pressed in a pressing container, secondary raw materials are pressed by the horizontal (channel) baler.

Mechanical recycling line is located in a conditioned enclosed facility for purpose of its minimal impact on the environment. Workspaces, where they are adequately lighted, heated and ventilated properly. The main components of recycling line are tipping floor with filling shaft and bag opener/breaker, feeding and picking conveyor belts, Trommel drum screen, magnetic and Eddy-current separators, ballistics separator, NIR (near infra red) optical identification system, PET (polyethilene terephthalate) perforators, baller press, sorting cabins and pens with containers for the separated waste fractions.

Technological flow diagram of mechanical recycling line of Waste collection centre Spodnji Stari Grad can be seen in Figure 5. Main technological processes of mechanical recycling lines are:

- delivery of waste in a tipping floor into closed facility,
- filling of waste with wheel loader into vertical shaft and bag opener/breaker,
- conveyor of waste in a Trommel drum sieve and waste separating into light and heavy fractions,
- waste separation in the ballistic separator depending on the specific weight; waste fractions after separation traveling on separate belt conveyors into different technological units on additional manual or optical NIR (near infra red) sorting,

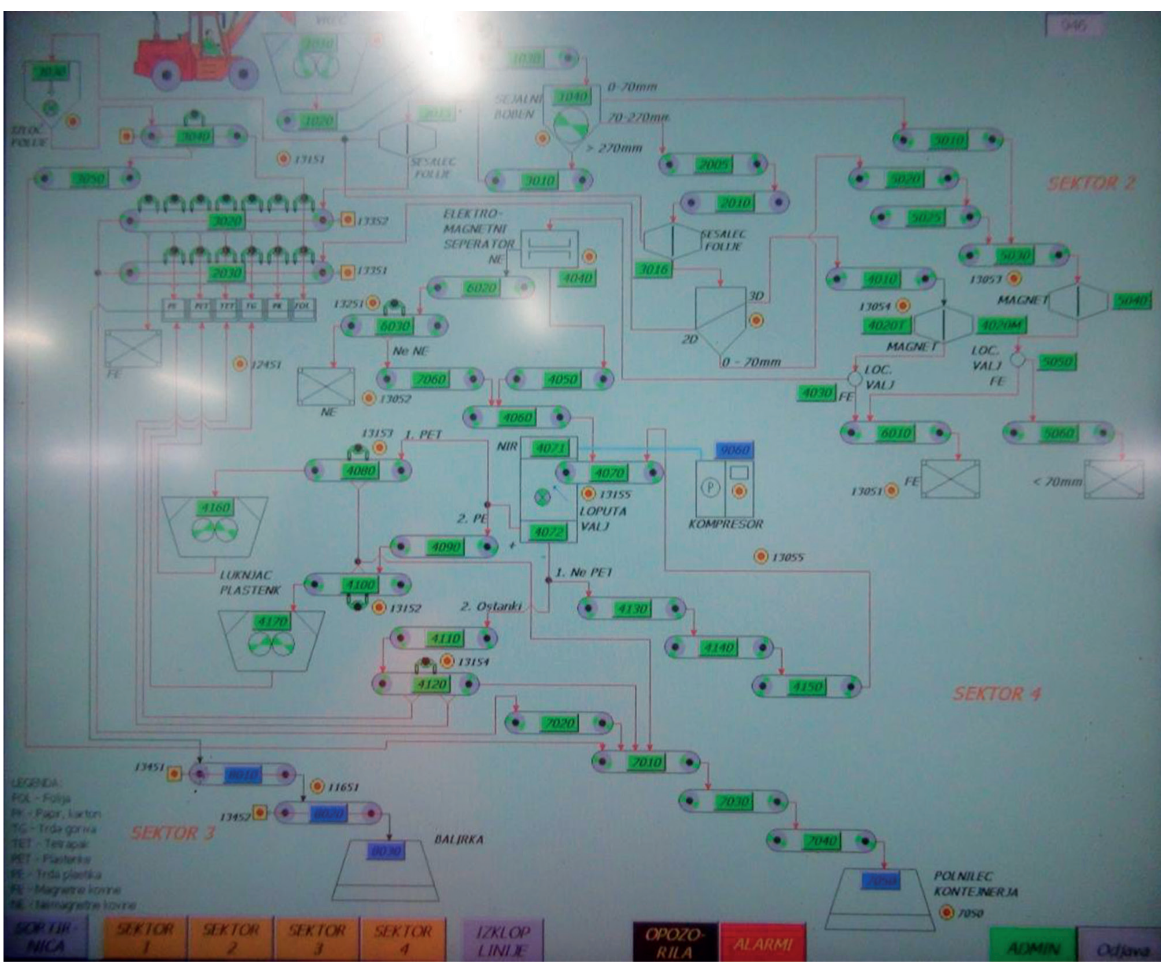

Figure 5: *Technological diagram of mechanical recycling line in Waste collection centre Spodnji Stari Grad.*

- NIR is a electronic device that allows sorting on 52 different types of waste; with optical sensor waste is determined by the type of material at the same time; for waste separate is using a nozzle under high pressure air,
- metal waste sorting is carried out on belt conveyors with magnetic and Eddy-current separators, whose job it is to separate iron from other non-ferrous metals,
- Individual waste fraction is eliminated and conducted with separate belt conveyor; finally storage is taking in separate pens with containers/bunkers.

Middle fractions with waste sizes from 80–320 mm; In this fraction of waste is expected to be present mainly plastics and metals. In order to increase efficiency of sorting ballistic separator is used. Ballistic separator separates middle fraction in three fractions 2D/3D/0–70 mm. Small fractions is combined with waste fractions from Trommel drum screen. Flat 2D fraction passes directly into the sorting facility. According to sorting analysis data in this fraction is expected mainly medium size plastic, paper, cardboard and textiles. As with a large fraction is also here possible carried out by manually sorting. At the sorting belt is space for 10 workers. Remain of wastes from the sorting belt is transported directly into press container. 3D-fraction is further separated, first via the overband magnet removes the magnetic metals and the Eddy-current separator eliminates non-magnetic metals.

The rest of the waste materiala separated in the NIR (near infra red) separator, at the first stage as a larger in waste presented portion separate only PET (polyethilene terephthalate) packaging and in the second phase separating all types of hard plastic. At the end of this sorting line, there are three fractions of PET (polyethilene terephthalate) plastic, hard plastic and scrap, who go to the final quality control in the sorting facility. According to the sorting analysis data in the sorting rest of the waste material are expected to have a composite packaging and fractions for substitute fuel preparations. It is also possible carried out by manually sorting, so as to reduce the amount of waste destined for dis-

Figure 6: *Details from mechanical recycling line of mixed municipal solid waste.*

posal on CeROD landfill. In the sorting shafts of PET (polyethilene terephthalate) plastic and hard plastic fractions are two perforators who perforating bottles and thus improve the efficiency of the (channel) baler.
Fine fractions with waste sizes from 0–70 mm; Fine fractions of the waste is composed mainly from organic and inorganic materials that go into the composting facility (heavy fraction). Magnetic metals from the fine fraction of waste are eliminated by overband magnet above the belt conveyor. Fine fraction of the waste is transported by a system of conveyor belts to the composting container, and will be further processed in the composting plant.
Energy usage in Material Recovery Facilities includes mainly electricity used for the operation of motors (belt conveyors, balers, optical separators, etc.) and diesel fuel used for heating and vehicle operations (front loaders and forklifts). Electricity consumptions ranging from 15 kW h/t to 20 kW h/t of feedstock depending on the degree of mechanization and diesel fuel consumption is estimated at 7.7 kW h/t of feedstock[12, 17]. According to data from Material recovery facilities in Greece, specific electricity consumption is 15–19 kW h/t of feedstock, while fuel consumption is up to 10,5 kW h/t.
Total instaled power of mechanical recycling line in Waste collection center Spodnji Stari Grad is 164.2 kW (conveyors 106.3 kW or 64.7 % and sorting devices 57.9 kW or 35.3 %)[7]. Average estimated electricy energy consumptions of mechanical recycling line Stari Spodnji Grad is 164.2 kW h/(15 t/h) = 10.9 kW h/(t/h), which ranks it as very energy efficient.

