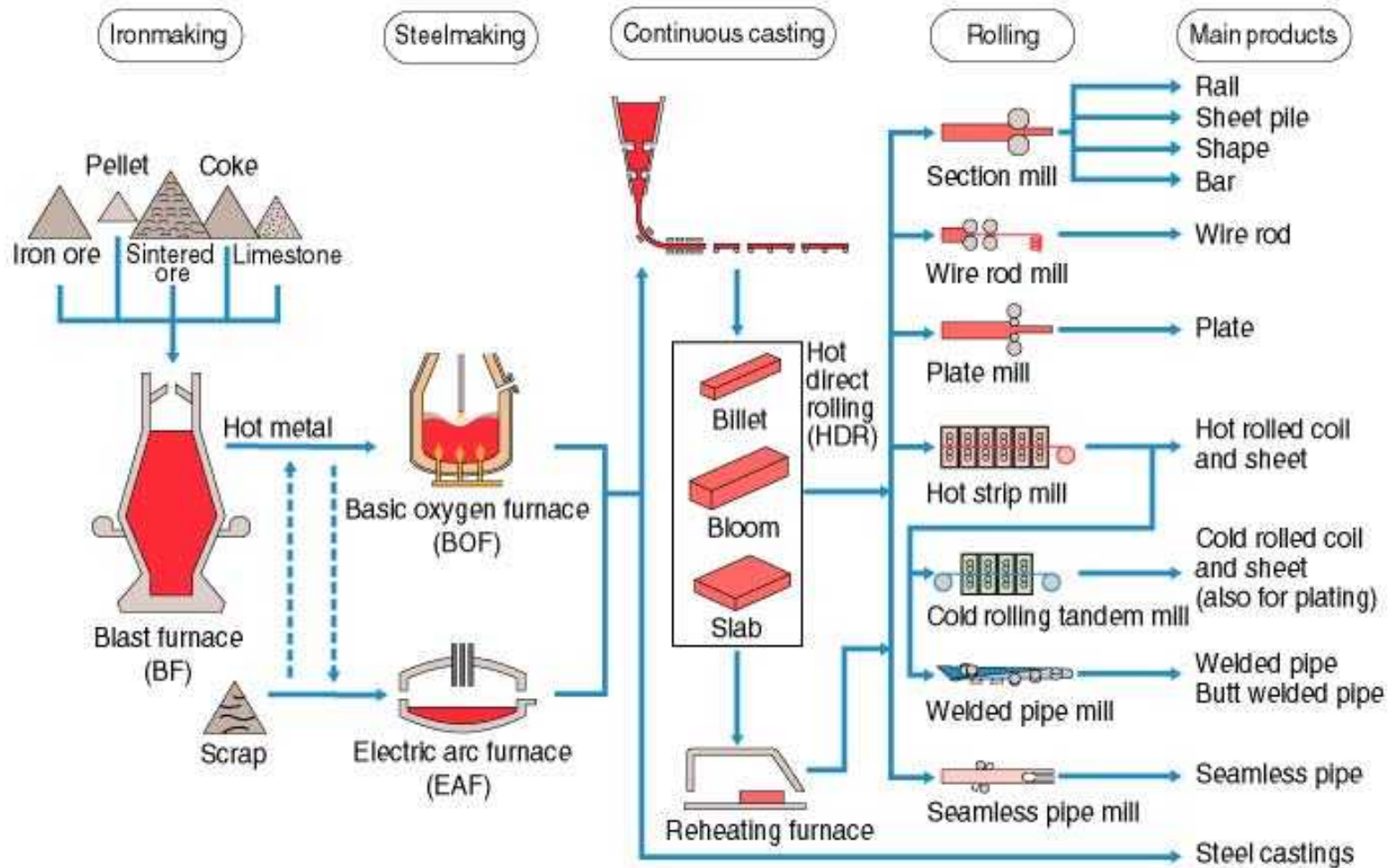


Produção de Ferro Gusa em Alto-Forno

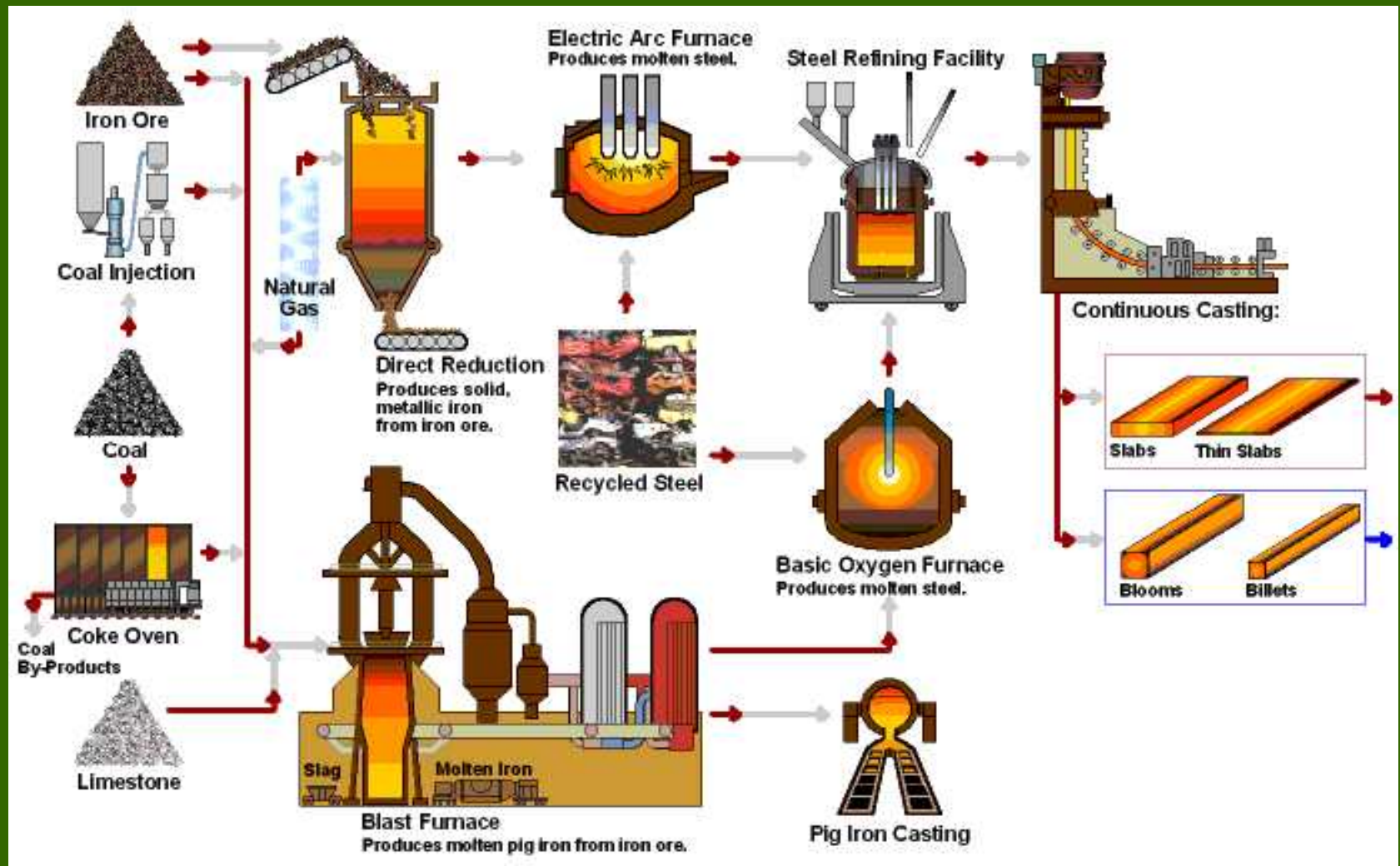
- O ferro é o metal mais barato e mais usado ao redor da Terra;
- Sua produção anual excede em muito a produção combinada de todos os outros metais;
- Somente no século XIV foram desenvolvidos fornos que podiam produzir o ferro no estado líquido (pig iron – ferro gusa), permitindo uma grande escala de produção e operação contínua. Tal forno é chamado alto-forno (Blast-Furnace);
- Nas Usinas Integradas, o ferro gusa é transferido no estado líquido para a planta de aciaria, onde será convertido em aço;

Processos de Produção de Ferro e Aço

2A Manufacturing Process for Iron and Steel



Processos de Produção de Ferro e Aço



Minério de Ferro

Magnetita (Fe_3O_4) – correspondente a aproximadamente 72%Fe/28%O, de coloração cinza-escura a preta, densidade 5,16 g/cm³. É altamente magnética, permitindo sua separação fácil de resíduos indesejáveis do minério (ganga)

Hematita (Fe_2O_3) – corresponde à composição aproximada 70%Fe/30%O, varia de cinzenta a avermelhada, tendo densidade de 5,26 g/cm³.

