Development of converter operation technology using iron-bearing concentrates and clinker-steel cakes

E V Protopopov, S V Feyler, A V Amelin and E P Chumov

1 Institute of Metallurgy and Material Science, Siberian State Industrial University, 42 Kirova Street, Novokuznetsk, 654007, Russia
2 EVRAZ Consolidated West-Siberian Metallurgical Plant, 16 Kosmicheskoye Road, Novokuznetsk, 654042, Russia

E-mail: feyler@rdtc.ru

Abstract. Technological process of steel production in converters using clinker-steel cakes and iron-bearing concentrates of “EVRAZ ZSMK” JSC slag processing unit ensuring liquid-phase reduction of iron from oxides is designed. Developed technology allows implementation of iron-containing materials recycling, reduces consumption of scrap, increases liquid metal yield, improves environmental safety in the region.

1. Introduction
Steel slags comprise significant part in metallurgical wastes. Their yield in average is from 150 to 200kg/t of steel [1]. At current steel production level in the Russian Federation annually about 9 million tons of steel slags are produced. They contain 10% of pure metal, and 15 - 40% of iron oxides. Total amount of iron is 20 - 30% of slag mass [2-4].

For processing of generated steel slags, slag processing unit was put into operation at “EVRAZ ZSMK” JSC in the end of 2014, the processing line allows to extract gradually iron-bearing inclusions from converter slag using magnetic separation technology. Performance of the unit is 1400000 tons of slag per year, metal-bearing concentrates yield is 250th. t. per year. Resulting iron-bearing concentrate is ferrous material of the following fractions: 0-10mm (U4), 10-80mm (29ADUZh) and 80-250mm (29CSC).

2. Research and results
To assess possibility of iron-bearing concentrates recycling in steel production and develop relevant technology of converter melting laboratory tests were conducted for U4 and 29ADUZh concentrates which consisted of sequential abrasion of 1kg of material for 5 minutes and its screening through a sieve with 0.5mm mesh size. Oversize product was subjected to subsequent abrasion. After five rounds of abrasion oversize material appeared to be metallic particles. Results of the tests are shown in Table 1.
Performed chemical analysis of minus (Table 2) has shown that in average mineral part of U4 and 29ADUZh contains 40.7 and 27.0% Fe\textsubscript{total}, respectively. Thus, total content of iron in the tested concentrates is 47 and 76%, respectively. Average iron content in U4 concentrate in form FeO and Fe\textsubscript{2}O\textsubscript{3} oxides comprises 25.6 and 11.06%, respectively, in 29ADUZh concentrate – 25.8 and 9.98 %.

Table 2. Chemical composition of minus.

| Sample No | Fe\textsubscript{total} | S | CaO | SiO\textsubscript{2} | FeO | MgO | MnO | Al\textsubscript{2}O\textsubscript{3} | Na\textsubscript{2}O | K\textsubscript{2}O | TiO\textsubscript{2} | ZnO | Fe\textsubscript{met} | Fe\textsubscript{2}O\textsubscript{3} |
|-----------|-----------------|---|-----|---------------------|-----|-----|-----|---------------------|------------------|-------|---------|------|------|---------------|-----------------|
| U4        |                 |   |     |                     |     |     |     |                     |                  |       |         |       |      |               |                 |
| 1         | 21.8            | 0.095 | 31.5 | 15.0               | 14.7 | 5.55 | 3.96 | 0.37               | 3.0              | 0.13  | 0.099   | 1.28 | 0.031 | -             | 14.9            |
| 2         | 29.5            | 0.085 | 28.9 | 12.7               | 31.5 | 9.16 | 3.94 | 0.39               | 1.42             | 0.12  | 0.070   | 1.28 | 0.023 | -             | 7.22            |
| 3         | 37.9            | 0.080 | 25.1 | 11.2               | 41.7 | 8.25 | 3.58 | 0.37               | 0.94             | 0.12  | 0.066   | 1.18 | 0.022 | 5.58         | -               |
| 4         | 55.8            | 0.055 | 16.9 | 7.22               | 21.6 | 6.41 | 2.49 | 0.31               | 0.93             | 0.12  | 0.078   | 0.75 | 0.019 | 41.1         | -               |
| 5         | 58.5            | 0.103 | 16.3 | 7.54               | 18.7 | 4.86 | 2.22 | 0.31               | 0.22             | 0.13  | 0.14    | 0.64 | 0.023 | 44.7         | -               |
| Average   | 40.7            | 0.084 | 23.7 | 10.73              | 25.6 | 7.65 | 3.24 | 0.35               | 1.70             | 0.12  | 0.091   | 1.03 | 0.024 | 30.46        | 11.06           |
| 29ADUZh   |                 |   |     |                     |     |     |     |                     |                  |       |         |       |      |               |                 |
| 1         | 26.0            | 0.065 | 34.1 | 13.4               | 23.5 | 8.47 | 2.8  | 0.34               | 3.96             | 0.090 | 0.055  | 0.63 | 0.019 | -             | 11.1            |
| 2         | 28.0            | 0.081 | 32.4 | 12.9               | 26.2 | 8.06 | 2.94 | 0.33               | 3.26             | 0.070 | 0.054  | 0.59 | 0.017 | -             | 11.0            |
| 3         | 27.2            | 0.092 | 33.8 | 13.2               | 28.0 | 8.81 | 2.79 | 0.35               | 2.77             | 0.070 | 0.051  | 0.62 | 0.022 | -             | 7.82            |
| 4         | 27.8            | 0.094 | 31.5 | 13.8               | 26.2 | 9.04 | 3.27 | 0.31               | 2.90             | 0.080 | 0.057  | 0.61 | 0.026 | -             | 10.7            |
| 5         | 25.9            | 0.076 | 31.4 | 14.2               | 25.0 | 9.03 | 3.52 | 0.32               | 3.22             | 0.080 | 0.061  | 0.63 | 0.021 | -             | 9.29            |
| Average   | 27.0            | 0.082 | 32.6 | 13.5               | 25.8 | 8.68 | 3.06 | 0.33               | 3.22             | 0.080 | 0.056  | 0.62 | 0.021 | -             | 9.98            |