Conclusions and future objectives and tasks regarding waste management in municipality Krško and region Posavje

First results of mechanical recycling line operation in Waste collection center Spodnji Stari Grad indicate on increase of waste separated fractions and higher purity of useful raw materials, about 26 % reduction of waste quantities for disposal on the landfill CeROD (deposition only about 25 % the origin of the waste) and

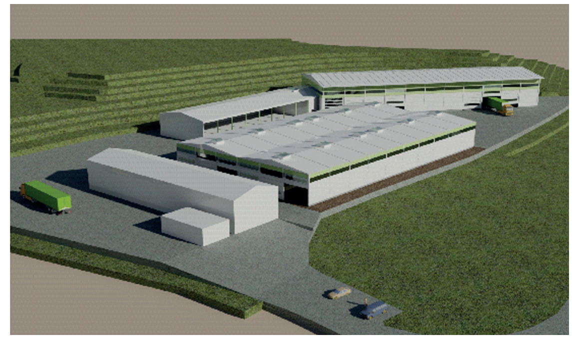

Figure 7: *Future view on Waste collection center Spodnji Stari Grad with facilities for mechanical and biological treatment of mixed municipal solid waste.*

the possibility of acceptance waste fractions for preparartion of alternate fuels from waste.
The advantages of mixed municipal waste treatment from municipality Krško, municipality Kostanjevica na Krki and in all Posavje region in Waste collection centre Spodnji Stari Grad can be divide into:

- economical; economic benefits are primarily in lower transport costs of mixed municipal wastes in CeROD, which have over the years amounted up to 50 000 EUR per year and lower the cost of waste treatment as in the case of processing waste in the mechanical biological treatment (MBO) facility in CeROD,
- ecological; ecological advantages are in reducing emissions of exhaust gases due to fewer waste transport services, a smaller quantity of wastes deposited in the landfill CeROD (Leskovec), and lesser impact on the environment due the indoors sorting and treatment of waste in halls,
- social; social benefits are primarily in new jobs and a lower cost of waste management in municipality Krško or Posavje region.

Future waste management objectives and tasks in the municipality of Krško and Posavje region aimed at upgrading the biological treatment facility, IPPC (Integrated Pollution Prevention and Control) permit authorization for 15 t/h or 50 000 t per year mixed municipal solid waste treatment, unification of separate waste collection in Posavje region, rank of Waste collection centre Spodnji Stari Grad into a new national waste management operational program, the promotion of efficient waste separation and collection system, the selection of contractor for mixed municipal waste treatment in the entire Posavje region, matching and confirmation rates of mixed municipal waste treatment, part of the environmental benefits paid to the development of separate waste collection system and to ensure adequate quantities of waste from Posavje region for CeROD or redefine of mass waste streams and the construction of relevant facilities. The annual quantity of mixed municipal solid waste from Posavje region into landfill CeROD was around 12 500 t.

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Review paper

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Analysis of global projections for primary energy resources supply – importance and role of coal in world and in Slovenia

Analiza globalnih projekcij za oskrbo s primarnimi energijskimi viri – pomen in vloga premoga v svetu in v Sloveniji

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Abstract

According to BRG (German Federal Institute for Geosciences and Natural Resources) data from 2010 in the world structure of global energy reserves, there is still available 24.2 % of oil, 17.6 % of gas, 4.3 % of uranium and thorium and other 53.8 % of all categories of coal. Coal is the only resource among the fossil fuels, which will remain in the energy market the longest, due to the large volume of reserves around the world. World proven reserves at the end of 2010 reached 729 billion tons. The EU's dependence on fossil fuel imports will significantly increase from 2010 to 2030[1] namely, the amount of coal will reduce in 2030 for 63 % (2010 – 48 %), for oil 95 % (2010 – 86 %) and for gas 84 % (2010 – 64 %). Fossil fuels remain the dominant primary energy resource worldwide and represent the projection of more than three-quarters of all consumption in the period up to year 2035.

The scope and effectiveness of strategic measures for preventing climate changes remains a major factor that cannot be predicted for the future direction of development of the coal market, but in any case the world cannot waive the coal. According to current scenarios, it is expected that the growth rate of CO_2 emissions from coal will amount to 1.5 % between 2007 and 2030 (1990 – 20.9 Gt, 2007 – 28.8 Gt, 2020 – 34.5 Gt, 2030 – 40.2 Gt). The combined efforts in the fight against climate changes we are currently facing around the world and development of new energy technologies including the usage of CCS (Carbon Capture and Storage) technologies could lead to lower CO_2 emissions.

Key words: energy demand, energy supply, coal, CCS (Carbon Capture and Storage), UCG (Underground Coal Gasification)

Izvleček

V strukturi globalnih energijskih rezerv po podatkih BRG (German Federal Institute for Geosciences and Natural Resources) iz leta 2010 imamo na svetu na voljo še 24,2 % nafte, 17,6 % plina, 4,3 % urana in torija ter 53,8 % vseh vrst premoga. Premog je med fosilnimi gorivi edini vir, ki bo na energijskem trgu zaradi velikega obsega zalog po vsem svetu ostal najdlje. Dokazane rezerve so konec 2010 dosegale 729 milijard ton.

Odvisnost EU od uvoza fosilnih goriv se bo od leta 2010 do leta 2030 bistveno povečala[1], in sicer bo za premog v letu 2030 63 % (2010 – 48 %), za nafto 95 % (2010 – 86 %) in za plin 84 % (2010 – 64 %). Fosilna goriva ostajajo dominanten primarni svetovni energijski vir in pomenijo v projekcijah več kot tri četrtine povečanja vse porabe v obdobju do leta 2035.

Obseg in učinkovitost strateških ukrepov za preprečevanje klimatskih sprememb ostaja še naprej glavni dejavnik, ki ga ni mogoče napovedati za prihodnje smeri razvoja trga premoga, se pa premogu v svetu po nobenem scenariju ne bomo mogli odpovedati. Po sedanjih scenarijih se pričakuje, da bo stopnja rasti emisij CO_2 iz premoga 1,5 % med leti 2007 in 2030 (1990 – 20,9 Gt, 2007 – 28,8 Gt, 2020 – 34,5 Gt, 2030 – 40,2 Gt). Združena prizadevanja v boju proti klimatskim spremembam, kot smo jim sedaj priča po celem svetu, bi z razvojem novih tehnologij v energetiki vključno z uporabo CCS-tehnologij (zajem in skladiščenje ogljika) lahko vodila do nižjih emisij CO_2.

Ključne besede: energijske potrebe, oskrba z energijo, premog, CCS (zajemanje ogljika in skladiščenje), UCG (podzemno uplinjanje premoga)

Introduction

The projections for world energy supply with primary energy products are nowadays facing a relatively large uncertainty, which was caused by the global economic crisis in the years 2008 and 2009.
In Slovenia, we are confronted with the consequences of the crisis in 2013. All the world's governments are confronting with three long-term challenges related to the climate changes, as well as the reliability and security of the energy supply[2]. Additional considerations of energy supply in the world arose in the recent natural disaster in Japan. The first move by the German government's decision was to close all nuclear power plants by 2022, bringing about radical changes in Germany's energy strategy, which substantially desires to accelerate the deployment of renewable energy resources, and thus by 2022 replace the nuclear energy. Expert public is sceptical towards a realistic estimation of policy decisions.

Primary energy demand in the world

In[3], published by the International Energy Agency (IEA) based in Paris; the world's future energy scenarios are focused on three projections, namely current policies scenario, in the publication[4] so-called reference scenario, new policies scenario (this is associated with already reached agreement on reduction of greenhouse gas emissions and despite the reduction of emissions there is considerable uncertainty as Kyoto Protocol commitments expire by 2013 and there haven't been no new agreements yet in Copenhagen and Cancun) and the third 450 scenario (this scenario takes into account to limit CO_2 emissions to 450 ppm CO_2).
The scenario and the direction we will adjust in the future, largely depends on the countries around the world. China and India will play an important role in these arrangements, and with their large reserves of coal, economic growth certainly will not be able to denounce them in the future.
The volume of primary energy demand in the world with regards to fuel type is described in Table 1. Fossil fuels remain dominant primary energy resource and represent in the projections more than three-quarters of all fossil fuels spent by the year 2035. Coal is mainly devoted to the energy sector or electricity production, increased consumption by 2035 is planned at an annual rate of 2.2 %.

Coal demand in the world

Five world's largest consumers of coal, China, the USA, India, Japan and Russia together account for 72 % of world coal consumption. Under the current scenario, the IEA (current policies scenario) should reach an average growth of coal by 2015 at 3.1 % per year until 2015 and 1.3 % per year between 2015 and 2035. Demand for coal will largely depend on envi-

Table 1: *Primary energy demand (based on fuel) in the world depending on particular scenario (in Mtoe – 1 t of oil equivalent = 42 GJ)*[3]

			new policies scenario		current policies scenario		450-scenario	
	1980	**2008**	**2020**	**2035**	**2020**	**2035**	**2020**	**2035**
Coal	1 792	3 315	3 966	3 934	4 307	5 281	3 743	2 496
Oil	3 107	4 059	4 346	4 662	4 443	5 026	4 175	3 816
Gas	1 234	2 596	3 132	3 748	3 166	4 039	2 960	2 985
Nuclear	186	712	968	12 773	915	1 081	1 003	1 676
Hydro	148	276	376	476	364	439	383	519
Biomass and waste	749	1 225	1 501	1 957	1 451	1 715	1 539	2 316
Other renewable	12	89	286	699	239	468	325	1 112
Total	7 229	12 271	14 556	16 748	14 896	18 048	14 127	14 920

ronmental commitments of all countries in the world the possible scenarios are shown in the Figure 1.

