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SYNERGY OF ENERGY RESOURCES OF COPPER PYROMETALLURGY IN RTB BOR-SERBIA

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Abstract

Copper production is a significant consumer of energy, consisting of almost all fossil fuels, and also including electricity. This work presents a comparison of the specific energy consumption of several metallurgical copper producers in the world, with the installed different technological processes, in comparison to the production of copper in RTB Bor (Serbia). An important place is dedicated to the quantitative participation of energy fuels in the production of copper. In addition to this, an analysis of cost structure for energy fuels was shown in the production process of copper. This work particularly emphasizes the aspect of use the secondary (waste) heat energy as a prerequisite to improve the energy efficiency and economy of pyrometallurgical copper production. Using the waste heat of pyrometallurgical process, the protection of working and life environment is improved

Selection and development of new metallurgical processes in order to achieve the best economic effects is achieved selecting the optimum technology, on one side, and selection of energy system with the best performances with the full utilization the secondary heat energy of the process. Concretization of this aspect also relates to the modernization of the Copper Smelter in RTB Bor installing the new technology for smelting of copper concentrates.

Introduction

For operation the technological process of copper production, a large amount of energy is consumed, which includes integrally mining and concentrate production, pyrometallurgical process of anode copper production, electrolytic refining of anode copper. The analysis of energy consumption in the process often comes down to making the heat balance of the entire process or only some of its stages. This analysis does not give a real evaluation of energy consumption. To obtain a complete overview of energy

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consumption, it is necessary to take into account the energy consumption in the overall technological process, considering all technological stages, and also energy "losses". All forms of spent energy are necessary to be reduced to the primary or the same form of energy that is equivalent of process energy, raw materials and process materials, and also it is needed to balance the energy equivalent of products and by-products (water vapor, heat energy, etc.).

This work presents the results of energy consumption in RTB Bor (Serbia). The Bor copper mine was opened in 1903 and is dealing with ore mining, production of copper concentrate, pyrometallurgical processing of copper sulfide concentrates and production of anode copper. The installed pyrometallurgical process includes the following technological units: batch roasting in the fluosolid reactor, calcine smelting in the reverberatory furnaces, converting in the Peirce Smith converters, flame refining of blister copper and anode production. In addition, this plant has the electrolytic refining of anode copper and production of sulphuric acid by the contact process in a plant with a single adsorption and single catalysis.

The existing technological process was low energy and economic efficiency and it has been environmentally unsustainable, which led to the modernization of technology in RTB Bor installing a new autogenous Flash Smelting process.

General trend of development the new autogenous smelting processes in the pyrometallurgical copper production occurs as the result of increasing demand for copper in the world market and increasingly stringent laws on environmental protection and impact of energy and economic crisis in the world. The new development-philosophical approach of some international companies has integrated all of its creative human resources creating a new generation of autogenous smelting processes of copper concentrate. This development trend has lasted for 50 years, and high energy value of sulphide copper concentrates was used for design of technologies in which the smelting process was almost brought to a complete autogenous.

Energy consumption in the copper production

Energy consumption in the copper production depends on copper content in the ore, copper content in the processed concentrate, perfection of technological process and efficiency of equipment, generators and devices. For the same technological process of copper production from the ore to the cathode copper, the power consumption [1], Table 1, is for 1.974 times lower than the realized structure of consumed energy in the copper production in RTB Bor during business year 2009 [2, 14].

For the copper production in RTB Bor, where the production process of cathode copper is developed according to the described production process, Figure 1, [19] in 2011 the copper content in the ore was 0.274% and the copper content in concentrate was 16.35%. Copper recovery from the ore in the flotation processes is an average of 75.60%, and technological copper recovery from concentrate in the smelting treatment is 92.97%. Total realized technological copper recovery from the ore to the cathode copper is 66.84%, what means, the rest are losses [2].

