Generation of Energy Conservation Measures for Sponge Iron Plants

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Abstract - **During the operation, a tremendous amount of heat is generated in the coal based sponge iron plant and a significant part of this heat associated with the waste gas, remains unutilized. While utilizing this heat in the process the energy demand of the process may be reduced, which decreases the coal consumption, which is the only source of energy for this plant. To utilize the heat associated with waste gas pinch analysis is applied on the actual plant data to identify three feasible cases for energy conservation. For these cases capital investment required for retrofitting as well as total profit in terms of coal and water saving are compared and best design is selected. The best design includes preheating of air using waste gas. It consumes 5.4% less coal in comparison to existing system. The payback period of the best design is 48 days only. This design also satisfies the practical conditions of the process.**

Index terms- **Capital cost, Coal consumption, Heat integration, Payback period, Sponge iron plant.**

I. INTRODUCTION

Sponge iron is not soft and spongy but a metallic mass with honeycomb structure having minute holes all over the surface and bulk. Since the last few years, sponge iron has emerged as a sound alternative raw material for steel making through the electric arc furnace (EAF) route. Seeing its tremendous potential in iron and steel making, Government has recognized sponge iron as vital sector for the growth of Indian steel industry. Again, India is fortunate to have high reserves of iron ore of good quality and large resources of non-coking coal.

Sponge iron manufacturing unit looked very profitable since the beginning of nineties. However, with the liberalization of import duties of scrap, increase in the input cost of raw material and comparatively decrease in the selling price, sponge iron industry found difficulty to survive in the market. Even today, when the situation has improved, sponge iron industry is passing through several problems like lack of optimization of main equipments and energy savings schemes, etc. So, this field appears very relevant and needs research and development.

Many investigators considered the process of sponge iron manufacturing and suggested improvement in that [1], [2]. It is found that during the operation in the coal based sponge iron plant, a tremendous amount of heat is generated and a significant part of this heat associated with the waste gas, remains unutilized.

Jena et al. [3] proposed a quantitative analysis based on waste gas, gas composition, dust loss, air requirement and efficiency of the process. They found that due to chemical reactions and combustion the heat generated inside the kiln is 174.28 GJ/h and the heat value of the coal input is 323.2 GJ/h resulting in a thermal efficiency of the process to be 53.9%. Considerable amount of heat is lost in the waste gas which is about 33% of heat generated in the kiln. The authors suggested that heat in waste gas may be recovered by putting a waste heat recovery system for generation of power. Although many plants have acquired the desired level of operational efficiency but from energy point of view various units is below optimum limit. The principal cost factor in direct reduction is energy cost as energy requirement for rotary kiln processes ranges between 14.63 GJ/t to 20.9 GJ/t [4].

Thus, it is obvious that energy conservation in these plants is of major importance and hence, heat integration is necessary to minimize the losses. Thus, in the present paper an approach is discussed to utilize the heat of waste gas for preheating the raw material. As a result the reduced amount of coal is predicted. The equipments required for retrofitted process are suggested and their economic analysis is also presented.

II. COAL BASED SPONGE IRON PLANT: A CONVENTIONAL PROCESS

The process flow diagram of conventional coal based sponge iron plant is shown in Fig. 1. The operating data, shown in Fig. 1, is taken from a typical Indian coal based sponge iron plant where iron ore, feed coal and dolomite are fed to the rotary kiln. A separate conveyor collects different size fractions of coal for injection into the kiln with the help of pressurized air from discharge end side. All along the kiln length air is injected through air fans and each of them can be adjusted separately. Further, air is injected at the kiln outlet by central burner pipe, which during normal operation serves as process air inlet. The inside kiln is lined with refractory and supported on three piers called support rollers with an inclination of 2.5%. Due to its inclination and rotation material in the bed of the kiln moves along the axis. Both end of the rotary kiln is provided by the mechanical air sealing so that no ingress of air takes place. As the charge moves through the kiln, it is heated by the gases which flow in opposite direction to the charge. Inlet side of the kiln, blowing of a controlled amount of air into the material charge increases the material temperature by direct combustion of volatiles within the charge.

