УДК 669.2.018.674 https://doi.org/10.51301/vest.su.2021.i5.10

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EFFECTS OF ADDITIONAL FUEL ON THE MELTING PROCESS IN THE VANYUKOV FURNACE

Abstract. Due to the change in the composition of the processed raw materials at the Balkhash Copper Plant (BCP), it is required to adjust the technology used to melt copper sulfide concentrates in the Vanyukov furnace (VF). It is promising to use additional carbon-containing fuel that burns in the bubbling zone increasing the melting temperature and partially reducing slag oxides to ensure the required autogenousity and melting temperature. However, part of the solid fuel does not burn in the bubbling zone with an oxygen-containing blast and does not participate in reduction reactions with slag oxides that result in its accumulation on the surface of the slag melt.

The results of the industrial tests performed earlier in the BCP to feed coal dust through tuyeres to the VF with the purpose to maintain the required temperature of the slag melt and satisfactory separation of slag and matte were considered. The reasons for the unstable operation of the tested system to feed coal dust to the VF through tuyeres were determined, and directions for its improvement were outlined. Laboratory experiments were performed to simulate the behavior of coal dust in the quiet zone of the VF. The regularities of the distribution of coal dust were determined, and it was shown that coal dust was concentrated on the slag melt surface. Thus, coal dust that did not react with blast oxygen or oxides of the slag melt in the bubbling zone was carried to the surface of the slag melt, promoted the formation of a viscous crust, and then practically did not interact with the slag melt and becomes practically useless.

Keywords: copper sulphide concentrates, Vanyukov furnace, autogenous smelting, solid fuel, coal, coal dust, slag, matte.

Introduction. Currently, there is a steady tendency towards a decrease in the autogenicity of the processed raw materials due to the involvement in the production of ores poor in non-ferrous metals and partially oxidized technogenic materials. A change in the chemical and phase composition of raw materials results in a violation of the heat balance, hindering the operation of VF, and a decrease in technical and economic indicators. To ensure a high speed and completeness of the oxidation reactions of the processed raw materials, the oxygen-containing blast is enriched with oxygen.

The main physical and chemical processes of the formation of matte and slag components occur in the main part of the VF; in the uptake zone, these processes end, and the formation of the slag phase begins. To intensify the reduction processes and the formation of a slag phase, it seems possible to supply additional fuel. Various options for the reduction of metal oxides are described [1-5] in an atmosphere including H_2, H_2O, CO, CO_2 in the absence or presence of carbon, in particular, the reduction of magnetite to iron oxide which is very important for the formation of the slag phase. Based on many studies, it has been established that depletion of slags from autogenous processes is most effective only with the use of reduction treatment of slags [6-8]. As a reducing agent and additional fuel, it is rational to use coal dust and supply it through tuyeres located in the area under the uptake, especially since they take a passive effect in the operation of the VF.

The reducing properties of the carbon-containing reagent are widely used in autogenous processes [9, 10]; the carbon-containing reductant that is used as coal dust, is supplied to the Vanyukov furnace and other units [11, 12].

The supply of a solid carbon-containing reductant to the melt limits the possibility of peroxidation of the particles of the processed raw material, binds the excess oxygen from the blast, and reduces dust emission. It is possible to supply a carbon-containing reductant together with a sulfide concentrate. The issues of preparing coal dust are important: drying coal, grinding it to a certain size, transporting coal dust to the furnace. In most cases, the particle size of the coal significantly affects the smelting process. The study of the effectiveness of mixing coal into the volume of the bath is of special significance. The lateral jet blowing of the melt with an oxygen-containing blast through the tuyeres forms a rather intensive vertical circulation of the slag that results in the mixing of a certain part of the coal deep into the bath.