Table 1. Specific energy consumption in the production of cathode copper according to the literature data [1, 2, 3]

Process	Energy consumption, measure	Ref. [1]	RTB Bor [2]	Ref. [3]
1.Parameters of raw materials	%Cu in the ore	0.67	0.247	
	%Cu in copper concentrate	25	15.27	
	Copper production. kt/a	1,568.0	16.839*	
2. Mining	Liquid fuel. dm^3/t Cu	235.025	679.173	
	Electric energy. kWh/t Cu	742++	2,702.264	
	Coal. kg/t Cu	1.157		
	Natural gas. m^3_n/t Cu	9.842		
	Total 2. t_{ec}/t Cu	**0.600**	**1.528**	
3. Flotation process	Electric energy. kWh/t Cu	3.577	14.854.663	
	Liquid fuel. dm^3/t Cu	17.552		
	Natural gas gas. m^3_n/t Cu	56.290		
	Total 3. t_{ec}/t Cu	**1.423**	**4.009**	
4. Roasting, smelting, converting and flame refining of copper	Liquid fuel. dm^3/t Cu	125.356		
	Natural gas. m^3_n/t Cu	870.958		
	Oxygen. t/t concentrate		0.138	0,106
	Coal. kg/t Cu	105.298	1.239	0,25t/$t_{concentrate}$
	Coke. kg/t Cu	24.300		
	Wood for reduction. m^3/t Cu		0.059	
	Electric energy. kWh/t Cu	148.610	2,199.463	430
	Total 4. t_{ec}/t Cu	**1.336**	**1.979**	
5.Production of sulphuric acid	Heating oil. dm^3/t Cu		8.501	
	Electric energy. kWh/t Cu		336.794	
	Total 5. t_{ec}/t Cu	**0.086**	**0.102**	
6. Electrolytic refining	Electric energy. kWh/t Cu	260	448.573	300
	Water vapor. t/t Cu		0.478	0,230
	Total 6. t_{ec}/t Cu	**0.113**	**0.165**	
Total(2÷6), t_{ec}/t cathode Cu		**3.558**	**7.783**	**-**

* Raw materials of RTB Bor,

++ Equivalent of electric energy is 10,802 kJ/kWh [1]

Energy consumption from the ore to the cathode copper (cc) in RTB Bor, in the period from 2007 to 2011, reduced to the equivalent coal (ec), respectively, was realized in the amount of 6.300-7.783 t_{ec}/t_{cc}. Based on the data, Table 2, it is observed that the energy consumption is far over the realized consumption in the smelters with the modern smelting technology [8].

Table 2. Energy consumption in the cathode copper production

OPERATION	Energy consumption, t_{ec}/t_{cc}					
	C. H. Pitt [8]	RTB Bor [2]				
		2007	2008	2009	2010	2011
1. Mining	0.599	1.190	1.139	1.528	1.318	1.401
2. Flotation process	1.424	3.259	3.308	4.009	3.167	3.280
3. Pyrometallurgy	1.337	1.708	1.569	1.979	2.278	2.024
4. Production of sulphuric acid	0.086	0.163	0.127	0.102	0.178	0.147
5. Electrolytic refining of copper	0.112	0.121	0.157	0.165	0.177	0.171
TOTAL:	3.558	6.441	6.300	7.783	7.118	7.023

Energy consumption in the copper production is mostly below 15 GJ/t_{Cu}, except in the smelters where the flame furnaces are used, where consumption is over 20 GJ/t_{Cu}, Figure 1 [6]. In the smelter of RTB Bor, the energy consumption in 2011 was realized in the amount of 55.949 $GJ/t_{anodeCu}$ (1,909 $t_{ec}/t_{anode\ Cu}$).

The realized equivalent of electric energy in RTB Bor, since it is generated in hydro and thermal power plants of EPS, has a value of 7,430 kJ/kWh. Processing capacity of copper concentrate in the Smelter of RTB Bor in 2008 was reduced by 3.12 times (time utilization of 62.03%) than in the achieved one in 1990, and the capacity of technological line of smelting is lower for 67.03% than the achieved one in 1990 (time utilization of 89.25%).

Production of anode copper in 2008 was reduced by 4.34 times compared to 1990 and cathode copper by 4.48 times, and the energy consumption was increased from 0.633 (in 1990) to 1.319 $t_{ec}/t_{anodeCu}$ (in 2008).

In the copper production in RTB Bor, reduced to the equivalent of energy(ee), electric energy has the largest share up to 70% of total consumption, and in the cost of energy up to 50%. The largest consumer of electric energy in the copper production is the ore flotation, mining, smelting and electrolytic refining of copper, Table 3.

