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COMPARATIVE ANALYSIS OF ENERGY CONSUMPTION AND CO_2 EMISSION IN THE EXAMPLE OF COMBINED RECONFIGURED SYSTEM AT THE OPEN PIT POTRLICA[**]

Abstract

This paper presents the calculation of CO_2 emission on the example of the CCS[1] *system at thew open pit Potrlica in Pljevlja. Calculation was made before and after reconfiguration of the CCS system. It can be seen from calculation that the CO_2 emission, caused by the CCS system operation, have been reduced by about 3.5 times compared to the pre-reconfiguration state.*

Keywords*: CO_2 emission, CCS system reconfiguration, open pit Potrlica, energy efficiency, surface exploitation*

1 INTRODUCTION

Production of energy and other mineral resources is, as a rule, related to the management and manipulation of significant quantities of materials that are not found in the other industrial areas. In addition to the significant energy consumption necessary in the production of mineral resources, the environmental impacts and ecological factors of exploitation are also significant. Due to this reason, the issue of energy efficiency and application the procedures that enable the entire system to remain within the permitted limits of the impact on ecology is very important, that is, these two issues in the modern world become the crucial ones for assessment the success of exploitation.

As for the surface exploitation of coal, it is always related to the excavation, transport and disposal the large quantities of waste that exceed many times the quantities of coal. The focus of equipment engagement, total energy consumption and impact on the immediate environment is just related to the processes of overburden and waste that have to be excavated to provide the designed coal capacities, and which take place closer to the surface of the site where the consequences of these activities are more pronounced. Implementation of more efficient methods for excavation, transport and disposal of waste, both in terms of reducing the energy consumption and reduced time utilization of equipment, the use of easier and equipment requiring lower maintenance is the primary task in the process of optimization the exploitation.

The energy-efficient systems have a direct impact on a unit cost reduction, or

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an increase in the production efficiency. In addition to this primary factor, in the concrete examples of exploitation the lignite basins in Serbia and region, their ecological effect is also significant. Namely, in the last decades, there is a significant tendency for the diesel fuel production systems to be replaced with the modern systems and equipment that would be directly supplied by electricity from the thermal power plants, which, as a rule, with the coal mine, represent a unique organizational unit. Considering the structure of energy consumption within the exploitation system, they are realized in a part of transport of masses (waste and coal) in several ways:

1. Replacement of discontinuous systems with combined or continuous systems in which a significant part of transport the total masses takes place by the belt conveyors.
2. Reducing the length of transport by better use of the available excavated space within the open pits, managing the front of progress the excavation works of overburden and useful mineral raw materials, implementing the additional measures for protection the open pits from water, and indirectly changing the geometry of benches on excavation and disposal and better organization, efficiency and reliability of the basic equipment.
3. Using the modern, energy-efficient equipment.

Supply of electricity for the needs of lignite open pits is directly related to the thermal power plant in the immediate environment. The coal open pits, in addition to belonging to large energy systems for electricity production, are also big consumers. On the other hand, the production of electricity in the thermal power plants is related to the significant environmental impacts. These effects are very different in their character and, in the last decades, carbon dioxide emission is the most recognizable in the general public as a direct cause of the greenhouse effect, that is, the cause of global climate change.

In addition, there are legally formal obligations at the national and international levels relating to the maximum carbon dioxide emission and a need for its reduction. In the concrete case of reconstruction the CCS system at the OP Potrlica, the reduction of carbon dioxide emission was analyzed as a consequence of a more efficient system for transport of overburden and waste. This side effect is not a direct economic parameter of the exploitation system, but it contributes to a better understanding the overall benefit of introducing more energy-efficient procedures and equipment.

EXAMPLE FROM THE OP POTRLICA

Excavation of overburden at the open pit Potrlica is carried out with equipment with a discontinuous operation, and transport is combined, inside the open pit by trucks, and further on the external landfill by a conveyor belt system. Disposal is continuously carried out by a stacker, and a transitional element between the discontinuous and continuous part of the system by a crusher.

