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Productivity Increment of Coal based Sponge Iron Plant using Simulation

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Abstract

Objective: A typical coal based sponge iron plant is investigated to utilized waste heat to preheat the feed coal and air as well as increase the productivity of sponge iron by applying heat integration using simulation process. **Methods**: In the present work, utilized waste heat to preheat the feed coal and air, heat integration process using modified pinch approach is applied and to increase the productivity simulation process is applied by taking quantity of feed materials is same as 500 t/d conventional coal based sponge iron plant. **Findings**: Some of the cases from literature based on pinch technology are taken and simulation process is applied. Three cases are generated in which productivity of sponge iron is increased but quantity of feed materials is same as conventional plant. In Case-1, feed to kiln and injected coal is preheated by waste gas from ESP and ABC thus coal consumption reduced to 17.9 t/h but the productivity is same as conventional coal based sponge iron plant i.e., 20.83 t/h. By applying present simulation process, productivity can increased to 21.84 t/h. In Case-2, waste gas from ESP at 220°C used to preheat air. In this modification, coal consumption is reduced to 19.325 t/h similarly by applying present simulation process; productivity can increase to 21.31 t/h. In Case-3, design modification using heat integration in which coal consumption is reduced to 14.892 t/h by preheat air using waste heat from ABC at 850°C. Likewise by applying present simulation process, productivity can increased to 22.7 t/h. **Improvements:** In Case 1, 2 and 3 by applying heat integration process, the consumption of coal decreased. As coal consumption is decreased, using simulation process productivity increased to 21.84 t/h, 21.31 t/h, 22.7 t/h respectively. As the productivity of coal based sponge iron plant is increases, profit is also increases and payback period is decreases.

Keywords: Coal Base, Increment, Productivity, Sponge Iron Plant, Simulation

Nomenclature

C	Coal/Cold/specific heat capacity (J/kg°C).
d	Dolomite.
D	Diameter (m).
F_m	Feed materials.
Fe	Iron.
h	Hot/Individual heat transfer coefficient (W/m^2°C).
L	Length (m).
m	Mass flow rate (kg/h).
NHV	Net heating value.
Q	Heat load (kW).
T	Temperature (°C).
t	ton (1000 kg).
t/h	Ton per hour.
t/d	Ton per day.

Greek letters

Δ	Difference between two parameters.
λ	Latent heat of vaporization (kJ/kg).

Subscripts

a	Air/ambient.
c	Coarse.
f	Feed.
i	Inlet.
hu	Hot utility.
loss	Heat loss.
m	Moisture.
o	Outlet.

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p Process.
s Iron ore/supply.
t Total.
w Waste gas.

1. Introduction

Sponge iron industry is relatively new and hence facing many teething problems. The literature survey indicates that the productivity is always main issue for the want of higher and higher production. The article makes an attempt to identify the facts and figures of iron and steel industry of which the sponge iron is an integral part. Design modification and increment of productivity are discussed to understand overall scenario of sponge iron in the World and in particular in India. Overall, it highlights the need of framework development of productivity improvement for sponge iron industry.

Although direct reduction was the first iron making method and has been practiced for thousands of years, the economic conditions require for commercialization did not occur until the late 1950's. Since then, annual production of DRI has grown to over twenty million metric tons. It has now become key component in keeping steel makers competitive. Availability of raw materials, economical scenario, skill manpower with knowledge of present process, pollution free environment, local people acceptance are few important criteria for overall growth of sponge iron industry.

According to[1] published by WSA in June 2015, India is the World's largest producer of sponge iron with a host of coal based units, located in the mineral rich states of the Country. Over the years, the coal based route has emerged as a key contributor and accounted for 90% of total sponge iron production in the country. Capacity in sponge iron making too has increased over the year and stood at 46.23 MT in 2014-15. Rapid rise in production has resulted in India becoming the 3rd largest producer of crude steel in 2015 and country continues to be the largest producer of sponge iron or DRI in the World.

In[2] an attempt has been made to validate the quality – productivity improvement framework developed through its implementation in two different sponge iron plants. The study proved that the developed framework is valid and reliable for coal based sponge iron industry in India.

