Achieving Low Coke Rate Using Calibrated Iron Ore as the Sole Iron Source in Burden Charge During the Successful Recommissioning of Blast Furnace in Syria

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ABSTRACT: *In the backdrop of war and amid sanctions on Syria, a mini blast furnace has been successfully recommissioned in Hassia, Syria, and the hot metal produced is used for the production of 130 mm^2 mild steel billets, providing import substitution as presently the billets are being imported from countries such as Russia, Ukraine, etc. Emmar Steel (ES) is an integrated steel plant having a production capacity of about 0.5 million tons of steel per annum. ES operates a mini blast furnace (MBF) with a designed capacity of 500 TPD (tons per day) to produce hot metal. ES is the only steel plant, which houses a blast furnace and the first of its kind in the whole of Syria, the Gulf region and in the countries surrounding Syria (excluding Turkey). In the past two decades, almost all blast furnaces across the globe use a charge burden consisting of various permutations and combinations of iron ore, sinter/pellets of iron-bearing materials as sources of iron depending on their availability, ease of operation, and economies of scale. But, sometimes due to the non-availability of iron ore fines, sintering, and pelletizing facilities, it becomes necessary to manage the charging burden only with iron ore as the sole source of iron. The present paper describes the efforts taken to achieve a low coke rate of 568 kgs/ton of hot metal (THM) during the recommissioning period of about 4 months (May to August 2018), wherein it produced about 56800 tons of hot metal from about 86100 tons of calibrated iron ore with peak production of 650 TPD against the designed capacity of 500 TPD in the mini blast furnace of ES located at Hassia, Syria.*

KEYWORDS: *Emmar Steel; Mini Blast Furnace; Iron making; Metallurgical coke; Coke rate; CRI & CSR; M40 & M10; Burden charge.*

INTRODUCTION

Ironmaking is a capital and energy intensive process. Blast furnace, still is the predominant ironmaking process across the globe. The blast furnace is a counter current moving bed chemical reactor to reduce iron oxides to iron, which involves complex transport phenomena and chemical reactions. In this process, iron-bearing materials, coke and flux are charged in alternate layers from the top of the furnace. The raw material is heated up to 2,000°C in the blast furnace and melts at about 1,500°C. It then separates into hot metal (molten iron) and slag and accumulates at the bottom of the furnace [1].

The overall economy of an integrated steel plant is very sensible to the performance of blast furnace. Quality of raw materials is the prime factor, which contribute

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to the success of iron making. Quality of burden materials affects the techno-economy and efficiency of the furnace operation. Intensive burden can be prepared by utilizing raw material of improved quality, strength, size consistency for uniform gas distribution, reducibility (sinter and iron ore) and reactivity (limestone, dolomite and coke). The advantages of higher percentage of sinter in the burden like low silicon in hot metal, higher productivity and low fuel rate have been well established. Iron ore and sinter proportion in burden and its chemical properties have a great impact on the operation, performance and success of iron making blast furnace [2]. But, sometimes in the absence of sinter and pellet machines and iron ore fines, it becomes essential to manage the whole charge burden with only the available iron ore despite the advantages of using iron ore sinter / pellets. Apart from quality of raw materials, coke rate plays a vital role in determining the cost of hot metal produced. Many steel plants inject pulverized coal (PCI) [3] in blast furnace, enrich oxygen percentage in hot blast and inject steam and operate the blast furnace with high top pressure [4] to reduce coke rate.

One of the two mini blast furnaces at ES was recommissioned in 2018 after shutting it down for the past 5 years. ES is an integral part of "Aman Group ", one of the biggest commercial and industrial companies in Syria & Middle East. ES consists of two mini blast furnaces, an Energy Optimizing Furnace (EOF), two Induction Furnaces (IF), a Ladle Refining Furnace (LRF) and a four-strand Continuous Casting Machine (CCM) with auxiliary facilities such as oxygen plant and scrap processing facilities. In the absence of sintering and pelletizing facilities, calibrated iron ore was used as the sole source of iron in blast furnace. The present paper discusses the challenges faced while achieving a low coke rate of 568 kgs/THM in the first campaign extending for about four months during the successful recommissioning of the first mini blast furnace in Syria.

EXPERIMENTAL SECTION

Materials

Quality of raw materials used in MBF

In the absence of iron ore mines and coke oven batteries in Syria, iron ore and coke were imported from other countries. Fluxes such as limestone, dolomite and quartzite available in Syria were used. The raw materials received were stored separately in lots and these lots were sampled and tested as per standard procedures in the laboratory established in-house.

