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Articles are published in Uzbek, Russian, and English, ensuring a wide-reaching audience and fostering cross-cultural academic exchange. As a beacon of academic excellence, the "Journal of Transport" continues to serve as a vital conduit for knowledge dissemination, collaboration, and innovation in the transport sector and related fields.

The influence of hot briquetted iron on technological, thermodynamic and economic factors in the arc steelmaking process

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Abstract:

In this article, the effect of hot briquetted iron (HBI) on the steel smelting process in electric arc steel smelting furnaces (EASSF) is comprehensively studied. The main focus is on the analysis of the composition of the semi-product, which is formed under conditions of changes in energy-technological parameters, the process of slag formation, the mechanisms of metal slag melting and an increased share of HBI.

It turns out that when HBI is used, the specific consumption of electricity increases, the amount of slag and the degree of oxidation of the metal-slag system increases. At the same time, the amount of carbon in the metal decreases. When the HBI share exceeds 25-30%, the likelihood of the formation of solid insoluble shlako-metallic conglomerates under portioned loading conditions increases, which can damage the inner lining of the furnace.

A thermodynamic analysis of the phosphorus loss process has been carried out, taking into account the calculation of the distribution coefficients of phosphorus and the assessment of the equilibrium level. When HBI is used, the steel content has been found to decrease in harmful impurities (phosphorus, sulfur, nitrogen, copper, nickel, chromium, tin). This was due to the high purity of HBI raw materials and the strong oxidation of slags.

In addition, a method has been developed to estimate the amount of copper in half the product in different combinations of shikhta. This applied normal distribution functions and regression analysis. Also given is the feasibility of using HBI instead of precious metal scrap and recycled cast iron. It has been proven that using HBI through proper loading and slurry regime control can be a cost-effective and from a technological point of view acceptable solution.

Keywords:

Hot briquetted iron (HBI), electric arc steel smelting furnace (EASSF), dephosphorylation, slag formation, energy consumption, metal slag, oxidation level, slag-metal conglomerates, thermodynamic analysis, economic efficiency, precious metal mixture, shingle regime, phosphorus distribution, normal distribution, regression analysis

Issiq briketlangan temirning yoyli po'lat eritish jarayonida texnologik, termodinamik va iqtisodiy omillarga ta'siri

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¹ Milliy texnologik tadqiqotlar universiteti MISiSning Olmaliq filiali, Olmaliq, O'zbekiston

Annotatsiya:

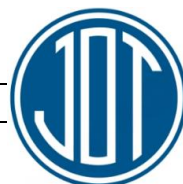
Mazkur maqolada issiq briketlangan temirning (IBT) elektr yoyli po'lat eritish pechlarida (EYPE) po'lat eritish jarayoniga ta'siri har tomonlama o'rganilgan. Asosiy e'tibor energiya-texnologik parametrlardagi o'zgarishlar, shlak hosil bo'lish jarayoni, metall shixta eritish mexanizmlari va IBT ulushi oshgan sharoitda hosil bo'ladigan yarim mahsulot tarkibini tahlil qilishga qaratilgan.

Aniqlanishicha, IBT ishlatilganda elektr energiyasining o'ziga xos sarfi ortadi, shlak miqdori va metall-shlak tizimining oksidlanish darajasi oshadi. Shu bilan birga, metalldagi uglerod miqdori kamayadi. IBT ulushi 25–30% dan oshganda, porsiyali yuklash sharoitida qattiq erimaydigan shlako-metall konglomeratlar hosil bo'lish ehtimoli ortadi, bu esa pechning ichki qoplamasiga zarar yetkazishi mumkin.

Fosforning taqsimlanish koeffitsientlari hisobi va muvozanat darajasi bahosini hisobga olgan holda fosfori yo'qotish jarayonining termodinamik tahlili o'tkazilgan. IBT ishlatilganda po'lat tarkibida zararli aralashmalar (fosfor, oltingugurt, azot, mis, nikel, xrom, qalay) kamayishi aniqlangan. Bunga IBT xomashyosining yuqori tozaligi va shlaklarning kuchli oksidlanishi sabab bo'lgan.