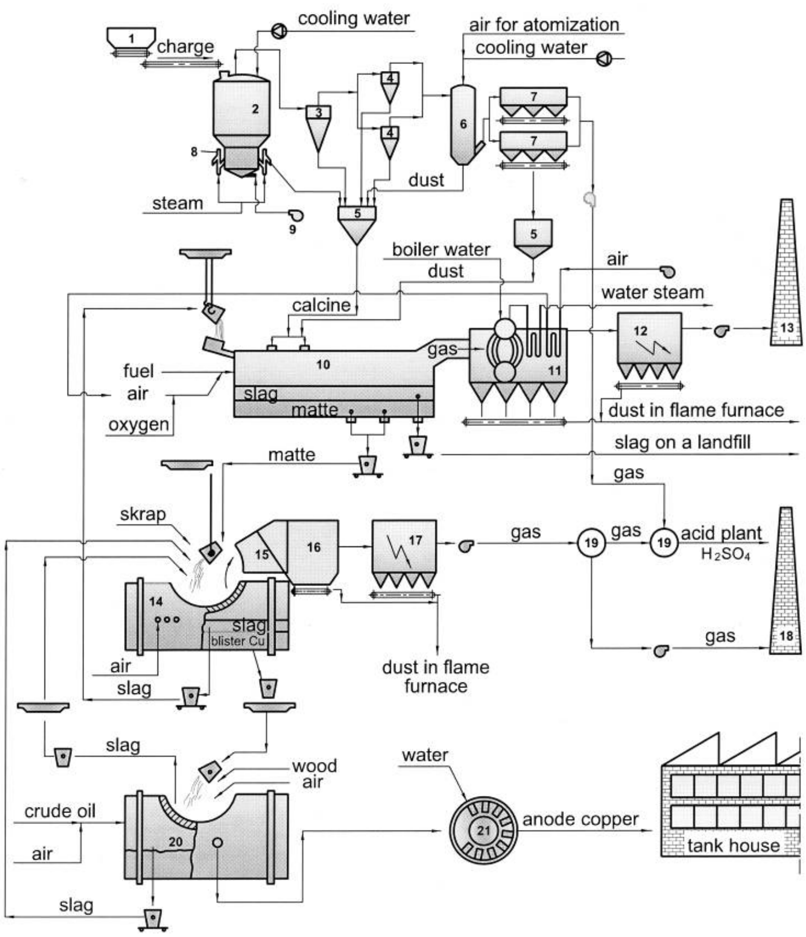


Fig. 1. Technological scheme of pyrometallurgical process of copper production in the Smelter in Bor, RTB Bor, Serbia

1-warehouse for charge, 2-fluosolid reactor, 3.4-cyclone, 5-silo, 6-tower for gas cooling, 7,12,17-electrostatic precipitator, 8-overflow of calcine (fluosil), 9-air blower, 10-flame furnace, 11-utilizing steam boiler, 13-stack, 14-PS converter, 15-fume catcher, 16-cooling chamber, 18-stack, 19-mixing tower, 20-anode furnace, 21-casting machine

Figure 2, presents a change of specific energy consumption per types of energy, and Figure 3 presents the same per stages of copper production. Using the literature data, [2,4,5,6,15], an analysis was made of realized technological and energetic parameters of smelting furnaces of the most present technologies for copper production in the world. The result of these analyses show that the largest consumer of energy is the flame furnace and the most energy-efficient technology is the ISA Smelt, then Teniente converter, autogenous pit furnace, etc.

Table 3. Electric energy consumption in the cathode copper (cc)production

Technological Stage	Electric energy consumption for cathode copper production, kWh/t_{cc}					
	C.H.Pitt [8]	RTB-Bor [2]				
		2007	2008	2009	2010	2011
Mining	742	3,040.281	2,345.103	2,702.3	2,621.3	2,530.2
Flotation process	3.577	13,357.9	13,558.16	14,854.7	12,491.3	12,937.3
Pyrometallurgy	736	1,859.611	1,831.1	2,199.5	1,954.0	1,695.2
Production of sulphuric acid		429.798	431.310	336.8	609.987	484.672
Electrolytic refining of copper	280	502.021	500.644	448.6	445.436	438.580
TOTAL:	5.335	19,189.50	18,666.33	20,541.8	18,122.1	18,085.9