Iron Ore

Calibrated iron ore in the size range of 10-40 mm was imported from Brazil for use in MBF. Samples were collected from various lots and were characterized for their physical and chemical properties with the available infrastructure [5]. Table 1 presents the weighted average physico-chemical properties of iron ore.

Lot analysis revealed that, the cold strength of iron ore (TI and AI) are good and suitable for use in MBF. Furthermore, the alumina content was low (0.86%), which is advantageous for blast furnace operation, but, the supplies of iron ore were found to be inconsistent with respect to iron, phosphorus and alkali contents. The results of lot analysis were plotted in the form of graphs and are presented in Figs. 1, 2 & 3 respectively.

From the graphs it could be observed that, iron content varies from 63.4% to 65.30%, phosphorus varies from 0.120 to 0.220%, Na_2O varies from 0.09-0.23% and K_2O varies from 0.08-0.198% indicating fluctuations and inconsistency in iron ore received.

Metallurgical coke

The most important raw material in terms of operational efficiency and hot metal quality fed into blast furnace is metallurgical coke. Coke performs three functions namely, thermal: as a fuel providing the energy required for endothermic chemical reactions and for melting of iron and slag, chemical: as a reductant by producing reducing gases for reducing iron oxide and mechanical: as a permeable medium providing passage for liquids and gases in the furnace, particularly in the lower part of the furnace [6]. In the absence of coke oven batteries, metallurgical coke was imported from Slovakia. The characterization studies of coke [7] such as physical properties and proximate analysis of various lots of coke were analyzed and the mean values are presented in Table 2.

To determine the inorganic constituents present in coke, coke ash was analyzed for its chemical composition and is presented in Table 4.

The ratio of MPS of iron ore and coke is 1:2.3, which confirms their suitability for iron making in MBF. The resistance property of coke towards degradation due to

Table 1: Physico-Chemical properties of iron ore.

Sl. No	Parameter	Value
1	Mean Particle Size (MPS) (mm)	22.10
2	Bulk Density (BD) (tons/m^3)	2.11
3	Tumbling Index (TI) (%)	88.74
4	Abrasion Index (AI) (%)	4.70
6	Loss on Ignition %	1.45
7	Silica %	3.84
8	Iron content %	64.26
9	Alumina %	0.86

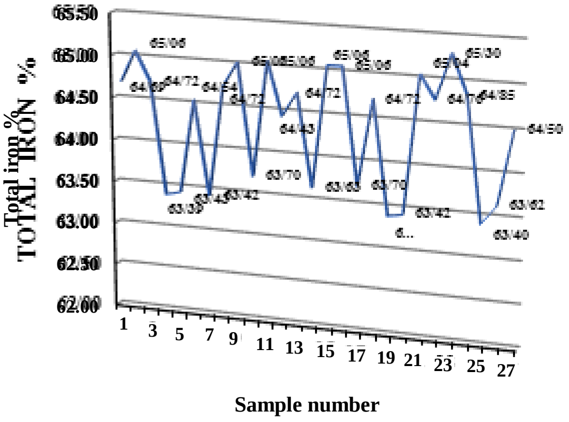

Fig. 1: Iron content in various samples

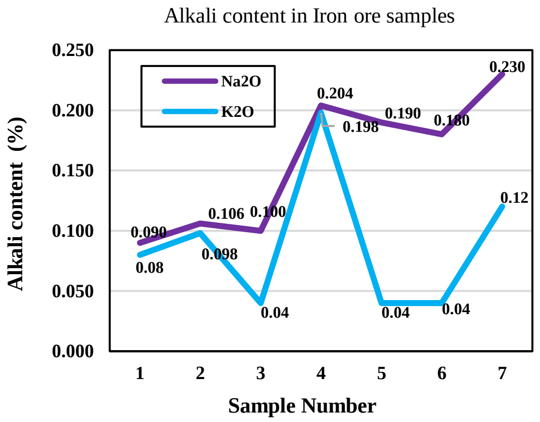

Fig. 3: Alkali content in various iron ore samples.