The distribution of coal particles along the height of the bath is non-uniform - their highest content is noted in a thin surface layer. Coarse particles of coal are concentrated in the upper horizons of the bath, and small particles are present throughout the volume of the bubbling slag. More complete use of the volume of the molten bath occurs in the lance torch, where the combustion of coal particles occurs. The accumulation of coal in the surface layer of the bath results in particle aggregation and reduces the surface area of the coal. In the normal course of the technological process, the oxygen-containing blast is completely consumed for the combustion of coal in the lower part of the bubble columns, this area is the source of the greatest heat release [13-16]. All the main physical and chemical processes take place in this area: heating of coal dust particles, removal of moisture from particles, gasification of coal particles, dissolution of fluxes, reduction of oxides by carbon of coal particles. If the content of coal particles decreases, the limit for the disappearance of oxygen in the gas phase of the bubble column rises higher, as does the limit for the completion of the formation of CO_2. If the conversion of CO_2 is incomplete, a gas containing CO_2 and O_2 will be released from the slag bath, the heat release in the slag will increase, since coal combustion goes to CO_2. Optimal processes begin to prevail in the volume of slag, recovery slows down that will entail an increase in the content of oxides in the slag. Coal dust is concentrated in a thin surface layer of the slag bath even with intensive bubbling. An increase in the coal load results in an increase in its content in the surface layer, the coal layer in the VF is distributed along the periphery of the areas where the bubble columns exit from the gas bath, in these areas the slag melt is depleted in coal. Accordingly, the intensity of heat transfer decreases [17]. The increase in coal dust in the surface layer of the slag increases the viscosity and changes the composition of the slag.

The study of the regularities of the distribution of coal dust in the bath of molten slag is required for the development of technology to feed additional fuel to the VF.

To clarify the mode of operation on oxygen-containing blast with the introduction of coal into the VF process, industrial tests were performed on the supply of coal dust through tuyeres to the VF melt at BCP. The conditions for carrying out smelting VF are shown in Table 1 (concentrate consumption - 100 t/h, air consumption - 2000 nm^3/h).

Table 1. **Conditions for carrying out industrial melts of the BCP**

No.	Melting temperature, °C	Coal consumption, t/h	O_2 consumption, nm^3/h	O_2 consumption for afterburning, nm^3/h	Cu content in matte,%
1	1,167	0.5	14,110	1,500	45.01
2	1,194	1.0	14,650	1,500	45.03
3	1,218	1.5	15,150	1,500	44.97
4	1,242	2.0	16,630	1,500	44.98
5	1,264	2.5	16,140	1,500	45.01
6	1,284	3.0	16,600	1,500	44.99
7	1,302	3.5	17,050	1,700	44.99
8	1,320	4,0	17,490	2,000	44.99

For the supply of coal dust, air without oxygen enrichment was used for safety reasons. The dust pipeline was purged from the Kinyon pump to the vent on the tuyere site using a purge valve with compressor air. During the period of coal dust supply, the temperature of the drain water on the right side, wall caissons on the right and left sides, as well as the caissons of the slag partition were recorded. The change in the temperature of the gas duct was not observed due to the periodicity of the supply of coal dust. During industrial tests with a low level of coal dust in the bunker, dust was hanging at the junction of the conical part of the bunker in a square chute between the bunker and the Kinyon pump that indicates the need for smooth adjustment of the coal dust supply that, in turn, indicates the need for reconstruction of the bunker dust and dust-conducting pipelines.

The pulverized coal supply system must operate with the introduction of the blast, in which the additional amount of oxygen for combustion of pulverized coal should be calculated at the rate of 1,500 m^3 of oxygen per 1 ton of pulverized coal. Coal supplied to the surface of the slag melt, due to the large difference in specific gravity with the slag, was almost not mixed into the slag melt, the blast oxygen was almost completely consumed at a slag bath depth of 500 mm. If the depth of the slag melt above the tuyeres exceeds this value, then there is no oxygen in the exhaust gases. With a still bath height of 2,400 mm (the total height of the melt bath up to the tuyeres is 1,660 mm, the height of the melt above the tuyeres is 740 mm), the coal practically did not have the opportunity to interact with the blast oxygen and was burned mainly due to air leaks on the bath surface, and fine coal fractions performed with dust, burned in the gas phase, heating to a greater extent the upper caissons and exhaust gases, creating the illusion of an increase in the melting temperature.

Moreover, unburned coal entered into reductive endothermic reactions with slag oxides, mainly with iron oxides, and contributed to the cooling of the slag in the tail zone of the furnace (zone without blast) that led to foaming of the cold slag with the hindered escape of gases from the viscous slag. Figures 1, 2 show the results of tests on the use of coal to improve the heat balance of smelting, performed in 2018-2019 on the VF-2. It was found that with an increase in coal consumption, the melt temperature decreased and foam formation increased not only in the slag siphon but also in the tail part of the furnace, near the slag partition. It should be noted the positive side of coal supply to the surface of the melt in the loading zone that contributed to the local “deoxidation” of the slag melt and a decrease in the content of magnetite in the slag from 10-12 to 7-8%.