In[3] an attempt has been made to access the Quality and Productivity (Q&P) situation in global, national and regional plants. Subsequently seven factors affecting the gap and Critical Success Factor (CSF) are identified in which common indicators of low productivity: High volume of material waste, high volume of rejects and rework which could be helpful in improving quality and productivity situation.

In[4] productivity in scenario-2 is increased from 18.6 t/h to 20.5 t/h, however the feed materials is increased from 30 t/h to 33 t/h while the coal consumption is 0.97 t/t DRI. The author analyses that, in conventional coal based sponge iron plant huge amount of heat is released with the waste gas. Through the heat integration process, this amount of waste heat is used to preheat the feed materials using rotary drier.

In[5] designed to integrate the heat of stack gas in sponge iron process in 200 t/d sponge iron plant by installation of few additional equipment and reduced coal consumption to 5.423 t/h to produce 4.166 t/h sponge iron giving profit of $0.16 million per year.

In[6] suggested a new design modification and evaluated that kiln coal consumption reduced by 72% which offer 27.8% higher profit in Case-2. In this modification, they use double pipe heat exchanger to recover the waste heat.

In[7] evaluated that coal consumption comes to 19.325 t/h to produced 18.6 t/h sponge iron by preheating air upto 170ºC using waste gas from ESP. Air is preheated from 300ºC to 170ºC using waste gas. For this purpose, 59738.8 m^3/h waste gas is used which is cooled from 220ºC to 80ºC as 50ºC temperature difference is required for transferring heat between air and waste gas. Due to air preheating by waste gas 5.4% coal consumption is reduced.

In[8] discovered that Case-2 saves 30.5% of coal in comparison to conventional process using waste heat from ABC. In this case, along with the preheating of feed material, air preheating is also considered. Waste gas at 850ºC from ABC is used for this purpose.

In[9] suggested consumption of coal is 12.5% less in comparison to existing system by using waste gas from ABC at 1050ºC to produced 18.6 t/h sponge iron. Air is preheated up to 300ºC using 18776.9 m^3/h waste gas. Waste gas is cooled down from 1050ºC to 250ºC. Further, waste gas of 2332 m^3/h is used to preheat the feed to kiln (iron ore, feed coal and dolomite) from 30ºC to 120ºC.

In[10] considered proper design modification and thus coal consumption decreased to 17.9 t/h with total payback period is 55 days. Air is preheated up to 300°C using 18776.9 m^3/h waste gas. Due to this, waste gas is cooled down from 1050°C to 250°C. A G-G shell and tube heat exchanger is required for this purpose. Further, waste gas of 2332 m^3/h is used to preheat the feed to kiln (iron ore, feed coal, and dolomite) from 30 to 120°C. The modified design consumes 93.7% and 12.3% less water and coal in comparison to the existing system.

The literature indicates that for Indian coal based sponge iron industry productivity of sponge iron was always a problem, although the coal consumption was reduced in different ways but at the same time sponge iron production is not increased.

Based on above discussion, it is observed that for heat recovery authors consider many potential areas where unutilized waste heat is present and those waste heat is used to preheat kiln feed, air and water, thus coal consumption is reduced. However, at the same time productivity is not increased. For the purpose of increment of productivity of coal based sponge iron plant, few cases from literature is taken and increased productivity through proper simulation and modifications.

2. Stepwise Problem Solution

In the present work, simulation in the Figure 1 shows that after applying heat recovery using heat integration of each cases given in research paper[7,8,10], coal consumption is reduced. Due to coal consumption is decreased, the amount of feed materials (Iron ore, feed coal and dolomite) is also decreased significantly but the productivity remains same. It has been great opportunity to increase the amount of feed materials upto 44.59 t/h, thus the sponge iron production is increased, thus productivity of sponge iron plant is significantly increased.