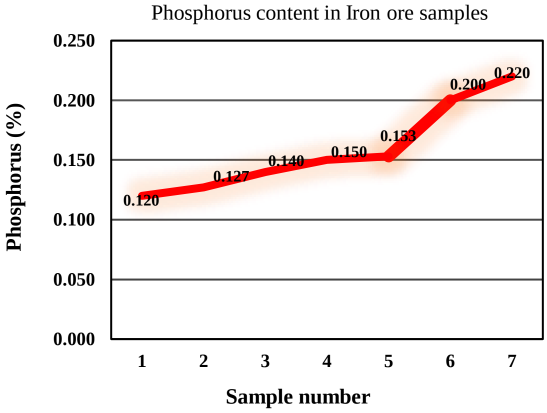

Fig. 2: Phosphorus content in various samples.

impact (M40) and due to abrasion (M10) were found to be suitable for MBF use. Though volatile matter is marginally on the higher side, ash content is found to be less (Table 3), which is advantageous for MBF operation. Ash analysis infer that, alkali contents and sulphur are marginally higher in coke ash (Table 4).

To determine the hot strength of coke, samples were drawn from different lots and were analysed for CRI (Coke Reactivity Index) and CSR (Coke Strength after Reactivity) using CRI & CSR instrument [8] and the values obtained are presented in Fig. 4.

It could be observed from the graph that, coke reactivity indices vary from 22.5% to 27.5% with a mean value of 25.0% and coke strength after reactivity indices vary from 62.63% to 65.13% with a mean value of about 64.0%.

Table 2: Physical properties of coke.

Sl.No	Parameter	Value
1	MPS	51.9 mm
2	BD	0.52 tons/m^3
3	M 40	83.91 %
4	M 10	5.66 %

Table 3: Proximate analysis (dry basis).

Sl.No	Component	Value (%)
1	Volatile Matter	1.26 %
2	Ash	9.95 %
3	Fixed Carbon	88.79 %

Table 4: Chemical composition of coke ash.

Sl. No	Component	Value (%)
1	Silica	42.08
2	Iron oxide	14.77
3	CaO	11.76
4	MgO	8.87
5	Alumina	19.80
6	Phosphorus	0.288
7	Sulphur in coke	0.65
8	Na_2O in coke	0.125
9	K_2O in coke	0.245

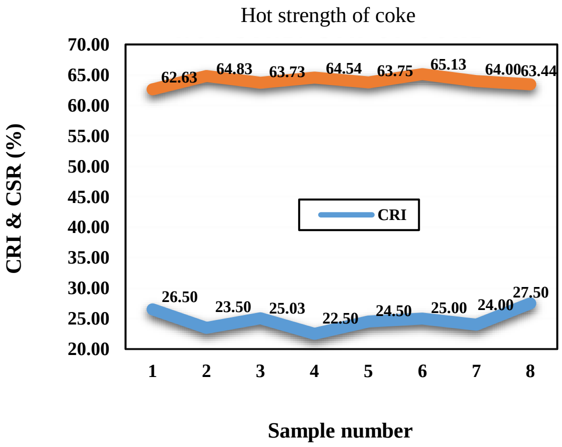

Fig. 4: CRI & CSR of coke.

The coke exhibiting these properties is considered suitable for a mini blast furnace.

Quality of Fluxes

Fluxes are integral part of the burden charge and they play an important role in slag making and removal of impurities [9]. Physical and chemical properties of fluxes viz., dolomite, limestone and quartzite are presented in Table 5.

It is observed from Table 5 that, the physical and chemical properties of fluxes were found to be good, but the concentration of alkalies in dolomite and limestone are higher than those used normally in blast furnace.

Table 5: Physico-Chemical properties of fluxes.

Sl. No	Parameter	Dolomite	Limestone	Quartzite
1	MPS (mm)	25.24	19.32	23.56
2	BD (tons/m^3)	1.34	1.38	1.32
3	Loss on Ignition (%)	44.60	43.78	1.34
4	Silica (%)	0.87	3.67	91.62
5	Calcium Oxide (%)	33.60	48.60	2.52
6	Magnesium Oxide (%)	19.35	2.8	0.42
7	Iron Oxide (%)	0.22	0.32	1.60
8	Alumina (%)	0.30	0.48	2.20
9	Phosphorus (%)	0.086	0.180	0.102
10	Na_2O (%)	0.28	0.31	0.12
11	K_2O (%)	0.12	0.28	0.18

Table 6: Specific features of Mini Blast Furnace.