Technological system of overburden exploitation at the open pit Potrlica (Figure 1) consists of the following technological processes [1]:

- Preparation works
- Drilling and blasting
- Excavation and loading
- Internal transport
- Overburden crushing
- External transport
- Disposal

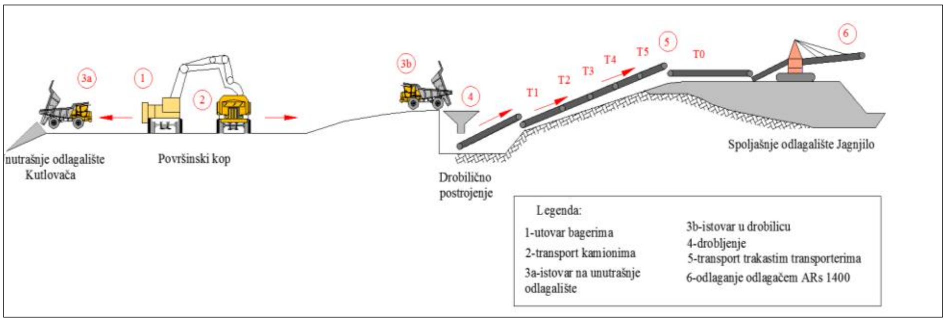

Figure 1 *Technological system of overburden exploitation [1]*

Configuration of the combined CCS system enables a continuous transport of overburden to the external landfill Jagnjilo in a length of 3680 m and overcoming of a height difference of 320 m. The transport system parameters before reconfiguration are shown in Table 1. [2]

Table 1 *Parameters of transporter before reconfiguration of the CCS system*

Belt conveyors	Length (m)	Slope (o)	Belt length (m)	Belt speed (m/s)	Lifting height (m)	Installed power (kW)
T1	212	9	1500	4.5	33.5	2*400
T2	543	6.26	1500	4.5	66.5	4*400
T3	529	7.53	1500	4.5	72.5	3*400
T4	620	9.5	1500	4.5	83.1	4*400
T5	500	10	1500	4.5	67	4*400
TO	1275	0	1400	4.5	0	3*400

Considering the applied exploitation system at the open pit, the costs of electricity for crushing and transport account for 40% of the total electricity consumption in the mine and these costs represent a significant part of the total exploitation costs.

By development of the open pit, the conditions have been created for further disposal of the total amount of overburden and waste on the internal landfill. For the purpose of forming an internal landfill by continuous equipment, reconstruction of the existing CCS system is needed, which has recently been carried out. The parameters of the reconfigured transport system are shown in Table 2.

Table 2 *Parameters of transporter after reconfiguration of the CCS system*

Belt conveyors	Length (m)	Slope (o)	Belt length (m)	Belt speed (m/s)	Lifting height (m)	Installed power (kW)
T1	303	1.37	1500	4.5	7.26	1*400
T2	623	0.43	1500	4.5	4.74	1*400
TO	1250	0	1400	4.5	0	1*400

Figure 2 presents the transport system after reconfiguration. Figure shows a disposal transporter TO set at a level of 750 m. There is a place for accommodation, installation and disassembly of equipment above the disposal transporter.

Figure 2 *Transport system after reconfiguration*

Justification of reconstruction was proven by the techno-economic analysis within which a configuration of the transport technology system and disposal of overburden for the next period are defined.

An integral part of the analysis is calculation the standardized electricity consumption for a continuous part of transport and disposal of excavated waste. This calculation was made on the basis of required power of the conveyor belt drive and measured average engaged force on the crusher and stacker. The electricity supply of the conveyor belt drive and stacker is carried out within the supply system of all consumers at the open pit. [2,3]

To produce the appropriate amount of energy, it is necessary to burn the appropriate amount of coal. In this case, based on the long-term monitoring of the production effects of the TPP Pljevlja, the average consumption of coal per kWh of produced electricity is 1.15 kg/kWh. This average consumption refers to coal from the OP Potrlica, whose mean values of the quality indicators are given in Table 3.