For solution of energy conservation problems, a methodology is developed. To solve the problem different programs are developed using Microsoft Excel-2000. The detail methodology is covered in following steps:

Step 1: The physical properties such as composition and specific heat of sponge iron, iron ore, dolomite, coal, air, char, dust and waste gas streams are computed after sampling. Proximate and ultimate analysis of feed coal, injection coal and char is carried out. Heat of formation and heat of combustion of different com-

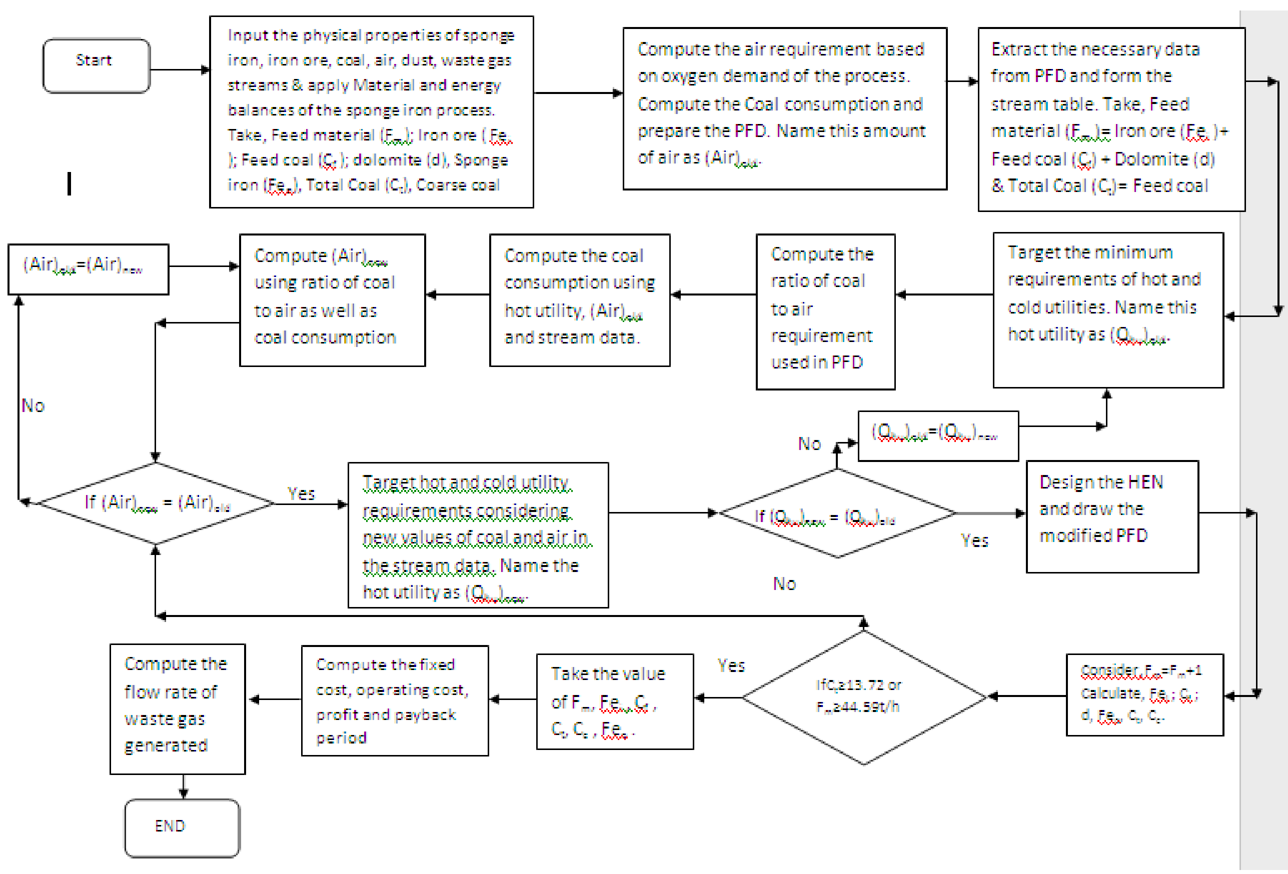

Figure 1. Simulation for productivity increment.

ponents such as Fe_2O_3, FeO, CO, CO_2, Fe, C, O_2, H_2 and H_2O is determined. Material and energy balance is performed for the sponge iron process. Take, Feed material (F_m); Iron ore (Fe_i); Feed coal (C_f); dolomite (d), Sponge iron (Fe_o), Total Coal (C_t), Coarse coal (C_c).

