Possibilities of coal conversion into gas fuel from the aspect of greater valorization of available energy resources in Serbia by implementing UCG

Možnosti uplinjanja premoga z vidika večje uporabnosti energetskih virov v Srbiji z uporabo podzemnega uplinjanja premoga (PPP)

David Petrović[1], Duško Đukanović[2], Miodrag Denić[3, *]

[1]4D KONSALTING, Beograd, Srbija
[2]PEU Resavica, Biro za projektovanje Beograd, Makedonska 33, Beograd, Srbija
[3]JP PEU Resavica, Petra Žalca 2, Resavica, Srbija

*Corresponding author. E-mail: miodrag.denic@yahoo.com

Received: May 25, 2009 **Accepted:** November 4, 2009

Abstract: Taking into account the quantity and quality of energy resources which are available, especially the growing need for more cost-effective use of primary energy resources (therefore, not only of secondary), we are now in the position to conquer the technology of exploitation of out-of-balance reserves, as well as of mining residues from the balance reserves. The method without alternative for such coal reserves is underground coal gasification (UCG).
In opting for activities in that respect the most important thing is the approach to the most possible reasonable choice of optimal location for UCG. Apart from that, it is necessary to envisage the quantities of coal which could be gasified and thereby to define the amount of total gas produced from UCG.

Izvleček: Ob upoštevanju kvantitete in kvalitete energetskih virov, ki so nam na voljo, posebej še, ob upoštevanju naraščajočih potreb po bolj cenovno uspešnem izkoriščanju primarnih virov energije (torej, ne samo sekundarnih), smo sedaj v stanju, da uporabimo tehnologijo pridobivanja zunaj bilančnih rezerv, kakor tudi ostankov rudniških bilančnih rezerv. Metoda, ki v primeru premoških rezerv nima alternative, je podzemno uplinjanje premoga (PPP).

Original scientific paper

Pri izbiri aktivnosti v tej smeri je najpomembnejše določiti optimalno lokacijo za uporabo metode (PPP). Ne glede na to, je neobhodno oceniti količino premoga, ki bi lahko bil uplinjen in s tem oceniti skupno količino proizvedenega plina z metodo (PPP).

Key words: energy resources, underground coal gasification (UCG)
Ključne besede: energetski viri, podzemno uplinjanje premoga (PPP)

Introduction

Having in mind that according to researches conducted so far, our country posesses very small amount of oil and natural gas as compared to its need, the necessity of continuous study and development of more complex technologies of coal usage, on order for our industry to be less dependant on imports of energy and energetic raw materials. Since better quality coal is located deeper under the ground, and is therefore more suitable for underground exploitation, it is logical that certain cases should be treated with corresponding methods, although any form of exploitation would eventually yield 30–40 % of coal.[5]

Along with other difficulties that underground coal mines have to face, these methods prove themselves non-profitable more than often, and the mine would simply be put out of comission. Does it always have to be this way? These significant amounts of coal (60–70 %) that are being left behind, with some layers of coal that have not even been treated, don't seem to have any significance to anyone. That could be well understood in case that energetic resources are abundant, so there would be no concern for the future and its generations.[3]

This could also be acceptable if there were no alternatives for coal exploitation. These alternatives have been an interesting subject of study from time to time, but a broader social and expert interest for realisation of these ideas, which were a subject of many studies, was not present.

If suitable comparative parameters of conventional underground exploitation related to possible underground gassification of certain coal site [1] are to be examined, and especially if the site in question is an unprofitable one, the preference would be more than obvious. Also, on of the alternatives is, in some cases, gassification and retorting of shale, which has already been written and discussed, but all activity has ended there.

Why UCG?

Considering significant non-balance reserves and spoil debris of balance reserves in Serbia, a question stands for a long time about our energetic tomorrow. With such intensity of reserve spending and with a very poor employment of coal layers, the possibility of exploitation of such reserves poses itself as an inevitability.[4]

The fundamental energetic resource of Serbia is coal: lignite with favorable characteristics for surface exploitation and brown and stone coal deeper underground, whose exploitation is only possible in pits. The non-balance of significant amount of reserves has mostly been determined because of technological and economic unduliness of existing unconventional exploitation.