The waste gas in the kiln flows in the opposite direction to the feed material movement. The flow is maintained by induction fan mounted before the chimney. The waste gas coming out from the rotary kiln is

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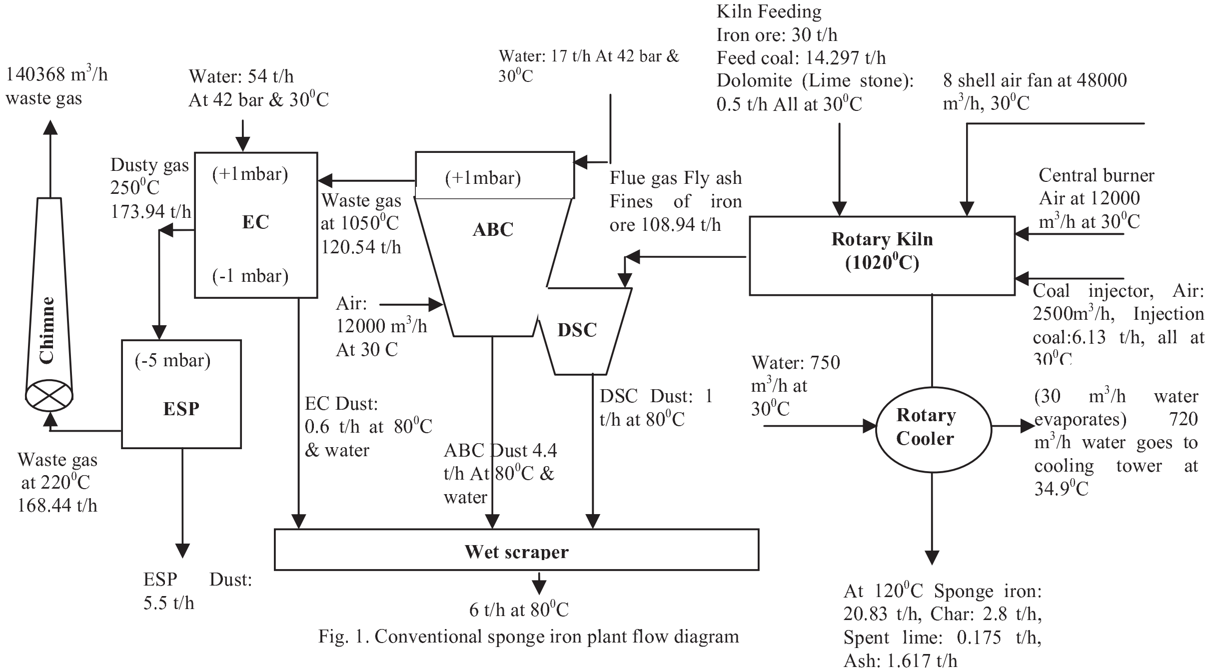

Fig. 1. Conventional sponge iron plant flow diagram

processed by the different equipment before it leaves to the open atmosphere. Generally, waste gas consists of N_2, CO_2, CO, H_2, H_2O, O_2 and CH_4. It comes out of the kiln at a temperature about 900^0C and then is taken to after burner chamber (ABC) and a horizontal dust settling chamber which is located beneath the ABC. Dust settling chamber (DSC) reduces the waste gas velocity, removes large dust particles by gravity, retards pressure fluctuation and achieves uniformity of waste gases with regard to temperature and concentration of combustible. At the end of DSC the waste gases change their direction of flow and move upward into combustion area of ABC. Here combustibles are mixed with fresh excess air and burnt completely to acquire temperature in a range between 950^0C to 1050^0C approximately.

To remove dust particles and toxic components from waste gas water is sprayed in the ABC. For this purpose eight to ten numbers of water gun is fitted along the different height. The water guns hold a nozzle at the discharge end for atomization. The pressurized water coming out from the guns falls on the waste gas carrying dust particle. The evaporating chamber (EC) is connected with the ABC as shown in Fig. 1. Here, the waste gas is quenched as temperature of waste gas needs to be brought down to a workable limit for downstream equipment. For quenching eight - ten numbers of water guns are provided at the top position of EC around the circumference at the same height. Water coming out from the guns is sprayed to reduce the temperature of waste gas at desired level. The bottom part of the EC, dust settling chamber and ABC is attached with wet scraper to collect the dust. Further, waste gas coming out from the EC, is entered the electrostatic precipitator (ESP) for final purification. The desired temperature of the waste gas is to be maintained below 250^0C. ESP is considered to be the most effective dust collector in industries. It has gained acceptance over other collectors due to its various advantages like low pressure drop, low sensitivity at high temperature and aggressive gases, high collection efficiency and low maintenance. ESP exit is connected to the chimney through the waste gas carrying duct. Induced direct fan placed before chimney. After ESP, the filtered waste gas goes to the surroundings through Chimney.

