FUEL AND ENERGY CONSUMPTION DECREASE IN ORDER TO PRODUCE PIG-IRON FOR STEELMAKING USING INJECTION REDUCING GAS IN THE BLAST FURNACE

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Abstract

Steel industry consumes a great amount of energy and much of it is consumed in the blast furnace. Increasing the amount of pig-iron produced in blast furnaces led to the mining metallurgical sector increasing efforts to cover ore and coke needs.

In terms of obtaining the pig iron of iron ore and metallurgical coke, through traditional flow, there are high costs of the finished product (pig-iron for steelmaking or iron foundry) due in particular to raw material and energy costs. Solid fuel used in blast furnace, coke, is not only poor but also very expensive, its unit cost equalizing the cost of the pig iron.

The fundamental objective of this paper is to establish further economic and technical analysis supporting the limits of rational use of injection reducing gas in the tank furnace in order to obtain improved furnace operating parameters values, to reduce material and energy consumption and to grow the productivity.

Keywords: pig-iron for steelmaking, reducing gas, blast furnace, specific consumption of metallurgical coke

1. Introduction

In terms of obtaining the pig iron of iron ore and metallurgical coke, through traditional flow, there are high costs of the finished product (pig-iron for steelmaking or iron foundry) due in particular to raw material and energy costs. Solid fuel used in blast furnace, coke, is not only poor but also very expensive, its unit cost equalizing the cost of the pig iron.

Current technology for obtaining pig-iron from ore and coke is strongly competes with conventional melting technologies reducing (Corex, Kawasaki, CBF, Mildrex, etc.) main advantage of these new technologies is that it eliminates the traditional flow chemical coke fully and partially the agglomeration of the ore.

Since the furnace unit is still providing over 85% of raw pig-iron, research in this field aim at reducing energy and material consumption. Great opportunities for reduction of all specific consumption and therefore manufacturing costs are provided by using the blast furnace of unconventional energy resources and materials (unconventional coke and ore pellets mixed crowded, auxiliary fuel, reducing gases unconventional thermal sources, etc.).

Currently there are known significant achievements in the field studied, all but belonging to companies in Germany, Japan, USA, and Russia. Remarkable results are communicated in terms of frequent use of modern techniques have led to continuous decrease of consumption in blast furnaces.

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2. Blowing reducing gas in the tank furnace

Blowing gas in the furnace with high levels of carbon monoxide and hydrogen is one of the newest methods to reduce specific consumption of coke and blast furnace productivity. In connection with this method are a few of the experimental results carried out either at pilot scale, or industrial scale, partly confirming the results of theoretical calculations performed.

Thus, the plants Japan-Hirohata used for blowing reducing gas in tank consisting mainly of hydrogen and carbon monoxide produced by splitting off furnace fuel oil, in a reactor, where Texaco process, it is characterized by partial oxidation of heavy oil with a mixture of oxygen and water vapor. The gas produced by this process becomes an optimum composition, i.e. high content of hydrogen and carbon monoxide and water vapor content and minimum carbon dioxide and carbon through dissociation to 1600^0C.

Since the dissociation be inspired gas in the tank at a temperature of 1200^0C, they require cooling to 400^0C, thereby safeguarding the possibility of using available heat recovery boilers. This method allows obtaining a replacement ratio 1[kgcoke/kgfuel]. The plant Azovstali experiments were performed on reducing gas use a furnace preheated to 1300 m^3 by instilling them with the help of gas holes in the same vertical plane with the mouth of the wind, but at a higher level of 600 mm and under 30^0 angles to the horizontal.

These gases were obtained by means of steam catalytic conversion of methane gas, using three transducers, heaters working in regenerative catalytic cycle of nickel. As shown by experimental phase of operation of the plant conversion, this method has some critical shortcomings and cannot be recommended for application to the furnace on an industrial scale.

Experimental batches performed of the blast furnaces confirmed, but the prospect for the insufflations preheated reducing gas and the urgent need to develop more effective methods to achieve them. In some subsequent experiments, preheated reducing gas was introduced into the crucible furnace with a complex plant blast holes with separate channels for gas and air, but associated with a single cooler.

