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DISCUSSION ON BLAST FURNACE'S CARBON MIGRATION RULES AND CO_2 EMISSION REDUCTION MEASURES[1]

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Abstract

Low carbon smelting is the developing direction of modern blast furnace. Using the principle of carbon balance, and combined with the relationship between the technologies of BF and its equipments, BF's carbon migration rules are studied in this paper. Meanwhile, the accurate CO_2 emission of BF's is calculated and the essence of BF's emission is analyzed as the production and emission of BFG. CO_2 reduction strategies are proposed based on the above findings.
Key words: Blast furnace; Carbon migration; CO_2 reduction; Carbon balance.

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1 INTRODUCTION

The energy consumption of Chinese iron and steel industry takes up about 15% of the country's energy consumption, of which blast furnace(BF for short) consumes 60% energy of the whole iron & steel process. For long process which includes coke, sinter, pellet, BF, converter, continuous casting and hot rolling, the CO_2 emission is about 2.1t [1-5]. BF plays as both major energy consumer and emission unit. This paper is dedicated to study the carbon migration rule of BF process and look for possible ways to reduce CO_2 emission.

2 CARBON BALANCE OF BF

BF is a typical reducing actor in which carbon is the main reducer. The carbon balance of BF is based on material balance. At the material input end of BF, there are ferro-materials(such as sinter), coke, coal fine, flux, blasting air; while at the output end, there are hot metal, slag, BFG, moister in gas, gas dust and volatile [6]. Here we raise a 2000m^3 level BF in China as example and list its material balance table 1.

Table 1 Material balance table of a 2000 m3 level BF in China

Input		Output	
Item	Qty. Kg/t	Item	Qty. Kg/t
Ferro-raw-material	1680	Hot metal	1000
Coke	362	Slag	321
Coal fine	153	Coal gas	2308.5
Flux	0.9	Moisture in gas	25
Blasting air	1480.6	Gas dust	20
		volatile	0.13
Total	3676.5	Total	3674.6

Although the carbon balance is based on material balance, there are differences. Some material, such as sinter, pellet, moisture in gas and slag, has little carbon, so if we deduct these carbon-free materials from material balance, we may conclude the carbon balance of BF. Take the 2000m^3 level BF in China for example, the carbon content of coke is 85%, that of PCI is 80%, the BFG contains CH4 0.3%;H2 1.7%;CO_2 19.4%;CO 24.5%;N2 54.0%;O2 0.1%, which means there is 0.273kg carbon in 1m3 BFG., and the following table is obtained.

Table 2 Carbon balance table of a 2000m3 level BF in China

Input end						Output end					
Material			Carbon content	C	proportion	Material			Carbon content	C	proportion
Item	Unit	Qty.		kg		Item	Unit	Qty.		kg	
Coke	kg/t	380	0.85 kg/kg	323.0	71.5%	Hot metal	kg/t	1000	0.04 kg/kg	40	8.87%
Coal fines	kg/t	153	0.8 kg/kg	122.4	27.1%	BFG	Nm3/t	1690	0.24kg/ m3	406.7	90.14%
Other raw material				6	1.3%	Gas dust	kg/t	15	0.3 kg/kg	4.5	1.0%
Total				451.4	100.0%	Total				451.2	100.0%

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From Table 2 it is clear that at the input end of carbon nearly 99% C which enters into BF comes from coke and coal fine, the other from sinter and other raw material which only takes up quite a small proportion. At the output end, about 90% C goes into BFG, 9% goes into hot metal, and only 1% goes into gas dust.

3 RULES OF CARBON MIGRATION

The analysis stated above is referred to BF proper. However, other systems such as hot stove, PCI, slag treatment, and coarse gas dedusting system also consume energy such as electricity, water, nitrogen, steam, which are eventually driven by electricity. Converted into standard coal consumption, it is calculated that nearly 95% of the energy used in BF process is from fuel of coke and coal, and only 5% is electricity and other kinds of energy. So the key points of carbon migration study are the reaction and migration rules of C when coke and coal fines are brought into BF.
After coke and coal fines enter into BF, some of them get combusted and supply caloric to various chemical reactions in BF; some participate in reducing reaction in the form of C and CO, most of which are in BFG in the form of CO_2 and CO, only a small quantity of C goes into hot metal and gas dust. This migration rule takes a good shape in Table 2.