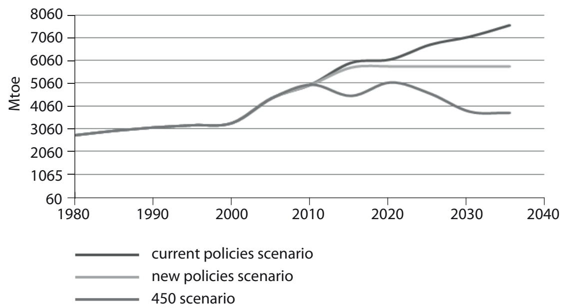

Figure 1: *Coal demand depending on scenario*[3].

The projections of coal demand in the world show a substantial reduction of its demand in OECD countries, whereas in other parts of the world as in Table 2 showing the increase of coal usage. Growth in the share of coal in total energy supply will increase from 26 % in 2006 to 29 % by 2025. By 2030, China will spend 50 % of world coal. In India, there has been the second largest growth in coal demand (in the year 2030 it would exceed the USA).

Reserves and production of coal in the world

Coal as a fossil fuel is among primary energy resources most widely available and the most geographically dispersed. The world proven reserves have reached 729 billion tons at the end of 2010 BRG (German Federal Institute for Geosciences and Natural Resources). Figure 2 shows the global energy reserves, whereas 53.8 % from all reserves present bituminous and sub-bituminous.

In the period between 2006 and 2030, it is expected that coal production will increase by 52 % (+ 2,397 Mtce)[2], at an average annual

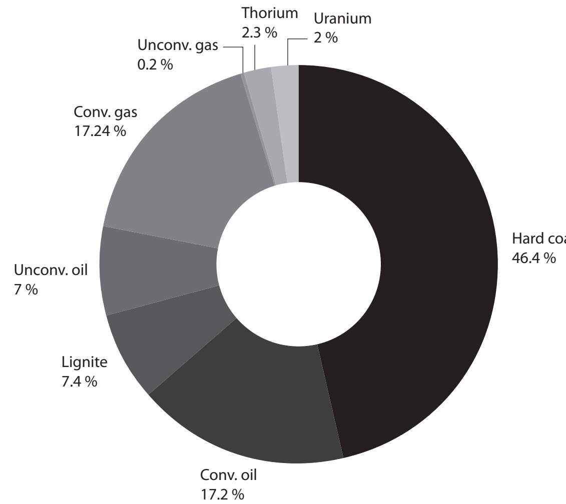

Figure 2: *Global energy reserves*[5].

rate of 1.8 % (OECD, in the same period registered a growth of only 0.3 % per year). The USA will remain the largest producer in the OECD with increase of 18 % between 2007 and 2030. In non-OECD countries, it is expected 2.4 % annual increase to meet domestic demand. Energy coal for electricity production is expected to grow by 2.2 % per year; its share in electricity production is expected to increase from 77 % in 2007 to 81 % in 2030.

Reserves and coal production in Slovenia

Of fossil fuel energy resources, Slovenia has only coal, which is the reason that Slovenia has to handle its reserves and exploitation in the most rational way. Since the EU does not control oil and gas markets, the risks in the supply are extremely high. Despite all the economic and environmental disadvantages of coal, EU will not significantly reduce its current consumption. Major coal beds in Slovenia are in Velenje, Zasavje and Prekmurje.

Table 2: *Coal demand in particular regions and scenarios (in Mtce – 1 t of coal equivalent = 29,3 GJ)*[3]

			new policies scenario		current policies scenario		450-scenario	
	1980	**2008**	**2020**	**2035**	**2020**	**2035**	**2020**	**2035**
OECD	1 379	1 612	1 452	1 021	1 596	1 507	1 348	709
Non-OECD	1 181	3 124	4 213	4 600	4 557	6 037	3 998	2 856
Total	2 560	4 736	5 665	5 621	6 153	7 544	5 347	3 566

Velenje

Balance reserves of lignite in a coal bed in Velenje coal mine (PV) in the Šalek valley are on the day 31. 12. 2008 estimated to 171 million tons[6] exploitation reserves are 131.67 million tons with an average calorific value 10.47 J/kg. The situation is summarized from the elaborate of the classification and categorization of the calculated reserves and resources of coal in the Velenje Coal Mine from December 2008[7]. Projections for future coal production are linked to long-term operation of Thermal Power Plant Šoštanj (TEŠ), which will with the investment in block 6 with a power of 600 MW replace the electricity generating compensation from blocks 1, 2, 3, 4 and 5. PV is the only supplier of coal for the TEŠ. In Šalek valley, in the so-called Šoštanj's part of deposit, there is approximately 90 million tons of coal balance reserves and based on estimation we could gain about 60 million tons of coal to the surface. The Velenje Coal Mine has temporarily waived to its exploitation. Using conventional methods of excavation and requirement of excavation without the surface subsidence in exploitation of this coal would not be economically justified[8].

Forecast level of coal production until 2015 is 4 million tons per year, by 2040 it will be gradually reduced to the amount of 2 million tons per year and will remain at that level until the end of exploitation of Velenje's excavation field, which is expected to be until 2054. Long-term preservation of lignite mining in the Velenje Coal Mine is important for diversification of energy resources, particularly for electricity production. As a domestic energy, resource lignite significantly reduces the risk of the energy supply in the exceptional economic and political circumstances. In accordance with the needs of the TEŠ, the level of annual coal production is consistent from the PV by the year 2054. After 2014, the starting price of coal from the PV will be 2.25 EUR /GJ.

Zasavje

The Republic of Slovenia has, with the law on the gradual closure of Trbovlje-Hrastnik mine (RTH) and development of restructuring of the region (Official Gazette RS, no. 61/2000)[9], decided to close the brown coal mines in Zasavje. The production price of coal by the end of the estimated production of coal shall not exceed more than 3.0 EUR/GJ. Thermal Power Plant of Trbovlje (TET) expires in 2017. TET is planning to produce electric energy with the existing facilities until this year, as more strict environmental protection requirements will be established for which the existing plant is not appropriate. Excavation of potential reserves, which in 2009 were still about 24 million tons of coal (detailed report on reserves with the situation on 31. 12. 2002), RTH has recorded 53 million tons[10] in the balance sheet reserves, of which 24 million tons were excavated at an average heating value 11 MJ/kg. TET is an important energy location for Slovenia, but there have not been any decisions taken regarding its modernization yet.

Prekmurje

In the western part of Goričko in Videm by Ščavnica, Presika and between Lendava and Petišovci, some potential sub-bituminous reserves 830 million tons[11] were discovered. The most important is the area in the western Goričko from Strukovci to Kuzma. The quality of coal is better than the quality of all brown coals in Slovenia. Calorific value is 17.5 MJ/kg and combustible sulphur content is 0.91 %. Coal is just below the surface. It is expected that on the area of 50 km^2 to a depth of 250 m there are around 450 million tons of potential coal reserves. Coal seam thickness is between 10 m and 12 m. Estimations of coal resources are based on Goričko research boreholes and well logging measurements from drilling for oil, and it would be necessary to confirm this coal reserves with appropriate geological research works (mapping, drilling and sampling) and pre-categorisation of reserves from existing category D in the category C2. Coal reserves, located in Prekmurje are needed to be explored in the future. Underground coal gasification technology (UGC) will in the future (because of the nuclear disaster in Japan) have experienced a significant development steps and the cost and environmental and will with cost and environmental high probability approximation approach to commercial applications. Coal reserves and their exploitation in Prekmurje is not appropriate to bind on the conventional mining, but on the mining of underground gasification technology, which is shortly described in chapter entitled: Alternative energy supply.

Coal and CO_2 emissions

The extent and effectiveness of strategic measures to prevent climate changes remains a major factor that can not be predicted for the outlook of development of the coal market in the future. Projections of the modernization of combustion plants and CO_2 reductions is shown in Figure 3 under the current scenario, it is expected that CO_2 emissions from coal reach an annual growth of 1.5 % between 2007 and 2030 (1990 – 20.9 Gt, 2007 – 28.8 Gt, 2020 –34.5 Gt, 2030 – 40. 2 Gt).

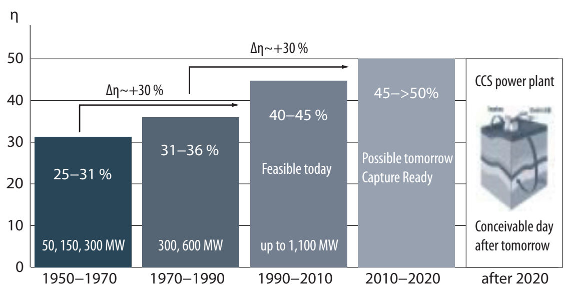

Figure 3: *Technology development and modernization of combustion plants and process of CO_2 reduction*[12].