The main deficiencies of this plant proved to be too much weight and clearances of complex holes and some design flaws related to the length of the gas nozzle. Settling a reference period of the methane gas blast, and of instilling a combined natural gas and reductant, could appreciate that while methane gas has been completely replaced with a reducing gas, furnace productivity increased by 9,2% and specific coke consumption decreased by 2,6%, and compared the combined use of methane gas and reducing the productivity increased by 0,4% while the specific coke consumption decreased by 3,5%. Tests of experimental furnace at L'Airba showed that the combined injection of gas and fuel oil conversion etalaj holes wind through the main additive effects.

This technique allowed reducing coke consumption of 275 [kg / t pig-iron] but attempts were allowed to answer questions relating to increasing the penetration of gas production and conversion into a large furnace size. At the same time as many indices can achieve an increase in furnace productivity.

Economic conclusions show that an index replacement 0, 25 [kgcoke /m^3gas], the maximum that can be removed in an industrial furnace may already have advantages. It may provide a not too distant future, getting very low coke consumption. All new squeeze coke consumption can be achieved only by replacing the fuel with others that will be less expensive and available in greater quantity. Should always consider the relative prices of different types of energy prices that can change unpredictably over time. It is therefore necessary to know that there are other technical possibilities and economic examination of the results that they can result in conditions of the moment.

Injection at the bottom of the tank of a hot gas conversion, containing about 90% hydrogen plus carbon monoxide, should enable reductions shown very strong growth. Best place for this injection will be the recovery area where the temperature does not allow carbon to react on Bell-Boudoard reaction.

If such reduction is reached, virtually all iron oxides in solid-Boudoard this reaction is completely suppressed Bell inside the furnace. It thus saves a large amount of carbon reduction and thermal needs of the work area at which the endothermic reactions are strongly reduced.

Allow calculations to be made gains achievable due to the injection of gas coke reductant in the cell. Can be said that the among various possible techniques, combined injections of reducing gas and fuel oil in the etalaj mouth. Wind is a very interesting opportunity to further reduce consumption of coke in the blast furnace. This has been clearly demonstrated. Economic calculations show that the process can be perfectly profitable in many circumstances, there remains only to prove the validity of test results for transposition of the industrial furnace.

Plan to inject hot gas conversion, is situated at 3,6 m height etalaj's i.e. above the mouth of the wind. Injection is done through the mouths of selling, which have cooling circuits, these holes are selling in equal numbers with mouths and blowers are powered by an annular pipe.

The distance between the furnace overheated and allows placing a pipeline isolation valves, valve instead of hot air. Conversion gas penetration inside the furnace is good and it depends on the amount of gas injected.

It is a known method of obtaining a reducing gas from methane converted to CO_2 and H_2O, the reducing gas with low content of CO_2 and H_2O.

It was calculated the effect it will have on the operation of the furnace, blowing gas tank on the basis of reducing methane gas produced by conversion of recycled blast furnace gas.

Figure 1 shows schematically the chemical composition of the gas balance for furnace operation under these conditions, the gas burners to a temperature of 1000^{0}C.