Step 2: Mass flow rate of air requirement [$(Air)_{old}$] based on oxygen demand of the process is computed from the reactions involved in sponge iron making process.

Step 3: Coal consumption of the process is computed using model developed through Equation (13).

Step 4: PFD of the process is prepared based on material and energy balanced data, air requirement and coal consumption, computed in Steps 2, 3 and 4.

Step 5: Necessary data from PFD are extracted and stream table is formulated. Then some energy conservations scenarios are formulated. These are detailed under heading formulation of energy conservation scenario. Take, Feed material (F_m) = Iron ore (Fe_i) + Feed coal (C_f) + Dolomite (d) and Total Coal (C_t)= Feed coal (C_f) + Coarse coal (C_c)

Step 6: Target minimum requirements of hot and cold utilities for the scenario. The hot utility computed in this step is referred as $(Q_{hu})_{old}$.

Step 7: Composite curve is drawn to find out the maximum possible energy which can be recovered through process to process heat exchange.

Step 8: Ratio of coal to air requirement, used in PFD is computed.

Step 9: Based on $(Q_{hu})_{old}$, $(Air)_{old}$ and stream data coal consumption is computed using Equation (13). The stream data of a scenario requires the temperature up to which a particular stream is heated up.

Step 10: Air requirement [$(Air)_{new}$] is computed using ratio of coal to air predicted in Step 8 and coal consumption computed in Step 9.

Step 11: If $(Air)_{old} \neq (Air)_{new}$ then replace $(Air)_{old}$ with $(Air)_{new}$ and Steps 9 to 10 are repeated. Here revised value of coal is computed and referred as $(coal)_{new}$.

Step 12: New values (mass flow rate) of coal and air [$(coal)_{new}$ and $(Air)_{new}$] in the stream data, formed in Step 6, are considered and the hot and cold utility requirements are targeted through composite curve. $(Q_{hu})_{new}$ is referred as hot utility.

Step 13: If $(Q_{hu})_{old} \neq (Q_{hu})_{new}$ then $(Q_{hu})_{old}$ is replaced with $(Q_{hu})_{new}$ and Steps 6 to 12 are repeated.

Step 14: Heat Exchanger Network (HEN) based on pinch design rules for the given scenario is designed with final values of hot utility (coal and air).

Step 15: The existing PFD is modified by converting HEN into new PFD.

Step 16: Consider, $F_m=F_m+1$ and Calculate, Iron ore (Fe_i); Feed coal (C_f); dolomite (d), Sponge iron (Fe_o), Total Coal (C_t), Coarse coal (C_c) using Step 3.

Step 17: If C_t is greater than equal to 13.72 t/h and F_m is greater than equal to 44.59 t/h than compute F_m, Fe_i , C_f , C_t, C_c , Fe_o otherwise repeat Step 11.

Step 18: The fixed cost, operating cost, profit and payback period for the modified PFD are computed.

Step 19: The flow rate of waste gas generated in the process through overall mass balance around the system is computed.

3. Model Development for Solving Simulation Problem

3.1 A Material and Energy Balance of the Sponge Iron Production

A material and energy balances of the sponge iron production[11] are on hourly basis using steps given below:

Step 1: Component mass balance such as iron, gangue, carbon and ash around rotary kiln based on plant data. Reduction and combustion reactions of the sponge iron making process are also involved in the calculation. Heat of reactions is given below[11]:

$$Fe_2O_3 + CO = 2FeO + CO_2 \qquad \Delta H = -2.06 \text{ GJ} \qquad (1)$$

$$FeO + CO = Fe + CO_2 \qquad \Delta H = -2.57 \text{ GJ} \qquad (2)$$

$$C + CO_2 = 2CO \qquad \Delta H = +75.07 \text{ GJ} \qquad (3)$$

$$2CO + O_2 = 2CO_2 \qquad \Delta H = -135.71 \text{ GJ} \qquad (4)$$

$$C + O_2 = CO_2 \qquad \Delta H = -98.07 \text{ GJ} \qquad (5)$$

$$2C + O_2 = 2CO \qquad \Delta H = -3.443 \text{ GJ} \qquad (6)$$

$$2H_2 + O_2 = 2H_2O \qquad \Delta H = -29.85 \text{ GJ} \qquad (7)$$

Step 2: Mass balance around Rotary Kiln, Dust Settling Chamber + After Burning Chamber,

Evaporating Cooler, Electrostatic Precipitator and Chimney are also performed.