The combined efforts in the fight against climate changes that we are currently witnessing around the world, including the use of CCS (Carbon Capture and Storage – capturing and storing carbon dioxide) technology, could lead to lower CO_2 emissions into the environment[13].

Alternative energy supply

Underground coal gasification (UCG) could become an alternative with usage of deep-lying coal as a clean gasification of fuel in order to provide fuel for producing electricity. UCG for the production of gas uses and requires two or three boreholes. With two boreholes, we impress the air, oxygen or steam in the first one and as a result from the second production borehole we get gas (mainly hydrogen and carbon monoxide), which must be cleaned with special procedures for its use. Both boreholes are connected with the zone, which represents a coal block in which combustion and gasification occur, which of course is monitored and controlled. Figure 4 shows the technological scheme of the underground coal gasification using two boreholes.

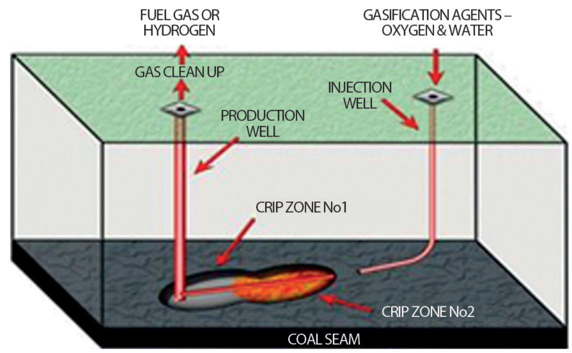

Figure 4: *Process of underground gasification with a usage of two boreholes*[14].

Figure 5 shows technological scheme of UCG with usage of three boreholes. UCG was commercially used in the former Soviet Union and Uzbekistan in the early sixties. Recent projects undertaken in China, Australia, Canada and South Africa have not led to commercial UCG projects yet. Development in these countries is oriented at improving drilling techniques and computer-aided modelling.

Results of previous studies are rather sparse in order to protect intellectual property rights. Some data has only been published on the temperature of the process, which should be higher than 1 000 °C. A discussion was held on the impact of environmental temperature on the geological formations. All the current pilot projects are estimated to be worked out in relatively small quantities of coal (15 to 20 million tons of coal), but it is likely that countries with large coal reserves will facilitate faster development of projects. UCG technology commercialization project will be extremely difficult, it will be necessary to pool knowledge and resources of interested countries, which will certainly happen in the future. This will occur fast, especially if the climate agreement is not favourable for coal.

One of the alternatives in the development of new clean coal technologies and the exploitation is gas from the coal. Methane, which is captured in the seams of coal at a great depth and layers that with an implementation of the

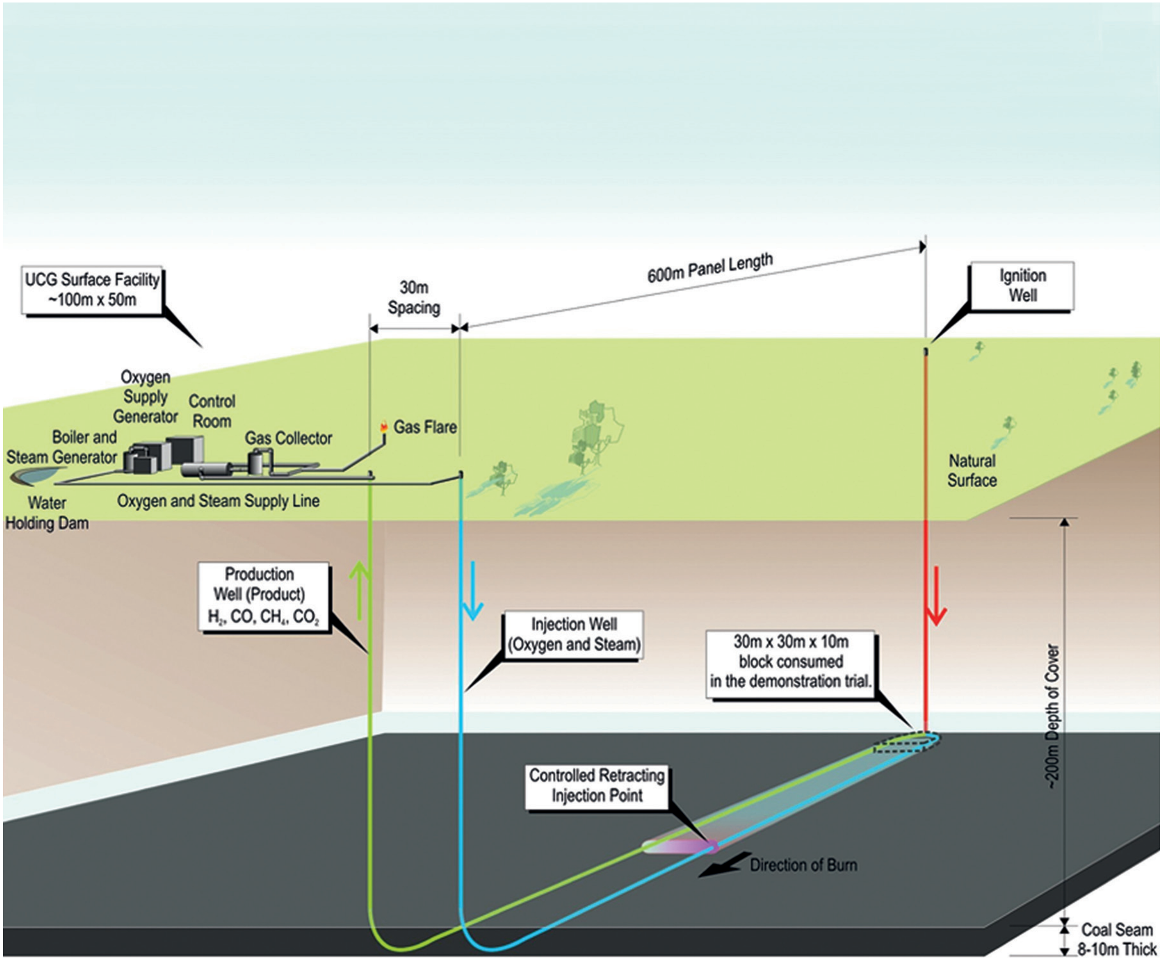

Figure 5: *Process of underground coal gasification (UCG) with a usage of three boreholes*[14].

conventional technology cannot be used, could be a potential energy resource for electricity production.

Conclusion

With domestic energy, resources in electricity production will continue to be handled in the most rational way. The fundamental objective of the Slovenian electricity sector is to maximize self-sufficiency in electricity supply[15] and use of synergy effects, building a balanced structure of energy resources in Slovenia (1/3 hydropower, 1/3 nuclear power, 1/3 thermal power). Long-term preservation of lignite mining in the Velenje coal mine is important for diversification of energy resources, particularly for electricity production. Being a domestic energy resource, it is important to reduce the risk in the energy supply. Let we remind you of 2003, when coal from Velenje was supplying 50 % of the country's electricity. That way we avoided electrical failure, which among the other countries also affected Italy. Usage of coal in block 6 in the TEŠ will be aligned with EU environmental obligations and our country will be limited to large combustion plant with high efficiency – 43 % based on BAT (best available technology) technology, and emission reduction commitments in the climate-energy package will be met in the context of the EU ETS. The remaining coal reserves in Zasavje will have a meaningful advantage in a conjunction with the investment stake in Thermal Power Plant Trbovlje, which is important for our country's energy location and will continue to be maintained. All investments in new energy facilities in Slovenia and in Europe are contributing to higher energy as environmental and economic efficiencies respectively.

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Opening, development and exploatation of coal deposit Mariovo in Republic of Macedonia with underground mining technology

Odpiranje, razvoj in izkoriščanje premoga v nahajališču lignita Mariovo – Makedonija z jamsko tehnologijo

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Abstract

Coal deposit Mariovo in Republic of Macedonia is one of many unused natural resources in Macedonia. The reason for unexploited energetic potential is relatively large distance from energetic locations, where the coal could be used for production of electric energy. Investor – ELEM (Macedonian Power Plants), Macedonian state owned company, that unites all major power producers in the country, wants to open the mine by the year 2017. Premogovnik Velenje participated in research of coal deposit with a team of design engineers, who directed the research works. The team of design engineers also completed all the design documentation from opening of the deposit till the full capacity of underground production which would be 2 million tons per year.