From our industrial and strategic point of view, it is very important for these reserves to be valorized, seeing that they are very significant. That would improve the country's situation concerning energy and lower import dependency. Thus, the technology of conversion of coal into gas fuels using the UCG is an achievement that opens the door not only to cheaper production of energy, but also to partial substitution of natural gas and fuel oil imports. From the perspective of country's energy strategies, by converting coal into gas fuels and by rationalizing energy consumption, this is the fastest and surest way of solving current energetic problems in the country.

Therefore, it is time to treat the problem of poor rationalization of coal production (i.e. taking the energy resources away from nature) in this manner, and not only the problem of rational use of energy created by coal treatment (e.g. electric energy).

The parameters by which determining whether or not a certain coal site is suitable for underground gasification are influenced, are, among many, the following: coal reserves (non-balanced and spoil debris of balanced reserves), maximum depth, thickness, angle of repose as well as ash, humidity and coal particles.

From this point of view, some general assumptions are important, such as:[2, 7, 8]

- With mines with sufficient reserves, facilities and tradition, it is important to determine is the underground gasification planned.
- Mines that can develop normally, as in the previous case, with a difference that their raw material basis demands additional investigation, based on which a decision could be made for their further development.
- Mines whose raw material basis is limited, and a limitation for coal marketing, must reorient their production and cease their previous

activities, as soon as reserves are depleted.
- Mines without larger perspective and mosty of local importance – the factors of exploitation are such that underground exploitation does not give assurance concerning profitability and work safety, and does not offer anything new technology-wise, although their coal reserves may be very significant.

UCG has a range of advantages over convntional underground exploitation:
- Lesser cost of building of an UCG station than a conventional pit
- Productivity is increased several times
- The price of final product per unit is lesser than the same unit made by pit exploitation
- UCG does not involve hard and dangerous work like conventional exploitation does
- Transport, loading and unloading of coal and other materials are not present as with conventional exploitation
- Ash and slag remain underground so there is no transport and therefore no environment and atmosphere pollution
- The UCG method is suitable for sites with difficult geological conditions, which are not suitable neither for underground nor surface exploitation.

Identification of JP PEU coal sites from the aspect of possible implementation of UCG

Balanced reserves of all types of coal on sites that are not being actively exploited and all coal types could be exploited by UCG, are shown in the following tables and diagrames.[4]

Comparative analysis of technical, physical and mechanical characteristics of coal on treated sites

The analysis is related to specific technical, physical and mechanical parameters of coal types in question such as:
- Reserve category (A,B,C)
- thickness
- max depth
- coal humidity
- ash level
- vaporizing materials
- lower heat power of coal (DTE/H_d).

This analysis is made by using the data from table 4, while table 5 will address:
- tectonics
- gas surface protruding protection
- hydrogeological properties
- site status (SAE / VE)
- necessity of land purchase
- number of gas consumers.

Table 1. UCG applicable stone coal reserves

Basin-pit	Balanced (10^3 t)	Non-balanced (10^3 t)	Total (10^3 t)	Rank
Vrška Čuka	2.361,230	350,000	3.711,230	4
Rtanjski Basen	1.598,000	-	1.598,000	5
Ibarski Basen	2.632,540	1.223,980	3.856,520	3
Mlavsko Pečki	-	6.100,000	6.100,000	2
Nova Jerma	12.290,000	-	12.290,000	1
Dobra Sreća	-	500,000	500,000	-
Podvis	-	500,000	500,000	-

