The authors have already carried out investigations into the kinetics and thermodynamics of the reduction-decarburization of an atomized cast iron powder by process 1 (self-reduction) followed by process 2 (reduction in a hydrogen stream) [1], and also by process 3 (simultaneous self-reduction and reduction by hydrogen) [2].

In this article the results are presented of an investigation into the reduction-decarburization-carburization of an air-atomized cast iron powder during a process in which simultaneous self-reduction (by the carbon present in the material of particles being annealed) and reduction by a converted gas (by the \( \text{H}_2 \), \( \text{CO} \), and \( \text{CH}_4 \) in the gas stream) were followed by the carburization of the resultant product (by the \( \text{CO} \) and \( \text{CH}_4 \) in the converted gas). The characteristics of the starting atomized cast iron powder were similar to those of the powder described in [1], and the \( \text{O}/\text{C} \) ratio was equal to 1.95. The laboratory apparatus and experimental procedure employed were the same as in [1, 2], but in all the phases of each experiment (scavenging, annealing, and cooling) a converted gas (\( 72.6 \% \text{H}_2, 0.1 \% \text{H}_2\text{O}, 24.4 \% \text{CO}, 3.0 \% \text{CO}_2, 1.5 \% \text{CH}_4 \), and \( 1.4 \% \text{N}_2 \)) was supplied to the reactor at a constant rate of 0.83 \( \text{dm}^3/\text{min} \).

The two series of experiments carried out differed in their temperature and time parameters: In processes 4 and 5 annealing consisted in heating to 1000 and 1100\(^\circ\text{C} \), respectively, which was followed by holding at those temperatures (Table 1). After being annealed and cooled to room temperature, the metal sponge in each experiment was ground to powder, which was then blended and analyzed for oxygen and total carbon (Table 1). Data on the compositions and weights of the starting powder and of the annealed material (after each temperature and time stage) as well as on the composition and amount of converted gas supplied to the reactor were employed for calculating amounts of gram-atoms of oxygen (\( \delta \text{O} \)) and carbon (\( \delta \text{C} \)) received by the gas from the powder (+) or delivered to it (−) (Table 1) as well as atomic fractions of oxygen \( \text{AO} \), carbon \( \text{AC} \), hydrogen \( \text{AH} \), and nitrogen \( \text{AN} \) averaged over the gas phase of each stage.

To assess the reducing and decarburizing (carburizing) powers of the gas phase averaged between the limits of each stage of the combined process of self-reduction and reduction by the converted gas (processes 4 and 5), a thermodynamic analysis was made, by a method similar to that described in [1], of stage-by-stage averaged gas phases at \( P = 980.7 \text{ GPa} \) and the mean temperature \( T_m \) of each stage. The results of the calculations carried out are presented in Table 1 and Figs. 1 and 2. From Fig. 2 it can be seen that, as in hydrogen annealing by process 3 with the same temperature curve \( T \) [2], the maxima of the reduction \( \nu_\text{O} \) and decarburization \( \nu_\text{C} \) rates in process 4 were identical within the limits of stage 2 but slightly smaller than those in process 3. While supply of hydrogen or the converted gas to the reaction space shifted the \( \nu_\text{O} \) and \( \nu_\text{C} \) maxima to the earlier, compared with self-reduction [1], stage 2, accelerated heating and the higher, compared with process 4, temperature of the corresponding stages of annealing in the converted gas by process 5 shifted these maxima to the still earlier stage 1.

The main self-reduction reactions, as is shown in [1], were

\[
\begin{align}
|\text{C}| + \text{FeO} &= \text{Fe} + \text{CO}; \\
|\text{C}| + 2\text{FeO} &= 2\text{Fe} + \text{CO}_2; \\
\text{Fe}_3\text{C} + \text{FeO} &= 4\text{Fe} + \text{CO}; \\
\text{Fe}_3\text{C} + 2\text{FeO} &= 5\text{Fe} + \text{CO}_2,
\end{align}
\]
TABLE 1. Materials Balance Sheet of Reduction-Decarburization-Carburization Stages and Thermodynamic Characteristics Averaged between Limits of Each Stage of Annealing by Processes 4 and 5

<table>
<thead>
<tr>
<th>τ, min</th>
<th>T, °C</th>
<th>Comp. of annealed material, %</th>
<th>Process 4</th>
<th>Process 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>20</td>
<td>6,62 3,40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>910</td>
<td>5,00 2,46</td>
<td>1 465</td>
<td>1 498</td>
</tr>
</tbody>
</table>
| 10     | 945   | 2,69 0,90                      | 2 928 0,2933 0,1266 0,1407 0,3955 0,2366 1,0013
| 15     | 960   | 1,40 0,12                      | 3 953 0,1558 0,0907 0,0756 0,2758 0,1488 1,0007
| 20     | 975   | 0,75 0,02                      | 4 968 0,03489 0,0076 0,0372 0,1819 0,0604 1,0002
| 25     | 990   | 0,41 0,085                     | 5 993 0,03996 0,0011 0,0193 0,1666 0,0685 1,0002
| 30     | 1000  | 0,23 0,075                     | 6 995 0,05273 0,0038 0,0102 0,1643 0,0655 1,0003
| 35     | 1000  | 0,21 0,10                      | 7 1000 0,1440 0,0019 0,0011 0,1670 0,0683 1,0008
| 40     | 1000  | 0,20 0,12                      | 8 1000 0,1858 0,0015 0,0006 0,1686 0,0696 1,0011
| 45     | 1000  | 0,14 0,20                      | 9 1000 0,1933 0,0060 0,0034 0,8064 0,3347 1,0011
| 50     | 1000  | 0,13 0,20                      | 10 1000 0,2950 0 0,0006 0,4926 0,2060 1,0018
| 55     | 1000  | 0,12 0,20                      | 11 1000 0,3018 0 0,0006 0,6582 0,2752 1,0018
| 60     | 1000  | 0,11 0,20                      | 12 1000 0,3021 0 0,0006 0,6581 0,2752 1,0018

Notes: τ and T are, respectively, the time and temperature at the limit of a stage; Tm, mean temperature in a stage; [C]_p, carbon potential of the gas phase; δC, decarburizing (+) or carburizing (−) power of the oxygen contained in the powder and of the converted gas; δO, realized reducing power of the carbon contained in the powder and of the converted gas; δO' = δO, and δO'' + δO, thermodynamic reducing powers of the carbon contained in the powder and of the gas phase relative to the oxides FeO and FeO2, respectively; and W = W', coefficient of increase in the amount of moles of gas after it has attained equilibrium with the oxide phase.

where |C| is the carbon dissolved in the austenite and which diffused from the nucleus of a particle to the austenite/FeO boundary.

Reactions (3) and (4) occurred in the initial phase of the process, when contact between the Fe3C inclusions and the inner FeO scale layers on the particle surfaces was still possible. The gaseous self-reduction