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Additive Enhances Iron Ore Reducibility and Pig Iron Productivity

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The reducibility of iron ore with coke is an important parameter in a blast furnace process which significantly affects the production of pig iron. When iron ore and coke mixed with developed high energetic additive in blast furnace it promotes low temperature iron ore reduction and leads to coke saving. Results of proximate analysis values for moisture, ash, volatile matter and fixed carbon content were 15.28%, 16.62%, 1.02% 67.07% and 14.15%, 15.29%, 0.48% and 70.07% respectively with and without additive. Additive increased metallization of iron (Fe) content from 48.61% to 51.89% and decreased the ferrous oxide (FeO) from 12.26% to 9.28%. Additive reduced the CaO, SiO_2, Al_2O_3 and MgO by 10.90%, 8.31%, 2.79%, and 1.47% respectively which showed improvement of quality of sinter and further reduction of the pig iron sulphur content from 0.22 to 0.08% which reflected improvement in metal product quality. Additive increased the slag chemical composition of CaO, SiO_2, MgO, Al_2O_3 and MnO by 4.79%, 2.62%, 7.35%, 2.82 % and 19.56% respectively and decreased the FeO by 32.23%. Additive reduced the consumption of coke by 700 kg and increased production by 2% resulting saving of coke by 91 kg per ton of pig iron production. Additive increased reducibility, quality and productivity of pig iron with decrease in batch maturing period. Further it exhibited better performance in sintering process and reduced the un-agglomerated material. This paper describes the effect of additive used in the blast furnace process during industrial pig iron production.

Key words: Additives, Blast Furnace, Coke, Iron and steel, Sinter

Introduction

Iron and steel have played an important role in development of the infrastructure and industrial growth of any nation. The Indian government has decided to increase the rural consumption of steel from current 19.6 kg/capita to 38 kg/capita by 2030-31 and exhibited 7.2% growth in the steel sector in 2019–20 and 2020–21 (ISA).[1] The iron manufacturing process is expensive due to high energy requirement for blast furnace heat source and flux, other processing like sintering, milling and coke preparation with more time taking for batch maturing. Efficient and fast production of iron is required to fulfill the nation’s demand as well as to minimize imports from other countries to become *Aatmanirbhar Bharat*, a mission of our Hon’ble prime minister of India.

Iron industry need suitable and innovative technology to reduce the coke and energy demand and to decrease batch maturing period with manufacturing of good quality pig iron. A comprehensive review of research works has been carried out to find a suitable solution for that. Iron ore sintered using waste heat in the green granulated sinter bed undergoes significant changes in its structure and mineralogy due to the formation of liquid in the flame front. These changes influence the sinter reducibility, which is an important parameter influencing the productivity and fuel efficiency of the blast furnace.[2] Reduction of iron ore pellets, sinter, and development of lump reduces the reduction rate in all test conditions.[3]

Mechanically activation has a positive effect on the first step of iron reduction with increasing the grinding time and the activation energy decreased.[4] The kinetic mechanism of reduction of hematite particles was studied in a hydrogen atmosphere and found that the activation energy of the reaction was suggested to be time-dependent for the overall reaction. The variations of activation energy is smoother after a heat treatment, reflecting the heat treatment of raw materials has a significant influence on the reduction kinetics.[5] The fired iron ore pellets reducibility at a temperature of 900°C during 2 hour time intervals is maximum to form iron ore lumps. The degree of reduction is higher in fired iron ore pellets.[6] The increase in metallization process increases the dissolved carbon and reduces porosity in the metal.[7] The injection of non-coking coal into the tuyere hold immense possibilities in reducing the coke in

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the blast furnace.[8] Reducibility decreases with increase in temperature and decrease in pellet size.[9] Additions of lime lower the reducibility of sintered hematite and magnetite ore pellets.[10] The reduction of Fe_2O_3(ferric oxide) by H_2 (hydrogen) confirms the formation of iron layer and get disappear by using CO (carbon monoxide) and rate of reduction increases substantially.[11] The temperature reaction rate and the effect of various gasses composition.[12]

The effect of CaO (calcium oxide) and MgO (magnesium oxide) on the reduction behavior of iron ore showed that oxides accelerate the reduction of iron ore at early phase and depend upon temperature and material compactness.[13] The reducibility of iron ore improves upgrading the iron ore by addition of $CaCO_3$ (calcium carbonate) and leaching process[14] and CaO produced beneficial effect only at high carbon level.[15] The effect of coated hematite pellets with lime increases the percentage of hydrogen in the reducer gas. Duration increases the reduction rate and the amount of Csol/Soot formation on the surface of pellets increases which has negative effect in the soot formation but positive effect on the reduction rate.[16] The reduction of iron oxide pellet with coconut char containing high carbon materials was also studied.[17] Along with saw dust and Bio-oil are the direct reductant during the biomass reduction of Fe_2O_3.[18] Reducibility of iron ore with palm kernel shell pellet increases upon increasing of temperature and it will reduce almost 18.69% of total CO_2 emission.[19]