Bundan tashqari, shixtaning turli kombinatsiyalarida yarim mahsulot tarkibidagi mis miqdorini taxmin qilish usuli ishlab chiqilgan. Bunda normal taqsimot funksiyalari va regressiya tahlili qo'llanilgan. Shuningdek, qimmatbaho metall qirindilari va qayta ishlangan cho'yan o'rni IBT dan foydalanishning texnik-iqtisodiy bahosi berilgan. To'g'ri yuklash va shlak rejimini nazorat qilish orqali IBT ishlatish iqtisodiy jihatdan samarali va texnologik nuqtai nazardan maqbul yechim bo'lishi mumkinligi isbotlangan.

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Kalit so'zlar:

Issiq briketlangan temir (IBT), elektr yoyli po'lat eritish pechi (EYPE), defosforlanish, shlak hosil bo'lish, energiya sarfi, metall shixta, oksidlanish darajasi, shlak-metall konglomeratlari, termodinamik tahlil, iqtisodiy samaradorlik, qimmatbaho metallar aralashmasi, shixtalash rejimi, fosfor taqsimoti, normal taqsimot, regressiya tahlili

1. Kirish

Zamonaviy po'lat ishlab chiqarish sohasi yanada toza va tarkibi barqaror bo'lgan xomashyo manbalaridan foydalanishga intilmoqda. Issiq briketlangan temirda (IBT) zararli aralashmalarning juda past miqdori va temirning yuqori darajada qayta tiklanganligi sababli an'anaviy metall qirindilari va qayta ishlangan cho'yan uchun jiddiy muqobil variant sifatida ko'rilmogda.

Biroq IBT dan foydalanish energiya sarfining oshishi va shixtaning issiqlik va fazaviy xususiyatlarining o'zgarishi bilan bog'liq. IBT qo'llanilishi shlak hosil bo'lish jarayoniga, pech qoplamasining yemirilishiga va yakuniy mahsulot sifatiga ham ta'sir ko'rsatadi. Ushbu tadqiqotning maqsadi IBT ning elektr yoyli po'lat eritish jarayonidagi texnologik, termodinamik va iqtisodiy omillarga ta'sirini har tomonlama o'rganishdir.

2. Tadqiqot metodologiyasi

Tahlil 201 ta sanoat eritish tajribasi asosida o'tkazilgan bo'lib, ularda shixta tarkibida turli miqdorda IBT ishlatilgan. Bundan tashqari, 49 ta nazorat eritish tajribasi to'liq metall

qirindisi asosida amalga oshirilgan. Tadqiqot quyidagi metodlarga asoslangan:

- **Termodinamik muvozanat hisoblari** (fosfor yo'qotish va oksid fazalar hosil bo'lish jarayoni tahlili);
- **Taqsimlanish koeffitsientlarini aniqlash** (formula (1), (2), (3), (4) bo'yicha hisob-kitoblar).

Fosforning metall va shlak o'rtasida muvozanatli taqsimlanishi quyidagi ifoda bilan tavsiflanadi [1]:

$$L_p = \frac{P}{[P]} = (31 * K_p * \Sigma n_i * f_p * aFeO_2) / \gamma_{P5+} \quad (1)$$

Muvozanat konstantasi quyidagicha ifodalanadi [2]:

$$\lg K_p = \frac{1074}{T} - 1,289 \quad (2)$$

Agar shlakdagi boshlang'ich fosfor miqdori nolga teng deb qabul qilinsa, unda [2]:

$$[P]_K = [P]_H / (1 + \lambda * L_p) \quad (3)$$

- STATISTICA va Excel dasturlarida ma'lumotlarni statistik tahlil qilish (approssimatsiya, regressiya, normal taqsimotga tekshirish);
- CaO–SiO₂–FeO va MgO–SiO₂–FeO diagrammalari asosida fazaviy holatni tahlil qilish;
- Iqtisodiy baholash (1-jadval).

