Verification of analysis model and the heat balance in lower furnaces

6, May.,'24 SimpLE-labo.co.Ltd
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Overview

(1) Our thermal analysis model (thermal equilibrium model) looks good with individual calculations, verified with Rist model, heat mass balance, calorific diagram, etc. However, since the reaction rate is not taken into account in the model, for comprehensive verification, here is checked with the actual BF operation data (lowest fuel ratio record in Japan*1) and verified its reproducibility.
(2) Using the same model, the heat balance in the lower furnace, which decides the fuel ratio, has been shown for ① actual BF, ② current BF (assumption), ③ *SimplLE* (ver.1.ck), and ④ Cupola (separately calculated). Also, clarifying the apparently supplied heat to the lower furnaces (latent heat of fuels, sensible heat of blown-in gas) and the Gross/Net heat supplied to the lower furnaces (total supplied heat), it is shown that the heat of *SimpLE (Duplex BF)* lower furnace is the minimum.

I. Material and Heat Balance in the furnace ; especially JFE Fukuyama 3BF in the furnace and Cupola in the lower furnace

Given data | Assumptions | Calc. results

			JFE Fukuyama 3BF*1		Conv. BF		*SimpLE* (ver.1.ck)		Cupola (Foundry)	
			Actual	Analysis		Analysis		Analysis		Estimation
Hot Metal	Temp.	°C	1481			1500		1500		1574
	C	%	4.48			4.5		4.5		3.1
	Si	%	0.27			0.4		0.4		1.9
Slag ratio		kg/tp	274			304	233			50
Hot blast	Blast ratio	Nm^3/tp	934	935		1031	Syngas ; 300+800			664
	Temp	°C	1353			1100	900,1300			450
	H2O	g/Nm^3	5.6			23.7		0		3.5
	O2 enrich.	Nm^3/tp	0			45		N/A		0
Cold Oxygen			N/A			N/A		106		N/A
Top gas	Temp.	°C	73			170		124	Coke-bed top	1500
	Top Gas ratio	Nm^3wet/tp	unknown	1377		1615		1343	ditto	697
	CO	%dry	20.2	17.2		24.5		32.2	ditto	8.3
	CO_2	%dry	24.5	26.2		21.3		27.8	ditto	15.6
	H_2	%dry	1.7	2.3		5.9		36.5	ditto	1.3
Sinter ratio		%	96.6			85		85	Return pig iron	50%
Fuel	Fuel ratio	kg/tp	396.1			505		N/A		117
	Coke ratio	kg/tp	**354.0**			305		**166.8**		117
	Blown-in fuel ratio	kg/tp	**Tar 42.1**		PCI	200	Tar	**16.3**		N/A
	CH_4	MJ/tp	0	0			Reform.	3,166		N/A
	COG	MJ/tp	0	0				1,093		N/A
Shaft gas efficiency		%	97.5			88.2		95		N/A
Direct reduction ratio			32.5			32		0		N/A
Coke gasification start temp.		°C	unknown	1100		1000		N/A		N/A
W point	Temp		unknown	810		950		817		N/A
Heat Loss			521	480		480		420	Lower Furnace	690

*1) source: Tesu-to-hagane_68(1982)_2362, operation data of 1981

Conclusions:

Inputting the values for calculation from the operation data of JFE Fukuyama 3BF and comparing the calculation results with actual values,

1. **Errors in the heat balance, including the starting point of coke gasification, are concentrated in the heat loss in the last line of the table, but the errors are seems sufficiently small compared to the overall heat described below.**
2. **Errors in the material balance are concentrated in the furnace top gas, and even with some errors, the results look sufficiently reproducible given that detailed conditions such as raw materials are unknown.**
3. **Therefore, it is seen that thermal material analysis of BFs can be analyzed and verified using a thermal equilibrium model once the main operating variables (DRR, TR, etc.) are determined. However, the DRR (direct reduction rate) of conventional BFs is affected by the lower furnace conditions including the cohesive zone, also by material/gas distribution, so determining it analytically is itself a challenge.**
4. **SimplLE (Duplex BF) is characterized by the fact that the main operating variables (DRR and TR) are uniquely determined*2 or adjustable, and a thermal equilibrium model can be analyzed and verified more practically than for conventional BFs.**

*2) see Home page(https://simple-labo.co.jp/en/) "*Duplex BF*"