III. HEAT INTEGRATION IN SPONGE IRON PLANT

It appears worth interesting to give a fresh look on the existing system with a view to retrofit it which facilitates the utilization of the heat. The possible areas of the flow diagram, shown in Fig. 1, where energy is being lost and can be conserved, are as follows:

1) An appreciable portion of the energy, i.e 43.5%, is being lost in the rotary kiln through untapped waste gas [5].

2) Hot sponge iron is being cooled from 1020°C to 120°C using water in the rotary cooler through an indirect heat exchanger and the vapor generated from it is at a temperature of 34.7°C, which goes directly to atmosphere.

3) Clean waste gas is vented through the chimney to the atmosphere at a temperature of 220°C.

Thus, these are a number of potential areas where energy is being lost and not tapped. This energy can be conserved and utilized in the process through proper heat integration to decrease the energy bills of the industry. For this purpose the stream data is extracted from Fig. 1 and presented in Table I.

Here, outlets streams of wet scrapper and ESP are considered as hot streams which cool down to ambient temperature (30^0C). Based on this data following possible cases for energy conservation are identified:

Case-1: Existing system as shown in Table I.

Case-2: Existing system without water and vapor streams. This case is an improved version of Case-1 where efforts are being made to save waste energy of the process. In this case waste gas, which is exiting from ESP as shown in Fig. 1, is used to cool kiln outlet.

TABLE I
STREAM DATA OF EXISTING PROCESS

	Coal cons., t	Water, t	Actual coal cons., t	Operating cost, Rs
Case-1	20.424	821	20.424	100322.1
Case-2	20.424	71	20.424	55322.13
Case-3	19.6	71	19.325	52571.75

TABLE II
COLD UTILITY REQUIREMENTS FOR THREE CASES

Cases	Cold utility(kW)
Case-1	9869.2
Case-2	198.8
Case-3	198.8

In fact, in real situation the kiln outlet stream is being cooled using cold water (stream c1 in Table I). In this case waste gas behaves as cold stream (from 70^0C to 161.15^0C) and is used to cool kiln outlet.

Case-3: In this case air preheating is considered over and above the Case-2. In other words, Case-3 is Case-2 plus provision for air preheating. The waste gas, which is exiting from ESP as shown in Fig. 1, is available at 220°C and need to be cooled down below 60°C. This was done by dissipating its heat to atmosphere in Case-2 where, it is cooled inside the duct. A better alternative will be to recover this heat by putting this to use for preheating the air. Here, air in included in Table I as a cold stream from 30^0C to 170^0C. Here cold waste gas is used to cool kiln outlet.

The energy requirement for these cases is computed using pinch analysis [6], which is a tool for process integration. The hot utility for all cases is zero; however, cold utility for each is shown in Table II. The cold utility for these cases is almost equal and it is due to outlet streams of wet scrapper (h3) and ESP (h4). It is not feasible to recover heat available in these streams as these are dust streams and may foul the surface of exchanger considerably. Thus, for heat integration these streams are neglected.

A. Model of Coal Consumption for Process

In the sponge iron plant the only source of energy is coal which is produced by its combustion. Model for computing coal consumption for each scenario depends on hot utility requirement (Q_{hu}), sensible heat requirement for preheating air (Q_a) and feed material (Q_s), heat of reaction of reduction process (Q_p), heat lost through the rotary kiln wall (Q_{loss}), preheating required by coal and latent heat required for evaporation of moisture of feed material. The model is expressed through following equation:

$$Q_{hu} + Q_s + Q_a + Q_p + Q_{loss} + 0.02\ m_s \times \lambda = m_c\,[NHV\,(0.7) - C_c\,(T_p - T_i) - 0.13 \times \lambda] \qquad (1)$$

TABLE III
COAL AND WATER REQUIREMENTS PER HOUR

Case	Water, t/h	Actual coal cons. t/h	Capital cost *HX*	Capital cost *Cost, (lacs)*	Profit (lacs)/day	Payback, days
2	71	20.424	G-S	399.14	9.72	41
3	71	19.325	G-G	94.18	10.31	48
			G-S	493.32		

Here, m_s, C_c, T_p, T_i and λ are flow rate of feed material, specific heat of coal, temperature of kiln at reduction process is carried out, inlet temperature of coal and latent heat vaporization, respectively. The value of m_c can be predicted from Eq. 1 considering the NHV of coal as 22930.5kJ/kg. The property data of air, ore and coal are constant and taken from literature [7], [8].