1-jadval

1x lomi va oldindan qayta ishlangan cho'yan o'rniga IBT ishlatishning iqtisodiy samarasi

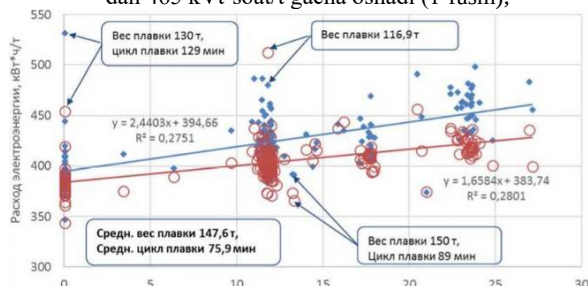
Metallom tarkibi (o'rniga ishlatilayotgan)	O'rniga ishlatilayotgan metallom narxi, \$/t	IBT narxi, \$/t*	Narx farqi, \$/t	O'rniga ishlatilayotgan loming ulushi, %	Bir eritishda almashtirilayotgan (shixta og'irligi 168,5 t bo'lganda), t	Metallom almashtirishdan tejalgan mablag', \$/eritish
1x po'lat lomi	275,6	248,6	27,0	12,9	21,737	586,85
Oldindan qayta ishlangan cho'yan	391,5	248,6	142,9	12,9	21,737	3106,11

3. Natija va Muhokama

Eritish jarayonining energetik va texnologik xususiyatlari

O'tkazilgan tahlillar shuni ko'rsatdiki, shixta tarkibida IBT ulushining 0% dan 27% gacha oshirilishi quyidagilarga olib keladi:

- o'rtacha elektr energiyasining sarfi 400 kVt·soat/t dan 465 kVt·soat/t gacha oshadi (1-rasm);



1-rasm. IBT ulushining o'sishi bilan elektr energiyasi sarfining solishtirma o'zgarishi

- shlak massasi 54 kg/t dan 92 kg/t gacha (70% ga) oshadi;
- shixta sarf koeffitsiyenti 1,13 dan 1,18 gacha ko'tariladi.

Bu holat IBT tarkibidagi FeO ni qaytarish zarurati va tarkibida bo'sh jinslarning mavjudligi bilan izohlanadi, bu esa issiqlik o'tkazuvchanligini yomonlashtiradi [3]. **1-rasm** – "IBT ulushining oshishi bilan elektr energiya sarfining solishtirma o'zgarishi" bu effektni tasvirlaydi.

IBT ning vannadagi harakati va yuqori erish haroratiga ega fazalarning shakllanishi

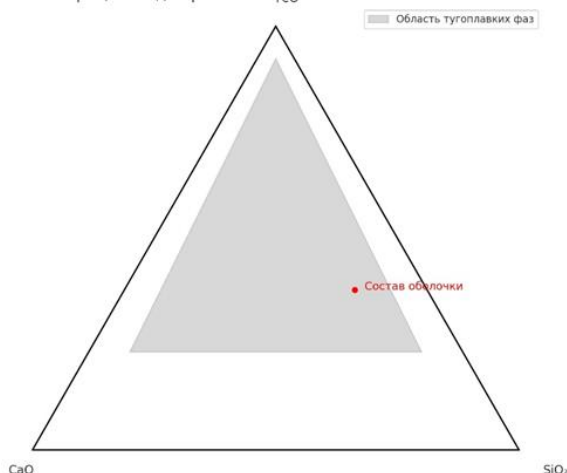
Shixta tarkibida IBT ulushi 25–30% dan yuqori bo'lsa, porsiyali yuklash sharoitida yirik shlak-metall konglomeratlar hosil bo'lishi kuzatiladi (2–4-rasmlar). Ular FeO, CaO va SiO₂ asosiy tarkibiy qismlaridan iborat erishi qiyin oksidli qobiq bilan qoplanadi. Ushbu qobiq issiqlik o'tkazuvchanligi past va yuqori g'ovaklikka ega ekanligi bilan ajralib turadi [4]