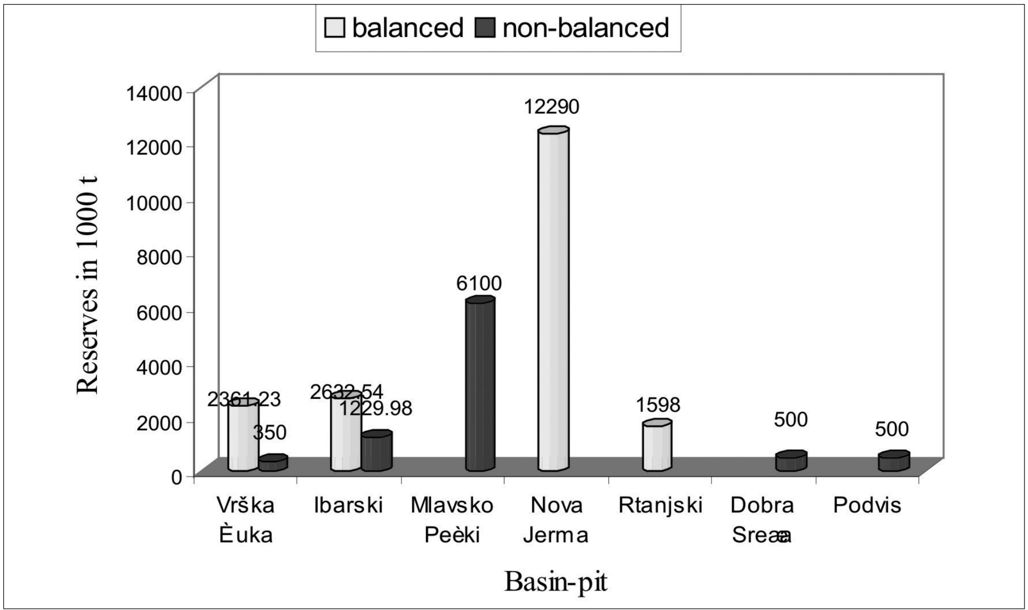

Figure 1. UCG applicable stone coal reserves

Tabela 2. UCG applicable brown reserves

	Basin-pit	Balanced 10^3 t	Non-balanced 10^3 t	Total 10^3 t	Rank
SAE	Rembas	12.207,33	540,06	12.747,39	3
	Bogovina	2.058,26	1.897,19	3.955,45	6
	Sokobanja	58.127,96	2.763,27	60.891,23	1
VE	Aleksinac	12.320,19	15.195,43	27.515,62	2
	Jankova Klisura	3.795,00	2.416,00	6.211,00	4
	Nova Manasija	3.351,00	934,00	4.285,00	5
	Jelašnica	-	1.800,00	1.800,00	-
	Vrdnik	-	588,00	588,00	-
Total (SAE+VE)		91.859,74	26.133,95	117.993,69	-

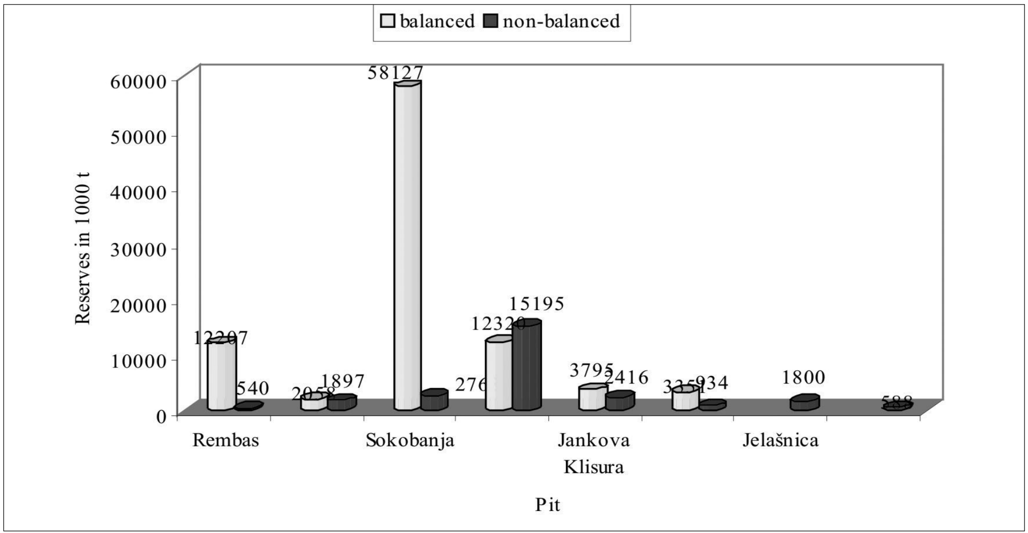

Figure 2. UCG applicable brown reserves

Table 3. UCG applicable brown-lignite reserves

	Basin - pit	Balanced 10^3t	Non-balanced 10^3t	Total 10^3t	Rank
SAE	Lubnica basin	13.591,190	2.319,630	15.910,820	4
	Sjenica basin	187.086,180	7.709,550	194.795,730	1
VE	Despotovac basin	27.956,970	684,480	28.641,450	3
	Melnica	39.537,400	-	39.537,400	2
Total (SAE + VE)		268.171,740	10.713,660	278.885,400	-