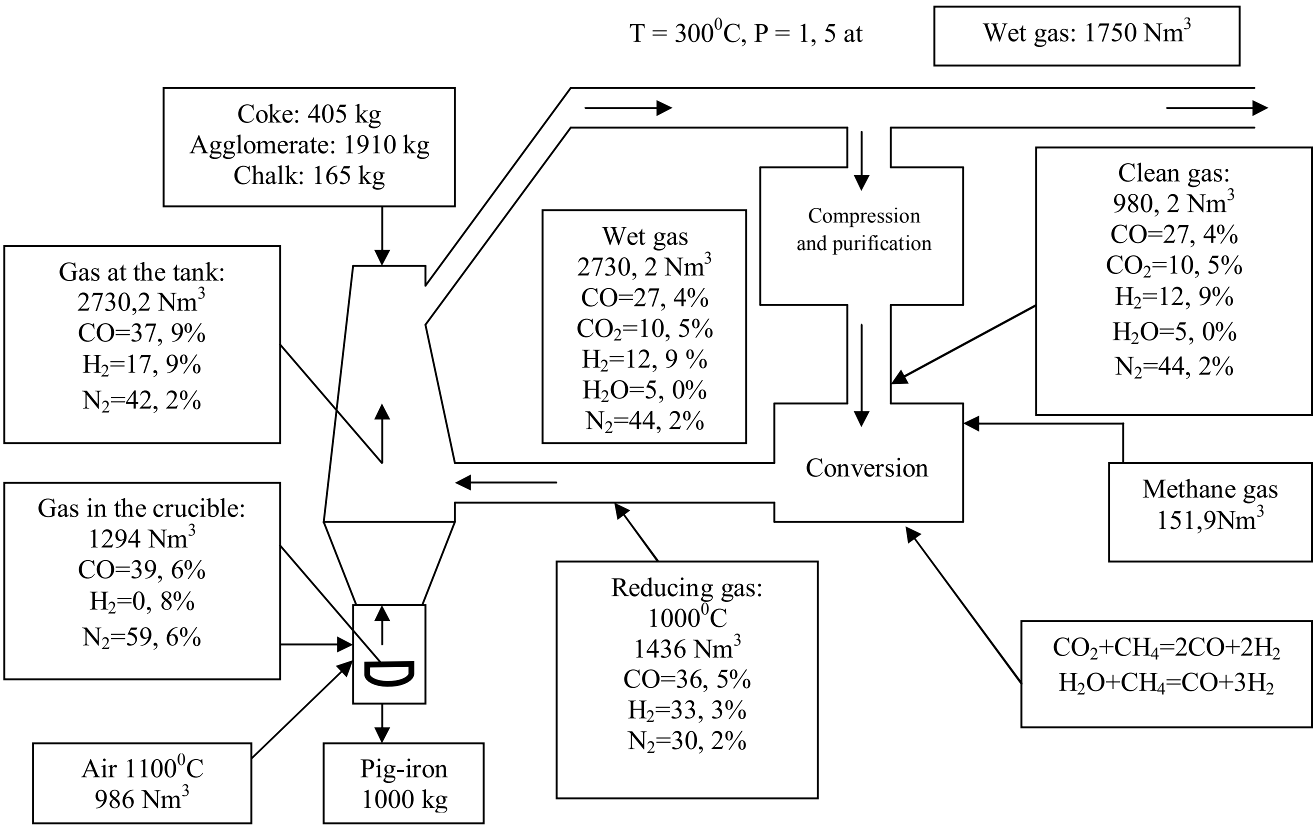

Figure.1. The blast furnace material balance when using reducing gas in the tank furnace

Comparing the results of calculations with those obtained from normal operation of a furnace (using methane blast of wind through the mouth) that is obtained a saving of coke about 100 [kg/t pig-iron], and increase furnace productivity by 10%. The process was studied in an experimental facility consisting of a furnace equipped with loading mechanisms, two air cowpers, two catalytic converters for the regeneration of recycled methane gas insufflations and related facilities for air, gas purification and recirculation and instrumentation and control.

In most blast from the tank furnace, blast furnace gas recirculated and regenerated so the oxidation of gas (CO_2 + H_2O) / (CO + H_2O + CO_2 + H_2) = 9% and assuming a degree of use (CO + H_2) wüstit's at 25%, calculations show:

- Replacement ratio of coke with a reducing gas (including nitrogen), instilled in the tank is about 0,084 [kg coke / Nm^3], or about 0,140 [kg coke/Nm^3] (CO + CO_2 + H_2O + H_2);
- Replacement ratio of coke used in the regeneration of a natural gas furnace gas from 0,7 to 0,75 [kg coke/Nm^3CH_4], compared to about 0, 57 [kgcoke/Nm^3CH_4], that would instill only converted

to methane and water vapor with the same degree of oxidation.

3. Average indicators for reducing gas furnace operation.

A. Indicators that characterize production were calculated and are as follows:

A.1. the average daily expressed in [t pig-iron/calendar days]; P_c = 345,787 [t pig-iron / calendar days]

A.2. the average daily expressed in [t pig-iron/actual days]; P_{ef} = 348,417 [t pig-iron/actual days]

A.3. the average hourly rate expressed in [t pig-iron/ h]; P_h = 14,517 [t pig-iron/ h]

A.4. Index of use of the furnace [t pig-iron/m^3 actual days]; $I_u = P_{ef} /Vu$ = 348,417/250 = 1, 4 [t pig-iron/m^3 actual days].