Designed converter melting technology with recovery of iron from oxides of slag component of the slag processing unit concentrates or clinker-steel cakes involves two-stage gas-oxygen refining of melt in converter with liquid-phase recovery elements. In accordance with proposed variation of technology melting is carried out in two stages (see Figure 1):

- on the first, reduction stage, high degree of reduction of iron from the slag component of concentrates is provided, for that purpose poured in iron ("supporting plate"), SPC concentrates and carbonaceous material (coke, anthracite) added to the aggregate, are mixed with nitrogen (at a rate of 400-500 m\textsuperscript{3}/min) or gas-oxigen mixture (nitrogen at a rate of 300-350 m\textsuperscript{3}/min and oxygen at a rate of 50-150 m\textsuperscript{3}/min) to intensify mass transfer processes during reduction;
- on the second stage oxidizing blasting in converter is implemented according to developed blasting and slag mode of melting.

To solve the assigned task preliminary thermodynamic analysis of processes accompanying steel production in oxygen converters using iron-bearing concentrates was performed. During BOF melting oxidative pattern of the processes is most clearly revealed, in this regard, iron reduction from oxides is the most difficult.

In determining the optimum parameters of technological mode it is advised to establish possible limits of iron reduction from oxide component, input of the accompanying processes in melting thermal balance, as well as the process rate.

Considering additional components of the BOF burdening, the following physical and chemical processes are possible:

Table 1. Mass of minus in sequential abrasion and screening of iron-bearing concentrates, g.

| Attrition round | Concentrate type |
|-----------------|------------------|
| 1               | U4               |
| 2               | 29ADUZh          |
| 3               |                  |
| 4               |                  |
| 5               |                  |
| Residue (metal part) |        |
| 106.90 (10.69 %) | 666.77 (66.68 %) |
heating of solid oxidizers to the bath temperature ($T_b$) and their dissolution in oxide melt;
heating of solid carbon to the bath temperature, and its dissolution in metal;
reduction of iron from oxides with carbon, manganese, phosphorus, silicon dissolved in metal [5]:

\[(\text{FeO}) + [\text{C}] = [\text{Fe}] + \{\text{CO}\};\]
\[(\text{FeO}) + [\text{Mn}] = [\text{Fe}] + (\text{MnO});\]
\[(\text{FeO}) + 2/5[\text{P}] = [\text{Fe}] + 1/5(\text{P}_2\text{O}_5);\]
\[(\text{FeO}) + 1/2[\text{Si}] = [\text{Fe}] + 1/2(\text{SiO}_2);\]

reduction of iron from oxides with carbon monoxide [6]:

\[(\text{FeO}) + \{\text{CO}\} = [\text{Fe}] + \{\text{CO}_2\};\]

oxidation of carbon dissolved in metal by gaseous oxygen [7]:

\[[\text{C}] + 1/2\{\text{O}_2\} = \{\text{CO}\};\]

iron oxidation with oxygen [8]:

\[[\text{Fe}] + 1/2\{\text{O}_2\} = \{\text{CO}\};\]

solid carbon burning [9]:

\[C_r + 1/2\{O_2\} = \{CO\}; C_r + O_2 = \{CO_2\};\]
- gasification reaction [10]:
  \[ C + \{CO_2\} = 2\{CO\}; \]
- iron oxide dissolution in slag, [11]:
  \[ (\text{FeO})_s = (\text{FeO})_l; \]
- carbon dissolution in metal [12]:
  \[ C = [C]. \]

Schematic diagram of the converter process with technological wastes liquid-phase recovery is presented on Figure 2.