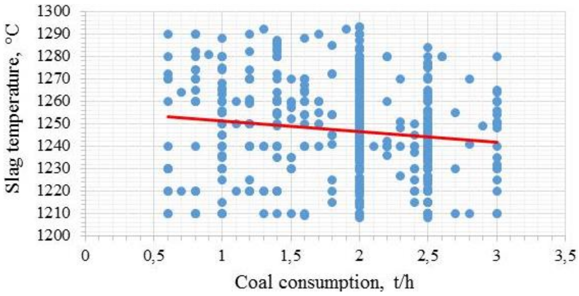

Figure 1. Dependence of slag temperature from coal consumption

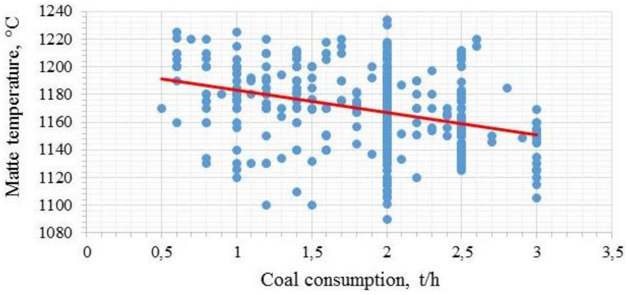

Figure 2. Dependence of matte temperature from coal consumption

The tests performed have shown the possibility of operation of the VF with coal supply, provided that the conditions for its complete combustion in the bubbling zone are met, the stable operation of the coal dust supply system is ensured, and the recommended technological parameters are observed. Conducting industrial smelting at BCP when feeding coal dust through tuyeres into the melt showed the complexity of the system for preparing and supplying coal dust, the problems of its combustion at the tuyere level, and the reduction of magnetite with its participation.

To study the regularities of the interference of coal dust in the slag bath on the change in the composition of the smelting products, laboratory experiments were performed to simulate the VF process.

Methodology. In the experimental part, BCP charge materials were used. The melting of the charge with the introduction of different amounts of activated carbon (0, 2, 4, 6, 8 g) was performed according to the well-known method [18]. The charge weight was 100 g, the melting temperature was 1300 °C, the exposure at the melting temperature was 30 minutes, each experiment was repeated 4-5 times. Oxygen-containing blast (oxygen content 50%) was supplied at a rate of 20 L/h. Activated carbon thoroughly interfered with the charge at the stage of its preparation. We used activated carbon-containing the main components, wt. %: 74.3 C, 1.12 Fe, 0.93 SiO_2, 1.56 Al_2O_3, 0.16 S, 0.025 P in the experiments. The compositions of the starting materials, including the charge material of the average composition and the quartz-containing flux, are given in Table 2. The addition of quartz-containing flux was 11.2% by weight of the charge for all experiments that provided a silicon dioxide content in the slags of more than 30% that positively affects the satisfactory separation of slag and matte.

Table 2. **Chemical composition of the materials used**

Material	Composition, %									
	Cu	Fe	S	Zn	Pb	As	SiO_2	CaO	Al_2O_3	other
Charge	16.65	24.65	29.31	1.77	0.1	0.1	17.48	0.75	2.45	6.74
Flux	-	-	-	-	-	-	97.00	-	-	3.00

The composition of the charge with different amounts of activated carbon is shown in Table 3. As a result of the performed smelting of the sulfide charge with the introduction of activated carbon, the products formed under the coal crust were analyzed (Table 4).

Table 3. **Composition of the charge with flux and activated carbon**

Charge No.	Coal Q-ty, g	Composition, %										
		Cu	Fe	S	Zn	Pb	As	SiO_2	CaO	Al_2O_3	C	other
1	0	14.79	21.89	26.03	1.57	0.088	0.088	26.37	0.67	2.18	-	6.324
2	2	14.50	21.48	25.52	1.54	0.086	0.086	25.88	0.65	2.16	1.49	6.608
3	4	14.22	21.10	25.04	1.51	0.085	0.085	25.41	0.64	2.16	2.97	6.780
4	6	13.95	20.71	24.55	1.48	0.083	0.083	24.93	0.63	2.15	4.46	6.974
5	8	13.69	20.36	24.10	1.45	0.082	0.082	24.50	0.62	2.14	5.94	6.298

Table 4. **Composition of products of smelting sulphide charge by main components**