4 CALCULATION OF CO_2 EMISSION

4.1 Measured Value of Emission Factor

Although there is no international standard and uniform method to calculate carbon emission, it is a prevailing practice to calculate carbon emission basing on emission factors[7,8]. To achieve a more precise result, we propose measured value of emission factor in this paper as table 3 shows.

Table 3 Measured values of materials and energy emission factors of a Chinese 2000m^3 BF

Type	No.	Item	Carbon content	Emission factor	Unit
Type I emission factor	1	Coke/coke lump	85%	3.117	tCO_2/t
	2	Coal fine	80%	2.933	tCO_2/t
	3	COG	CH425.0%;H258.0%;CO22.5%;CO6.0%;N25.0%;O20.5%;CmHn3.0%	0.776	$tCO_2/kNm3$
	4	BFG	CH40.3%;H21.7%;CO219.4%;CO2 4.5%;N254.0%;O20.1%;CmHn0.0%	0.346	$tCO_2/kNm3$
	5	Gas dust	30%	1.100	tCO_2/t
	6	Hot metal	4%	0.147	tCO_2/t
Type II emission factor	1～7	Electricity, steam, oxygen, nitrogen, compressed air,water and blasting air.	Converted into electricity consumption uniformly	0.361	tCO_2/MWh

Remarks: 1) All the emission factors hereinabove are directly emission factors. 2) Type I direct emission factor is calculated on the actual carbon content of materials

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and energy; 3) Type II direct emission factor is calculated on the reference value of 0.1229kgce/kwh of national standard coal coefficient issued in 2005.
There are two types.

4.1.1 Type I emission factor

For materials and energy that contain carbon, it is proposed to calculate CO_2 emission factor by measuring their carbon content, and then follow this formula: CO_2 emission factor=carbon content%×44/12. For BF, these material and energy include coke, coal fine, BFG, COG, gas dust and hot metal.
To make it more clearly, further explanations shall be put for BFG. In BF system, BFG is taken as the counteracted emission reference value. BFG contain 22~25% CO which can be reused, and it should counteract corresponding emission of CO_2. As 283.4KJ caloric value is generated when 1mol CO combusting into CO_2, and that is 393.8KJ when 1mol C combusting into CO_2, so CO only equals to 283.4/393.8 of C for counteraction of carbon emission. BFG's emission factor shall be CO%×44/22.4×283.4/393.8.

4.1.2 Type II emission factor

Carbon content of some material and energy cannot be directly measured, however, as their main consumption energy is electricity, their carbon content can be referred to the calculation of electricity they consumed. Type II emission factors are usually for dynamic energy mediums, including electricity, steam, oxygen, nitrogen, compressed air, water and blasting air.

4.2 CO_2 Emission Calculation Model

Carbon balance principle shall be applied in the calculation of BF process CO_2 emission, the emission carbon equals to the input carbon total minus carbon emission of products and byproducts. BF process CO_2 emission= CO_2 in equivalent at input end-carbon emission at the output end[9,10]. Details refer to fig 1.