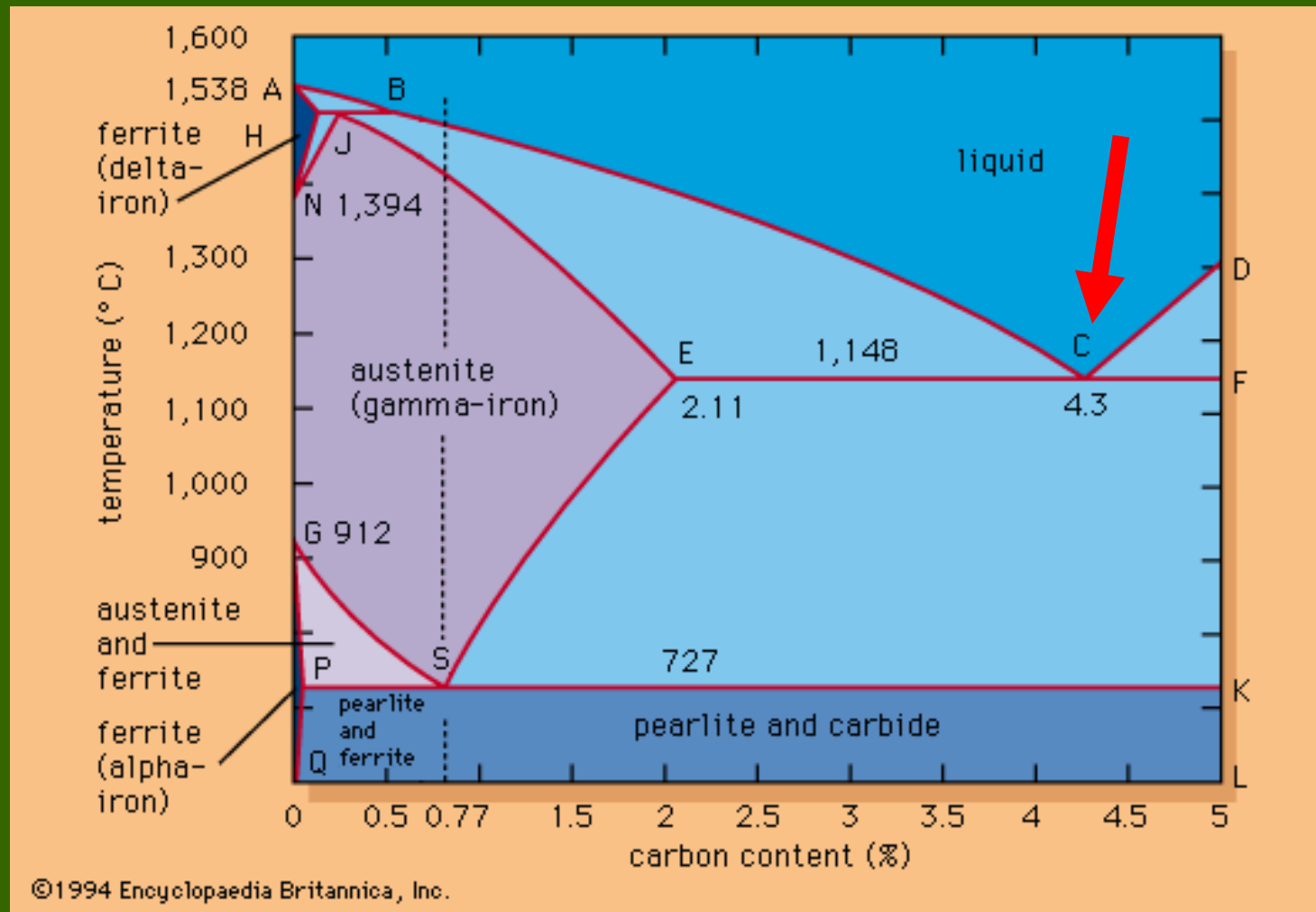
Coque

Funções do coque no alto-forno:

- Como combustível, para produção do calor necessário para redução e fusão do ferro;
 - Suprir o agente redutor (principalmente CO).
-
- As principais características do coque são: alto poder calorífico; alta resistência mecânica; baixa quantidade de impurezas.

- O coque queima intensivamente próximo das ventaneiras, a temperatura nesta região alcançando aproximadamente 1900°C;
 - Nesta temperatura, o CO_2 reage imediatamente com carbono para formar CO: $\text{C} + \text{O}_2 \rightleftharpoons \text{CO}_2$; $\text{CO}_2 + \text{C} \rightleftharpoons 2\text{CO}$;
-
- O enxofre do coque é responsável por aproximadamente 90% do enxofre total que entra no alto-forno;
 - Quando o coque contém excesso de enxofre, grandes quantidades de calcáreo devem ser adicionadas. Isto resulta em grande volume de escória e um correspondente alto consumo de coque, pois a decomposição do calcáreo é altamente endotérmica.

Diagrama Fe-C



- Uma pequena quantidade de carbono se dissolve no ferro líquido, abaixando o seu ponto de fusão.

Calcáreo

A função do calcáreo é ser fonte de CaO , que por sua vez irá se associar a ganga do minério e cinza do coque, principalmente SiO_2 e Al_2O_3 , formando uma mistura (escória) de baixa ponto de fusão e fluida

No alto-forno o calcáreo é decomposto a partir de 800°C através da reação : $\text{CaCO}_3 \rightleftharpoons \text{CaO} + \text{CO}_2$

Ar

O ar para o alto-forno precisa ser pré-aquecido na faixa de 500 a 1000°C e comprimido a 200-300 kPa

O ar sempre contém uma certa quantidade de umidade;

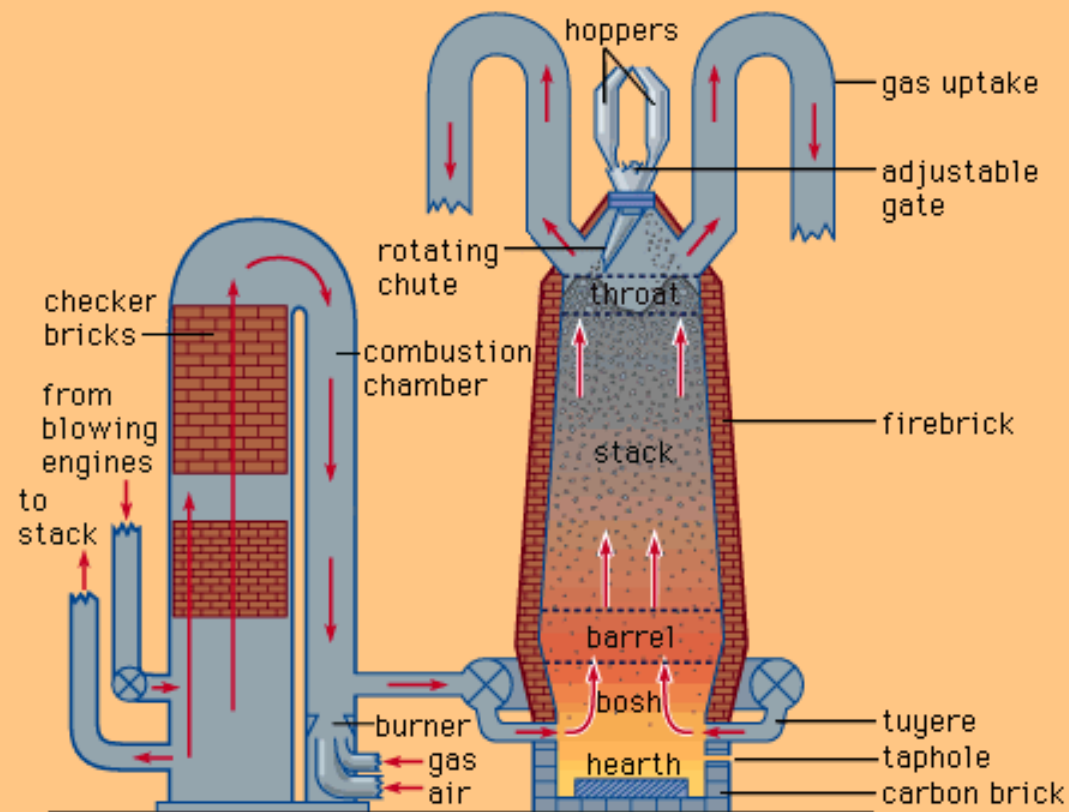
Próximo da zona das ventaneiras, qualquer umidade no ar reagirá com o coque através de $C + H_2O \rightleftharpoons CO + H_2$.