Charge	Products	Composition, %								
		Cu	Fe	S	Zn	Pb	As	O_2	SiO_2	CaO
1	Matte	45.56	19.1	22.90	1.25	0.060	0.050	1.20	0.30	-
	Slag	0.55	35.7	0.40	2.30	0.020	0.030	12.70	31.90	1.20
2	Matte	45.50	19.0	22.70	1.20	0.050	0.050	1.18	0.29	-
	Slag	0.55	35.6	0.40	2.30	0.020	0.030	12.70	31.70	1.20
3	Matte	45.40	19.0	22.60	1.18	0.050	0.040	1.16	0.28	-
	Slag	0.53	35.5	0.30	2.28	0.018	0.028	12.60	31.60	1.18
4	Matte	45.30	18.9	22.50	1.16	0.040	0.030	1.14	0.27	-
	Slag	0.52	35.4	0.30	2.25	0.017	0.028	12.60	31.50	1.16
5	Matte	45.20	18.8	22.40	1.14	0.040	0.030	1.12	0.26	-
	Slag	0.52	35.3	0.28	2.24	0.017	0.027	12.50	31.50	1.15

Results and discussion. Upon visual inspection of the melting pots after melting, a loose crust was found on the surface of the slag consisting mainly of unburned coal. Chemical and analytical studies have confirmed the presence of carbon in the crust over 70%. Figure 3 shows that the thickness and porosity of the crusts increase with an increase in the amount of coal in the charge (from 0 to 8 g).

a b c d e

Coal addition, g: a – 0, b – 2; c – 4, d – 6, e – 8.

Figure 3. View of the slag surface depending on the amount of added coal

Unreacted coal particles accumulated in the upper layer of the slag bath indicate the difficulty of mixing the coal particles into the melt and their incomplete combustion with blast oxygen and the impossibility of their participation in the reduction of slag oxides.

The calculated composition of the matte without taking into account the presence of coal contained 50% copper. The resulting matte contained from 45.2 to 45.56% copper that indicates that some of the coal had time to oxidize due to the blast oxygen and this part remained almost unchanged with a significant change in the amount of coal added to the charge. In this case, the overwhelming majority of carbon did not interact with the oxygen of the blast. The content of coal dust in the slag should be such as to ensure a certain rate of chemical reactions of reduction of iron oxides and combustion of coal particles in an oxygen-containing blast.

However, since a characteristic trend in the development of autogenous copper production is the work with rich mattes containing ~ 65% or more copper, it becomes required to transfer the process to a different physical and chemical state that allows creating optimal conditions for ensuring the required melting temperature and ensuring obtaining slags with the lowest possible copper content. It is practically impossible to achieve such conditions without the use of fuel that should not only provide additional heat but also prevent slag over-oxidation. It is also known that gaseous reducing agents - CO, H_2, CH_4 are more effective than solid carbon, methane is the most intense reducing agent, and natural gas is the best fuel. The natural gas reduction process is improved by co-charging coal or coke using an oxygen-containing blast. The use of natural gas in the VF, its supply through the tuyeres will solve the problem of increasing the energy potential of raw materials and improve the thermal mode of the furnace. However, it is not always possible to use gaseous fuels. In this case, solid fuels such as coal can be used that may even be cheaper.

Conclusion. In connection with the dramatically changed composition of raw materials, the energy potential of raw materials decreases, the heat balance of autogenous processing is violated, and technical and economic indicators decrease. The intensification of the process is possible with the introduction of additional fuel that is also a reducing agent. The most common use is coal dust. The regularities of the influence of coal dust on the process of smelting copper sulfide charge have been studied. The introduction of different amounts of coal dust into the charge by careful mixing and the melting of the BCP charge of averaged composition in the presence of quartz flux made it possible to establish that the highest concentration of coal was noted in the surface layer of the slag. An increase in the content of coal in the charge entails an increase in its amount on the surface of the melt that indicates a decrease in the process of coal gasification and, accordingly, a deterioration in technical and economic indicators, in particular, the extraction of copper into matte. Despite the increase in the content of coal in the charge, the process is not intensified, coal is not consumed either for improving the heat balance of the smelting due to its combustion, or for reducing reactions with oxides in the slag. Thus, coal should be considered as a reducing agent and an additional source of heat during smelting in the absence of the ability to use natural gas.

