SOME COMPUTATIONS REGARDING DIRECTLY REDUCTION OF THE IRON ORES

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În această lucrare, prezentăm o posibilitate tehnologică de reducere a minereurilor de fier sau a țunderului, mărunțite, în pat fluidizat, în care sursa energetică şi simultan agent termic reducător este cărbune, asociat eventual cu un alt combustibil gazos sau lichid, fără utilizare de oxigen tehnic; formarea de CO şi de căldură se realizează prin oxidarea carbonului şi hidrogenului din combustibili, folosind numai oxigenul provenit de la oxizii minereului .

In this paper, we present a technological solution to reduce the iron ores and specifically the tunder, broken in small pieces, in fluidised bed, where the energetical source and simultaneously, reducing thermal agent, is coal, eventually associated to another gaseous or liquid fuel, without use of technical oxygen; the forming of CO and heat are obtained by the oxydation of the coal and hydrogen from the fue, by making use of the oxygen contained in the initial raw material.

Keywords: iron ores, tunder, small pieces, fluidised bed

1. Introduction

The nowadays technologies of pig iron and steel making starting from coal and iron ores, subdued, before being introduced into the blast furnace, to some agglomeration and coking operations, using the furnace as the main elaboration aggregate. It is well known that in Romania the furnace departments are endowed with medium and big blast furnaces, having 1000…3500 m^3.

Because of the lower demand of pig iron into the internal consumption, a series of furnaces has been closed, and those which still run are forced to work very slowly, registering small productivities, big materials and energy consumptions, resulting implicitly big production costs for the elaborated cast.

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Because of the binding coal deficit and of the iron ores of a good metallurgical quality, the first fusion cast quantities necessary to the steel elaboration or to the cast pieces moulding are more and more difficult to ensure. Corroborated to the scrap iron deficit, this problem creates considerable difficulties to the steel producers. Thus, it imposes an alternative technology which allows the obtaining of the unconventional energo-technological resources from ferrous and coals wastes with small granulation which will be used as scrap iron substitute into the steel elaboration aggregates.

All over the world, the industrial implemented technologies allow the iron sponge obtaining from ball ore, reduced at Fe by a decelerator, usually gaseous (Hyl, Midrex, Wiberg, Purofer methods), from small ores reduced in fluidized bed by a gaseous decelerator (H_2, CO, H_2+CO) (Novalfer, Nu-Yron, H-Yron) or from balls ores and balls solid decelerator into circular furnaces (SLRN, Krupp - Renn). [2]

The pig iron is directly obtained from coal and ores as a result of some alternative technologies (Corex, Kavasaki, Midrex) which suppose investments costs heavily supported by the economic agents from Romania, even in the conditions of some eventual associations.

Those being the conditions, in a previous paper [2] we have proposed an unconventional technology that allows the iron sponge obtaining with a high metallization degree, and afterwards, by its melting, the pig iron obtaining directly from small iron ores and from small coal into a main aggregate as a rotary tube furnace type where the dispersor mass, the thermic agent and the heat exchanger are represented by metallic or ceramic granules heated beforehand at about 1300^0C into an aggregate which uses as an energetically fluid a re-circulated gas from its own process of fabrication.

It is necessary to mention that in Romania this technology is 100% original. So far there are no research units having such kind of preoccupations.

The proposed technology realizes with minimum technological and economical costs a very good scrap iron substitute, starting with the capitalization of some fine ferrous sub-products found as stored wastes.

In the present paper we intend to support the experimental results we have given in our previous paper [2] by a series of theoretical considerations and calculationsand also to give a more detailed technological description of the proposed technology.

2.Experimental

2.1. Some theoretical considerations

One considers a raw material, formed by: 76 % FeO, 17 % Fe_3O_4, 2 % Fe_2O_3 şi 5 % SiO_2 .

The content of Fe in the raw material will be: $76\frac{56}{56+16}+17\frac{3.56}{3.56+4.16}+2\frac{2.56}{2.56+3.16}$ = 59.1+12.3+1.4 = 72.8 % .

The oxygen extracted by a complete reduction is: $76\frac{16}{72}+17\frac{64}{232}+2\frac{48}{160}$ = 16.9+4.7+0.6 = 22.2 % (SiO_2 is not reduced).