Esta reação é endotérmica, de forma que variações importantes de umidade do ar podem afetar grandemente o balanço térmico do forno

Algumas plantas instalam unidades de separação da umidade do ar por refrigeração, antes de introduzir no forno





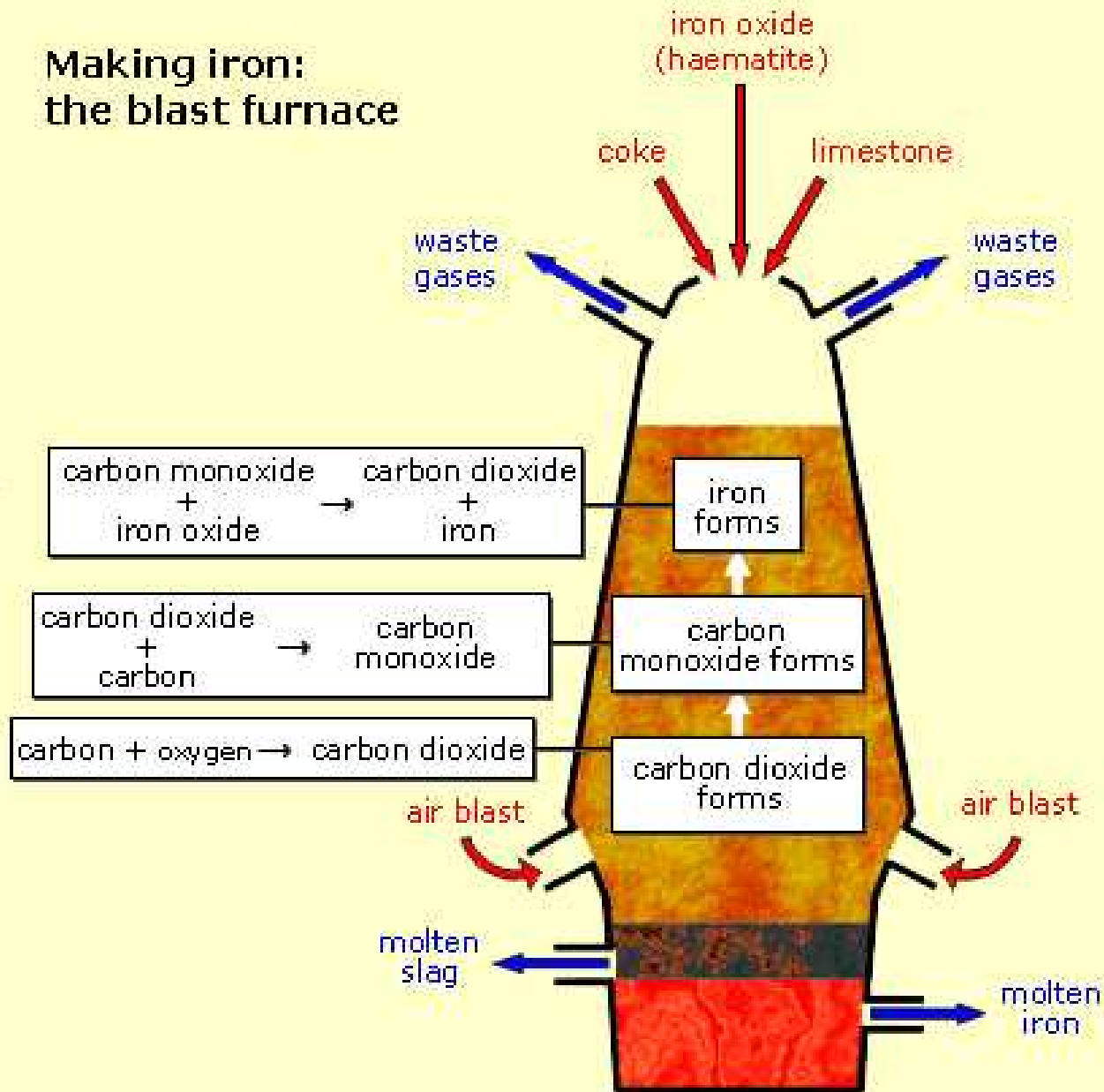


Blocos de Carbono no Cadinho de um Alto-Forno

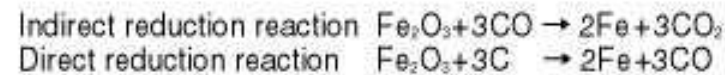


Por que o cadinho do alto-forno não é atacado quimicamente pelo ferro-gusa???

Making iron: the blast furnace



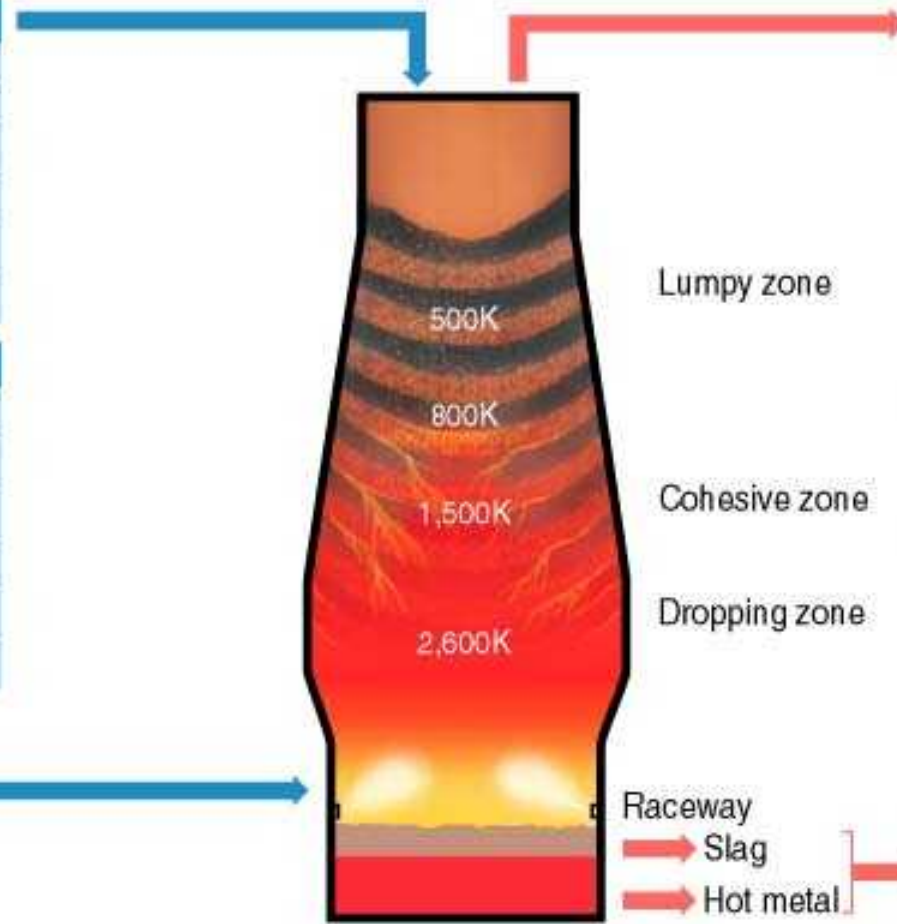
2D(2) Operating Conditions in Large Blast Furnace (BF)



Charging materials		
Materials	Mean dia. (mm)	Unit consumption (kg/t*)
Coke	50	380
Sintered ore	20	1,160
Lump	25	280
Pellet	12	190

Blasting conditions	
Blast volume (Nm ³ /t*)	995
Pulverized coal (kg/t*)	120
Humidity (kg/Nm ³)	28
Temperature (K)	1,453
Pressure (MPa)	0.40
O ₂ enrichment (vol.%)	2.3

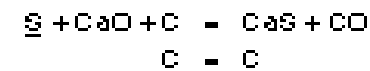
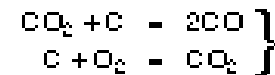
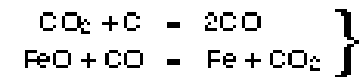
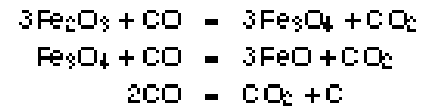
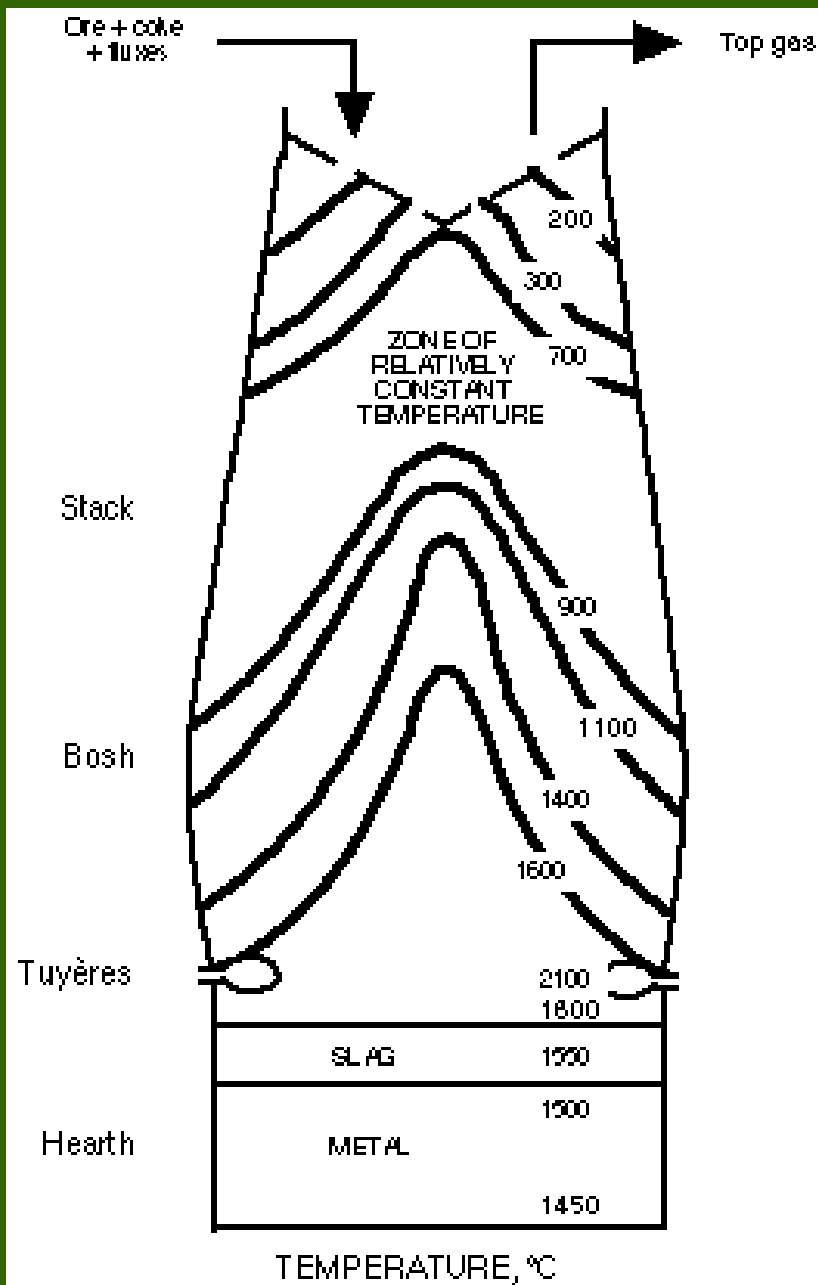
t* = Hot metal ton