B. Operating intensity:

B.1. Technical coke combustion intensity $I_a = K_tP/VuNef$ [t_{coke}/m^3 actual days],

Where P - total production of pig iron, P = 10719, 4 [t pig-iron/31 days]

Nef - number of days actually working, Nef = 30,766

I_a = 575, 2 * 10719, 4 / (250 * 30,766) = 801,638 [kg/m^3 actual days] = 0, 8017 [t/ m^3 actual days]

B.2. Equivalent intensity of coke combustion $I_{k, CH4}$ = 1

$K_e = K_t + I_{k, CH4} * Q_{CH4}$ = 575, 2 + 80, 3 = 655, 5 [kg coke ec.]

$I_a = K_e * P / (Vu * Nef)$ [t coke ec. /m^3 actual days]

I_a = 655, 5 * 10719, 4 / (250 * 30,766) = 913, 55 [kg coke ec. /m^3 actual days]

I_a = 0.91355 [t coke ec. /m^3 actual days]

C. Charging:

Charging remains largely the same as the functioning without reducing gas. It will change the specific fuel consumption and charging unit.

C.1. Net charge (M), M = 2089,615 [kg]

C.2. the removal of iron (s), s = 1/M * 100 = 1 / 2, 089 615 * 100 = 47.86%

C.3. Setting the boot drive

- Charging scheme used: KM

- Net volume of skip: Vu = 4, 5 [m^3]

It is considered that is used an skips for coke with γ_k = 500 [kg/m^3] (for technological coke)

- Weight skip with technological coke, G_{kthl} = 405 * 500 = 2250 [kg / UI]

- Technological coke consumed per ton pig-iron:

1) $K_{thl} = 100K_t/100-w$

2) K_{thl} = 575, 2*100/ (100 - 6.059) = 612, 3 [Kg /t pig-iron]

- The amount of iron obtained from a charging unit: G_{kthl} / K_{thl} = 2250/612, 3 = 3,68 [t pig-iron / UI]

- The amount of pig-iron and ore loading unit. For calculating used the specific consumption:

- Krivoi Rog Ore G_{MK-R} = 459, 83 * 3, 68 = 1692, 18 [kg / UI]

- Indian ore gross G_{MIb} = 529, 134 * 3.68 = 1947, 22 [kg / UI]

- Indian ore screening G_{MIc} = 23, 8 * 3, 68 = 87, 584 [kg / UI]

-Krivoi Rog pellets Gp = 322, 695 * 3, 68 = 1187, 52 [kg / UI]

- Iacobeni ore G_{MI} = 19, 665 * 3, 68 = 72, 37 [kg / UI]

-Indian ore sorting G_{MIs} = 260, 22 * 3, 68 = 957, 61 [kg / UI]

- Iron ore G_{MT} = 30, 04 * 3, 68 = 110, 55 [kg / UI]

- Agglomerate G_{AH} = 98, 466 * 3, 68 = 362, 36 [kg / UI]

- Pig-iron waste G_D = 16, 92 * 3, 68 = 62, 27 [kg / UI]

- Fluff G_S = 19, 425 * 3, 68 = 71, 49 [kg / UI]

- Chalk Gc = 309, 42 * 3, 68 = 1138, 67 [kg / UI]

- Technological coke G_{kthl} = 612, 3 * 3, 68 = 2250 [kg / UI]

- Total charging (ore + coke + chalk) Mtot = 9939, 824 [kg / UI]

Volume occupied by the material of the load:

- Krivoi Rog ore $V_{Mk-R} = G_{MK-R} / \gamma_{Mk-R}$ = 1, 69218 / 2, 0 = 0, 847 [m^3]

- Indian ore gross $V_{MIb} = G_{Mib} / \gamma_{Mib}$ = 1, 94722 / 2, 5 = 0, 779 [m^3]

- Indian ore screening $V_{Mic} = G_{Mic} / \gamma_{Mic}$ = 0, 087584 / 2, 5 = 0, 036 [m^3]

- Krivoi Rog pellets $V_{PK-R} = G_{Pk-R}/\gamma_{Pk-R}$ = 1, 18752 / 2, 5 = 0, 476 [m^3]

- Iacobeni ore $V_{MI} = G_{MI} / \gamma_{MI}$ = 0, 07237/ 1, 85 = 0, 04 [m^3]

- Indian ore sorting $V_{Mis} = G_{MIs} / \gamma_{MIs}$ = 0, 95761 / 2, 5 = 0, 384 [m^3]