The consumption of raw material is: $\frac{1}{0.728}$ = 1.374 t / t Fe, from which one extract 1.374 . 0.222 = 0.305 t O_2 / t Fe, theoretically refound, at 1050^{o}C, in 73.1 % CO and 26.9% CO_2 , and practically in 75 % CO and 25 % CO_2 . 1 m^3_n from this mixture contains 0.75 x 0.5 + 0.25 x 1.0 = 0.625 m^3_n O_2 / m^3_n = $0.625\frac{32}{22.414}$ = 0.8923 kg O_2/ m^3_n şi $\frac{12}{22.414}$ = 0.5354 kg C/ m^3_n. From reduction, it will result 305 /0.8923 = 342 m^3_n / t Fe and one consume 342 x 0.5354 =183.1 kgC / t Fe .

The heat ceded by the carbon refound in the gazeous mixture is: 0.25 x 8,140 + 0.75 x 2, 452 = 3,874 kcal / kg C = 0.7093 Gcal / t Fe .

The consumption of heat for the ore reduction is 0.76 x 1,150.5 + 0.17 x 1,583 + 0.02 x 1,758 = 1,178.7 kcal / kg Fe = 1.179 Gcal / t Fe. The carbon necessary to deoxidations has a energetic share of 183.1 x 8140 x 10^{-6} = 1.490 Gcal / t Fe. The surplus is equal to 1.490 – 1.179 = 0.311 Gcal / t Fe and it is consumed in the heat dissipations, in the drying of raw material (with 5 % water) and the coal drying (with 15 % water) and in the evacuation of the substances emerged with some sensible heat .

The burning of the reducing gaseous combustible fuel is made with 1.1 x 0.75 x 0.5 / 0.21 = 1.964 m^3_n air/ m^3_n mixture (with air excess of 10 %) and yields 1.000 (CO_2) + 0.79 x 1.964 (N_2) + 1.964 x 0.21 – 0.75 x 0.5 (O_2) = 2.589 m^3_n burning gas for any m^3_n gazeous mixture , with 38.6 % CO_2 , 59.9 % N_2 and 1.5 % O_2. In the focus-tubes, the gaseous mixture cedes 8,140- 3,874 = 4,266 kcal / kg C = 4,266 x 0.5354 kcal / m^3_n mixt. =2,283 kcal / m^3_n gas.mixt. (= 0.75 x 68,220 /22.414, as control) .

For the gaseous mixture (75% CO şi 25 % CO_2), at 1050^{0}C, C_p = 0.75 x 0.339 + 0.25 x 0.530 =0.387 kcal /m^3_nK, and at 950^{0}C, C_p = 0.75 x 0.336 + 0.25 x 0.522 = 0.382 .

The gas of complete burning , with 10% air excess , have C_p at 1,200^{0}C , which represents the temperature at the emergence from the focus-tubes , of 0.386 x 0.541 + 0.599 x 0.339 + 0.015 x 0.358 = 0.417 kcal/ m^3_nK , and at 150^{0}C (at the evacuation from exchangers), of 0.386 x 0.416 + 0.500 x 0.311+ 0.015 x 0.317 = 0.352 kcal/ m^3_nK.

In order to avoid the adhesion of the iron particles and faiallit between them, at 1050^0C= the temperature in the reactor in fluidised bed, one recirculates in reactor a mass of dust (silica, alumina, silicium carbide etc.), with a relatively high refractoriness and such that, associated with the sterile from the ore and with the coal ash, totalize about 50% massic şi 120% volumic in comparison with the iron .

2.2 . A short description of the proposed solution

The raw material and the coal, both at a granulation under 1...2 mm, are introduced in a reactor with fluidised bed, at a flow of gas formed at 600...$1,050^0$C, recirculated in the proportion required by bed; the energy necessary for the continuity of the endothermic processes of the deoxidation is assured by the focus-tubes, where the gaseous fuel, coming from the space of reduction, is burnt with air preheated at $1,000^0$C by the combustion gas collected from the focus-tubes .

The temperature in reactor is about 1050^0C, in the case of use of coal only and sensibly diminished if this is associated with the gaseous fuel; the reactor operates at a pressure up to 10 bars (limited by the pressure of the gaseous fuel). If the raw material is particularly FeO, scrap, considered under head 2.1, then one gets an excedent of gas, greater if less coal is used.

Due to the reduction of the iron ore in solid phase, the iron carburation is less than 0.8 %, much better than in the case of the liquid pig iron. In the case of iron ores having much sterile, the iron and sterile evacuation are made under the Curie point, thus allowing the sterile elimination bu magnetic separation. As advantages of the technology, one can mention: the possibility of iron ore reduction with inferior coal and waste coke, the consumption of fuel being smaller in comparison with the actual technologies, including the COREX procedure, diminishing the production of the „ gas export ”.