Key words: coal mine, coal deposit opening, underground mining technology, process of opening the deposit

Izvleček

Nahajališče lignita Mariovo v Republiki Makedoniji velja za enega od mnogih neizkoriščenih naravnih rudnih bogastev Makedonije. Razlog za neizkoriščenost tega energijskega potenciala je relativno velika odmaknjenost od energetskih lokacij, kjer bi lahko premog pretvorili v električno energijo. Investitor – ELEM (Elektrani na Makedonija), makedonsko državno podjetje, ki združuje vse večje proizvajalce električne energije v državi, želi rudnik odpreti do leta 2017. Premogovnik Velenje je sodeloval pri raziskavah nahajališča z ekipo projektantov, ki je usmerjala raziskave, in izdelal glavni rudarski projekt za odpiranje in razvoj nahajališča premoga, ki obsega vso projektno dokumentacijo od odpiranja do polne kapacitete premogovnika, ki je 2 mio. ton na leto.

Ključne besede: premogovnik, odpiranje nahajališča, jamska tehnologija, postopek odpiranja nahajališča

Introduction

Coal deposit Mariovo in Republic of Macedonia is one of many unexploited natural resources in Macedonia. The relatively large distance from energetic locations, where the coal could be used for production of electric energy is the reason why this deposit is still intact. Nonetheless, the extensive geological and hydrogeological research has been done. The complete deposit has been bored through with the last research series completed in 2010. Results of all the research work enable to start the work on mine design. Members of the design team of technical services of Velenje Colliery participated as consultants in the research work.

Scope of work

Investor – ELEM (Macedonian Power Plants) and Premogovnik Velenje (Velenje Colliery) signed a contract for elaboration of mining project containing all the necessary documentation – starting with research and ending with first tons of coal on the stockpile

The following studies and projects[1] were finished:

- technical – economical part of the report on classification in categorization of coal reserves,
- basic concept for exploitation of lignite in the Mariovo deposit,
- the main mining project that contains:
  - technical project for opening and development of the deposit,
  - technical project for mining technology (mining method),
  - technical project for ventilation,
  - technical project for dewatering,
  - technical project for underground coal haulage,
  - technical project for surface transport system;
- project for elaboration of industrial circle with infrastructure,
- project for supply of the mine with electric energy,
- project for lignite crusher system,
- project for automatic remote control of ventilation, fire protection and technological parameters of the Mariovo mine,
- project for supply of the mine with compressed air,
- project for supply of the mine with technological and drinking water,
- project for supply of the mine with fly-ash mixtures for isolating lining,
- project for supply of the mine with hydraulic emulsion,
- project for environmental impact of Mariovo mine and surface structures,
- project for fire protection of surface structures,
- project for organization of the work at coal production and service activities,
- project for disposal of tailings (mine dump),
- time plan for activities at mine construction until the planned production capacity is reached.

In addition we provided the investor all the necessary documentation demanded by EBRD (European bank for reconstruction and development) considering environmental impact of the mine and supporting facilities including Environmental impact report.

Project review has been done by Faculty of Natural Sciences and Engineering Ljubljana, and the project basics have been presented to the Macedonian expert public at symposium in Negotino town in July 2011.

During projects elaboration the need for quite many additional activities arose and for these we include the home companies from Šalek valley and surrounding regions. This is not coincidence as the knowledge on all aspects of mine design and construction is concentrated right in Šalek valley. The project partners were: Erico, d. o. o., Econo, d. o. o., PPS Prizma, d. o. o., Kova, d. o. o., Salus, d. o. o., Possi, d. o. o., and numerous individual experts covering various fields (miners, engineers, electricians, energy experts, environmentalists, civil engineers, biologists, geographers, geologists, chemists and experts for safety at work).

Mariovo deposit

Mariovo lignite deposit (Figure 1) extends over the area of 8 km × 2 km at the depth of 100–200 m under the surface. The region is uninhabited and there is hardly anything to be found there except the onyx quarry and a 400 kV power line connecting power plant TE Bitola and power plant TE Negotino. The average calorific value of the coal is relatively low reaching 8 MJ/kg, being otherwise characteristic for also other coal deposits in this region (Bitola, Pelagonia basin). The seam is in average 7 m thick, reaching maximum thickness of 16 m. The floor strata consist mainly of clays and sands but in the roof mostly mudstones and marls prevail. The coaly substance with calorific value above 6.5 MJ/kg is considered reserves and amounts up to 96 Mt, of which some 61 Mt can be won by mining. Considering the mine capacity of 2 Mt per year the operating time of the colliery is round 30 years.

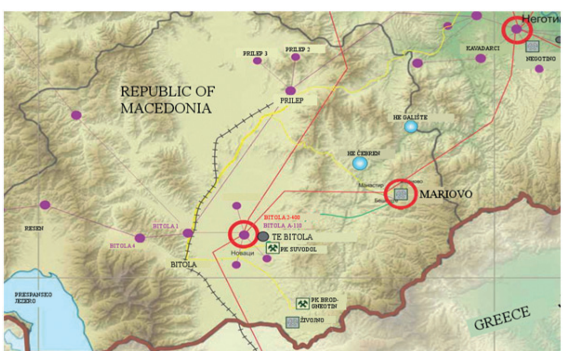

Figure 1: *Coal deposit Mariovo, Živojno and Negotino position according to location of Macedonian republic's energy producing localities (thermal power plant TE Bitola, thermal power plant TE Negotino, hydro power plant HE Čebren and hydro power plant HE Galište).*

The deposit opening and excavation concept

The layout of excavation panels enables a maximal seam recovery. General panel orientation is south – north. The panels are approximately 180 m wide and from 310 m to 1400 m long (Figure 2). At the delivery side of the excavation panels (eastern side) the blind end parts of longwall faces in length of approximately 20 m are positioned (in such way the mining losses are reduced).

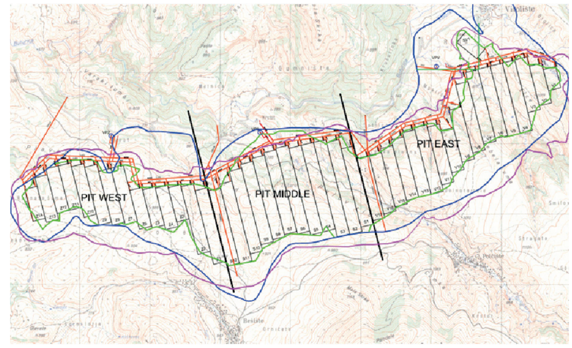

Figure 2: *The Mariovo mine opening and excavation concept.*

The basic technical conditions for mine opening and coal excavation with expected production results:

— coal production will reach approximately 2 Mt per year,
— two excavation panels working at the same time, two in developing phase,
— three sets of excavation equipment available,
— panel development will run at six worksites,
— worksite daily advance at elaboration of permanent (access) roadways will reach in average 2 m/d,
— worksite daily advance at elaboration of gate roads will reach in average 4.5 m/d,
— in average we plan 21 working days per month and 3 shifts per day,
— average production of one excavation panel will reach round 4000 t/d.

Mariovo mine is divided into three pits: eastern pit, middle pit and western pit. Production will start in the eastern pit and continue towards west. Ventilation is adapted to this sequence.
According to research results the Mariovo mine is a gassy one and therefore all the equipment must suit the appropriate requirements for intrinsic safety. Total installed power supply for electric machinery equipment in Mariovo mine amounts 16.5 MW.
Mine operation will require elaboration of:

— 25 770 m of permanent (access) roadways (main gates, ventilation roadways, tailgates, dewatering roadways) of cross section area from 12 m^2 to 14 m^2,
— 95 700 m of panel roadways (haulage (belt) roads, delivery (travel) roads, face roads) of cross section area 17 m^2.

Excavation technology in the areas where seam thickness is round 4 m enables to excavate only the lower part of the panel but in the areas where the seam is thicker the excavation is divided into lower part where the coal is cut by the shearer and the upper part where the coal is won by making it fall down in pieces.

At longwall face that is 180 m wide there are 120 longwall shields (chocks) installed (unit width is 1.5 m). These shields enable to control how the crushed coal from the upper section is falling down (coal flow). The coal is cut with two drum shearer. Face conveyor for coal haulage consists of two chains and its capacity is 530 t/h.

Hydrogeological conditions of the deposit dictate a complex and comprehensive dewatering process.

Dewatering of the mine is foreseen to be done completely from underground structures:

— the roof aquifers: preliminary dewatering of the roof aquifers (especially aquifer K2) will start with construction of the dewatering roadway that is located directly in the aquifer and continue with drilling of dewatering boreholes from this roadway,
— at worksites: the water will flow into convenient water tanks located at the worksites from where it will be pumped into the channels. From the predominant part of the mine the water will flow gravitationally.

In total it is going to be necessary to drill from 40 000 m to 50 000 m of dewatering boreholes.

Time schedule

The most important information from time plan is the following:

— start of preparation works is foreseen in July 2013,
— first production in 2016–2017 (1.5 Mt),
— full production (2 Mt per year) is reachable in 2018,
— in the first year of mine operation it will be necessary to employ 177 workers, for the second and the third year yet additional 100 workers, in the fourth year there will be 522 workers needed. In this the 20 % of fluctuation must be considered.