Table 3 *Statistical indicators of the quality parameters of the main coal seam*

Parameter	Mean value	Minimum value	Maximum value	Variation coefficient	Standard error	No. of drillholes
Wg (%)	20.18	15.00	28.00	21.46	4.33	11
Wh (%)	8.51	1.69	25.68	54.05	4.60	54
Wu (%)	31.11	21.46	37.69	10.35	3.22	56
P (%)	19.17	7.63	42.55	35.31	6.77	56
Ss (%)	0.61	0.12	1.79	54.10	0.33	54
Sp (%)	0.49	0.07	0.89	40.82	0.76	54
Su (%)	1.09	0.62	2.16	69.72	0.76	54
Zm (t/m^3)	1.35	1.22	1.57	5.18	0.07	49
CaO (%)	21.75	7.62	57.92	60.41	13.14	28
Isp (%)	27.30	14.93	43.29	15.24	4.16	52
Sag (%)	49.35	29.40	60.30	10.50	5.18	54
C-fix (%)	22.10	7.16	35.15	23.03	5.09	54
Coke (%)	41.43	21.08	53.38	13.15	5.45	54
GTE (kJ/kg)	12,947	5,347	15,673	24.15	3,127	56
DTE (kJ/kg)	11,648	4,409	14,281	12.33	1,436	56

METHODOLOGY OF CALCULATION THE CARBON DIOXIDE EMISSION

For calculation the carbon dioxide emission from coal combustion, the methodology given in the document "IPCC Guidelines for the National Greenhouse Gas Inventory, Volume 2 – Energy" [4] was used.

Generally, the emission of each of the greenhouse effect gases from stationary sources is calculated multiplying the fuel consumption and corresponding emission factor. Fuel consumption is first expressed in the mass or volume units, and then must be converted to the energy value of that fuel.

The energy values of individual fuels are determined by the statistical methods, collected systematically from the national agencies and processed and presented in a form of periodic inspections. The following tables presents the specific energy value of fuel (TJ/Gg) (Table 4) and carbon content (C) expressed in kg/GJ (Table 5).

Table 4 *Default net calorific value (NCV) and lower and upper limits of the 95% confidence intervals for different types of coal*

Coal type	Net calorific value (TJ/Gg)	Lower	Upper
Anthracite	26.7	21.6	32.2
Coking coal	28.2	24	31
Other Bituminous Coal	25.8	19.9	30.5
Sub Bituminous Coal	18.9	11.5	26.0
Lignite	11.9	5.5	21.6

Table 5 *Default values of carbon (C) content for different types of coal*

Coal type	Net calorific value (TJ/Gg)	Lower	Upper
Anthracite	26.8	25.8	27.5
Coking coal	25.8	23.8	27.6
Other Bituminous Coal	25.8	24.4	27.2
Sub Bituminous Coal	26.2	25.3	27.3
Lignite	27.6	24.8	31.3

The CO_2 emission factor is determined on the basis of the average carbon content in fossil fuel. In the case of CO_2, it is assumed that the oxidation factor of carbon is 1, or that the combustion is complete. Table 6 gives the content of carbon and emission factor of carbon dioxide. [5]

Table 6 *Carbon content and emission factor of CO_2 for various types of coal*

Coal type	Default carbon content (kg/GJ)	Emission Factor CO_2 (kg/GJ)
Anthracite	26.8	98.27
Coking coal	25.8	94.60
Other Bituminous Coal	25.8	94.60
Sub Bituminous Coal	26.2	96.07
Lignite	27.6	101.20

The gas emission with the greenhouse effect is calculated as:

*Emission = Fuel Consumption * Emission Factor * Oxidation Factor*

EXAMPLE FROM THE OP POTRLICA

Calculation the conveyor belt parameters in the CCS system configuration was made using the standard method according to JUS M.D2.05. Calculated conveyor belt parameters before and after reconstruction are given in Tables 7 and 8.