Another important point is that no technical oxygen is used, the oxygen from raw material being enough. Due to the intensification of the heat and mass transfer, the plants applying the technology will be compact and cheap.

In what follows, we present as an example, the main components of a plant which yields 3 t/h iron, from the raw material initially considered, under head 2.1.

The iron ore from a silo enters the plant, being mixed up with coal; the mixture enters a preheater, then a reactor, organized as fluidised bed, where it takes place the reduction of the oxydes from ore, with C, CO, H_2; in order to proceed the endothermic reactions, the heat consumption is recovered by burning gaseous fuel in the focus-tubes.

The reactor has a cylindrical construction, with a vertical axle, having the interior diameter about 3 m and the interior height of the fluidised bed of 1,7 m and that total of 3 m, with walls in refractory concrete, platied with corindonic plates for max. $1{,}300^0$C. The focus-tubes will have the diameter 120 mm, the length 2.4 m and the wall thickeness about 1 cm, being carried-out of vibrated tubular alumina. The ore heater is vertical and has as a shape of truncated cone, with 9 fluidised beds in series, with a total height of about 3 m and the inferior diameter 1.1 m and that superior 2.5 m ; the maximum interior pressure is 0.8 manometric bars at the inferior part, the construction of the heater being carried-out of usual materials for 900^0C. The deoxidated ore is evacuated by a hook-up and cooled .

The ore cooler is similar to the ore heater, having the pressure at the inferior part of 1.5 manometric bars and at the superior one of 0.8 man. bars, for max. $1{,}100^0$C.

The circulation of nitrogen (in fact air with the oxygen retained by a small share of carbon), with the flow of 4,200 $m^3{}_n$ / h, is assured by a compressor with a flow 1.7 m^3/ s which compress it at 1.6 bars , by consuming max. 100 kW.

The plant also includes a compressor which compress 0.8 m^3 /s gaseous compresses combustible mixture at max. 80^oC, from 3 to 3,5 manometric bars and is mounted in a metallic precinct, where a pressure of 3 bars is setting up; the consumed power is only 5 kW. There also is an air ventilator for 800 m^3 / h and 150 mm water spout (CA), trained by a motor of 1 kW; one also needs an exhaustor for the burning gas, for 1,300 m^3 /h at max. 2000C and 200 mm water spout, trained by a motor having an installed power of 3 kW (that consumed being of 1.2 kW).

The plant also includes two metallic silos, each 50 m^2, one for ore and another for coal, raised at about 14 m height .

The specific consumption of heat is about 1.55 Gcal/t Fe and it is recovered exclusively by the carbon from coal; one can also use small coke, coke dust or coke of oil with an acceptable content of sulphur. One can also use any liquid or gaseous fuel, replacing partially or even totally the coal, remarking that, on one hand, the temperature of reduction decreases and, on the other hand, the production of excedentary gaseous combustible increases.

In order to avoid any glueings of the particles of iron ore in evolution, we have above underlined some accurate measures and cautions.

The plant is higly ecological: indeed, the component CO circulates by airtight pipes only, the gas evacuated in atmosphere result after a complete results combustion, without CO, NO_x or dioxines (by an air excess 20 % and by burning at favourable temperatures).

The plant can be carried-out with materials of current use.