This research was funded by the Science Committee of the Ministry of Education and Science of the Republic of Kazakhstan (Grant No. AP08855511).

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ҚОСЫМША ОТЫННЫҢ ВАНЮКОВ ПЕШІНДЕГІ ҚОРЫТУ ПРОЦЕСІНЕ ӘСЕРІ

Аннотация. Балқаш мыс қорыту зауытындағы (БМҚЗ) қайта өңделетін шикізат құрамының өзгеруіне байланысты Ванюков пешінде (ВП) мыс сульфидті концентраттарды балқыту технологиясын түзету талап етіледі. Қажетті автогенділікті және балқыту температурасын қамтамасыз ету үшін барботаж аймағында жанатын, балқыту температурасын арттыратын және қож тотықтарын ішінара қалпына келтіретін қосымша көміртегі бар отынды пайдаланудың болашағы бар. Алайда, барботаж аймағында оттегімен үрлеуден қатты отынның бір бөлігі жанбайды және қож тотықтарымен қалпына келтіру реакцияларына қатыспайды, бұл оның қож балқымасының беткі қабатына жиналып қалуына алып келеді.

Қож балқымасының қажетті температурасын ұстап тұру және қож бен штейннің қанағаттанарлық бөлінуі үшін ВП пешіне үрлеуіштер арқылы көмір тозаңын беру бойынша БМҚЗ-да бұрын жүргізілген өнеркәсіптік сынақтардың нәтижелері қаралды. ПВ пешіне үрлеуіштер арқылы көмір тозаңын жіберудің сынақтан өткізілген жүйесінің тұрақсыз жұмыс істеуінің себептері анықталды және оны жетілдіру бойынша жұмыс бағыттары белгіленді. ВП пешінің тыныш аймағында көмір тозаңының әрекетін модельдейтін зертханалық тәжірибелер жүргізілді. Көмір тозаңының таралу заңдылықтары анықталды және көмір тозаңының қож балқымасының бетіне жиналатынын көрсетті. Осылайша, барботаж аймағында оттегімен үрлеу немесе қож балқымасының тотықтарымен әрекеттеспеген көмір тозаңы қож балқымасының бетіне шығады, тұтқыр қабықтың қалыптасуына ықпал етеді, әрі қарай қож балқымасымен өзара әрекеттеспейді және іс жүзінде пайдасыз болады.

Негізгі сөздер: мыс сульфидті концентраттар, Ванюков пеші, автогенді балқыту, қатты отын, көмір, көмір тозаңы, қож, штейн.

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ВЛИЯНИЕ ДОПОЛНИТЕЛЬНОГО ТОПЛИВА НА ПРОЦЕСС ПЛАВКИ В ПЕЧИ ВАНЮКОВА

Аннотация. В связи с изменением состава перерабатываемого сырья на Балхашском медеплавильном заводе (БМЗ), требуется корректировка технологии плавки медных сульфидных концентратов в печи Ванюкова (ПВ). Для обеспечения необходимой автогенности и температуры плавки перспективно использование дополнительного углеродсодержащего топлива, сгорающего в зоне барботажа, повышающего температуру плавки и частично восстанавливающего оксиды шлака. Однако, часть твердого топлива не сгорает в зоне барботажа кислородсодержащим дутьем и не участвует в восстановительных реакциях с оксидами шлака, что ведет к накоплению его на поверхности шлакового расплава.

Рассмотрены результаты проведенных ранее промышленных испытаний на БМЗ по подаче угольной пыли через фурмы в печь ПВ для поддержания необходимой температуры шлакового расплава и удовлетворительного разделения шлака и штейна. Определены причины нестабильной работы испытанной системы подачи угольной пыли в печь ПВ через фурмы и намечены направления по её усовершенствованию. Проведены лабораторные эксперименты, моделирующие поведение угольной пыли в спокойной зоне печи ПВ. Определены закономерности распределения угольной пыли и показано, что угольная пыль концентрируется на поверхности шлакового расплава. Таким образом, угольная пыль, не прореагировавшая с кислородом дутья или оксидами шлакового расплава в зоне барботажа, выносится на поверхность шлакового расплава, способствует образованию вязкой корки, в дальнейшем практически не взаимодействует со шлаковым расплавом и становится практически бесполезной.

Ключевые слова: медные сульфидные концентраты, печь Ванюкова, автогенная плавка, твердое топливо, уголь, угольная пыль, шлак, штейн.