Sl.No	Parameter	Remarks
1	Furnace Height	24.2 m
2	Inner / Useful Volume	292 m^3
3	Working Volume	252 m^3
4	Charging Equipment	Conveyor belt
5	Burden charging system	Big bell, small bell and rotary hopper
6	Cooling system	Only external cooling
7	Number of stoves	3 (kalugin shaftless stoves)
8	Number of tuyeres	14
9	Type of tuyeres	Single chamber
10	Blast pressure	1.5 kg/cm^2
11	Furnace top pressure	0.4 kg/cm^2
12	Injection facilities	NO facilities for PCI, Steam injection and Oxygen enrichment
13	Number of Tap Hole	1
14	Tap Hole length	1.5 m
15	Hearth Diameter	4.2 m
16	Gas cleaning	Wet cleaning system consisting of dust catcher, saturator, two venturi scrubbers.
17	Slag treatment	Water quenching to produce granulated slag

Methodology

The mini blast furnace of ES was designed by M/s. Minitec Technologies, Brazil. The specific features of mini blast furnace are presented in Table 6.

Burden charging system

Distribution control and monitoring

Burden distribution plays an important role as far as stable and efficient furnace operation is concerned. Increased utilization of CO gas at the furnace increases the heat transfer and indirect reduction, which in turn decreases the requirement of reducing agents for direct reduction [10]. In this furnace, in the absence of bell less top charging system, burden distribution is controlled by two bell charging system consisting of a rotary hopper, a small bell and a large bell. Once the furnace is charged with iron ore, coke and fluxes, the distribution at the furnace top could only be controlled by changing the direction of rotary hopper, controlling the feed rate and changing the order in which the materials are fed in [11].

Preparation of burden for the production of 1 ton of hot metal

Burden load is one of the key operating parameters influencing blast furnace performance. It depends mainly on the chemical and physical properties of iron bearing material and coke. Burden charge for 1 ton of hot metal is presented in Table 7.

Kalugin Shaftless Stoves

The hot blast air is produced by passing cold blast air through stoves, and heating it up to about 1150°C. The stove is first heated up by burning gas and combustion air within the chamber and allowing the heat to be absorbed into the brickwork (chequered work). This mode is called on-gas. When sufficient heat has been absorbed, the stove is put on-blast. In this mode, no combustion takes place, but cold blast air is forced through the stove and absorbs the heat to become hot blast. This is then mixed with cold blast to bring it to the right temperature, and is then forced into the blast furnace via the tuyeres.

Wet gas cleaning system

MBF raw gas at the furnace top is usually contaminated with dust particles. The dust content needs to be removed to improve its calorific value for further use. Primary gas cleaning consists of passing the raw gas from down comer to the dust catcher wherein most of the heavier dust drops out of the gas stream and are deposited at the bottom of the dust catcher. The dust catcher dust so obtained is collected separately. The gas is then passed to a saturator, wherein water is sprayed to remove dust particles and to cool the gas from a temperature of about 140ºC to 70ºC. The temperature of the gas is reduced to prevent the gas from absorbing moisture in venturies. The secondary gas cleaning involves passing the gas to a primary venturi scrubber and a secondary venturi scrubber for more effective particulate removal. Blast furnace gas so obtained is used for heating the stoves and remaining gas is burnt and vented out through flare stack.

RESULTS AND DISCUSSION

Problems faced while Charging Iron ore

Iron ore was found to have as high as 20% of fines (below 10 mm). Because of this, fraction of feed size (10-40mm) has considerably reduced. To compensate this quantity, it was decided to feed 8-10 mm also in the feed. Furthermore, some of the lots were found to contain clay minerals and were found to be sticky. Due to the sticky nature, the iron ore sometimes sticks on to the conveyor belt and onto the liner plate of bunker. This coupled with high fines fraction made it difficult to feed iron ore at the required rate to blast furnace. Due to these problems, the speed of screening was needed to be slowed down, optimized and screens were needed to be cleaned frequently, which has at times resulted in stoppage of charging system.

Descent of charge burden

The blast furnace, except at its hearth, is basically a passage for gases and burden particles that flow in opposite directions. The basic requisite for stable operation of the blast furnace is to maintain a moving layer of the burden which does not fluctuate much. The mechanism for the descent velocity distribution involves the disappearance of ore and coke through their reactions, melting and combustion, the motion of burden particles at the top of the burden layer and near the furnace wall and the infiltration of fine-grained raw material into a coarse-grained layer [12].

It is known that, iron ore has low permeability than sinter/pellets. Hence, during charging, the thickness of iron ore layer is kept minimum as compared to the charge

Table 7: Burden charge for 1 ton of hot metal.