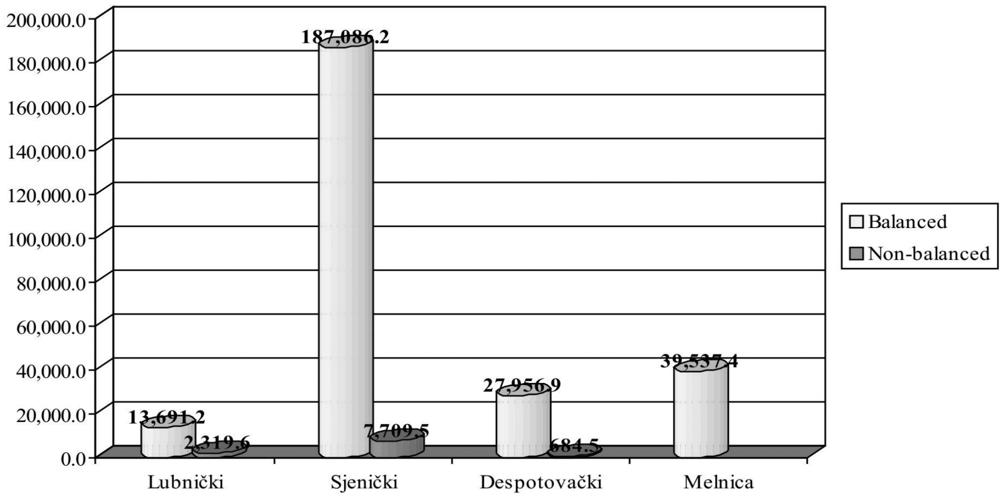

Figure 3. Reserves of brown-lignite coal for UCG

Table 4. Comparative analysis of internal technica, physical and mechanical parameters

Site/ Basin / Parameters	NOVA JERMA **(SC-VE)**	MLAVSKO-PEČKI **(SC-VE)**	IBARSKI BASEN **(SC-SAE)**	VRŠKA ČUKA **(SC-SAE)**	SOKOBANJSKI BASEN **(BC-SAE)**	ALEKSINAČKI BASEN **(BC-VE)**	REMBAS **(BC-SAE)**	JANKOVA KLISURA **(BC-VE)**	SJENIČKI BASEN **(B/LC-SAE)**	MELNICA **(B/LC-VE)**	DESPOTOVAČKI BASEN **(B/LC-VE)**	LUBNICA **(B/LC-SAE)**
Reserves (B+VB+POT.) 10^3 t	**12.290**	**6.100**	**3.856,52**	**8.717,23**	**60.891,23**	**37.515,62**	**27.747,39**	**6.211**	**244.795,73**	**49.537,40**	**48.641,45**	**15.910,19**
Thickness m	**2÷8** +	**2÷5** +	**1,2÷20** +	**>0,5-5** +	**20÷30** +	**5÷7** +	**1÷20** +	**2÷9** +	**10÷14** +	**5÷7** +	**2÷8** +	**4÷10** +
Max depth m	**300÷700** +	**300** +	**100÷900** +	**300÷600** +	**400÷700** +	**500÷700** +	**150÷400** +	**150÷300** +	**150÷300** +	**50÷360** +	**80÷250** +	**150÷300** +
Coal humidity W %	**4,90** +	**3,87** +	**0,6÷6,35** +	**0,96** +	**19,22** +	**10,01** +	**6,20÷21,35** +	**22,50** +	**30,85** +	**26,8÷31,4** +	**24,08** +	**26,43** +
Ash quantity p %	**35** +	**35** +	**16÷59** -	**13,19** +	**11,83** +	**23,16** +	**9,12÷13,72** +	**24,00** +	**11,90** +	**17,6÷25,4** +	**13,82** +	**16,34** +
Vaporizing mat. %	**14,25** +	**26,7** +	**16÷30** +	**8,82** +	**36,52** +	**42,79** +	**32,19÷36,52** +	**27,20** +	**32,31** +	**26,82** +	**25,69** +	**33,94** +
DTE/H_d kJ/kg	**22.500** +	**21.000** +	**18.000÷ 24.000** +	**29,73** +	**18.964** +	**19.974** +	**18.490÷ 19.473** +	**19.200** +	**14.134** +	**11.637** +	**11.858** +	**14.681** +
Angle of repose °	**10÷40** +	**15÷22** +	**10÷40** +	**20÷45** +	**40÷50** +	**10÷30** +	**5÷30** +	**15÷30** +	**5÷20** +	**15÷30** +	**12÷25** +	**10÷20** +