Economic evaluation of the project

Elaboration of the economic evaluation of the project is based on the following premises:

— exploitation reserves: 61 260 000 t,
— average calorific value of exploitation reserves: 8.3 GJ/t,
— mine production round 2 Mt per year,
— investments taken into consideration until production start,
— material and services costs taken into consideration,
— ongoing investments during production taken into consideration,
— labor cost (gross gross): = 700 EUR/worker/month, 500 employees,
— financing costs taken into consideration,
— two simultaneously running longwall faces,
— two panels in the preparation phase,
— three sets of excavation equipment available,
— panel development will run at six worksites,
— two ventilation stations,
— one crusher station,
— in average 21 working days per month and 3 shifts per day,
— no time wasted between one panel excavation finish and next panel excavation start (this is possible because of the third set of the excavation equipment),
— average production of one excavation panel will reach round 4000 t/d,
— for dewatering of aquifers drilling of dewatering boreholes is foreseen,
— from the predominant part of the mine the water will flow gravitationally,
— elaboration of three dewatering roadways in the roof aquifer,
— from 40 000 m to 50 000 m of dewatering boreholes,
— surface coal transport not taken into consideration,
— unexpected expenses that might occur because of local conditions not taken into consideration,
— constant prices from May 2011 taken into account.

Results of the technical - economic evaluation:

- the version with 30 % own funds and 70 % debt sources structure,
  - internal rate of return: 5.94 %,
  - payback period: 18 years,
  - total cost of operation from 2013 to 2045 as the mine is closed: 781 million EUR,
  - total revenue is 980 million EUR.

The project is positive, appropriate funding is needed to finance the project until 2018 when complete production starts and begins to pay the money back.

Conclusion

Depending on the chosen financing model the complete investment value is round 110–121 million EUR. Two different financing models have been treated with on one side larger and on the other side smaller investors' share. The model using 30 % of the own funds shows the investment to be returned in 18 years. Economic calculation can confirm the statement on exploitation of own natural energy sources in combination with appropriate excavation methods to be most rational. Such approach is certainly placed in front of cheap coal import as the socioeconomic effects are in case of mine construction not insignificant.

As foreseen, the excavation will go on at two simultaneously running longwall faces. Six worksites will meet the needs of panel development and elaboration of permanent roadways.

Considering Premogovnik Velenje Company, elaboration of design documentation represents additional income, a good reference and a good opportunity for Slovenian companies to collaborate in potential opening operations and introduction of Velenje mining method in Republic of Macedonia.[1]

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Development process of introducing new stell arch in supporting roadways at Velenje Coal Mine

Vpeljava novega jeklenega ločnega podporja pri gradnji prog v Premogovniku Velenje

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Abstract

Due to increasingly demanding montan geological conditions in the Velenje Coal Mine, centralization of excavation (excavation of pit Pesje and Preloge are coming closer to each other and this leads to interactions), because of greater depths and increasing pressures we accede to the introduction of a new type of steel arch support TH29. The differences between the old K24 and the new TH29 supports is in the form of profile that enables continuous loosening and less threat in the release of rock burst in the roadways. Another difference is in material itself, the old steel arch were thermally processed (quenched and tempered), the new material has adequate strength ensured with the appropriate metallurgical additives and additional processing is not required, so production cost are achieved in savings. New steel arch support provides greater load capacity and lower risk for release of rock burst in the roadways. Introducing the new steel arch support units is a very complex operation, because this means changes in the technological process, even logistics and maintenance of equipment for repairing steel arch support.

Key words: coalmine, steel arch support, metallurgical additives, roadways, TH29 support, K24 support

Izvleček

Zaradi vse bolj zahtevnih montan geoloških razmer v Premogovniku Velenje, centralizacije odkopavanja (jami Pesje in Preloge se z odkopi vse bolj približujeta druga drugi in zaradi tega prihaja do medsebojnih vplivov), zaradi večjih globin in vse večjih pritiskov smo začeli uvajati nov tip jeklenega ločnega podporja TH29. Razlike med starim podporjem K24 in novim TH29 so v obliki profila, ki omogoča bolj zvezno popuščanje in s tem manjšo nevarnost pri sprostitvah napetosti v jamskih progah. Druga razlika pa je v samem materialu, ki je bil pri starem podporju dodatno termično obdelan (poboljšan oz. kaljen), novi material pa ima ustrezno trdnost zagotovljeno z ustreznimi metalurškimi dodatki in dodatne obdelave tako niso potrebne, zaradi česar je dosežen prihranek pri proizvodni ceni. Novo podporje zagotavlja večjo nosilnost in manjšo nevarnost za sprostitve napetosti v jamskih progah. Uvajanje novega podporja je zelo kompleksna operacija, saj za sabo potegne spremembe v tehnološkem procesu, celo logistiko in vzdrževanje opreme za popravilo jeklenega ločnega podporja.

Ključne besede: premogovnik, jekleno ločno podporje, toplotna obdelava, jamske proge, podporje TH29, podporje K24

Introduction

For many years, the Velenje Coal Mine has been systematically engaged in development in the construction of roadways. With the development we adapt to the increasingly demanding roadway construction conditions and to the increased needs of the load-bearing capacity of the pit support. With the development and introduction of new mechanical equipment, the need for greater loading gauge of the roadway increased. Thus the development of installation of support elements led to introduction of innovations in supporting the roadways with steel arch support. We have successfully introduced new screw clamps which helped us achieve greater carrying capacity of joints, ties between the frames of the steel arch support and anchoring substructure. At the moment, the potential for improvement is seen in the use of the new type of the steel arch support – TH29.
Currently, the most widely used arch support in the Velenje Coal Mine is K24. This type of steel arch support is thermally treated, as such treatment improves its load-bearing capacity characteristics. However, the required load-bearing capacity of the support is increasing due to pit centralization, excavation impact, and increasing depths, and can no longer be reached by reducing the distance between the arches. For that reason we started testing a new type of steel arch support TH29 for roadway construction.

Table 1: *Characteristics of the K24 arch support*

Yield limit (MPa)	Min. 510
Plasticity limit (MPa)	690–930
Moment of inertia (cm^4)	372.37
Mass (kg/m)	23.67

Table 2: *Characteristics of the TH29 arch support*

Yield limit (MPa)	Min. 480
Plasticity limit (MPa)	650
Moment of inertia (cm^4)	598.0
Mass (kg/m)	29.00

Comparison of characteristics of K24 and TH29 arch support

Currently, the K24 arch support is used in the pit of the Velenje Coal Mine. This type of support is thermally treated (tempered), which means that the arch is more steeled. In cases where there is major pressure on the K24 steel arch support, discontinuous yield of arch support occurs (instantaneous release).
The new arches TH29, which are still being tested at the pit, are softer than the K24 arches, but certain metallurgical additives improve their load-bearing capacity characteristics. They have a higher moment of resistance which is the result of a larger cross section of the arch. Under the increased pressure, these arches are a lot friendlier to the material itself. In the event of increased pressure, these arches continually yield and there is no instantaneous movement of the arcs as in the K24 support.
It is evident from the tables that the mass of the arches only differs by 4 kg/m. Despite the fact that the K24 arch has been thermally treated, its yield limit is only 9 % higher than in the TH29 arch, to which only certain chemical compounds have been added. When comparing the moment of inertia in arch supports, we determined that the moment of inertia was 62 % higher in TH29 arch support than in K24 arch support. Therefore, as far as the load-bearing capacity is concerned, the T29 arches are more appropriate for installation in the pit of the Velenje Coal Mine[1].
In addition to the difference in material between the arches K24 and TH29, the difference is also in their cross sections and in abutment of arches. In the K24 arch, the arches abut on a greater surface than in the TH29 arch, where the arches only abut on the edges. The difference in the shape of the arches is visible in Figures 1 and 2.

Figure 1: *Cross section of the arch K24 (left).*

Figure 2: *Cross section of the arch TH29 (right).*

Laboratory tests of steel arch support

Numerous laboratory tests were carried out on the new TH29 arches and on the K24 arches before the installation of the new arch support began. The tests were performed in a certified laboratory for mining support testing in Opava, Czech Republic.
The following tests were carried out:

Test A: Standard joint carrying capacity test according to CSN 44 4410 or DIN 21538 standard

Test B: Bending joint test according to DIN 21538-2003-5 standard

Performance of the tests

The tests were ordered by our supplier of steel arch support and their representative was present at the laboratory. The laboratory has all the necessary accreditations and is engaged in testing of steel arch support for the mines and for the manufacturers of steel arch support elements, located nearby. They also carry out stress tests of wide-front support and hydraulic cylinders. They also have an electrical department where they test the electrical mining equipment[1].

Results of the tests

Summary of test results for joint carrying capacity (Table 3).