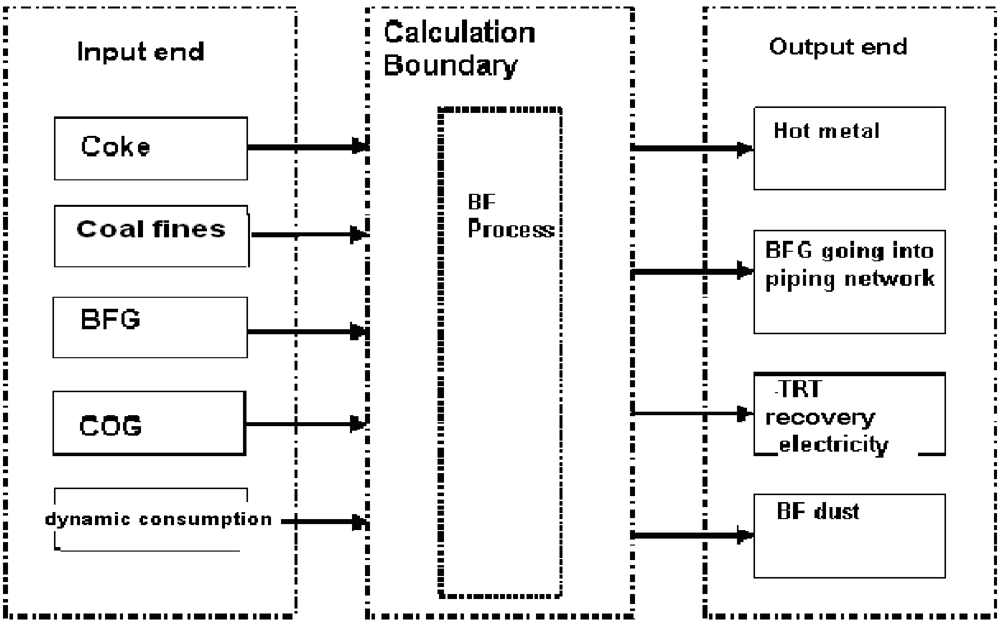

Fig.1 CO_2 emissions calculation model of BF process.

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It shall be noticed that at the calculation of BFG emission, the BFG incorporated into piping network shall be counted into the deducted value, and as hot stove and PCI are included in BF process, which consume about 40% and 1% BFG respectively, so the BFG used by hot blast furnace and PCI shall be deducted.

4.3 Example of a Chinese 2,000 m3 BF

The CO_2 emission is calculated for a 2000m3 BF in China by employing carbon balance principle, and the result turns out to be 1185.91185.9kg/t. the calculation details refer to Table 4.

Table 4 Calculation result of process CO2 emission

Input end			Output end		
Item	CO_2 in equivalent	Proportion	Item	CO_2 in equivalent	Proportion
Coke	1184.87	69.54%	Pig iron	147.0	8.63%
Coal fines	449.37	26.37%	BFG entering into piping network	347.9	20.42%
COG	8.98	0.53%	TRT reclaiming qty.	12.47	0.73%
Dynamic consumption	66.18	3.88%	Gas dust	16.5	0.97%
			Process CO_2 emission	1185.9	69.33%
Total	1703.9	100.00%	Total	1703.9	100.00%

From Table 4 it is obvious that at the input end, about 96% CO_2 is from coke and coal fine, which is with the same proportion of BF process energy consumption; at the output end, total counteracted CO_2 in hot metal, gas dust and TRT reclaiming takes up 10% of the total CO_2 emission, and 20% goes into gas main network, and the rest 70% emitted into the air.
It shall be noticed that this model is focused on the BF process CO_2 emission, if the study is focusing the CO_2 emission per ton iron, the emission of upstream process shall also be taken into consideration. Here we do not consider this case in the paper.

5 CO_2 EMISSION REDUCTION MEASURES

5.1 Essential of BF CO2 Emission

By studying the carbon balance of BF and CO_2 emission of BF process, we can come to the conclusion that the key point to determine BF CO_2 emission lays in the generation and emission of BFG. As the above example demonstrated, the BFG generated of proposed BF is actually 1690 Nm^3/t. according to the BFG content and following the calculation of "∑C content×44/22.4", we know that 1 Nm^3 BFG would convert into 0.87kg CO_2 in equivalent in this case, the BFG shall be converted into 1690×0.87=1470.30 kg CO_2, then deduct 347.9kg that goes into piping network, the actual CO_2 emission of BFG is 1470.3-347.9=1120.4 kg. This figure takes up 95% of the total CO_2 emission of BF process (1185.9kg). Then how is the rest 5% produced? From Table 4 we know that converting the dynamic medium (COG, electricity, etc,) consumed by PCI and other systems into CO2, the emission CO_2 in this part is 75.16kg, so 1120.4 kg+ 75.16kg totals 1195.6kg, which is merely 0.8% deviation from the figure 1185.9kg(the total BF process emission).

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Based on above analyses, BFG is the production of oxidation reaction between coke & coal fines and blasting air, so the C in BFG actually comes from coke and coal fines, and the CO_2 emission of BFG is referred to the emission inside the BF; while the CO_2 emission triggered by COG, electricity and other dynamic medium covers the emission outside the BF, however, this part of CO_2 emission takes only a small proportion, so it is believed the essential issues to determine BF CO_2 emission is the generation and emission of BFG.