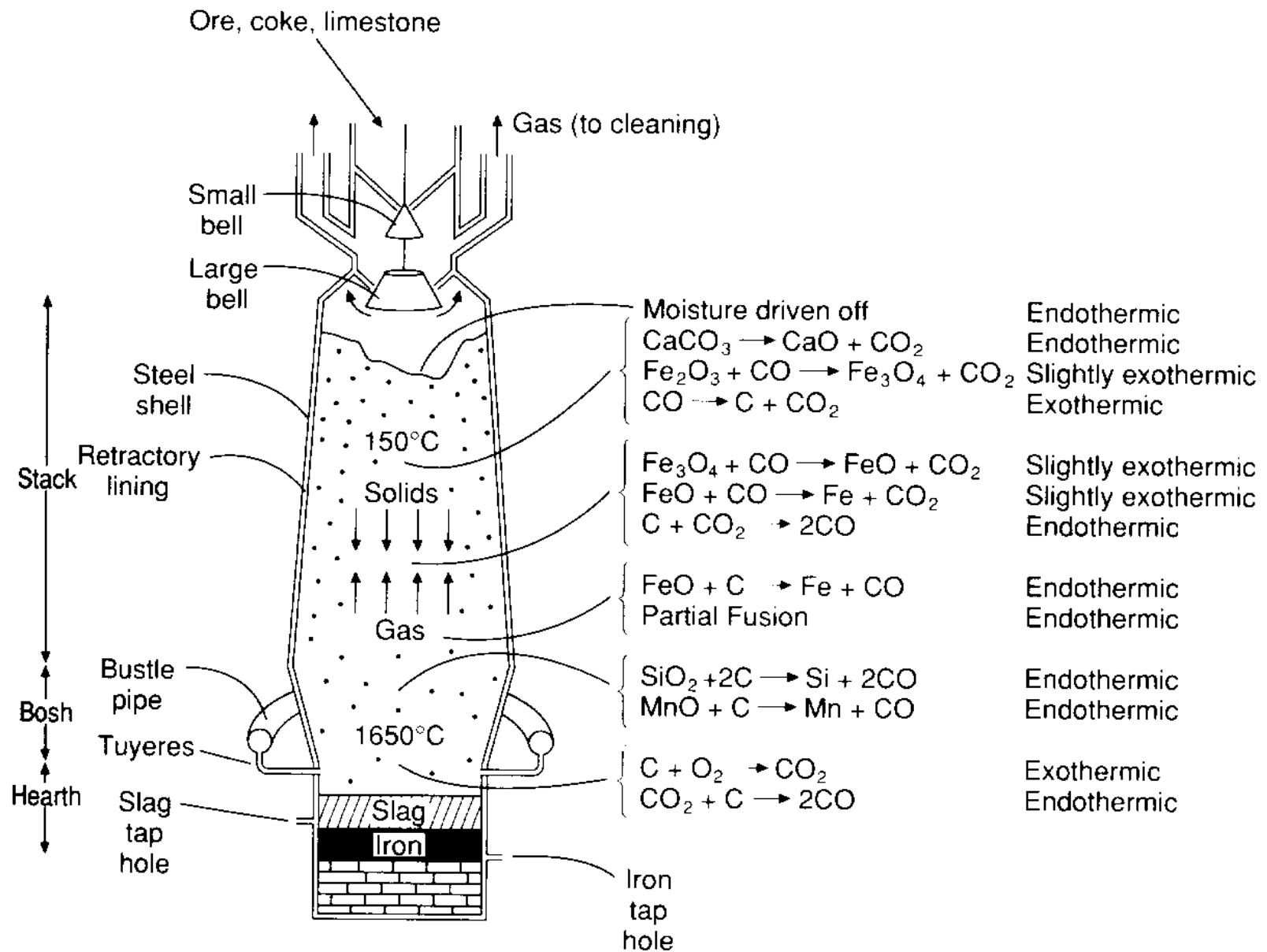


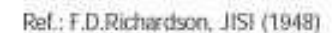
Top gas	
Dust (kg/t*)	16
Volume (Nm ³ /t*)	1,533
Temperature (K)	430
Pressure (MPa)	0.25
CO (vol.%)	22.0
CO ₂ (vol.%)	22.8
H ₂ (vol.%)	4.2

Hot metal, Slag	
Hot metal temp. (K)	1,800
Slag / hot metal ratio	0.30

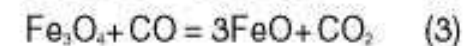
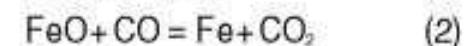
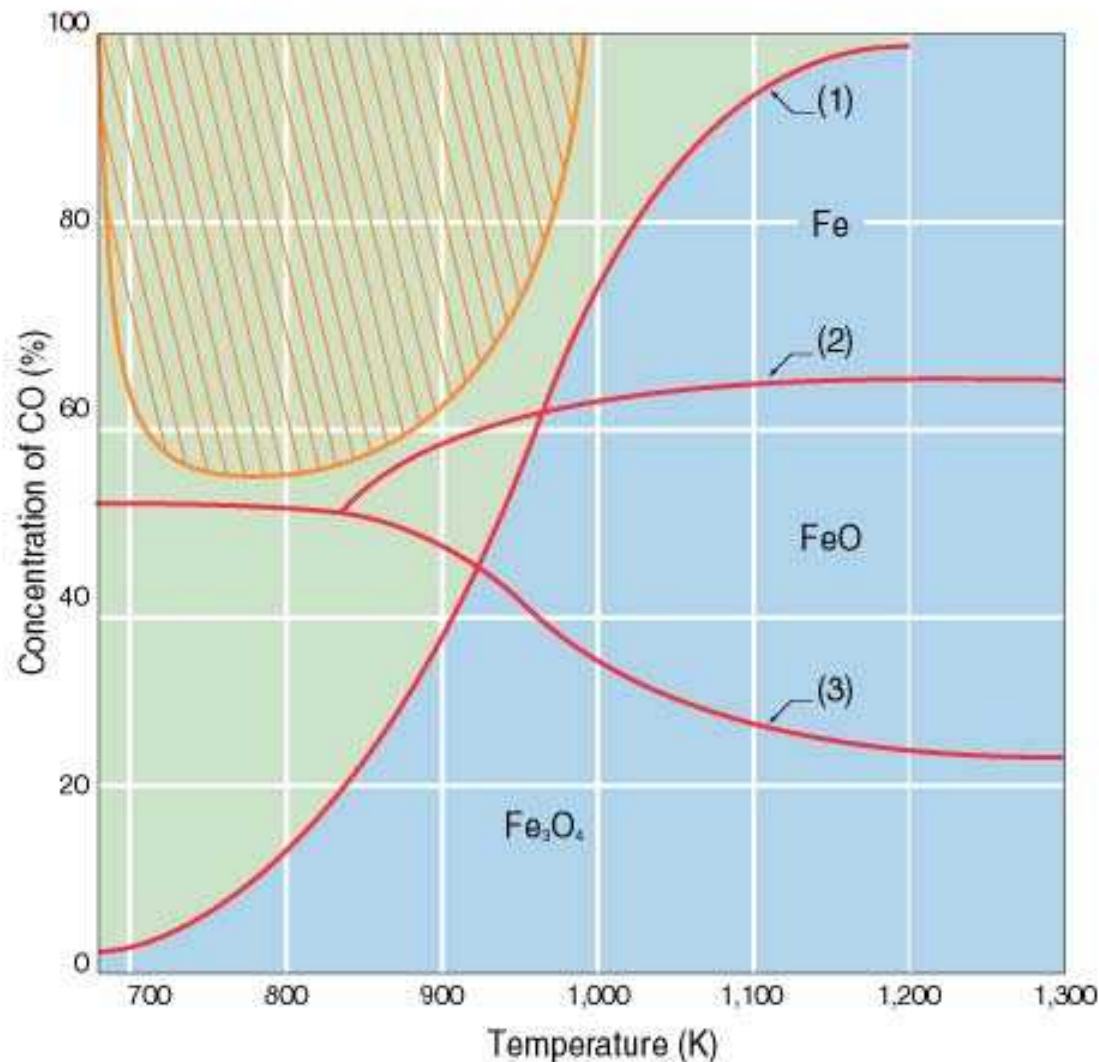
Composition (mass %)			
	Hot metal		Slag
C	4.50	SiO ₂	33.8
Si	0.39	CaO	42.5
Mn	0.27	Al ₂ O ₃	14.3
P	0.10	MgO	6.5
S	0.03	MnO	0.26
		S	0.96