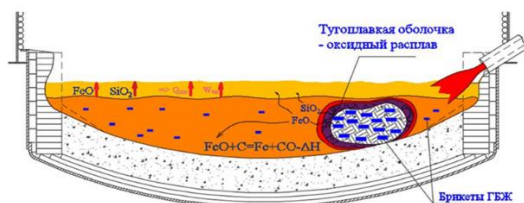
2-rasm. Pechdan chiqarilgan shlak-metall konglomerati
Pechdan chiqarilgan shlak-metall konglomerati taxminan 2,5 tonna og'irlikka ega bo'lib, u IBT ulushi yuqori bo'lgan metall shixtani qayta ishlash jarayonida uzoq muddatli ekspluatatsiya natijasida hosil bo'lgan.

Упрощённая диаграмма состава системы CaO-SiO₂-FeO



3-rasm. CaO-SiO₂-FeO tizimining soddalashtirilgan fazaviy diagrammasi [6]

Ushbu diagrammada shlak-metall konglomerati qobig'ining holati va tarkibiy o'zgarishlari ko'rsatilgan. Qobiq asosan CaO, SiO₂ va FeO oksidlaridan iborat bo'lib, issiqlik o'tkazuvchanligi past va yuqori g'ovaklikka ega [7].



4-rasm. IBT bilan hosil bo'lgan konglomeratning sxematik joylashuvi

Kimyoviy tahlil natijalariga ko'ra (2-jadval):

- FeO – 42,0 %
- CaO – 33,5 %
- SiO₂ – 13,2 %
- Asosiylik darajasi ($CaO + MgO / SiO_2$) = 2,95

2-jadval

Qattiq eruvchi konglomerat tashqi qobig'ining kimyoviy tarkibi (%)

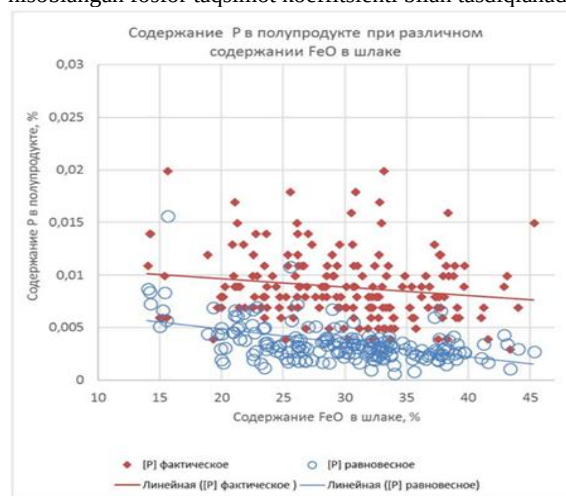
Qattiq eruvchi konglomerat tashqi qobig'ining kimyoviy tarkibi (%)	FeO	CaO	SiO ₂	MgO	MnO	TiO ₂	Asosiylik darajasi (CaO+MgO)/SiO ₂
Qiymalar	42,0	33,5	13,2	5,5	5,6	0,4	2,95

Shixtlash sxemalarini yuklash va futerovkani himoya qilish

G'ovak temirmi qatlamlar bo'ylab po'lat chiqindisi bilan berish eng kam nuqsanli usul bo'lib chiqdi. Tarkibida 10–20% GBJ bo'lgan shixtada futerovka yuzasida himoya qatlami hosil bo'lib, yong'inga chidamli materiallarning uzoq muddat xizmat qilishini ta'minlaydi.