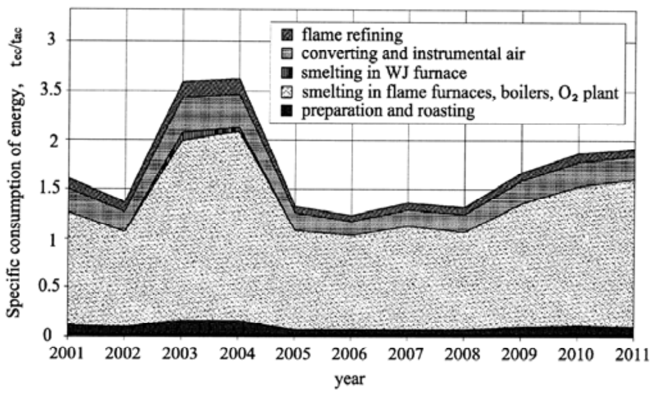


Fig. 2. Specific energy consumption in the production of anode copper in the Smelter RTB Bor, reduced to kg of mass of equivalent coal per ton of anode copper for the period from 1994 to 2011.

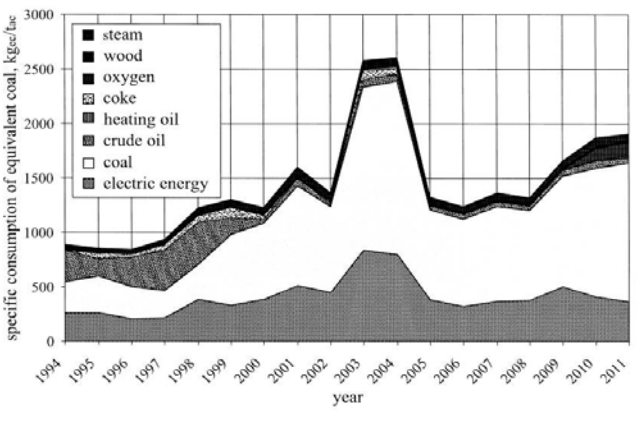


Figure 3. Consumption of conditional fuel per technological units in the Smelter in Bor for the period from 2001 to 2011.

Specific energy consumption, among other effects, depends on capacity in the copper production and copper content in concentrate. With increase in the copper production capacity *(for each 1,000 tons of copper)* the energy consumption decreases by about 8.5%, Figure 4, with increase the copper content in concentrate *(for each % Cu in concentrate)* the energy consumption decreases by about 21.4%, Figure 5 [2]. This is directly proportional transmitted to the total costs of copper production. Due to these reasons, the justification of direct ore smelting in the flame furnace containing copper 4÷7% is extremely questionable. On this question, the company management has a really responsible task that is contrary to the previous practice.

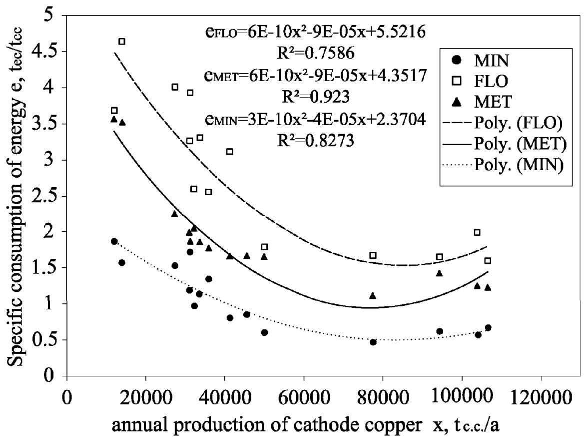


Fig. 4.Specific energy consumption in the cathode copper production from ore to the cathode copper in: mining (MIN), flotation process (FLO) and smelting, electrolytic copper refining and sulphuric acid production (MET-smelter, electrolytic refining and sulphuric acid production)