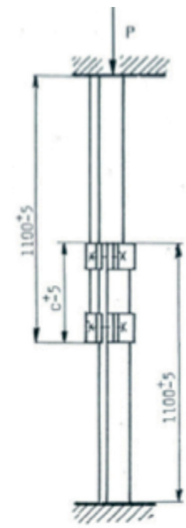

Figure 3: *Illustration of test A.*

Screw tightening torque 400 Nm
Arch covering: 450 mm

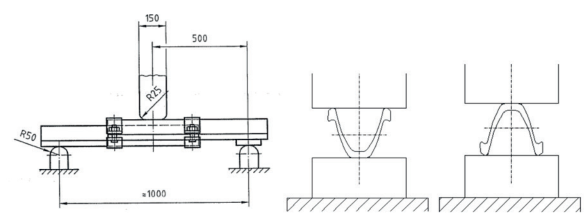

Figure 4: *Illustration of test B.*

Screw tightening torque 400 Nm
Arch covering: 450 mm

Bending test results

The sample was tested according to DIN 21530-4 Art. 4.1.2.2.2 “Biegetrag fähigkeit” – joint load bending test. Maximum force F_{max} was measured in the test. The test ended with the maximum bending of the sample, allowed by the test device. The value was determined by the reading from the graph (Table 4).

Conclusions of the tests

Sliding joint carrying capacity decreases with the wear of the arch to 15–20 % in arches that are worn out to the extent that they cannot be used and to 10 % with the used arches R2 which can still be used. The load-bearing capacity of R1 quality arches is practically the same as in the new ones.

Bending joint carrying capacity is decreasing with the wear of the arch in the same proportion, on average, as in the sliding tests.

Tightening. When testing sliding joint carrying capacity, the joint carrying capacity is even more dependent on the tightening torque than it is in the new arches. Applying additional tightening is of little use if the arch does not sit better in the joint after the tightening. This phenomenon is even more present, due to the fact that the arches that have already been repaired, are bent. Therefore, maximum attention should also be given to proper functioning of tightening machines in the nut tightening stage also in the future. It would be reasonable to introduce further joint tightening when they start to yield – it is best to do it just before making the cover. The reason for that is in the form of the K support – which is slightly deformed in the used ones; a greater number of turns of the thread is needed for the arch to sit in the other arch. This phenomenon is much less present in the TH support, as the latter does not rest on the wedge but on the edge of the joint[1].

Table 3: *The stated values are calculated as the average of three test items for each quality*

Sample	Central sliding joint carrying capacity N_{zsr}/kN	Maximum sliding joint carrying capacity $N_{Z\ max}\ F_{max}$/kN	Measurement uncertainty U/kN
R1	372.9	431.0	3.3
R2	355.7	394.8	3.1
R3	305.7	377.9	3.2

Table 4: *The stated values are calculated as the average of three test items for each quality*

Sample	Demolition - type	Load F_{max}/kN	Measurement uncertainty U/kN
R1	yes - screws	621.4	5.0
R2	yes - screws	574.3	4.8
R3	yes - arch	512.7	4.6

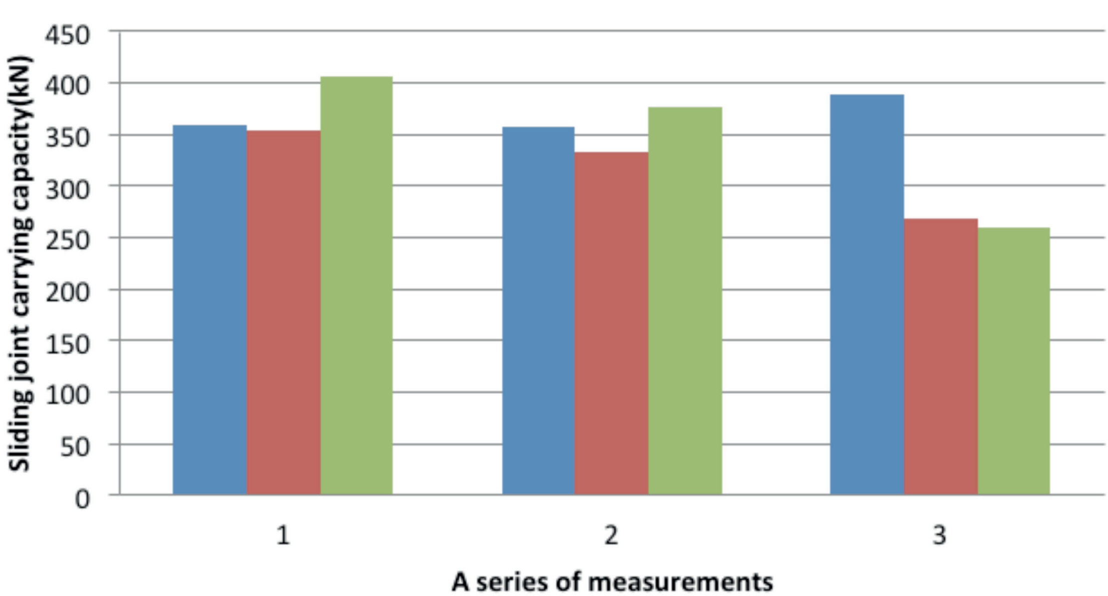

Figure 5: *Sliding joint carrying capacity (kN).*

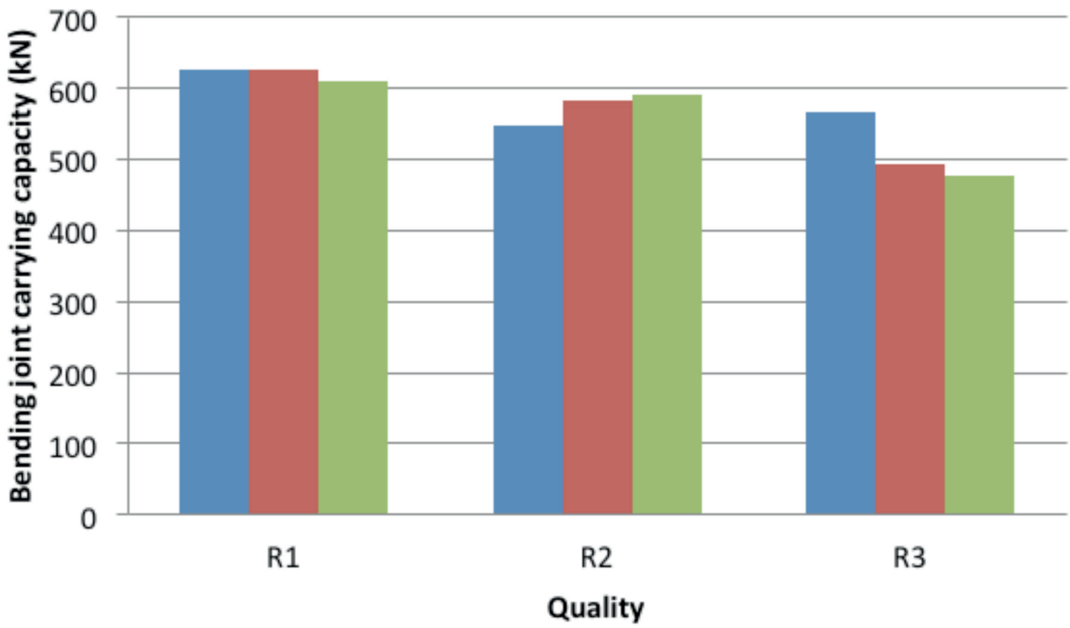

Figure 6: *Bending joint carrying capacity.*

Tearing of screws. Tearing of screws occurred in all cases, except in the R3 quality (the worst) when the arch yielded. Strong deformation of the screw occurred in all cases in the axial direction and in the rear and front zone (see Figures). It was also necessary to modify the test device in this series of tests. If it is assessed that the tearing of the M20 screws is a problem, it would be reasonable to start using the M24 screws. This will not eliminate the problem, but it will be present to a lesser extent[1].

Yielding of the arches is even more impetuous than with the new K24 arches. We have assessed that the yielding in TH29 arches is less impetuous and that less energy is released in the process. The introduction of TH29 would also have a positive impact on reducing the number of accidents due to the release of tension. On one hand, the reason for that is the form of the profile, where the sliding occurs on the edge of the profile and less on the side (side of the profile). On the other hand, however, the TH29 material is softer and contains less steel and consequently accumulates less energy which is released upon the release of tension[1].

Tests in the pit of the Velenje Coal Mine

In the recent years, we have carried out several tests of installation of TH29 arches in the pit of the Velenje Coal Mine. The first test was performed at the outlet roadway of the A k–130 excavation site in the Preloge pit.

The first section in the length of 13.4 m was installed 90 m away from the assembly chamber of the excavation site, whereas the second section in the length of 17.5 m was installed 458 m away from the assembly chamber of the excavation site (Figure 7). The rest of the outlet roadway was supported by the K24 steel arch support[2].