The highest reduction efficacy was observed when blast furnace dust and anthracite coal was mixed in proper ratios.[20] The presence of copper metal in reduced CuO (copper oxide) doped Fe_2O_3 facilitates the CO_2 catalytic decomposition forming carbon flake.[21] The Rhodium doped Fe_2O_3 shows a higher reducibility as compared to Fe_2O_3 at 650°C..[22] The additive (CaO and FeO) promote the ignition and prevent the oxidation of nitrogen.[23] The catalyzing effect of alkali leads to loss of reaction at a lower temperature and hinders the permeability and the productivity of the blast furnace and showed more problems in blast furnace upon addition of alkali metal.[24] Calcium-rich highly reactive coke decreases the temperature of the thermal reserve zone and increased the reduction degree of sinter.[25] The effect of another additives ($CaCO_3$, Na_2CO_3 and K_2CO_3) on the reducibility of iron ore causes increased temperature within the selected experimental range under specific conditions.[26] $BaCO_3$ (Barium carbonate) catalyzes the reduction process of iron ore when added to coal powder and charged to iron ore.[27] Nickel and chromium (Cr^{3+}) containing additive increases the reducibility of iron oxide.[28]

In the present paper an attempt has been made to describe the industrial trial efficacy of new developed additive upon reduction of iron ore in the manufacturing of pig iron using blast furnace in different condition and their output and to compare with conventional manufacturing process of pig iron quality.

Materials and Methods

The following essential materials were used in the study:

Coke: The coke having low ash (15.29%), low moisture (14.15%), low volatile matter (0.48%) and high fixed carbon (70.07%) used as main reducing agent in reduction of iron ore in blast furnaces.

Iron Ore: The hematite and magnetite ore (Fe 60–62%) in different sizes viz. fines (0–3mm) and chips (30–60mm) were used in this study.

Sinter: Sintering is a thermal lump process that is applied to a mixture of iron ore fines, sponge iron products, fluxes, slag-forming agents, solid fuel (coke) and various additives using waste heat of blast furnace. The sinter mixture was partially melted at a temperature between 1300–1480 °C. The size of sinter used in the process was 40–80mm and having good crushing strength.

Additive: High energetic materials having active points and good catalytic properties prepared by mixing Copper phthalocyanine, Copper ethanolamine and Zinc nitrate prepared by mixing in the ratio of 20:70:10 was used to increase iron ore reducibility and decrease the coke consumption with production of good pig iron quality

Methods

The following experimental steps were conducted on raw materials as well as process for making pig iron.

Coke: Random coke samples were collected, grinded and passed through 200 mesh screens in a ball mill of M/S. Swati Steel and Power Pvt. Ltd., Giridih, Jharkhand and following the procedure detailed in IS: 436 (Part-II). The proximate analysis (Ash, Moisture, Volatile Matter, Fixed Carbon) of coke with and without additive was done as per procedure detailed in IS: 1350 (Part1) 1984.