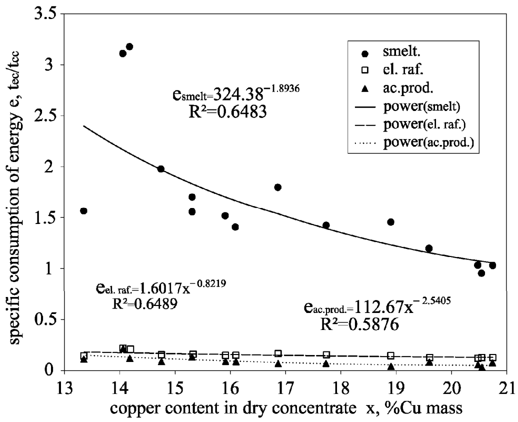


Fig. 5. Specific energy consumption in the cathode copper production from concentrate to the cathode copper per production stages in: Smelter, electrolytic copper refining and sulphuric acid production depending on copper content in dry concentrate

The reduction of energy consumption and production costs per unit mas of product, except for rational energy management, adequate quality of copper concentrate and energy, it is necessary to achieve also the optimal capacity in order to realize maximum capacitive and time utilization of metallurgical aggregates.

Cooling water consumption

Cooling water has an important role in the copper production. It is used for cooling of aggregates (parts of metallurgical furnaces, pumps, compressors), drill operation in the mine, in the flotation process, wet dedusting of gases and similar. The amount of used water for cooling depends on the cooling system (flow or recirculation), available water quantity, and philosophy of water understanding as an essential fluids, etc.

Water consumption in the copper production:	**Ref [9]**	**RTB Bor [2]**
Mining and flotation process	0.37	2.174 m^3/t ore
Smelting	7.8	2.912 m^3/t Cu
Refining	0.6	8.775 m^3/t Cu

Correlation equation for water consumption is [9]**:**
w=167.7 M – 0.9039, (r2=0.916), m^3/t cathode copper,
where M, % metal – metal content in the ore.

Costs of copper production

According to the analysis of Brook Hunt [20], for the period from 2004 to 2007, the share of consumption, labor, capital, and others in the production of copper, consisting of:

Energy	10-25%
Labor	10-30%
Capital	6-20%
Other	13-41%

Operating costs of smelting and refining in the copper production, if the smelting process of batches is done in the ISA Smelt furnace in the Mount Isa Mines Limited (Australia), with the concentrate smelting capacity of 194 t/h for the first three months of 2001-2002 was total of 190.48 USD/t_{Cu}. Consumption of fossil fuel in April 2001 in the processing of 97,344 t of concentrate spent: 636 t of coal, 602.790 m_n^3 of natural gas and 100.9 m^3 of liquid fuel, which amounts to 0.47 GJ/$t_{concentrate}$. In April 2002, 104.345 t of concentrate was processed and spent 326 t of coal, 395.475 m_n^3 of natural gas and 109.2 m^3 of liquid fuel, what is 0.28 GJ/$t_{concentrate}$ [10].

Two aspects of acceptance the costs of copper production were discussed for the company RTB, as follows: for the existing technological scheme – aspect 1, and copper concentrate smelting in in Flash Smelting Furnace – aspect 2.

1. Costs of the existing copper production at the plant amount to 5,827 USD/t_{Cu} (mine and flotation to 4,660 USD/t_{Cu}, smelting to 668 USD/t_{Cu}, converting and flame refining to130 USD/t_{Cu},, sulphuric acid to 112 USD/t_{Cu}, Oxygen Plant 25 4.660 USD/t_{Cu}, electrolytic refining of 201 USD/t_{Cu}, sulpfuric acid storage and maintenance 8 USD/t_{Cu} and steamproduction 23 USD/t_{Cu} Costs of pyrometallurgy, copper electrolytic refining, and production and storage of sulfuric acid total of 1,167 USD/t_{Cu} (1 €=1.27 USD). The structure of costs is as follows: human labor 1.514 USD/t_{Cu}, equipment and

maintenance 793 USD/t_{Cu}, electric energy, water, steam, oxygen, fuel 2.780 USD/t_{Cu}, and indirect costs 740 USD/t_{Cu}.