2B(2) Equilibria among C, CO and CO₂ (Boudouard's Equilibrium)



Corrida de Gusa



O ferro-gusa é transferido no estado líquido ou lingotado na forma de barras



Lingotamento de Gusa



Barras de Gusa



Escória

A escória formada no alto-forno serve a dois propósitos:

Coletar as impurezas do metal líquido;

Proteger o metal contra oxidação da atmosfera do forno

A escória do alto-forno é vazada no estado líquido e normalmente derramada em um compartimento com água, produzindo um particulado que encontra aplicação na fabricação de concreto

Escória



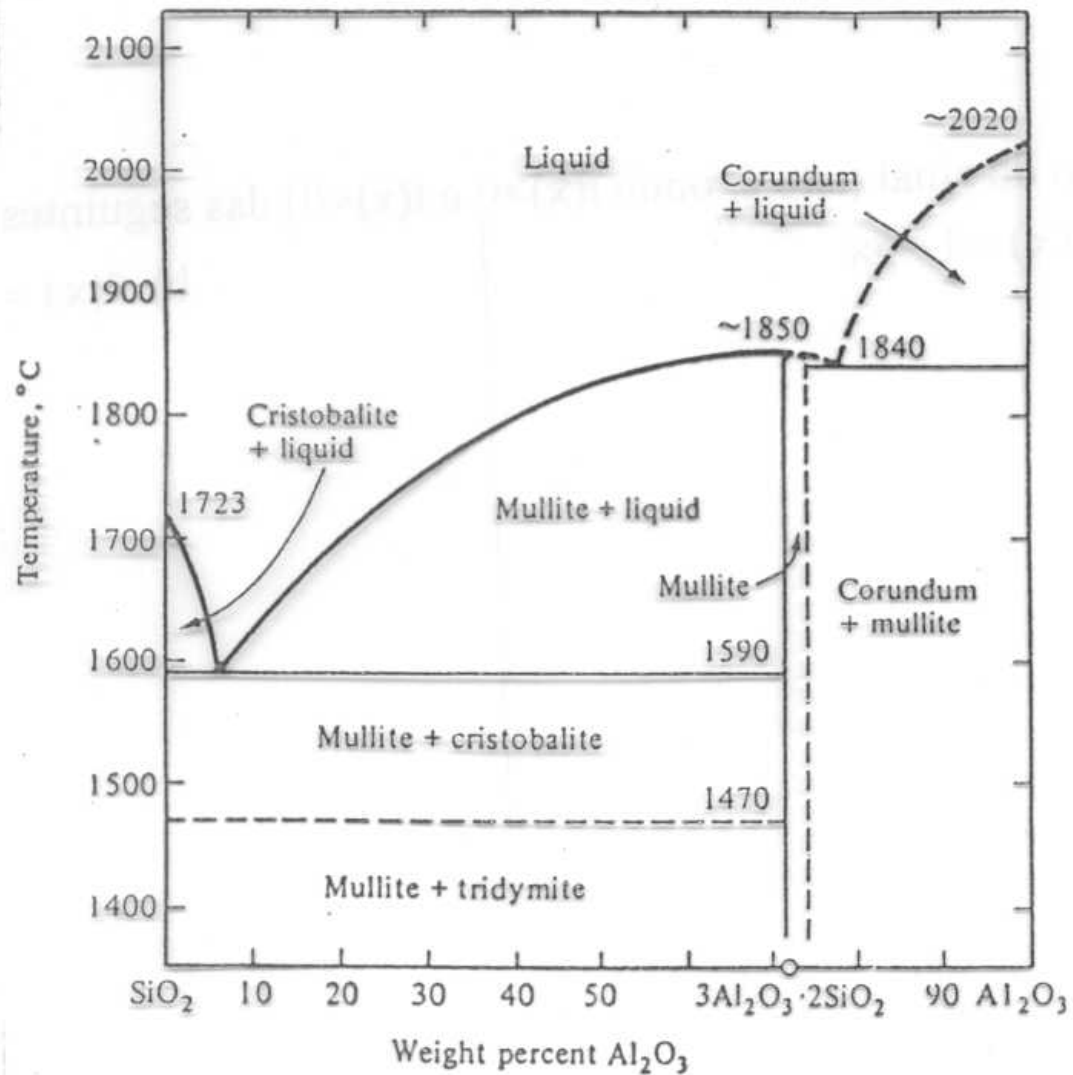
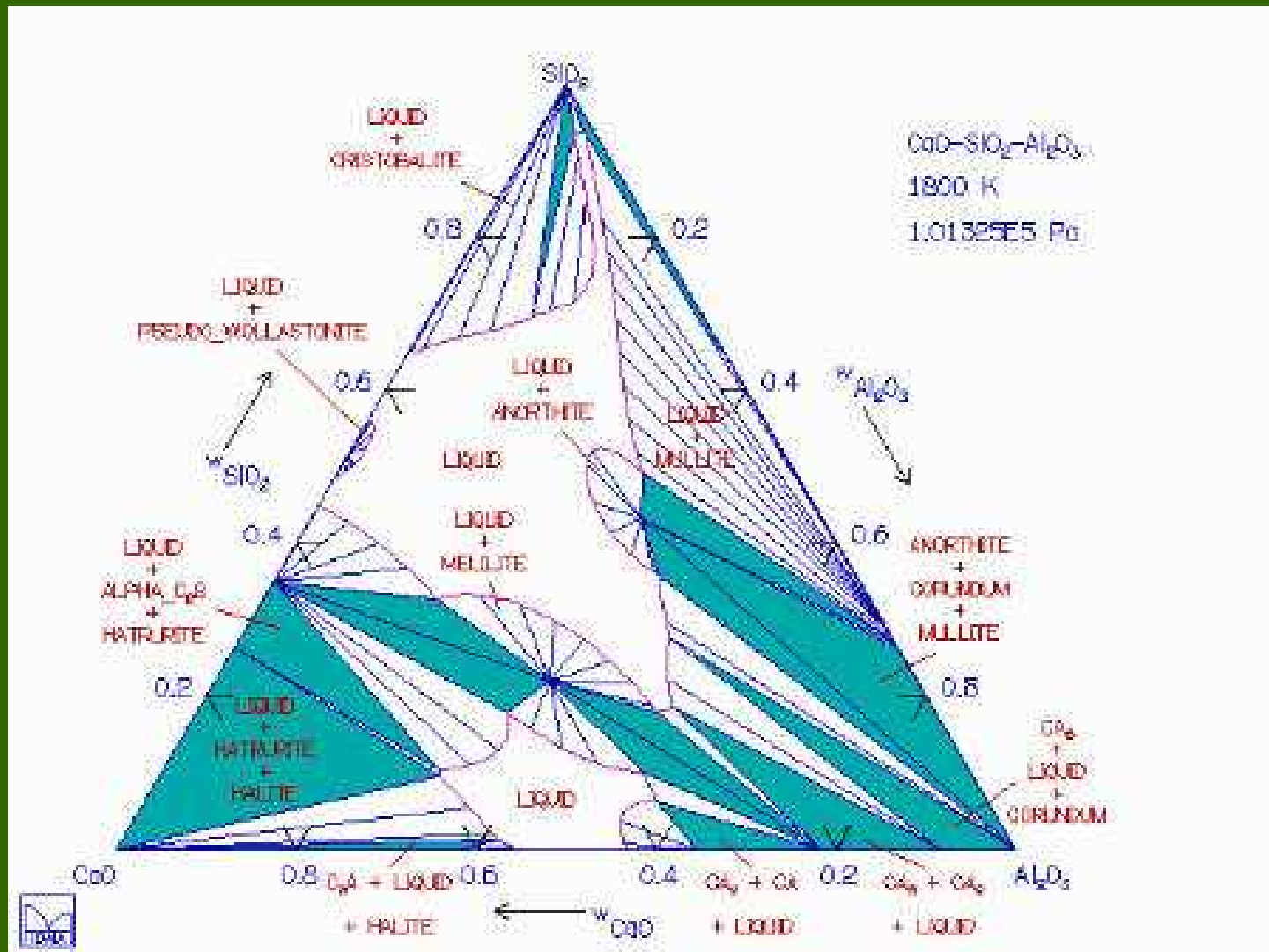


Figure 11-11 Binary SiO_2 - Al_2O_3 system. (From A. Muan and E. F. Osborn: "Phase among Oxides in Steelmaking," © 1965 Addison-Wesley, Reading, MA, Fig. 19. Ref permission.)