Note: Plus sign marks every data that is within favourable limits for UCG implementation; minus sign marks data that are out of such limits

Table 5. Comparative analysis of external influences

	Reserves points (1÷4)	**Tectonics** points (1÷2)	**Hydrogeol.** points (1÷3)	**Natural gas protection** points (1÷3)	**Land Purchase** YES NO -2 +2 (points)	**Gas consumers** existing potential (3) (1÷2)	**Total** points
NOVA JERMA (SC-VE)	4	1	2	2	-2	1	8
MLAVSKO-PEČKI (SC-VE)	3	1	2	2	-2	1	7
IBAR BASIN (SC-SAE)	2	2	2	2	+2	2	12
VRŠKA ČUKA (SC-SAE)	1	1	3	1	+2	1	9
SOKOBANJA BASIN (BC-SAE)	4	1	2	2	+2	1	12
ALEKSIN. BASEN (BC-VE)	3	2	3	2	+2	2	14
REMBAS (BC-SAE)	2	2	3	2	+2	2	13
JANKOVA KLIS. (BC-VE)	1	2	2	2	-2	1	6
SJENICA BASIN (B/LC-SAE)	4	2	1	2	+2	1	12
MELNICA (B/LC-VE)	3	1	3	2	-2	2	9
DESPOTOV. BASEN (B/LC-VE)	2	2	3	2	-2	2	9
LUBNICA (B/LC-SAE)	1	2	3	3	+2	1	12

By analysing this data, one comes to a concslusion that selected mines meet the criteria for implementation of UCG, with the exception of Ibar stone coal mines which have 50 % larger quantities of ash that the allowed bottom level. But, this information (59 % of ash) does not relate to all sites, but only the Progorelica site, while Jarando, Tadenje and Ušće meet the above criteria.

It is imperative to emphasize that data from this table is different in three cases from those in tables 1 and 2, because in this table, potential coal reserves data for Vrška Čuka, Soko Banja, Aleksinac, Rembas, Sjenica, Melnica and Despotovac basins has been added, based on reserve situation data of PE PEU from the beggining of 2007.

As far as coal thickness is concerned, values are also favourable (it is profitable to gasify layers from 0.6 m thickness onward), as well as for coal humidity, and especially angles of repose.

Based on knowledge of problems concerning UCG and based on values of these parameters, a preliminary ranking list of UCG suitability has been made, but only taking into consideration the data from this table (a final list is given in section 3.3, after table 6).

As far as the status of treated sites for UCG implementation goes, a point system has been made based on tectonic influences, hydro geology etc. Such system is also being used worldwide (it is necessary to emphasize that in cases where land property purchase is necessary, negative points have been given because of increase of investment costs).

Based on the data from these two tables, a final list can be made for possible implementation of UCG on certain coal sites.

Available energetic potential of certain sites in relation to possible UCG implementation

If by available reserves we mean the quantities in current balanced reserves and complete non-balanced reserves, by taking experiences from all over the world into consideration, where 'endangered' quantities have been used between 72 % and 96 %, we can assume that 80 % is a reasonable average, and can therefore determine available energetic potentials for the mines in question (RASENPOT).

Of course, SAE (with active exploitation) and VE (without exploitation) mines will also be considered with their balanced and non-balanced reserves, i.e. 80 % out of those (it is clear that all available energetic potentials for UCG would be even larger if potential reserves should be brought into consideration, but not for now).

RANKING OF SUBTERRANEAN EXPLOITATION BASED ON UCG SUITABILITY CRITERIA

In table 6, in each of 4 SC trestles points from 1 through 4 have been assigned based on given RASENPOT; it is similar for dark and lignite coal (therefore, each group has been assigned points 1 through 4).