II. Heat Balance and heat transfer in the lower furnace

1) Heat Balance in the lower furnace

			JFE Fukuyama 3BF*1		Conv. BF		SimpLE(ver.1.ck)		Cupola (Foundry)	
Subject zone of heat balance(gas temperature)				≧1100°C		≧1000°C		≧1300°C		≧1500°C
INPUT		MJ/tp		**14,660**		**17,310**		**9,170**	estimation ↓	**4,750**
Sensible heat	Burdens preheated	MJ/tp	1100 °C	1,340	1000 °C	1,250	1300 °C	1,440	1200 °C	1,040
	Coke	MJ/tp	1100 °C	460	1000 °C	330	1300 °C	200	1200 °C	210
	Hot blast	MJ/tp	1353 °C	1,790	1100 °C	1,590	1300 °C	460	450 °C	380
							lowest tuyeres only ↑			
Latent heat	Coke	MJ/tp	LCV	9,510		7,810		3,580		3,120
	Fuels	MJ/tp	LCV	1,560		6,330		610		0
	Hot blast	MJ/tp		0		0		2,880		0
OUTPUT		MJ/tp		**14,660**		**17,310**		**9,170**		**4,750**
Sensible heat	Pig iron & slag ※1	MJ/tp	1481 °C	2,070	1500 °C	2,150	1500 °C	2,020	1574 °C	1,680
	Gases	MJ/tp	1100 °C	2,080	1000 °C	2,200	1300 °C	900	1000 °C	1,620
Latent heat	Gases	MJ/tp		8,010		10,550		5,890	superheated ↑	820
Reaction heat	Qr: decomposition heat of FeO, SiO_2, MnO, & P_2O_5									
	Qr ※2	MJ/tp		2,220		2,200		150	Oxidation heat	-60
Heat Loss	Qhl in the lower furnace									
	Qhl ※3	MJ/tp		280		210		210		690
Balance				**0**		**0**		**0**		**0**

2)Apparent heat supply to the lower furnace (Fuels & gas heat supplied)

		JFE Fukuyama 3BF*1	Conv. BF	*SimpLE(ver.1.ck)*	Cupola (Foundry)
Fuels; primary combustion heat	MJ/tp	11,070	14,140	7,070	3,120
Fuels & gases; sensible heat	MJ/tp	1,790	1,590	460	380
Apparent heat supply	MJ/tp	**12,860**	**15,730**	**7,530**	**3,500**

3) Actual heat supplied to the lower furnace (Heat trasfered in the lower furnace)

			JFE Fukuyama 3BF*1	Conv. BF	*SimpLE(ver.1.ck)*	Cupola (Foundry)
Incoming heat	on a 25°C basis	MJ/tp	14,660	17,310	9,170	4,750
Outgoing heat	on a 25°C basis	MJ/tp	10,090	12,750	6,790	2,440
Gross heat supply (= Σ※1～3)		MJ/tp	**4,570**	**4,560**	**2,380**	**2,310**
Subtracting the sensible heat of pig iron and slag (S.H. of P.iron & Slag) at the incoming temperature from the Gross heat supply,						
S.H. of P.iron & Slag		MJ/tp	1,550	1,510	1,400	1,040
Net heat supply	on a boundary temp. basis	MJ/tp	**3,020**	**3,050**	**980**	**1,270**

Discussions on II.:

Net heat supply means the heat supplied to pig iron, slag and external heat loss within the boundary. If the boundary temperature and the quality of iron and slag are the same, the difference in net heat supply is due to the difference in slag ratio, reaction heat (decomposition heat), and external heat loss. **Although the apparent heat supplies of Fukuyama 3 BF and current BFs differ by 3GJ/tp, the net heat supplys are almost the same since their direct reduction ratios and slag retios are close.** It also means that **the difference in fuel ratio mostly comes from the difference in latent heat of the exhaust gas (2.5GJ/tp), which means that a large amount of heat is consumed for fuel gasification** (reducing gas production) rather than that in the heat to produce pig iron and slag.

Conclusions on II.:

1. ***SimplLE* can reduce the net heat supply to the lower furnace to 1/3 of current BFs by eliminating the direct reduction reaction there.**
2. In addition to eliminating the direct reduction heat, **the heat for fuel gasification (reducing gas production) in the lower furnace is also cut off by supplying reducing gas separately through maulti-stage tuyeres**. Sum of them **reduces the apparent heat supply by 8 GJ/tp from the current BFs, reducing the coke ratio and fuel ratio so much**.

III. Amount of outgoing gas from the Lower furnace (for reference)

Outgoing gas ratio	Nm^3/tp	1377	1615	500	697
Gas pressure of the zone	MpaG	3.6	3.6	3.5	0
Actual outgoing gas ratio at 1300°C	m^3/tp	1,725	2,023	640	4,018

Conclusions:

1. Outgoing gas ratio is minimized in SimpLE, one third of conventional BF and even less than cupola.

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