Diagrama $\text{CaO-SiO}_2\text{-Al}_2\text{O}_3$ a 1800 K



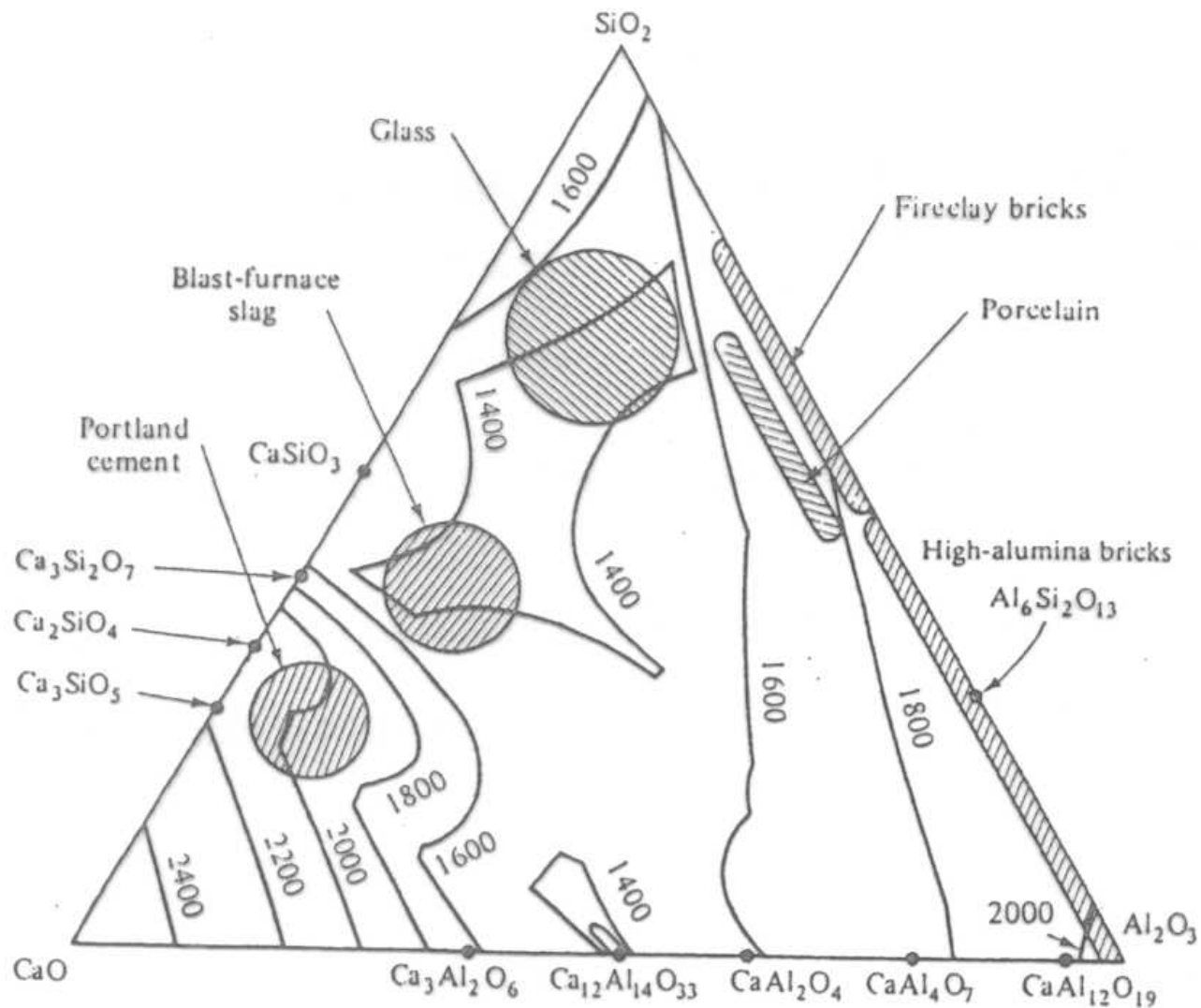


Figure 11-1 Liquidus isotherms in the SiO_2 - CaO - Al_2O_3 system. (After A. Muan and E. F. Osborn: "Phase Equilibria among Oxides in Steelmaking," © 1965 Addison-Wesley, Reading, MA, Fig. 80. Reprinted with permission.) Approximate areas for portland cement, iron blast furnace slag, glass, porcelain, and alumina-silicate bricks are indicated. In glass and porcelain most of the lime is replaced by alkali oxides.

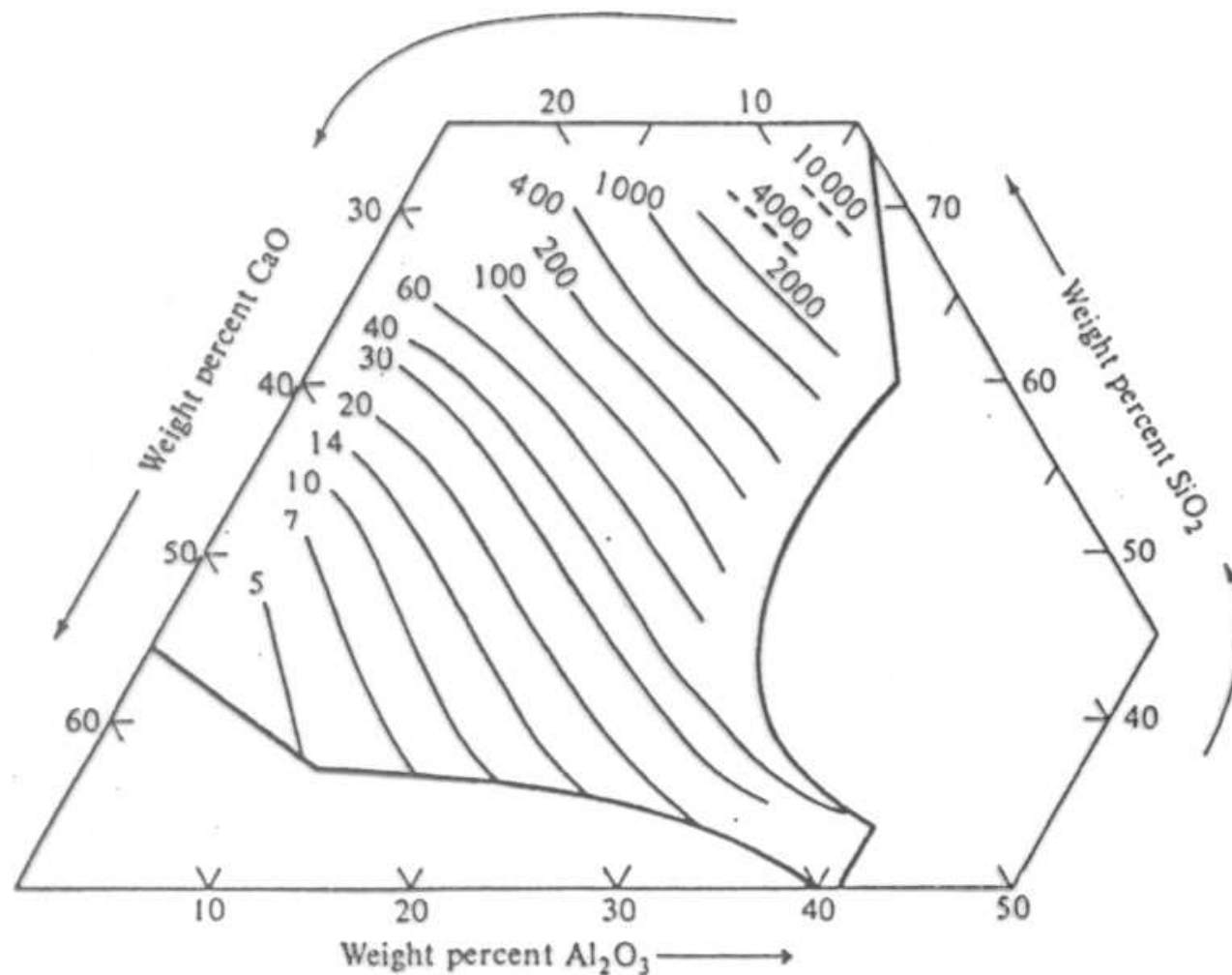


Figure 11-9 Viscosity in poises for SiO_2 - CaO - Al_2O_3 slags at 1450°C . (After J. S. Machin and T. B. Yee: *J. Am. Ceram. Soc.*, vol. 3, p. 200 (1948)). 1 poise = $0.1 \text{ Pa} \cdot \text{s}$.

Gás

- O gás que sai no topo do forno é mais que aquele que é introduzido pelas ventaneiras, especialmente devido a gaseificação do carbono;
- O CO do gás é devido à reação $\text{CO}_2 + \text{C} \rightleftharpoons 2\text{CO}$;
- Esta reação não apenas consome coque, mas também calor pois é endotérmica;
- O dióxido de carbono é um produto da redução do minério e decomposição do calcáreo;
- Devido à presença de CO, o gás de alto-forno é usado como combustível para pré-aquecer o ar que entra pelas ventaneiras.

Poeira de topo

Este material é composto de 15% material carbonáceo, 15% ganga e 70% Fe_3O_4 , embora somente Fe_2O_3 tenha sido carregado. A razão para isso é a ocorrência da reação $3\text{Fe}_2\text{O}_3 + \text{CO} \rightleftharpoons 2\text{Fe}_3\text{O}_4 + \text{CO}_2$ no topo do forno

O particulado mais fino é recuperado na forma de uma lama e é usado posteriormente nas plantas de sinterização

The iron blast furnace - improvements.