Based on table 5 and data from table 6, a final ranking of suitability of treated trestles can be made. Table 7, which follows,

Table 6. Available energetic potentials of some sites in PE

Basin/site	80 % (BIL+VB) t	Heat power H_d/(kJ/kg)	Available en. pot. RASENPOT, GJ	teu	mld kW h	Rank
SC-VE **NOVA JERMA**	9.832.000	22.500	221.220.000	7.547.595	61,45	8.
SC-VE **MLAVSKO-PEČKI**	4.880.000	21.200	103.456.000	3.529.717	28,74	10.
SC-SAE **IBAR**	3.085.216	21.000	64.789.000	2.210.474	18,00	5.
SC-SAE **VRŠKA ČUKA**	2.168.984	29.730	64.484.000	2.200.068	17,91	11.
BC-SAE **SOKOBANJA**	48.712.984	18.904	920.870.000	31.418.287	255,81	2.
BC-VE **ALEKSINAC**	22.012.496	19.974	439.678.000	15.000.955	122,14	1.
BC-SAE **REMBAS**	10.197.912	19.000	193.760.000	6.610.713	53,82	4.
BC-VE **JANKOVA KLISURA**	4.968.800	17.500	86.954.000	2.966.700	24,15	12.
B/LC-SAE **SJENICA (ŠTAVALJ)**	155.836.584	15.000	2.337.549.000	79.752.610	649,35	3.
B/LC -VE **MELNICA**	31.629.920	11.637	368.077.000	12.558.069	102,25	7.
B/LC -VE **DESPOTOVAC**	22.913.160	12.000	274.958.000	9.381.030	73,38	9.
B/LC -SAE **LUBNICA**	12.728.656	15.000	190.930.000	6.514.159	553,04	6.

1teu = $2,931 \times 10^{10}$ J = $29,31 \times 10^9$ J = 29,31 GJ = $8,142 \times 10^3$ kW h = 8,142 MW h

quantities of gas at normal conditions (m^3) that could be obtained from available coal for UCG (column 1, table 6).

World experiences point that quantity of gas yielded from 1kg of coal depends on its heat power and varies

Table 7. Ranking of trestles according to UCG suitability

Rank	Basin/trestle	Points (tab.5+6)	RASENPOT mil. GJ		mld. kW h		Quantity of gas mld. m^3	
			SAE	VE	SAE	VE	SAE	VE
1.	ALEKSINAC (BC-VE)	14 + 3 = **17**		439,68		122,14		38,5
2.	SOKOBANJA (BC-SAE)	12 + 4 = **16**	920,87		255,81		85,5	
3.	SJENICA (B/LC -SAE)	12 + 4 = **16**	2.337,55		649,35		152	
4.	REMBAS (BC-SAE)	13 + 2 = **15**	193,76		53,82		18	
5.	IBARSKI (SC-SAE)	12 + 2 = **14**	64,79		18,00		8	
6.	LUBNICA (B/LC -SAE)	12 + 1 = **13**	190,93		53,04		12,5	
7.	MELNICA (B/LC -VE)	9 + 3 = **12**		368,08		102,25		31
8.	NOVA JERMA (SC-VE)	8 + 4 = **12**		221,22		61,45		24
9.	DESPOTOVAC (B/LC -VE)	9 + 2 = **11**		274,96		73,38		22
10.	MLAVSKO-PEČKI (SC-VE)	7 + 3 = **10**		103,46		28,74		12
11.	VRŠKA ČUKA (SC-SAE)	9 + 1 = **10**	64,48		17,91		5,5	
12.	JANKOVA KLIS. (BC-VE)	6 + 1 = **7**		86,95		24,15		9
TOTAL		**SAE**	**3772,38**		**1047,93**		**281,5**	
		VE		**1494,35**		**412,11**		**136,5**

Legend (marks): JPPEU-Public enterprise for underground coal exploitation; B/L-brown-lignite coal, SC-VE- stoun coal-withoau exploitation; SC-SAE- stoun coal-with active exploitation; BC-VE- brown coal without exploitation; BC-SAE- brown coal-with active exploitation; B/LC-VE- brown-lignite coal without exploitation; B/LC-SAE-brown-lignite coal-with active exploitation; RASENPOT- available energetic potentials.

from 1.5–5.5 m^3/kg. For stone coal this value is 3.5–5.5 (let's say 3.80), for lignite 2.5–4 (let's say 2.70), and for dark lignite 1.5–2.5 (let's say 1.5 m^3/kg). If gas usage ratio (on conversion of coal to gas) is 65 %, then (for example, Aleksinac lignite):

$m_g = 22 \times 10^{-3}$ mld t × 2700 m^3/t × 0.65 = 38.5 mld. m^3 of gas at normal conditions.