Fosfor miqdori va defosforlanish jarayoniga ta'siri

Tahlillar shuni ko'rsatdiki, metall tarkibidagi fosfor miqdori IBT ulushi 27% ga oshganda 0,012% dan 0,006% gacha kamayadi (rasm 5). Bu quyidagi formula asosida hisoblangan fosfor taqsimot koeffitsienti bilan tasdiqlanadi:



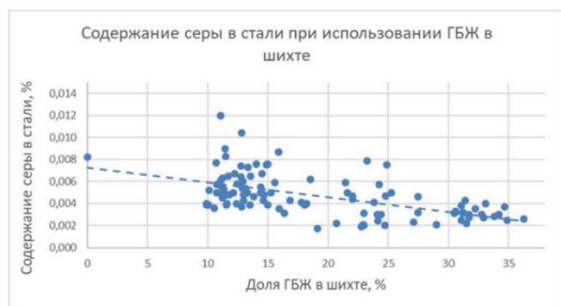
5-rasm. Shlakning oksidlanish darajasining po'lat tarkibidagi fosforning muvozanatli va amaliy miqdoriga ta'siri (IBT ishtirokida oksidlovchi defosforlanish mexanizmi amalga oshganda) [8]

Shuningdek, fosforning yakuniy miqdorini baholash uchun quyidagi formula ishlatilgan:

Amaliy taqsimot koeffitsienti (formula 4):

$$L_{\phi} = (P_2O_5) * \frac{62}{142} \frac{1}{[P]} \quad (4)$$

Natijalar 5-rasmda keltirilgan [9][10].



6-rasm. IBT ulushining metall tarkibidagi oltingugurt miqdoriga ta'siri sulfid faolligi va tiklovchi atmosfera sharoitlarining o'zgarishi hisobga olingan holda [11]

Rangli metallar aralashmalariga ta'siri

IBT ulushining oshishi bilan Cu, Sn, Ni, Cr miqdorining barqaror kamayishi kuzatilgan [12]. Rasm 3.63 da GBT ulushining mis miqdoriga bog'liqligi ko'rsatilgan: "IBT ulushining ortishi bilan yarim mahsulotdagi mis miqdorining kamayishi" [13].

Mis tarkibining Gauss taqsimoti bo'yicha modellashtirilishi rasm 3.76 da ko'rsatilgan – «Metall goldiqlardagi mis miqdorining normal taqsimot modeli» [14].

Iqtisodiy samaradorlik

Iqtisodiy tahlil quyidagi jadvallarga asoslangan:

- **Jadval 3.** IBT bilan ikkilamchi lom va cho'yan almashtirishning iqtisodiy ta'siri».

Almashtirish natijasidagi tejamkorlik:

- **ikkilamchi lom** → **IBT**: 96,27 \$/eritish;
- **Cho'yan** → **IBT**: 2615,53 \$/eritish.

Aniqlangan qonuniyatlar defosforlanish va shlak hosil bo'lish jarayonlarining termodinamik asoslanganligini tasdiqlaydi. IBT yuzasida yuqori haroratda hosil bo'ladigan qattiq qobiq quyidagi reaksiyaga bog'liq:

Oksidlanish darajasining oshishi va shlak asosiylikligining yuqorilashi defosforlanish jarayonini kuchaytiradi, ammo shlakning qovushqoqligi jarayon kinetikasini cheklaydi.

4. Xulosa

1. IBT energiya sarfini va shlak hosil bo'lishini oshiradi, ammo zararli aralashmalar miqdorini kamaytiradi.
2. IBT ulushi 25–30% dan oshganda, erishi qiyin bo'lgan konglomeratlar shakllanadi.
3. Qatlamli yuklash issiqlik rejimini optimallashtiradi va favqulodda holatlarning oldini oladi.
4. Defosforlanish va tozalash jarayonlari termodinamik modellarga mos keladi.
5. Ikkilamchi lom va cho'yaning bir qismini IBT bilan almashtirish iqtisodiy jihatdan maqsadga muvofiqdir.

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