2. The forecast costs of copper production after the start of the new Flash Smelter Furnace in RTB Bor are specified as follows:

1. Mining and flotation process	2,737 USD/t_{Cu}
2. Pyrometallurgy	110 USD/t_{Cu}
3. Electrolytic copper refining	203 USD/t_{Cu}
4. Sulphuric acid production	110 USD/t_{Cu}
5. Storage of sulphuric acid	9 USD/t_{Cu}
6. Steam and heating	23 USD/t_{Cu}
Total	**3,192 USD/t_{Cu}**

Pyrometallurgy and electrolytic refining realize costs in the amount of 313 USD/t_{Cu}, and the sum of items 2÷6 achieves 455 USD/t_{Cu}. Specification of costs in the copper production from ore to the cathode copper and sulpfuric acid production by sectors is: human labor 560 USD/t_{Cu}, equipment and maintenance 512 USD/t_{Cu}, energy (electricity, water, steam, oxygen, fuels, etc.) 1.645 USD/t_{Cu}, and indirect costs 475 USD/t_{Cu}, what is in total 3,192 USD/t_{Cu}. Table 4 shows an overview of thes cost of copper production from ore to the cathode copper for copper concentrate smelting technology in the Flash Smelting Furnace [14] and the second part of the Table shows the realized costs in the copper complex RTB Bor in the period from 2007 to 2011 [2].

Table 4. Costs in the cathode copper production

OPERATION	Costs of copper production, US$/$t_{cc}$					
	Schlesinger [14]	RTB-Bor [2]				
		2007	2008	2009	2010	2011
Mining	500					
Flotation process	1,000	6,139.54	5,088.88	3,221.25	4,847.67	7,595.08
Pyrometallurgy		957.54	764.68	1,008.78	1,076.91	1,188.99
Production of sulphuric acid	300	194.13	172.95	95.96	262.93	109.46
Electrolytic refining of copper	100	236.06	160.57	276.20	118.94	284.55
Management, depreciation, others	1,100					
TOTAL:	3,000	7,527.27	6,187.08	4,602.19	6,306.45	9,178.07

For comparison, Figure 6, presents the annual produced quantity and costs of cathode copper production in the copper complex RTB Bor (Smelter and Tank House) for the period from 2004 to 2010 in cents of US dollar per libre of copper. Production costs in the observed period, are in the range from 31.96 to 84.99 USc/lb in the realized cathode copper production from 11.998 to 41.387 kt.

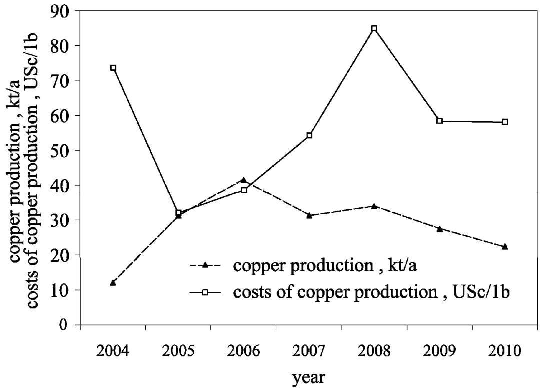


Fig. 6. Costs of cathode copper production in RTB Bor (Smelter and Tank House) for the period from 2004 to 2010 (1 USD/t Cu=0.045359 USc/lb Cu)

Correlation dependence the costs of copper production (Smelter and Tank House) on the copper production capacity, based on Figure 6, is

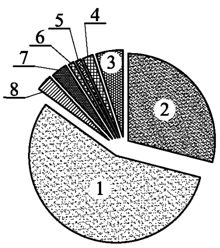
y= - 0.8655 x+81.706, USc/lb

where

y, USc/lb- costs of copper production,

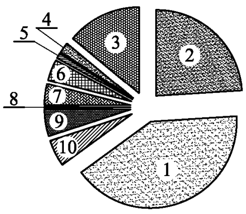
x, kt/a-copper production.

In the total energy consumption (with a value of 538.45 USD/t_{cc}), reduced to an equivalent coal in the pyrometallurgical production of cathode copper in RTB Bor, the electric energy accounts for 28.98%, fuel in the Smelter 59.97%, steam 5.90%, etc. On the other side, the largest consumer of energy is the Smelter with 86.53%, electrolysis with and sulphuric acid plant with 6.73% of the total energy consumption. Structure of spent energy, reduced to the equivalent of coal in smelting, electrolytic refining of copper and sulphuric acid production is shown in Figure 7, and the price structure for energy in Figure 8 [11].



		tec/tcc	%
1	coal in flame furnace	1.447	56
2	eletric energy	0.763	29
3	gaseous oxigen in flame furnace	0.135	5
4	steam for heating of electrolyte	0.064	2
5	light liquid fuel	0.029	1
6	wood for reduction	0.021	1
7	own steam in the smelter	0.092	3
8	crude oil	0.082	3