Step 3: Overall mass balance around the complete plant considering all inputs and outputs to the process are performed.

Step 4: For energy balance, heat of reactions, shown in Step 1, radiation loss from kiln,

vaporization of moisture of coal and ore has been accounted for. Along with this, energy

lost through char, dust, sponge iron, waste gas and volatile matters are also considered. Step 5: Air requirement is computed based on overall oxygen consumed by the reactions, shown in Step 1, as well as excess air up to 8% is considered as per the plant practice. The coal consumption is computed using the model developed for the present work.

Step 6: Based on the predicted values of air and coal, Steps 1 to 6 are revised.

Step 7: Mass and Energy contents of all input and output streams are determined and reported.

3.2 Developed Model for Coal Requirement in Sponge Iron Making

The demand of coal in sponge iron making is decided by the energy demand. Hot utility demand, Q_{hu}, is estimated from the composite curve using pinch analysis[12–14]. Requirement of further energy for sponge iron production is given below:

The sensible heat acquired by iron ore and waste gas is calculated by the equations given below:

$$Q_w = m_a C_a (T_p - T_i) \tag{8}$$

$$Q_s = m_s C_s (T_p - T_i) \tag{9}$$

Where, T_p the reaction temperature and T_i is the ambient temperature.

The heat of reaction of the reduction and combustion reactions are computed using heat balance of the process. It is found that only Equation (3) is the endothermic reaction. Heat required in the process is the addition of heat of reaction of Equation (3), heat required for coal devolatization and decomposition of dolomite and is referred to as Q_p.

The heat lost through the kiln wall comprises the heat lost through shell of the kiln, inlet and outlet hoods, after and post combustion ducts of kiln. Thus, the heat lost through the kiln wall is considered two times as that of the heat lost through the kiln shell[15–17].

$$Q_{loss} = 2 \times (\pi DL \times h_f) \tag{10}$$

Where, h_f is the heat transfer coefficient.

The coal is also required to be preheated up to the reaction temperature and sensible heat involved for this is shown as:

$$Q_c = m_c C_c (T_p - T_i) \tag{11}$$

The iron ore and coal contains the average moisture to a value of 2% and 13%, respectively by weight in Indian circumstances. The heat needed to vaporize this moisture is estimated as:

$$Q_m = (0.02 m_s + 0.13 m_c) \times \lambda \tag{12}$$

It is assumed that the combustion efficiency of such type of rotary kiln is 70%[18,19]. The 30% of available carbon of the coal does not burn fully. The most part of the unburnt carbon is exhausted with the waste gas and remaining parts are conveyed along with sponge iron and ash without contributing anything to the process. The ultimate empirical formula for computing coal consumption is emanated below:

$$Q_{hu} + Q_s + Q_w + Q_p + Q_{loss} + 0.02\, m_s \times \lambda = m_c\,[\mathrm{NHV}\,(0.4) - C_c (T_p - T_i) - 0.13 \times \lambda] \tag{13}$$

Where, NHV of coal is 22721 kJ/kg in present case. The value of m_c is estimated from Equation (13). The other property data of iron ore, air and coal are taken from the literature[20,21].