Table 7 *Parameters of a belt conveyor before reconfiguration of the CCS system*

	Engaged power (kW)	Installed power (kW)	Coefficient of engaged power
CRUSHER	566	1132	0.50
T1	460	800	0.58
T2	940	1600	0.59
T3	989	1200	0.82
T4	1142	1600	0.71
T5	926	1600	0.58
TO	594	1200	0.50
SPREADER	161.4	538	0.30
Σ	**5778.4**	**9670**	

Table 8 *Parameters of a belt conveyor after reconfiguration of the CCS system*

	Engaged power (kW)	Installed power (kW)	Coefficient of engaged power
CRUSHER	566	1132	0.50
T1	243	400	0.61
T2	359	400	0.90
TO	332	400	0.83
SPREADER	161.4	538	0.30
Σ	**1661.4**	**2870**	

Specific coal consumption per kWh was measured by a long-term monitoring and amounted to 1.15 kg/kWh. The specific coal consumption and CO_2 emission per kWh was determined and are shown in Tables 9 and 10. For the CO_2 emission calculation, the amount of carbon in coal was taken on the basis of testing results the quality of coal of the main coal seam of the deposit Potrlica which accounts for more than 90% of the total balance. The average carbon content is Cfix = 22.1%. It was assumed that during combustion the reaction with C was complete.

Table 9 *Calculation the emission of CO_2 (t) before reconfiguration of the CCS system*

	Engaged power (kwh)	Operation time (h)	Total energy (kwh)	Equivalent coal (t)	Total C (t)	Total CO_2 (t)
Crusher	566.00	3,000.00	1,698,000.00	1,952.70	431.55	1,582.34
T1	460.00	3,000.00	1,380,000.00	1,587.00	350.73	1,286.00
T2	940.00	3,000.00	2,820,000.00	3,243.00	716.70	2,627.91
T3	989.00	3,000.00	2,967,000.00	3,412.05	754.06	2,764.90
T4	1,142.00	3,000.00	3,426,000.00	3,939.90	870.72	3,192.63
T5	926.00	3,000.00	2,778,000.00	3,194.70	706.03	2,588.77
TO	594.00	3,000.00	1,782,000.00	2,049.30	452.90	1,660.62
Stacker	161.40	3,000.00	484,200.00	556.83	123.06	451.22
					Σ	**16,154.38**

Table 10 *Calculation the emission of CO_2 (t) after reconfiguration of the CCS system*

	Engaged power (kwh)	Operation time (h)	Total energy (kwh)	Equivalent coal (t)	Total C(t)	Total CO_2 (t)
Crusher	566.00	3,000.00	1,698,000.00	1,952.70	431.55	1,582.34
T1	243.00	3,000.00	729,000.00	838.35	185.28	679.34
T2	359.00	3,000.00	1,077,000.00	1,238.55	273.72	1,003.64
TO	332.00	3,000.00	996,000.00	1,145.40	253.13	928.16
Spreader	161.40	3,000.00	484,200.00	556.83	123.06	451.22
					Σ	**4,644.69**

On the basis of realized calculation, it can be concluded that the CO_2 emission, caused by the operation of the CCS system, has been reduced by about 3.5 times compared to the previous state. This indicator is the result of reduced specific energy consumption.

CONCLUSION

Reconfiguration of the CCS system is carried out on the basis of the results of techno-economic analysis for justification the relocation of the CCS system from the external to the internal landfill at the OP Potrlica of the Coal Mine Pljevlja. During economic evaluation, the costs of dismantling and assembly, equipment transport and other costs were analyzed, while the costs of transport and maintenance of the new CCS system were analyzed on the side of revenues [2]. Reduction of carbon dioxide emission and consequently reduction of deposit costs or CO_2 emission allowances have not been considered. The current legislation does not foresee any costs due to the CO2 emission. This situation will be changed in the future.

When analyzing the construction of a new or replacement block of the Thermal Power Plant Pljevlja, the costs of CO_2 emission have been discussed from 2025 onwards with a gradual increase in the prescribed fee from 0 to 100% over a period of 5 years [6]. These costs will fall into the electricity price and will also affect the exploitation economics. This will further aggravate the issue of energy efficiency of the surface exploitation system, and their participation in the CO_2 emission will be an important indicator of efficiency. In this case, the CO_2 emission is reduced by about 3 times with the reconfiguration of the CCS system and is a direct consequence of only reducing the length and height difference in the waste transport. Even better results can be achieved by:

- Optimal mass control at the open pit,
- The use of modern, energy efficient equipment supported by the automatic control,
- Better maintenance, primarily the elements of belt conveyor,
- Applying the new materials for conveyor belts, drums, rolls, etc.

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