- Iron ore $V_{MT} = G_{MT} / \gamma_{MT}$ = 0, 11055 / 1, 85 = 0, 06 [m^3]

- Agglomerate $V_{AH} = G_{AH} / \gamma_{AH}$ = 0, 36236 / 1, 85 = 0, 196 [m^3]

- Pig-iron waste $V_D = G_D / \gamma_D$ = 0, 06227 / 4 = 0, 016 [m^3]

- Fluff $V_S = G_S / \gamma_S$ = 0, 07149 / 5 = 0, 015 [m^3]

- Chalk $V_C = G_C / \gamma_C$ = 1, 13867 / 1, 6 = 0, 712 [m^3]

- Technological coke Vkthl = G_{kthl} / γ_{kthl} = 2, 250 / 0, 5 = 4, 5 [m^3]

Total volume = 8, 061 [m^3]

It follows that the charging scheme remains the same: KM

C.4. Specific consumptions of technical coke.

- Specific consumption of technical coke K_t = 575, 2 [kg / t pig-iron]

- Specific consumption of technology coke Kthl = 100K_t / (100-w) = 612 [kg / t pig-iron]

- Specific consumption of supply coke

K_S = Kthl + powder; K_S = 643, 09 [kg / t pig-iron]

- Specific consumption of natural gas Q_{CH4} = 80, 3 [Nm^3/t pig-iron]

- Specific consumption of reducing gas $Q_{G.R.}$ = 558, 055 [Nm^3/t pig-iron]

C.5. Percentage of agglomerate and pellets:

- Total consumption of ferrous raw materials: 1780, 195 [kg / t pig-iron]…100%

- Specific consumption of agglomerate: 98, 466 [kg / t pig-iron] ... 5, 53%

- Specific consumption of pellets: 322, 695 [kg / t pig-iron] ... 18, 127%

- Specific consumption of ore…76, 343%

D. Operating Parameters

- Blast furnace gas flow [Nm^3/t pig-iron] Q_{gas} = 3059, 04 [Nm^3/t pig-iron]

- Air flow calculated [Nm^3/t pig-iron]:

- Air humidity: Q_{ah} = 1802, 27 [Nm^3/t pig-iron]

- Dry air: Q_{da} = 1784, 27 [Nm^3/t pig-iron]

- Calculate air flow [Nm^3/h] Q_{af} =1802, 27 [Nm^3/t pig-iron] *14, 517 [t pig-iron /h] = 26164 [Nm3 / h]

- Air flow [Nm^3/m^3 useful volume and minutes] Q_a= 26164 / 69,250 = 377, 81

- Hot air temperature: ta = 1064,5^0 C

- Insufflations temperature for the reducing gas: t_{GR} = 1000^{0}C

- Blowing air pressure: Pa = 689,7 [mmHg]

- Gas flow [Nm^3/h] Q_{CH4} = 80, 3 [Nm^3/t pig-iron] * 14, 517 [t pig-iron / h] = 1166 [Nm^3 / h]

- Characteristics of slag and pig-iron remain unchanged

- Characteristics of blast furnace gas:

- The quantity of blast furnace gas [Nm^3/h] Q_{bf}= 3059.04 [Nm^3/t pig-iron] * 14, 517 [t pig-iron/ h] = 44408 [Nm^3 / h]

- Blast furnace gas temperature: tg = 350^{0}C

- Blast furnace gas composition (% volume) CO = 25, 128%, CO_2 = 14, 193%, CH_4 = 0, 587%, H_2 =7, 561%, N_2 = 52, 531%

E. Balance data

E.1. Passing manganese in pig-iron (%) [Mn] / $\langle Mn \rangle_{all}$ = (7, 2 / 10, 424) * 100 = 65, 08%

E.2. Index distribution of sulfur

$L_{S\ (nec)}$ = 29, 8

L_S = (S) / [S] = 1, 135 / 0, 03 = 37, 8

E.3. Yield carbon monoxide η_{CO}= $CO_{2R.i.}$ * 100 / ($CO_{2R.i.}$ + CO_f)

Where: CO_f = COg.f. - COm.v. [Nm^3] = 768, 65-2, 4 = 766, 25 [Nm^3]