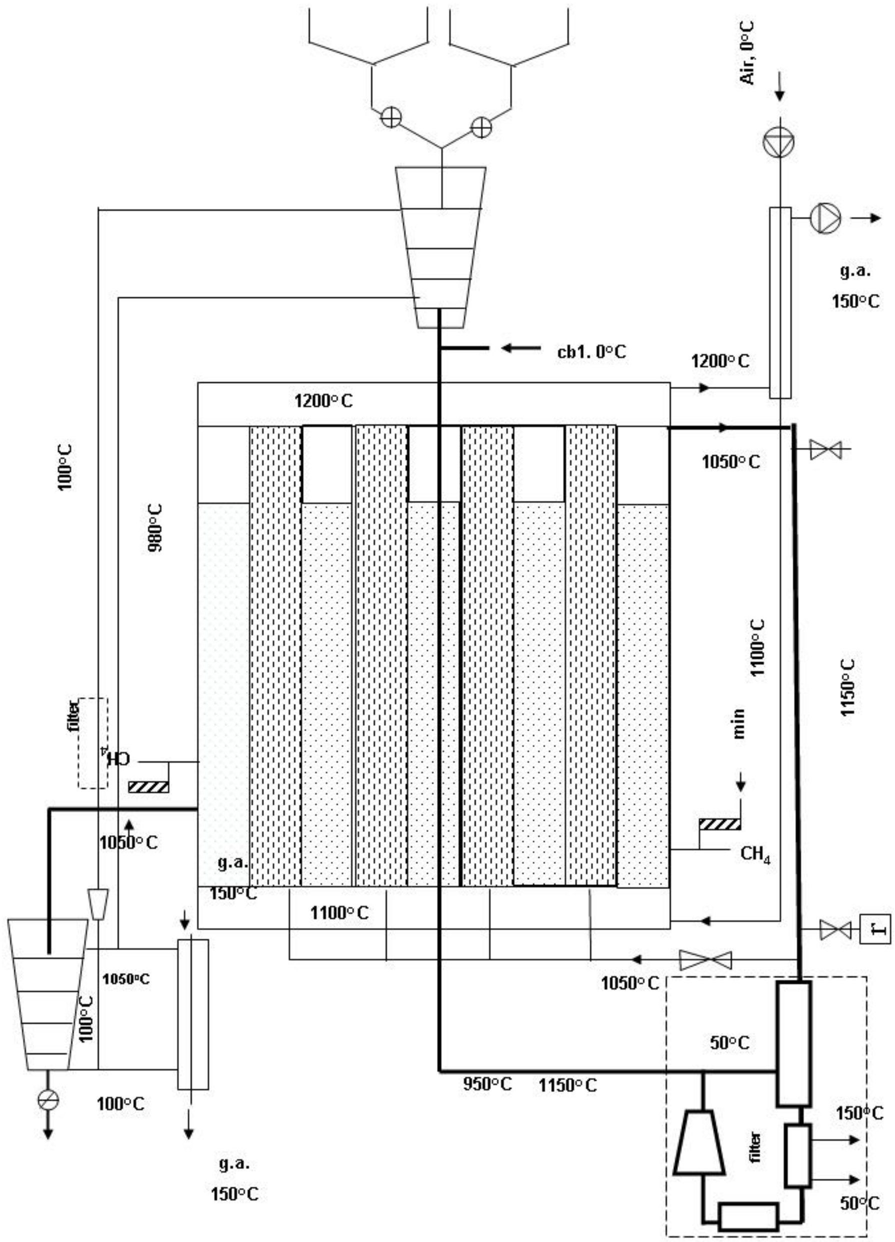

Fig.1. Technologycal scheme of a new dried solution with heated air.

3. Results

In order to simplify the thermic and mass balances, one considers that the dried raw material and the coal (only dried C) are introduced in the plant together with 500 kg sterile per any tone of iron. One admits that the drying of the iron ore and coal takes place in the reactor (water is benefic, by the dissociation and reassociation in reactor, with the catalytic effects of the transient H_2, which proceed from some water molecules and is refound in others; in fact, H_2 and H_2O spreads through the ore easier than CO and CO_2). The temperature of reduction descends towards 800^0C, with a metallization degree over 99 % and, by replacing the coal with liquid and/ or gaseous fuel ,which massively generates H_2 in reactor, the temperature could descend to 570^0C. But one encounters the disadvantage of producing some excedentary gaseous combustible, which cannot be available in the plant and must be exported.

In what follows, we present the thermic balance and the mass balance on the components of a plant which produces 1 t iron, under the above mentioned hypothesis (Table 1):

Table 1

Thermic balance and the mass balance

Component	kg	m^3_n	^oC	kcal
1. COOLER OF REDUCED ORE				
Inputs				
- Reduced ore=iron +sterile	1069	-	1050	199,796
- Ash + sterile	431	-	1050	126,714
- Nitrogen	-	965	100	30,012
			TOTAL	356,522
Outputs				
- Reduced ore	1,069	-	200	29,290
- Ash + sterile	431	-	200	17,240
- Nitrogen	-	965	950	304,361
- Dissipations				5,631
			TOTAL	356,522
2. PREHEATER OF THE COMBURENT AIR				
Inputs				
- Burning gases	-	569	1,200	284,728
- Air	-	672	0	0
			TOTAL	284,728
Outputs				
- Air	-	672	1,100	251,328
- Burning gases	-	569	150	30,043
- Dissipations				3,357
			TOTAL	284,728

3. PREHEATER OF NITROGEN WITH BURNING GASES

Inputs

- Burning gases	-	316	1,200	158,126
- Nitrogen	-	413	100	12,844

TOTAL 170,970

Outputs

- Burning gases	-	316	200	22,752
- Azot	-	413	1050	145,273
- Dissipations				2,945