IV. RESULTS AND DISCUSSION

Coal consumption for Case 1, 2 and 3 are computed using Eq. 1 and results are summarized in Table III. For these cases air of same amount, as shown in Fig. 1, is considered. In fact, in the process air requirement for combustion is depemdent on coal consumption so when it reduces inlet air requirement also decreases. Based on trial and error method actual amount of air is computed which gives actual coal consumption as shown in Table III.

In this process operating cost depends on coal and water requirements. The costs of coal and water are Rs 2500/t and Rs 60/t, respectively. Based on these values the operating cost for all cases are found and presented in Table III. It shows that maximum saving of 5.4%, 91.3% and 47.6% are found in coal consumption, water requirement and operating cost for Case-3 in comparison to the existing system. While integrating heat in Case 2 and 3, some additional equipment, as mentioned in Table IV, are required. This table does not include the equipment for Case-1 as it is the existing system where no integration is carried out. For Case-2 and 3 capital costs of gas-solid (G-S) heat exchanger (double pipe) and gas-gas (G-G) exchanger (shell and tube), shown in Table III, are taken from the work of Prasad et al. [9] and Shenoy [10], respectively.

In all these cases production of sponge iron remains constant, thus, reduced amount of coal and water show the gain in the process. The profit and payback period of two cases are also shown in Table IV. The results of Case-2 and 3 based on data shown in Table III and IV are discussed in the subsequent sections.

A. Case-2

1) In this case waste gas is used to cool kiln outlet. It reduces water requirement by 91.3% in comparison to existing system as shown in Table III and IV.
2) Exit of kiln is to be cooled from 1020^0C to 120^0C which require waste gas to be entered at 70^0C as 50^0C temperature difference is required for heat transfer between gas and solid [6]. However, waste gas is available at 220^0C. This temperature

TABLE IV
ECONOMIC DATA FOR CASES

Stream	Type	T_s	T_t	C (J/kg◦C)	Flow (kg/s)	MC (kW/C)
Kiln Outlet	h1	1020	120	678.03	7.09	4.81
Water	c1	30	34.9	4187	208.3	872.29
Vapor	h2	34.9	33.9	1864	8.33	15.53
Wet scrapper out	h3	80	30	881.33	1.67	1.47
ESP out	h4	125	30	896.42	1.53	1.37
Waste gas	h5	220	30	1140	46.78	53.33

cools down to 70^0C due to heat loss while passing it through a non-insulated duct. The detailed design of duct is shown in the work of Prasad et al. [9].

3) For this purpose an indirect gas-solid heat exchanger is required which can be designed based on the work of Prasad et al. [5].

The coal consumption for this case remains unchanged in comparison to existing system as integration of heat is not done between streams which are entering and exiting from the process. Here, waste gas and kiln exit are outlet streams of process. Thus, energy demand of process also remains unaltered.

B. Case-3

1) Air is preheated from 30^0C to 170^0C using waste gas. For this purpose 59738.8 m^3/h waste gas is used which is cooled from 220^0C to 80^0C as 50^0C temperature difference is required for transferring heat between air and waste gas [6]. A gas-gas shell and tube heat exchanger is employed as additional equipment with heat transfer coefficient and area as 50 W/m^2 ^{o}C [11] and 847.5 m^2, respectively. Due to air preheating by waste gas 5.4% coal consumption is reduced.
2) Waste gas of 59738.8 m^3/h cools to 80 ^{0}C by supplying its heat to air. Further, this waste gas is mixed with remaining gas of 69760.4 m^3/h(at 220^0C). Then it is heated from 70^0C to 151.15^0C by taking heat from kiln outlet. Consequently, the kiln outlet is cooled down to 120^0C. Waste gas achieves 70^0C by moving through the non-insulated duct. Here, 91.3% water consumption can be reduced. For this purpose a gas-solid heat exchanger as used for Case-2 is employed.