Sl. No	Raw material	Feed Size	Fraction of charge per ton of hot metal (MT)
1	Iron ore	8 – 40 mm	1.50
2	Coke	> 20 mm	0.545
	Nut coke	10 – 20 mm	0.023
3	Limestone	< 50 mm	0.14
4	Dolomite	< 50 mm	0.05
5	Quartzite	< 50 mm	0.01
	Total raw material charge		2.29

burden containing sinter / pellets. In the absence of sinter / pellets, the total raw material charge in the burden for the production of one ton of hot metal using 100% iron ore becomes higher.

Effect of alkali

The menace of alkali is well known and it causes degradation of iron bearing materials and coke as well as premature failure of refractories, thereby adversely affecting the blast furnace performance. It is known that, under conditions of high slag basicity and high hearth temperature, alkalies rapidly accumulate in the furnace. As the alkali concentrations in iron ore and fluxes is much higher, slag basicity was maintained at around 0.90-0.95. To find out the alkali load in blast furnace, analysis of input and output materials were carried out periodically and the results are presented in Table 8.

It can be seen from the Table 8 that, alkali input in ES blast furnace is quite high with wide fluctuations in output and accumulation. Whenever alkali accumulation was high in the furnace, there were hanging inside the furnace and silicon went down drastically. Similar findings were reported by *Kundu et.al (2004)* [13]. Furthermore, the accumulated alkalies decomposed and joined the circulating load inside the furnace instead of getting purged through the slag in front of tuyeres. This has led to high RAFT operation in the range of 2100-2150 deg C. The accumulated alkalies were removed by the process of “flushing and making acidic slag” and during which time, the slag basicity was maintained at 0.85-0.90. Due to repeated flushing, the accumulated alkalies were removed through slag as mentioned in Table 8.

Furnace Top temperature and pressure

Operating the furnace with higher top pressure is advantageous as it enables

a) Better control of silicon in hot metal (as the chances for the reaction between SiO_2 in slag and carbon in coke is lesser [13])

b) Uniform ascent of gases towards furnace top and

c) The quantities of dust removed from the furnace is lesser.

Furthermore, it avoids free movement of material at the top (flooding) and ensures lesser fluidization near tuyeres. Lesser fluidization leads to increased blast acceptance and smooth furnace operation. Considering these factors, the furnace was operated with the top pressure of 0.35 - 0.40 kg/cm^2 throughout the campaign against the designed pressure of 0.4 kg / cm^2. Pressure could not be increased further as GCP is designed only for 0.4 kg/cm^2. The top temperature was maintained between 120-180 ^{o}C.

Hot blast quality

It is known that, increasing hot blast temperature reduces coke rate and improves blast furnace performance. In ES, stoves do not have facilities for oxygen enrichment and steam injection. Hence, the hot blast temperature was maintained at around 920^{o}C and was not increased due to absence of PCI (pulverized coal injection) and steam. Hot blast volume was found to be in the range of 42000-45000 m^3 and hot blast pressure was maintained at 1.3 kgs/cm^2 during normal furnace operation. To compensate for high alkali input RAFT was maintained at 2100-2150^{o}C.

Table 8: Alkali mass balance in MBF.

Period of sampling	Alkali input (kg/THM)	Alkali output (kg/THM)	Alkali accumulation (kg/THM)
June -18	5.41	3.38	+ 2.03
July – 18	5.22	6.72	- 1.50
August – 18	5.76	3.96	+ 1.80

Effect on thermal reserve zone and use of nut coke

The temperature in the thermal reserve zone is approximately equal to the starting temperature of the solution loss reaction ($CO_2 + C = 2CO$), which is an intensive endothermic reaction. If the starting temperature of the reaction (namely the thermal reserve zone temperature) can be lowered, the equilibrium concentration of FeO–Fe reduction reaction will be shifted to higher CO gas utilization efficiency, resulting in the improved CO gas utilization efficiency at the furnace top and the decreased rate of reducing agents.

But, literature study reveals that, in case of fluxed sinter, thermal reserve zone starts at around 850ºC and slightly extended at vertically upward, whereas, in the case of 100% iron ore charge, thermal reserve zone forms at 900ºC. Area under thermal reserve zone is smaller for iron ore as compared to fluxed sinter. As, percentage of indirect reduction is lower in case of 100% iron ore as comparing with sinter charge in burden, fuel rate is higher for 100% iron ore charge [2].