In the first test section, stirrup clamps were used in the installation of the K24 steel arch support, while in the TH29 steel arch support, new screw clamps were used (Figure 7). In the second test section, the new screw clamps were used in the K24 steel arch support and in the TH29 steel arch support (Figure 7).

By testing the TH29 steel arch support (the first section), the following conclusions were made:

— JLP TH29 tolerates the arising pressure well,
— deformations of JLP are small and occur approx. 3–5 m before the excavation site.

Deformations in both types of the arch support were only shown in slips (covering of the steel arch support).

Only the straight floor arches K24 and TH29 were deformed (rolled in a spiral), but no other deformations were observed in TH29.

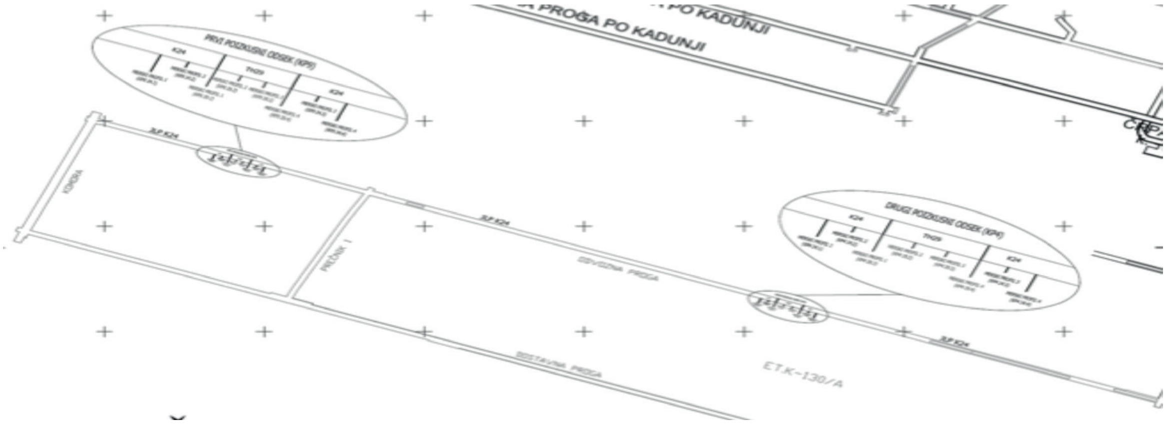

Figure 7: *Test locations.*

Comparison of the measurement results of the first test section shows that:

1. The TH29 arches started yielding somewhat sooner and to a somewhat greater extent. On average, the TH29 arches started yielding 1.5 weeks (11 d) before pillaging. However, on average, the K24 arches started yielding 1 week (7 d) before pillaging.
2. On the joint (covering), the TH29 arches yielded to a somewhat greater extent than the K24 arches. The average measured slip at the K24 joint was 3.25 cm on the left and 5 cm on the right side. The average measured slip at the TH29 joint was 4.5 cm on the left and 8.5 cm on the right side.

Visual assessment of arch bending at the mouth of the excavation shows that the TH29 arches are far less deformed than the K24 arches. Since the deformations are very small, this cannot be assessed according to the assessment key.

The first assessment shows that in the second and third uses, the ZH29 arches would be less deformed than the K24 arches and the percentage of reuse could be higher. The reason for that is a more favourable ratio between the yield and the bending carrying capacity of the arch.

No major problems occurred due to the weight of the arches in the construction (pillaging) of the steel arch support. However, it has been assessed that the arches of 29 kg/m represented the upper limit of acceptability for manual handling.

The second test of TH29 arch installation was performed at the outlet roadway of the G3/C excavation site in the Preloge pit (north wing). The distance between the frames was 0.5 m, because we wanted to check if these arches can bear greater loads and to determine the consequences at the time of the crossing of the adjacent excavation site –65/F and of the excavation site for which this outlet roadway is intended (G3/C).

The first section in the length of 30.0 m was installed 606 m away from the assembly chamber of the excavation site G3/C, whereas the second section in the length of 40.5 m was installed 576 m away from the assembly chamber of the excavation site. The rest of the outlet roadway was supported by the K24 steel arch support (spacing between the frames is 37 cm).

In the first test section, repaired arches were used in the installation of the TH29 steel arch support, which had already been installed in the outlet roadway K.–130A, in combination with the new screw clamps. The new TH29 arches were installed in the second section, also in combination with the new screw clamps.

Convergence profiles were also installed in these two test locations. The first profile is located at 245 m and the second at 260 m from the starting point of the outlet roadway. Periodic profile measurements are performed at these two locations, in order to obtain information on the extent of deformation, caused by the pressure on the steel arch support.

Monitoring of measurements of the convergence profiles has shown no significant support deformation. The first deformations in these sections can be expected in the crossing of the adjacent excavation –65/F through these sections. Another impact will come from the crown of G3/C in the crossing of these two sections[2].

Results of the convergence point measurements on the test sections

Convergence profiles are measured every 14 d. It can be concluded, according to the obtained results, that the support is well tolerant of rock pressure, as the support displacement was minimal.

Conclusion

The method of introducing new support elements in pit roadways and the technological process of construction can be regarded as successful, particularly in testing and introduction of new arch support TH29. However, at this point we cannot say that we recommend the replacement of support, despite some successful experiments in the pit and good laboratory results. Definitive introduction of new support elements requires changes in the entire technological process of repairs of these support elements. In addition, we need to get further information on the behaviour of this type of arch support by carrying out additional tests in the pit.

Its successful introduction would bring at least 65 % increase in load-bearing capacity due to a higher moment of resistance and weaker yield due to the shape of the profile and less steel material.

The introduction of TH29 support is necessary in the light of the increasingly demanding conditions. Namely, with the roadways and excavations, the conditions are such that we no longer achieve the necessary load-bearing capacity by reducing the distance between the frames of the steel arch supports.

Table 5: *Measurements of the convergence*

Date of installation	Date of measurement	Method of measurement	Length of profile sides (mm) side A	side B	side C
20 July 2012	25 July 2012	measurement lath	3 110	3 152	4 545
	7 August 2012	measurement lath	3 110	3 152	4 545
	13 August 2012	measurement lath	3 110	3 152	4 545
	29 August 2012	measurement lath	3 109	3 152	4 543
	27 September 2012	measurement lath	3 100	3 152	4 534
	4 October 2012	measurement lath			
	15 January 2013	measurement lath	3 098	3 152	4 536
	1 February 2013	measurement lath	3 098	3 152	4 536
	15 February 2013	measurement lath	3 098	3 152	4 536

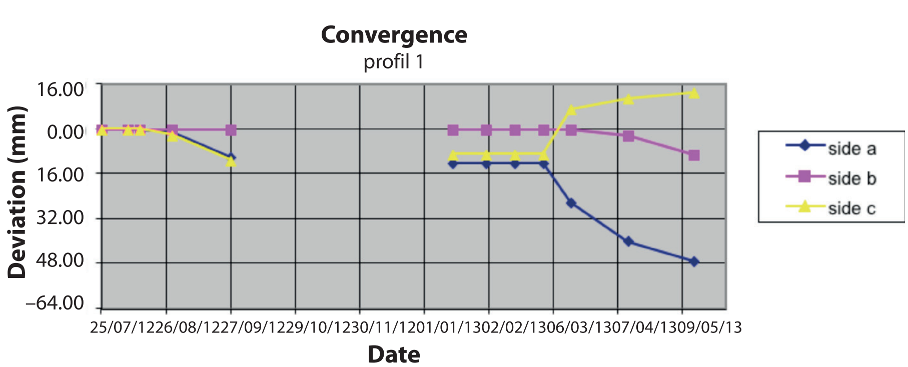

Figure 8: *Measurement of convergences on profile 1.*

References

[1] Pohorec I., Sotler B., Mayer J., Lednik S. (2011): Zbor poizkusov v okviru razvojne skupine za izdelavo etažnih jamskih prog v Premogovniku Velenje za leto 2011. Tehnična dokumentacija Premogovnika Velenje, pp. 62–69.

[2] Pohorec I., Sotler B., Mayer J., Lednik S. (2012): Zbor poizkusov v okviru razvojne skupine za izdelavo etažnih jamskih prog v Premogovniku Velenje za leto 2012. Tehnična dokumentacija Premogovnika Velenje, pp. 35–44.

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[2] Higashitani, K., Iseri, H., Okuhara, K., Hatade, S. (1995): Magnetic Effects on Zeta Potential and Diffusivity of Nonmagnetic Particles. *Journal of Colloid and Interface Science*, 172, pp. 383–388.

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[2] Higashitani, K., Iseri, H., Okuhara, K., Hatade, S. (1995): Magnetic Effects on Zeta Potential and Diffusivity of Nonmagnetic Particles. *Journal of Colloid and Interface Science*, 172, str. 383–388.

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