4. Result and Discussion

In the present work, some research paper[7,8,10] is taken where some energy conservation scenarios using heat recovery with various design modifications by applying heat integration process is done. In those research papers,

Table 1. Productivity data for Case-1

Case 1- Feed materials- 42882 kg/h Feed Coal- 11450 kg/h Coarse Coal- 6450 kg/h					
Feed Materials	**Feed Coal**	**Coarse coal**	**Coal Requirement**	**Iron ore**	**Sponge iron**
Kg/h	Kg/h	Kg/h	Kg/h	Kg/h	Kg/h
41861.00	11450.00	6450.00	17900.00	30000.00	20830.00
41861.00	12420.77	6863.15	19283.92	30000.00	21080.00
42861.00	12554.36	6936.96	19491.32	30717.43	21328.13
43861.00	12693.95	7014.09	19708.04	31467.14	21848.69
44861.00	12827.53	7087.90	19915.44	32184.57	22346.82

coal consumption is reduced but productivity is not increased. By taking advantage of productivity increment, increased the productivity of sponge iron plant using simulation discussed in previous section.

4.1 Modification for Productivity Increment

Case-1: According to[10] in Case-8 air, feed to kiln and injected coal are preheated by waste gas from ESP and ABC thus coal consumption reduced to 17.9 t/h but the productivity is same as 20.83 t/h. By applying present simulation process, productivity can increased to 21.84 t/h is shown in Table 1.

Case-2: Author in[7] evaluated waste gas from ESP at 220°C used to preheat air from 30°C to 170°C for this purpose waste gas is cooled to 220°C to 80°C. In this modification, coal consumption is reduced to 19.325 t/h however; sponge iron production is 20.83 t/h. By applying present simulation process, productivity can increased to 21.31 t/h is shown in Table 2.

Case-3: Author in[8] suggested design modification using heat integration in which coal consumption is reduced to 14.892 t/h by preheat air upto 385.7°C using waste heat from ABC at 850°C for production of 20.83 t/h sponge iron. By applying present simulation process, productivity can increased to 22.7t/h is shown in Table 3.

5. Conclusion

The sponge iron industry is passing through several problems, such as productivity, in the present work; an effort is made to increase the productivity in terms of sponge iron. For this purpose, a modification using simulation for productivity increment in which Case 1, Case 2 and Case 3 are developed. For the above purpose, reduced coal consumption of the research papers[7,8,10] are taken and present process i.e., simulation for productivity increment is applied. The salient features of the present study are as follows:

- In Case 1, Case 2 and Case 3; productivity of 500 t/d sponge iron plant is same conventional plant i.e., 20.83 t/h.
- In present work; by applying simulation process productivity of sponge iron of Case 1, Case 2 and Case 3are21.84 t/h, 21.31 t/h and 22.7 t/h respectively.

Table 2. Productivity data for Case-2

Case 2-Feed materials- 42882 kg/h Feed Coal- 12486 kg/h Coarse Coal- 6839 kg/h					
Feed Materials	**Feed Coal**	**Coarse coal**	**Coal Requirement**	**Iron ore**	**Sponge iron**
Kg/h	Kg/h	Kg/h	Kg/h	Kg/h	Kg/h
42882.00	12486.00	6839.00	19325.00	30000.00	20830.00
42882.00	12651.21	6990.48	19641.69	30000.00	21080.00
43882.00	12786.85	7065.42	19852.27	30699.59	21315.75
44882.00	12922.48	7140.37	20062.85	31399.19	21801.50

Table 3. Productivity data for Case-3

Case 3-Feed materials- 39592 kg/h Feed Coal- 9592 kg/h Coarse Coal- 5299 kg/h					
Feed Materials	**Feed Coal**	**Coarse coal**	**Coal Requirement**	**Iron ore**	**Sponge iron**
Kg/h	Kg/h	Kg/h	Kg/h	Kg/h	Kg/h
39592.00	9592.00	5299.00	14891.00	30000.00	20830.00
39592.00	9660.70	5338.06	14998.76	30000.00	20830.00
40592.00	9715.34	5368.25	15083.58	30757.73	21299.00
41592.00	9769.97	5398.44	15168.41	31515.46	21769.58
42592.00	9824.61	5428.63	15253.24	32273.19	22239.38
43592.00	9879.25	5458.82	15338.07	33030.92	22709.17
44592.00	9933.89	5489.01	15422.90	33788.64	23178.96

- By applying simulation for productivity increment; productivity of sponge iron is increase by taking the amount of feed materials are same as 500 t/d conventional sponge iron plant i.e., 44.59 t/h.

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