Table IV shows that minimum and maximum payback periods of 41 and 48 days are observed for Case-2 and 3, respectively. Based on this information Case-2 should be selected as best design. However, the difference between minimum and maximum periods is only 7 days which is not appreciable. Thus, Case-3 may be selected as best option as after 48 days of operation it will provide maximum profit in terms of coal and water saving. The process flow diagram for Case-3 is shown in Fig. 2 where modification in the design is drawn with bold lines.

V. CONCLUSIONS

It appears that during the operation, a tremendous amount of heat is produced and a significant part of this heat associated with the waste gas remains unutilized. If this useful heat content of waste gas is utilized then plant yield can be enhanced subsequently. The salient features of the present study are as follow:

1) Based on heat integration Case-3 is selected as best design amongst the four. It consumes 91.3% and 5.4% less water and coal in comparison to existing system.
2) Case-3 gives total profit of Rs10.31 lakh/day. However, to achieve this capital investment of Rs 587.5 lakh/- is required. Thus, total payback period is 48 days.

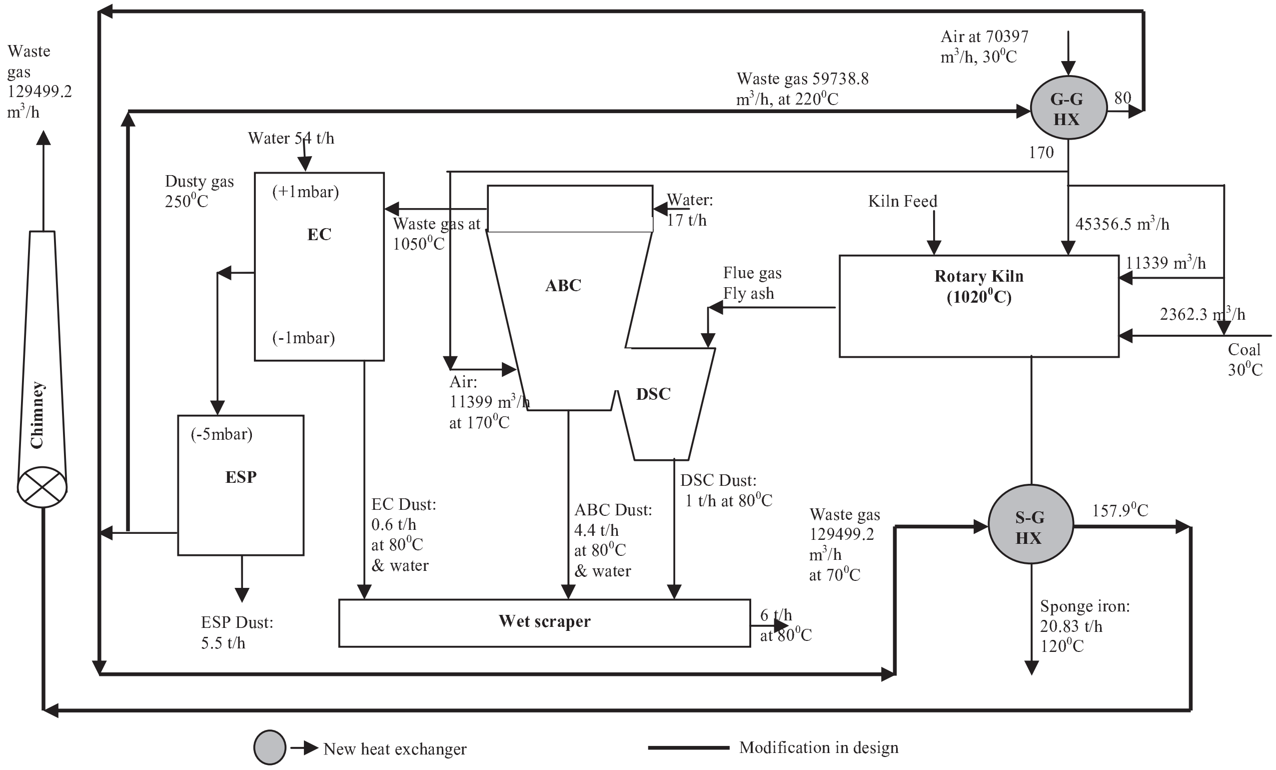

Fig. 2. Process flow diagram for Case-3

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