Intriguingly the iron blast furnace is a reactor where virtually complete reaction (reduction of iron oxide to iron) is achieved. This raises the interesting possibility that the productivity of the iron blast furnace could be increase by simply driving it harder. I.e. we would increase the feed rate of the coke, ore and limestone and simultaneously increase the flow rate of the blast. Actually we have gone about as far as we can go in this direction. To force the blast into the bottom of the furnace a high pressure is needed; the higher the flow rate the higher this pressure and the power required is proportional to.....

The iron blast furnace - improvements (cont).

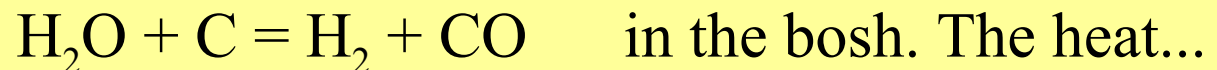
.....the flow rate times the pressure. Therefore very substantial amounts of energy are required to force the blast into the furnace. Furthermore, at high blast flow rates the downward flow of liquid iron and slag, or even of the solid can be impeded by the up-flow of gas.

The iron blast furnace - improvements (cont).

Higher blast temperature. Coke costs \$ while the blast furnace gas is essentially free. Consequently, if the heat requirements are met to a greater extent by preheating the blast (and therefore to a lesser extent by burning coke), the furnace will be more economical. The limitation on this is that raising the blast temperature raises the bosh temperature and therefore the tendency for the iron to be contaminated with impurities (see Ellingham diagram).

We can circumvent this limitation by humidifying the blast.

This results in the endothermic (therefore cooling) reaction



The iron blast furnace - improvements (cont).

....absorbed is recovered higher in the furnace when H_2 and CO reduce iron oxides.

Oxygen enrichment of the blast. This is using air with extra oxygen added for the blast. Improves the economics of the technology because I now have less hot nitrogen leaving the system. Tends to increase bosh temperatures and is therefore coupled with higher blast humidity.

Injection of hydrocarbons or coal. Rarely done these days. Idea is to reduce the amount of carbon supplied as relatively expensive coke. Tends to cool the bosh region by endothermic reaction, e.g. $C_nH_{2n+2} = nC + (n+1)H_2$

The iron blast furnace - improvements (cont).

Higher top pressure (actually throughout the furnace).

Increasing the pressure in the furnace should **inhibit** the reduction reactions because they are associated with a large increase in volume (gasses formed). Actually, from the Ellingham diagram the reduction of the iron oxides by carbon at blast furnace temperatures have large negative ΔG_R i.e the reactions are irreversible and the effect of the pressure increase (at atmosphere or two) is negligible.

The positive effect of higher top pressure is that it reduces the **volumetric** flow rate of gas which then reduces the tendency of the gas flow to interfere with solid/liquid down flow.

The iron blast furnace - improvements (cont).

Improvements in feeding solids. Purpose here is to avoid “channeling” where the gas flowing up passes through only part of the furnace (rendering the rest of the volume almost inactive). Carefully sized feed, layering of feed, movable chutes, inspection inside furnace by TV cameras etc.

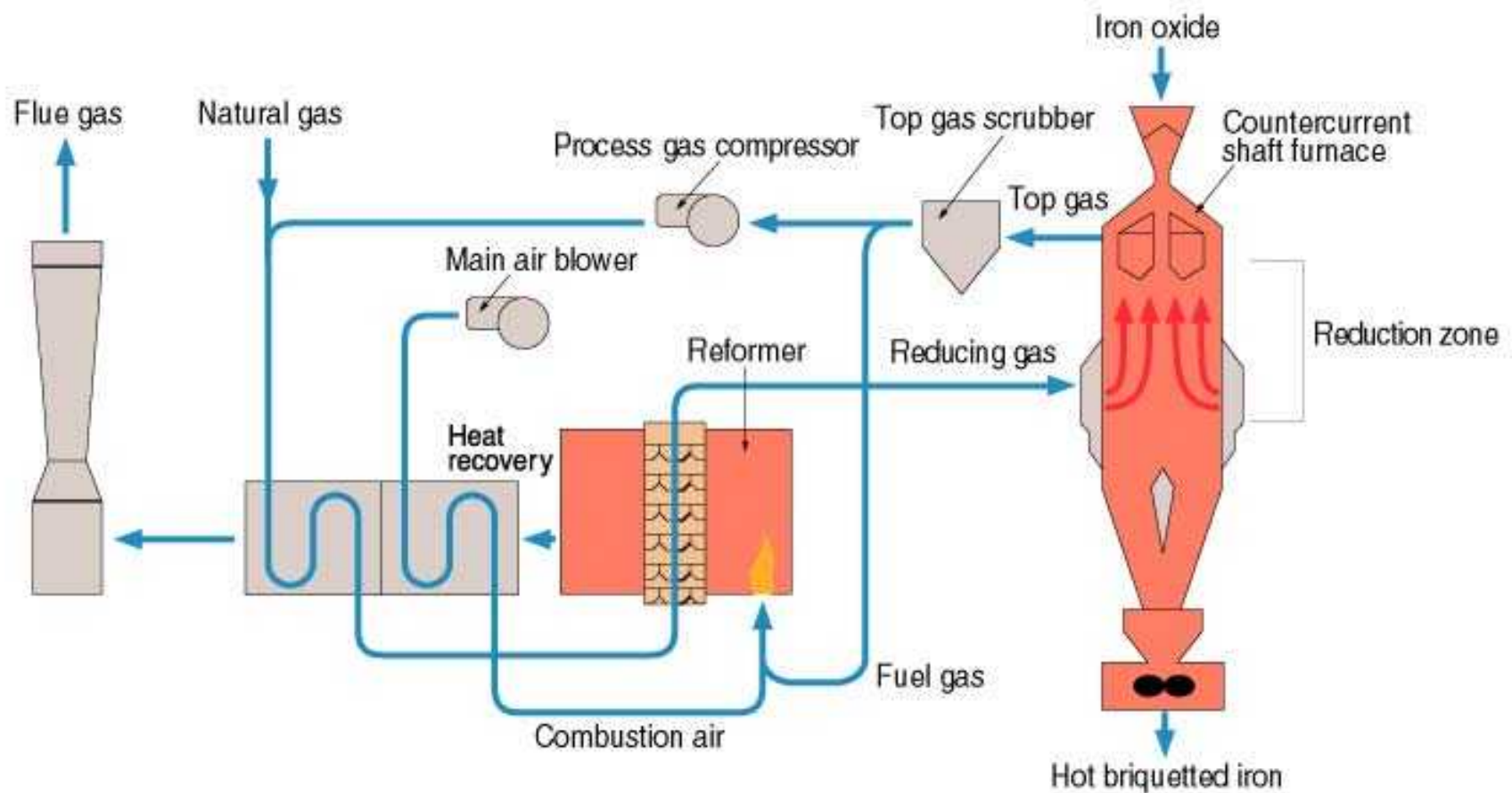
“Direct reduction” of iron ores...

.....is a technology for reducing iron ores to iron without using coke. Typically the iron produced is in solid form, rather than the liquid form of the blast furnace. This DRI is frequently used as a substitute for steel scrap in the steelmaking operation. The technology is used in countries with poor supplies of coking coals, but good supplies of hydrocarbons and iron ore (e.g. Venezuela). The reducing agent is typically H_2/CO produced by “reforming” natural gas or other hydrocarbons.

2G Example of Direct Reduction Process



MIDREX process



Production of cast iron.

Cast iron is iron with a fairly high carbon and silicon content which have the effect of increasing its modulus and hardness. This material is therefore used where a very rigid and hard material is needed but the material must be inexpensive (e.g. engine blocks of automobiles). Usually the shapes are cast in near final form (minimal machining), hence the name.

Production of cast iron (cont).

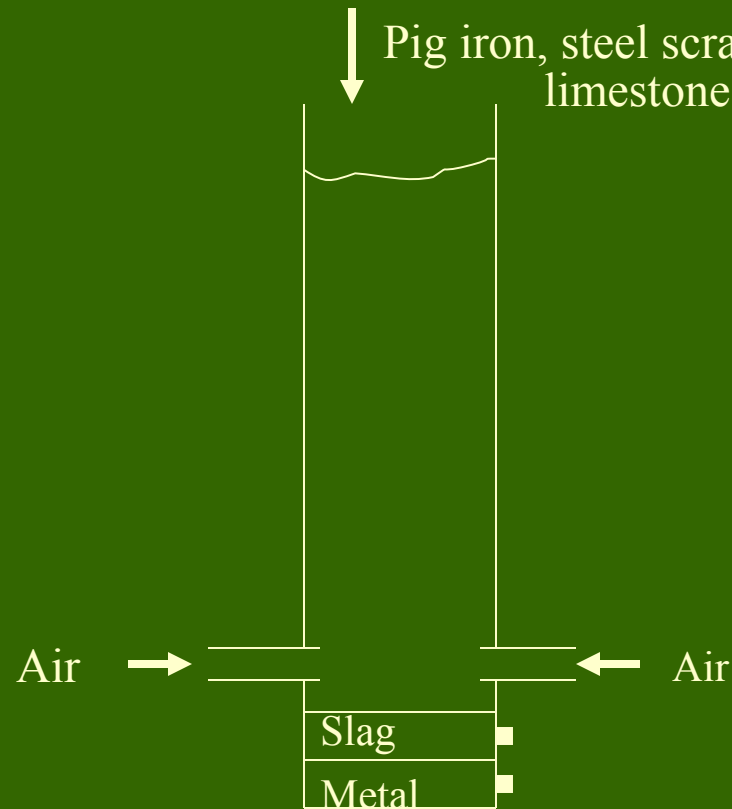
Pig iron from blast furnace (typically 4%C, 1-2%Si, 1-2%Mn) melted with steel scrap (0.05-0.4%C, low levels of Si, Mn, P, S) ferrosilicon (75%Si, little C, Mn, P, S) in a “cupola”.