TOTAL 170,970

4. PREHEATER OF ORE AND COAL

Inputs

- Nitrogen from 1	-	965	950	304,361
- Nitrogen from 3	-	413	1,050	145,273
- Ore	1,374	-	0	0
- Carbon	183.1	-	0	0
- Ash	150	-	0	
- Recirculated sterile	281	-	200	11,240

TOTAL 460,874

Outputs

- Nitrogen	-	1,378	100	42,856
- Iron ore	1,374	-	880	263,588
- Coal	183.1	-	880	53,172
- Ash + recirc.sterile	431	-	880	92,924
- Dissipations				8,334

TOTAL 460,874

5. THE PLANT OF REDUCTION (REACTOR)

Inputs

- Iron ore	1,374	-	880	263,588
- Coal – sensibile heat	183.1	-	880	53,172
- Coal- potential energy	(183.1)	-	880	1,490,434
- Ash + recirc.sterile	431	-	880	92,924
- Gas. mixt. –sensible heat	-	283	1050	113,511
- Gas. mixt. – potent.heat		(283)		646,089
- Preheated air	-	672	1,100	251,328

TOTAL 2.911,046

Outputs

- Heat for reduction	-			1,179,000
- Reduced ore	1,069	-	1,050	
		-		199,796
- Ash + sterile	431	-	1,050	
- Gas. mixt. – sensible	heat -	342	1050	126,714
-Gas. mixt. potent heat	-	342		137,176
- Supplem. cooling of the recirc. gas. mixture	-	700		780,786
- Burning gases	-	885	1,200	23,450
- Dissipations				21,270
		TOTAL		2.911,046

4. Discussion

The nitrogen from the system of ore heating- cooling is formed in some minutes after the air introduction, which loses the oxygen retained by a part of the carbon from the heater of ore and coal .

The carbon imposed by deoxidations brings more heat than the plant consumes and this implies the production of that excedentary gaseous combustible (59 % m^3_n / t Fe = 0.16 Gcal / t Fe, hence over 10 % of the coal contribution), however about 10 times less than the COREX technology. One also mentions that the final iron will contain only 0.5 % = 5 kg C / t Fe, due to the ore reduction in solid phase (in liquid phase this content would be at least 4 %) .

From the above balances, it follows that the specific consumption of carbon is 183.1 kg/t Fe, imposed by the deoxidations, but including the production of the excedentary gaseous combustible; adding the carburation of the final iron, all lead to a specific consumption of 1.52 Gcal / t Fe = 6.36 GJ / t Fe. The above mentioned excedent is less than 60 m^3_n / t Fe .

The total energy entered the plant is

$E = 183.1 \times 8140$ kcal = 1,490,434 kcal $\approx$ 6,240 MJ .

The dissipations of all 5 components included in the above balances cumulate: δ = 5,631 + 3,357 + 2,945 + 8,334 + 21,270 = 41,537 kcal $\approx$ 174 MJ (representing about 3% of E) .

Other losses are, according to the above balances the following: the supplementary cooling (from the component 5 – the reactor): 23,450 kcal; the burning gas (from 2): 30,043; the burning gas (from 3): 22,752 kcal; the ash+ sterile from 1 : 17,240 kcal; the reduced ore (= iron + sterile from 1): 29,290 kcal and finally, the excedent of sensible heat (from 5): 137,176 – 113,511 = 23,665 kcal. All these totalize:

λ = 146,440 kcal ≈ 613 MJ (representing about 10 % of E) .

The energetic efficiency of the plant is

$1 - (\delta + \lambda) / E = 1 - (174 + 613) / 6{,}240 \approx 0.874 = 87.4\ \%$

This is superior to many similar technologies. Moreover, the above presented technology could be improved in many points: the useful cooling of the excedentary gaseous combustible (for instance, to heat the raw material and the coal), the valorification of this excedent, the use of the sensible heat to produce hot water.

5. Conclusions

The implementation at the industrial level of the unconventional technology proposed by the present research paper, offers new and profitable adaptation possibilities without high costs of the Romanian metallurgy to the international economic situation imperatives.

From the multiple offered advantages the following are worth to be mentioned:

-the reduction of the un-oxidization processes lasting from at least 20 hours to 0,5 hours;
-the direct utilization of the ore powder, eliminating the granulation;
-the capitalization of the pyritic ashes and the dusty ores;
-the capitalization of the waste chalk obtaining an acceptable quality lime and a carbon dioxide of high purity having multiple utilizations;
-the cheapness under 70% of the obtained iron, provided in granules;
-the utilization of the non-binding coal instead of the coke;
-there is no necessary another type of energy;
-the charge preparation is not so expensive as in blast-furnaces case;
-small units of production permit the easy adaptation at diverse requests.

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