η_{CO} = 360.58*100/ (360.58+766.25) ≈32%

E.4. Hydrogen yield

ηH2 = $H_{2R.i.}$*100/$H_{2\ all}$ =7, 337*100/29, 35 = 25%

E.5. Total heat consumption

Q_h= 3272, 335 * 10^3 [Kcal / t pig-iron]

E.6. The difference in balance: 248, 523 * 10^3 [Kcal / t pig-iron] = 7, 586 [%]

E.7. Thermal yield of the blast furnace

η_t = Qu * 100 / Qintr, [%]

Qu = 2554, 066 * 10^3 [Kcal / t pi-iron]

η_t = 2554, 066 * 10^3 * 100 /3272, 335 *10^3 = 78%

E.8. Carbon yield of the blast furnace

For this case (insufflations reducing gases) not calculated.

4. Economic conclusions

Reducing gases were obtained from the process of catalytic conversion of methane gas with carbon dioxide and water vapor from the recirculated gas furnace. For economic calculation was considered that the daily average production volume index remain unchanged even though the furnace may require an increase in production due to lower average daily volume of gas from the crucible.

Following the theoretical calculation of the furnace number 1 – IV Călan reached the following conclusions:

Burning intensity decreases for both technical and coke equivalent of reducing coke consumption by reducing the gas blowing the tank. He obtained a reduction of coke per ton of iron rather high 81,72 [kg / t pig-iron] leading to a decrease in the cost per ton of pig-iron. With the decrease of coke consumption has decreased and the flow of air blown and thus the amount of gas in the crucible. Blast furnace gas flow but significantly increased due to the reducing gas and also insufflations increased the percentage of carbon dioxide gas, which shows a better use in the furnace. A very low percentage of hydrogen and methane which makes blast furnace gas is a combustible gas produced with relatively high calorific value 1010 [kcal/Nm^3].

In addition to reducing the consumption of coke, to produce a combustible gas that can be used for different purposes. With the decrease of coke consumption per ton of iron decreases and the consumption of gas, so that the ratio $Qcoke/Q_{CH4}$ to remain stable.

Furnace gas temperature at the neck will have a slight increase, reaching 350-400^{0}C due to the introduction of reducing gas tank in addition to a significant amount of heat (t_{GR} = 1000^{0}C).

Reducing gas heat has led to an overall increase in the total quantity of heat in the gap and thus the balance of 6,489% to 7,586%. Yield carbon monoxide and hydrogen yield increased significantly, which shows a better use of gas in blast furnace operation to cases without reducing gas insufflations.

But the furnace thermal efficiency decreases from 82,781% to 78,05% due to the large amount of gas furnace and high temperature as it is, and balances due to the temperature difference higher reducing gas furnace operation.

Despite these small drawbacks, the use of blast furnace gas is reducing cost and price conditions existing in the economy per ton of iron is 34,819 RON / t pig-iron. Only what is consumed in reducing methane gas production.

The process of instilling in the reducing gas tank, obtained by converting natural gas furnace gas furnace recirculated, allowing better use of blast furnace gas. In relative terms, 58,717% of the total gas furnace is used and only the remainders are sent to other customers.

As a general conclusion, that the operation of blast furnace gas in the tank is a reducing process for the future and fails to replace a significant amount of coke, fuel that is becoming increasingly expensive, with minimum expenses.

5. References:

1. Nicolae CONSTANTIN, Cristian DOBRESCU, Raluca PETRACHE, Miron BUZDUGA "Mathematical model on the correlation of the combustion`s zone parameters in case of using different auxiliary combustibles" Metalurgia International , Nr.4/2008, pag.7-11, ISSN 1582-2214, indexata ISI , ISI Web of Science [Science Citation Index Expanded]

2. Nicolae CONSTANTIN "Ingineria producerii fontei în furnal" Editura Printech Bucureşti 2002, 298 pagini, ISBN-973-652-672-0

3. Nicolae CONSTANTIN "Procedee neconvenționale de obținere a materialelor feroase" Editura Printech Bucureşti 2002, 161 pagini, ISBN-973-652-682-8

4. Nicolae CONSTANTIN "Tratat de stiinta si Ingineria Materialelor vol 2 "Bazele teoretice si ingineria obtinerii materialelor metalice" Editura AGIR 2007, cap 5, pag.642-757, ISBN 978-973-720-064-0, ISBN-978-973-720-162-1