Recovery reaction zones: Zone 1 - Surface of the up-floating ferric wastes particles (FW) contact with liquid cast iron; Zone 2 - Surface of up-floating slag drops (S) contact with liquid cast iron; Zone 3 - Surface of up-floating slag drops contact with carbonaceous material suspended in melt (CM); Zone 4 - Surface of slag contact with liquid iron; Zone 5 - Surface of slag contact with carbon material suspended in the melt.

Liquid iron I is the initial heat "capacity" and constant "storage" for reduced iron.
II - solid mixture of CSC (concentrate) and carbon (anthracite, steam coal, coal dust) in which the main reduction processes flow; the liquid phases, the oxide phase (slag) and the metal phase (iron-based) which transfers into I, subsequently allocate here.
III - gas phase, zone of conversion products, natural gas and carbon monoxide and hydrogen combustion products mixing. This zone is distributed throughout all inner volume of the unit with possibility of process gases supply through the upper primary and possibly auxiliary tuyere into gas mixing zone, into the oxide phase and, possibly through basal tuyeres into the metallic phase.

![Figure 2. Scheme of BOF process with liquid-phase reduction of iron-containing materials.](image-url)
IV – separation "auxiliary phase", solid carbon (reducing agent and fuel) consists of two conventional areas: in the lower part between the metallic (I) and the oxide (II) phases carbon concentration in metal at saturation level is kept, and iron is recovered from its monoxide; in the upper part between the gas mixing zone and oxides there is a conventional space separation boundary with predominance of deoxidizing (II) and oxidizing (III) properties; moreover, in IV a certain portion of carbon burns reacting with not consumed oxygen of process gases and serves as a source of heat.

3. Conclusions
To implement presented process scheme technically acceptable is the following distribution of process gases among tuyeres. Through the top tuyere 1 in certain periods technically pure oxygen, neutral gas or gas mixtures for oxidation, heating and bath mixing are supplied. Through tuyere 2 natural gas and oxygen for flue gases reburning are supplied. Mixture of natural gas and oxygen in 2:1 rate for metal conversion reaction. Basal tuyeres 3 are primarily intended for supply of neutral gas for additional mixing of the bath. To improve process thermal balance and more complete reduction reactions oxygen can be supplied through basal tuyeres mixed with neutral or natural gas.

Presented technological scheme of converter melting allows for better use of technogenic materials potential in steel production.

4. Acknowledgements
The work was performed at Siberian State Industrial University in the framework of the state task of the Ministry of Education and Science of the Russian Federation No. 2556.

5. References
[1] Yusfin Yu S et al 2002 Industry and Environment (Moscow: Akademkniga) p 469
[2] Butorina I V 2005 Fundamentals of Iron and Steel Industry Stable Development (Donetsk: Kashtan) p 332
[3] Das B, Prakash S et al 2007 Resources, Conservation and Recycling 50 40–57
[4] Mihok L, Demeter P et al 2006 Metalurgija 45 163-168
[5] Kudrin V A 2003 Theory and Technology of Steel Production (Moscow: Mir) p 528
[6] Bugayev K et al 2001 Iron and Steel Production (The Minerva Group, Inc) p 252
[7] Deo B and Boom R 1993 Fundamentals of Steelmaking Metallurgy
[8] Boichenko B M et al 2006 Converter Steel Production: Theory, Technology, Steel Quality, Units Design, Materials Recirculation and Environment Protection (Dnepropetrovsk: Dnepr-VAL) p 454
[9] Ryman C and Larsson M 2006 ISIJ International 46 1752–58
[10] Baptizmanskiy V I et al 1988 Thermal Work of Oxygen Converters (Moscow: Metallurgiya) p 174
[11] Yavoyskiy V I 1967 Theory of Steel Production Processes (Moscow: Metallurgiya) p 467
[12] Baptizmanskiy V I 1960 Mechanism and Kinetics of Converter Bath Processes (Moscow: Metallurgizdat) p 286