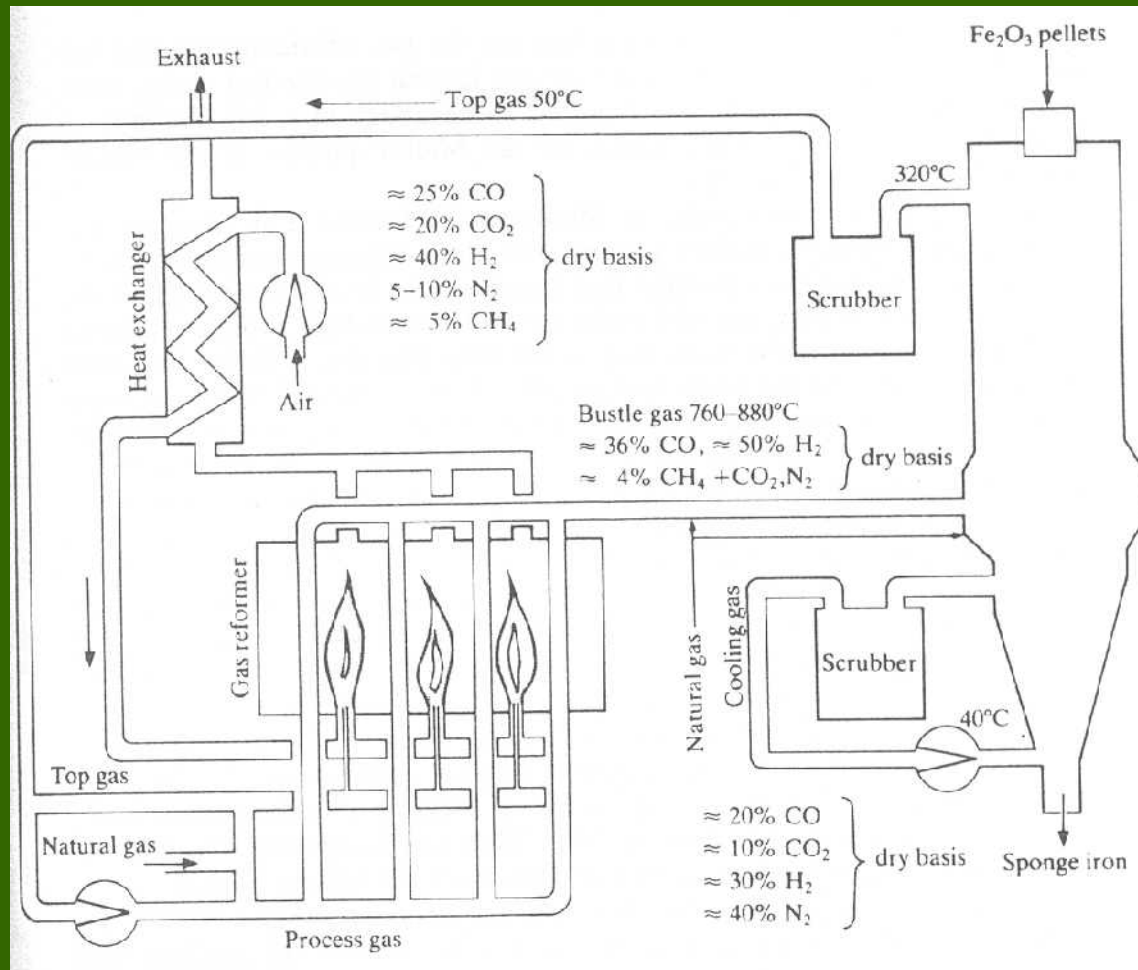
Also some limestone added to flux the oxide impurities

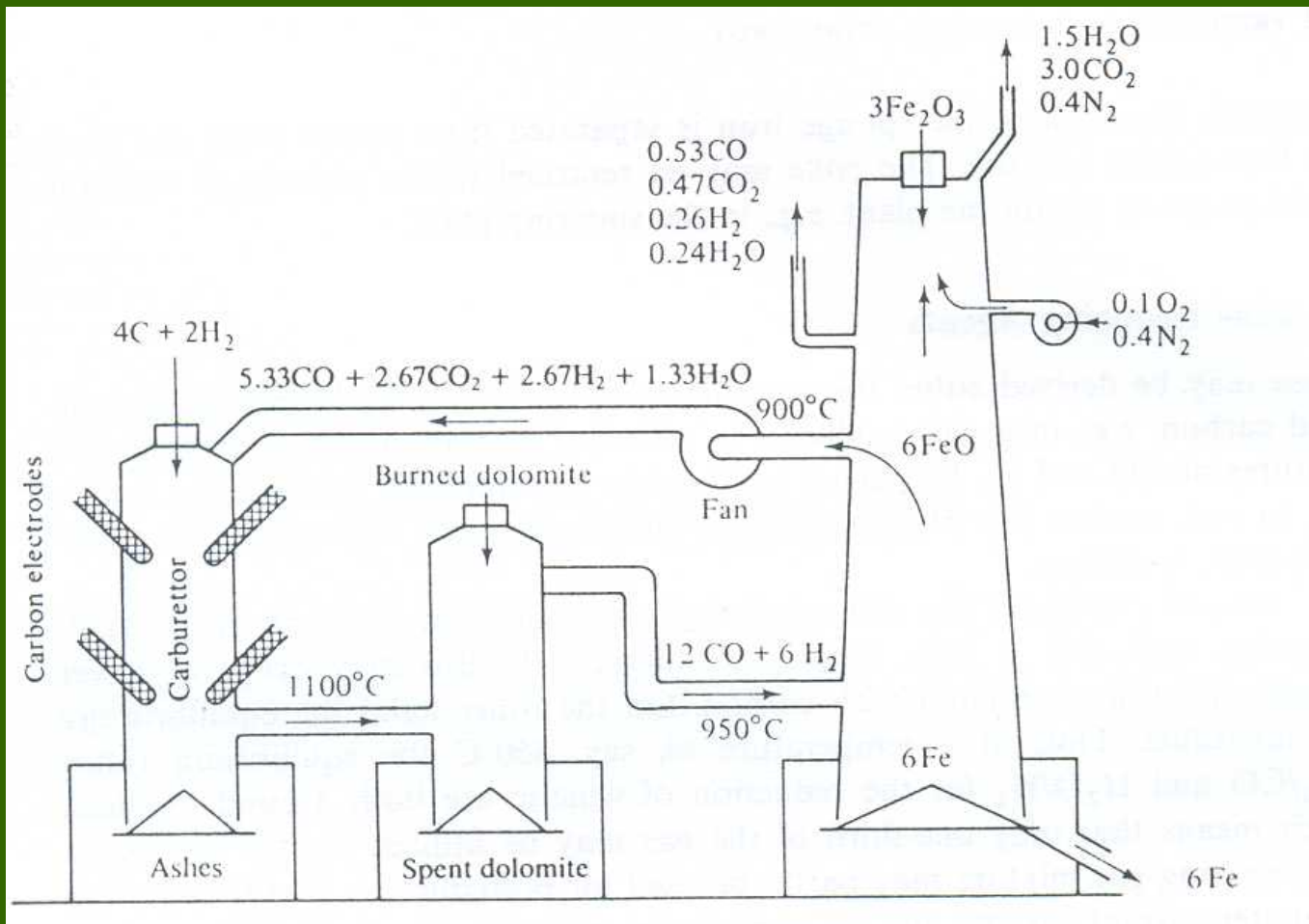
Heat is generated by combustion of coke. Batch operation.

Slag and cast iron drained separately from the cupola..

Production of cast iron (cont).







The iron blast furnace (cont).

...gangue oxides (largely silica) in the slag (i.e to yield a slag with a low enough melting point and viscosity that it will flow readily out of the furnace). The slag, a molten mixture of oxides, is a waste product. The gasses passing up through the furnace are in counter-current flow with the descending solid (and liquid iron in the bosh); the gases leave from the top of the furnace, at which point they are a mixture of nitrogen, carbon monoxide, carbon dioxide, hydrogen and water vapor. This is a low grade fuel which is usually burned in “stoves” to preheat the blast.

The iron blast furnace (cont).

If we look at the Ellingham diagram for oxides we see that at the temperatures (about 1650°C) in the bosh region, carbon is on the verge of reducing SiO_2 to silicon. Therefore the iron produced is typically contaminated with Si (also Mn, S and P). Furthermore, iron at these temperatures can dissolve carbon to the level of about 4% and because it is in close contact with coke in the bosh region, the iron will usually contain this level of carbon. These impurities are removed in the subsequent operation known as “steelmaking”. But let’s first look at changes in blast furnace technology in recent years.