5.2 Measures for CO2 Emission Reduction

Once coke and coal fines being conveyed into BF, quantity of BFG shall be generated by series of complicated chemical reactions, then the BFG shall be dedusted into purified gas and go into TRT. About 40% of purified gas shall be supplied to hot stove and the rest purified gas shall enter into gas piping network to supply to other users in the steel plant. Fig.2 shows the carbon migration of BF proper.

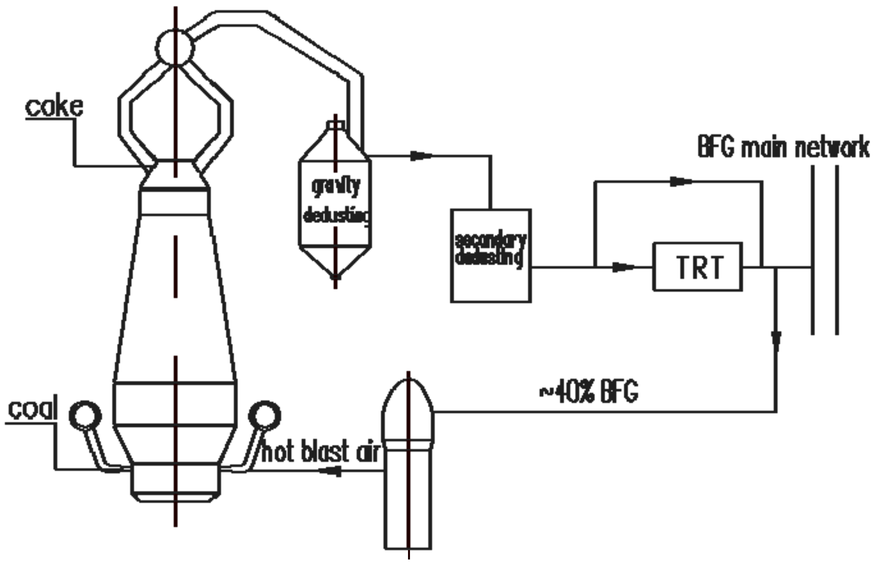

Fig.2 Carbon migration figure of the BF proper system

It is proved in the above analyses that 95% of CO_2 emission is from BFG, so in order to achieve efficient CO_2 emission reduction, it is of great importance to cut down the generation of BFG and promote low-carbonization utilization of BFG. To reduce the BFG generation, it is proposed to adopt proper smelting intensity during the production, take good control of the BF bosh gas index, and improve BFG utilization rate; on the other hand, proper throat material distribution mechanism shall be obeyed for a better stability and lower fuel ratio of BF. In addition, some energy saving technologies, such as beneficiated material technology and high blast temperature measures, greatly help to reduce the fuel ratio, blasting and BFG generation, and finally attains a low CO_2 emission. Methods for low-carbon utilization of BFG include:

- Utilize BFG as much as possible in hot stove combustion for raising the blast temperature. The caloric efficiency of hot stove is high up to 80%, which facilitates the caloric of BFG converting into high-temperature blast air, reduces the fuel ration of BF and BFG generation, and it achieves emission reduction thereby.
- Separation treatment shall be proposed for BFG. Experts in Europe and Japan have suggested to arrest and separate CO_2 in BFG after being treated by TRT,

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then heat and blast the rest CO into BF again, hence the self-circulation of BFG works. This process shall reduce about 30% of the BF emission, however, it is the headache of how to seal the arrested CO_2, currently benthal sealing, underground sealing, and ammonia treatment are proposed, however, these methods are very expensive and their sealing capacity is far from demands.

- Further develop low cost conversion technology of CO_2, and reduce the carbon emission of BFG.

6 CONCLUSIONS

Based on above calculation and analysis, we come to the following conclusions:

- The carbon source of BF process differs that of BF proper, the carbon source of BF proper takes up more than 95% of that of BF process.
- The carbon migration rule inside the BF: nearly 99% C going into BF proper which comes from coke and coal fines, about 90% C goes into BFG and the rest 10% goes into hot metal and gas dust.
- Carbon balance principle can be applied to calculate the CO_2 emission per ton iron in BF process. The example illustrated in this paper says that the CO_2 emission per ton iron of a 2000 m^3 BF is 1185.9kg, in which 95% is generated by BFG, and the rest 5% is from the dynamic energy consumption.
- The essential issue for BF emission reduction is to reduce the BFG generation and its low-carbon utilization. And the methods remain for further study.

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