Literature study revealed that, when small size coke is mixed into the ore bed, with the increase in the amount of small size coke, the thermal reserve zone temperature decreases (due to improved contact between coke and iron ore), resulting in the improved CO gas utilization efficiency [14]. Hence, in order to lower the starting temperature of thermal reserve zone temperature, small sized coke namely “nut coke” in the size range of 10-20 mm (23 kgs/THM) is charged with iron ore, whereby CO_2 generated reacts with carbon of nut coke to generate CO, which in turn reduces FeO to Fe. Hence, solution loss reaction can be controlled by adding nut coke. In the absence of control on distribution pattern and control on top pressure, addition of nut coke increases the efficiency of CO gas utilization. Moreover, use of nut coke increases permeability as it is charged with iron ore. Otherwise, charging only iron ore will decrease permeability as the thickness of cohesive zone is higher.

Effect on cohesive zone

The iron bearing material layers start softening and melting in the cohesive zone under the influence of the fluxing agents at the prevailing temperature which greatly reduces the layer permeability that regulates the flow of materials (gas/solid) in the furnace. It is the zone in the furnace bound by softening of iron bearing materials at the top and melting and flowing of the same at the bottom [15].

Cohesive zone consists of a number of ring shaped and semi-molten layers of charge materials. At this zone, the permeability of ascending gases is greatly reduced. The iron oxides in the charge burden is partially reduced in the granular zone before entering the cohesive zone [2]. Literature study reveals that, when only iron ore is used in the burden cohesive zone forms much earlier when compared to sinter in burden, which is due to wide softening-melting range of iron ore viz. 700 - 1300ºC as against 1100-1300ºC for sinter. Such an early formation of cohesive zone decreases the reducibility of iron ore and has resulted in hanging of the furnace.

Tapping practice

Tap to tap cycle (closing to opening) is approximately 1 hour. Tapping speed was controlled by means of drill diameter. Drill diameter was changed from 45 mm-32 mm to have uniform burden descent and for better hearth drainage.

Slag properties

The advantages of low alumina in raw materials were well utilized and due to low alumina in input material, MgO input could be maintained low, which led to low slag volume of 255kgs/THM. The viscosity of slag was found to be less due to less alumina (8.5-9.5%) and slag-metal separation was found to be good. Slag basicity was maintained between 0.92-0.98 during normal operation and between 0.85-0.90 during flushing.

Hot metal chemistry

In the absence of PCI, sinter/pellets and steam injection, control of silicon in hot metal was difficult.

To achieve low coke rate, silicon level was maintained between 0.7-1.0% and hot metal temperature was maintained in the range of 1450-1480ºC. Due to high phosphorus input in iron ore, hot metal phosphorus went up to 0.30%, which was subsequently dephosphorised in EOF and LRF. During this campaign, MBF produced about 56800 tons of hot metal from about 85100 tons of calibrated iron ore and it has achieved a maximum production of 650 TPD against the designed capacity of 500 TPD.

Coke rate

Coke rate is an important parameter in BF operation and is measured as the quantity in kilogram of coke required to produce one ton of hot metal [16]. The average coke rate (coke + nut coke) for the entire campaign was found to be 568 kgs/THM. This coke rate is compared with those of other mini blast furnaces when they were operated with 100% iron ore and the data is presented in Table 9.

It could be seen from Table 9 that, unlike ES blast furnace, other steel plants were using steam injection. The advantage of steam injection is twofold:

a. steam acts as a coolant and due to this the hot blast temperature could be increased.

b. steam dissociates to produce hydrogen which acts as a reducing agent [17]. As hydrogen reduces iron oxide to iron, its formation reduces coke rate.

Owing to these factors other steel plants could operate blast furnaces with lower coke rate. These advantages could not be utilized in ES blast furnace. But, still in the absence of steam injection, ES blast furnace has achieved a coke rate lower than M/s. X steel, which is a feat to reckon with.

Hence, based on these factors, the performance of ES blast furnace is considered to be in par (if not better) with the performance of other blast furnaces mentioned in Table 9.

CONCLUSIONS

1) A mini blast furnace has been successfully recommissioned in Hassia, Syria and the hot metal produced is used for the production of 130 mm^2 mild steel billets.

2) When the country is under reconstruction, recommissioning of ES blast furnace enables providing import substitution for billets and provides support to the country towards self-sufficiency in billet production in the long term.

3) The achievements of mini blast furnace are:

a. Achieved a highest production 650 TPD against the designed capacity of 500 TPD.

b. Achieved an average productivity of 2.4 for the entire campaign

c. Achieved a coke rate of 568 MT/THM during this campaign, which is considered to be a better performance when compared with similar blast furnaces in India.

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