CONCLUSION

When overwieving the data from previous tables one can conclude that Ibar mines, although suitable for UCG, couldn't be of special interest fot UCG because of small amounts of gas expected with applyng the UCG. The quantities of coal that would be gasified are not very significant. Their status would therefore remain unchanged.

Other mines named in the table could yield billions of m^3 of gas - SAE as well as VE. Aleksinac is of special interest, because of the following:

- It has been VE for years, almost forgotten
- Large quantities of high-quality coal (38.5 billion m^3) would be an embarassment if neglected.

In addition to this information, cogenerator power plant Sokolov in the Czech Republic produces one billion m^3 of gas out of 400 MW (electr.) a year in a surface gas generator (surface gasification is more expensive than subterranean). Ten percent of natural gas is also being used for 'straightening out' encumberance.

Mines with underground exploitation are short-lived. A period of a few decades passes quickly. At that point, there is no use to wondering about solutions.

Direkcion next activities connected for Aleksinac mine (as first ranking-table 7.) are show through:

- By re-activating the mine, significant quantities of abandoned coal could be used, with all well known energetic, ecological and economic effects and advantages
- It would be a massive opportunity for employment and the city of Aleksinac would be moved away from idleness that has been going on since the last tragic accident at the end of 1980s
- Other mines, that have been closed because of non profitable underground exploitation, could follow suit
- Gas obtained in this way could be used for power plants (existing, as well as purposely built) and therefore lower the dependancy on imported energy resources
- It the case of Aleksinac mine, the

gas could be used to heat the city itself, but also Niš and Kragujevac. It could used as well as a technological gas, and the building of a special gas powered power plant would be justifiable, and eventually a co-generated power plant (this is justified by enormous amounts of UCG yielded gas, which has been presented earlier).

After realized results in Aleksinac mine, similar activites it could be expected and developing in other deposits.

References

[1] Dunajewski, J. (1984): *Przeplyw ciepla i masy u procesie podziemnego zgazowania wegla*, Gliwice, str.1–8.

[2] Krejnin, E. V.(1982): *Podzemna gasifikacija ugljenih slojeva*, ''Nedra'', Moskva, 250 p

[3] Medved, M., Dervarič, E., Skubin, G. (2008): Premog in njegova vloga v EU ter na področju JV Evrope. V: *Prihodnost energije : nafta - vpliv cen na energetsko politiko in gospodarstvo : ali bomo zaslužili ali plačali: (16. septembra 2008)*. Ljubljana: Planet GV, 2008, str. 28–39.

[4] Palarski, J. (1986): *Gas and heat transport in the underground coal gasification*, Symposium UCG, Saarbricken, 6 p.

[5] Petrović, D. (1988): *Izučavanje primjene PGU kod vanbilansnih rezervi uglja na području SB ugljenog basena*, Disertacija, Tuzla.

[6] Petrović D., Ivković M., Denić M., Dragosavljević Z. (2008): *Studija identifikacije i klasifikacije podzemnih ležišta uglja u Srbiji sa aspekta moguće primene PGU*, "4D KONSALTING" Bg i JP PEU Resavica. 140 p.

[7] Vižintin, G. et al. (2008): Advance 3D finite elements modelling of groundwater drawdown in Velenje coal-mine=Napredno 3D modeliranje odvodnjavanja spuštanjem nivoa podzemnih voda-primenom metode konačnih elementa u rudniku uglja Velenje. V: VIDANOVIĆ, Nebojša (ur.), TOKALIĆ, Rade (ur.). Zbornik referatov. Beograd: Univerzitet u Beogradu, Rudarsko-geološki fakultet, str. 21–27.

[8] Vižintin, G. et al. (2008): Using virtual tools for 3D oil and gas presentations= upotreba virtuelnih alata za 3D prezentacije nafte i gasa. V: RISTOVIĆ, Ivica (ur.). Savremene tendencije u razvoju energetskog rudarstva: zbornik radova = proceedings. Beograd: Rudarsko-geolološki fakultet Univerziteta, str. 220–230.