Fig. 7.Specific energy consumption in the cathode copper production (Smelter, Electrolytic refining, Sulphuric acid production) reduced to a ton of equivalent coal (ec) per ton of produced cathode copper (cc)



		RSD/tcc	%
1	coal in flame furnace	17411.55	40,5
2	eletric energy	9934.98	24
3	gaseous oxigen in flame furnace	5693.05	14
4	demineralizad water	761.62	2
5	cooling water	423.83	1
6	steam for heating of electrolyte	1529.37	4
7	light liquid fuel	1816.93	4
8	wood for reduction	193.99	0,5
9	own steam in the smelter	2068.38	5
10	crude oil	2085.97	5

Fig. 8. Participation of energy prices in the costs for energy (Smelter, Electrolytic refining, Sulphuric acid production) in RSD per ton of produced cathode copper (exchange rate 1 USD=77.8532 RSD).

The effect of use the secondary on energy and economic efficiency and improvement the environmental conditions

Using the secondary *(waste)* heat energy of technological processes, which are available to any producer of copper as specificity, the consumption of primary energy will be reduced, which will help, beside the economic efficiency also less pollution of the environment. Using the secondary *(waste)* energy increases the energy and economic efficiency of the current technological process. This issue needs to be given greater importance in the construction of new production line for smelting and sulphuric acid plant within the project of modernization the Smelter in Bor, primarily using the high temperature waste heat from the process of smelting and converting in order to implement more modern and more efficient energy system.

By construction the Copper Smelter by autogenous Outokumpu Flash Smelting technological process in RTB Bor, which should start in 2013, the elimination of excessive emissions of sulfur dioxide and dust should be expected, and also lead, zinc, mercury, cadmium, arsenic and other components, and reduction the amount of emission the carbon dioxide and nitrogen oxides. This will decrease the impact of the copper production process on the effects of global warming such as the effect of "greenhouse" gases and the phenomenon of "*acid*" rains in the vicinity of the Smelter and beyond, as well as the elimination of direct damage from smelter gas emissions on agriculture and ecosystem in the area.

Selecting the favorable decisions of technological process and overall energy system and rational management of energy would reduce the energy consumption by more than three times compared to the current situation, and the equivalent energy in copper production will be several times lower. Also, the production costs will be lower by more than 50% of the actual costs of copper production

Emission of sulfur dioxide SO_2 gas in the environment [18] from the current 1,363.591 m_n^3/t_{Cu} (directly 1,356.347 m_n^3/t_{Cu} and indirectly with electric energy from EPS and the production of electric energy from the thermo power plants amounting to 7.244 m_n^3/t_{Cu}) will fall below estimated, 10 $m_n^3/t_{Cu.}$ Emission of carbon dioxide (CO_2 gas) in the environment [18] from the current 2,993.424 m_n^3/t_{Cu} (directly 1,524.894 m_n^3/t_{Cu} and indirectly with electric energy from EPS and heat from the thermo power plants amounting to 1,468.53 m_n^3/t_{Cu}) will fall below estimated 130 m_n^3/t_{Cu} of direct emission. Rational management of secondary energy and good selection of energy systems and equipment are guarantee that the Smelter can cover the most of its electric and heat energy consumption, i.e. an indirect emission of CO_2 should not exist.

Conclusion

In the copper production, as a major consumer of energy, from ore to the cathode copper, the optimal amount of energy is needed to be 3,5 t_{ee}/t_{cc} [19], bearing in mind that in some parts of production the energy consumption is: mining 61 MJ/t of ore, grinding 270 MJ/t of ore, pyrometallurgy 11 GJ/t of refined copper [13].

In the total production costs, the energy makes up to 50% of the costs of copper production. Thus, the reduction of energy consumption and production costs per unit mass of the product is a permanent task.

In addition to the rational management of energy is necessary to provide an adequate quality of copper concentrate and energy. As part of measures to improve the economic parameters of copper it is necessary to define the optimal processing capacity of the concentrate will contribute a maximum capacitive and time utilization of metallurgical aggregates. This activity must be carried out at all stages of production and in all periods of operation.

Acknowledgement

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