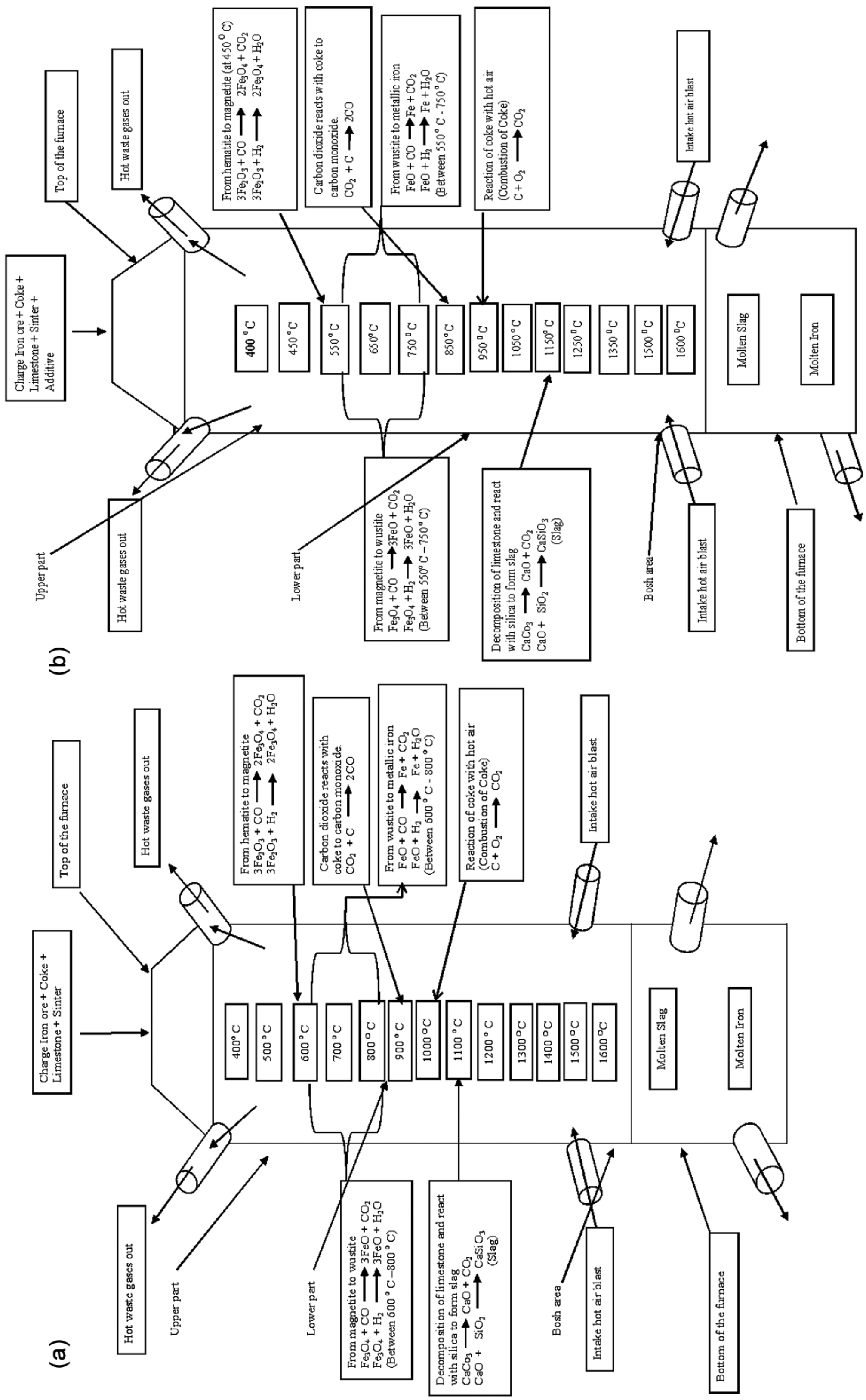

Fig. 1 — The blast furnace process flow chart (a) without and (b) with additive [29,30]

Sinter: A synergetic mixture of iron ore (0–3mm size), lime powder (1–5mm size) and coke dust (Fixed carbon : 62–65%) in ratio of 80:10:10 was charged on the rotary reaction conveyer and waste heat of blast furnace having temperature in 1300–1480°C was applied to study the agglomeration properties. The sinter was discharged from the conveyer at the end of the cycle. The experiments were conducted with addition of catalyst (high energetic additive, iron ore, lime powder, coke dust) in ratio of 1:1000. The chemical composition of sinter cake were analyzed following IS code 1493:1959

Blast furnace: The plant trial experiment was conducted in blast furnace at M/S. Swati Steel and Power Pvt. Ltd., Giridih, Jharkhand, India to study the reducibility of iron ore using manufactured new energetic additive and results were compared without addition of additive. Twenty-eight trials have been conducted in which 14 trials each were conducted with and without using additive. The trials were conducted using additive with a dosage ratio of 1:1000 ratio. The iron ore chips, sinter, limestone and coke in the ratio 50:20:10:20 were charged in the blast furnace and the production cycle and hot metal maturing period along with quality of the pig iron was studied. The comparative study was also conducted with addition of additive with the same experimental conditions. The process flow chart without and with additive are shown in Fig. 1a & 1b.

Quality Evaluation of Pig Iron :

The raw materials used for the production of pig iron in the blast furnace include iron ore, sinter, coke, lime, various aggregates and additives. The pig iron has a carbon content (3.3–4.8%), along with silica and other constituents. The raw materials are regularly charged from the top of the furnace and molten iron (pig iron) and slag are tapped from the bottom of the furnace at regular intervals.

Blast Furnace Slag:

Blast furnace slag is a non-metallic by product produced during the process of iron making in a blast furnace. The chemical composition of slag is depends on the raw material used in the blast furnace process. Slag is usually a mixture of metal oxides, silicon dioxide (SiO_2) and calcium oxide (CaO). However, slags can contain metal oxides and elemental metals. During smelting ore is exposed to high temperatures and the impurities are separated from the molten metal and removed as slag. The effect of additive on slag chemical composition during iron making in blast furnace was studied with and without addition to study the efficacy of the additive.

Results and Discussion

The results of proximate analysis values of coke with and without additive are presented in Table 1. The proximate analysis resulted values for moisture, ash, volatile matter and fixed carbon content were 15.28, 16.62, 1.02 and 67.07% and 14.15, 15.29, 0.48 and 70.07% respectively without and with energetic additive. Addition of additive showed significant positive impact in the coke properties such as decrease of moisture, volatile matter and ash was observed which leads to more fixed carbon content.

Table 1 — Proximate analysis of coke with and without additive

	Without additive				With additive			
Sr. No.	Moisture (%)	Ash (%)	Volatile Matter (%)	Fixed Carbon (%)	Moisture (%)	Ash (%)	Volatile Matter (%)	Fixed carbon (%)
1	16.08	18.95	0.96	64.01	15.20	15.85	0.42	68.53
2	16.59	15.66	0.86	66.89	15.58	15.35	0.51	68.56
3	13.46	15.91	0.91	69.72	13.25	15.25	0.35	71.15
4	15.79	16.41	0.95	66.85	14.44	15.12	0.56	69.88
5	13.51	16.18	0.82	69.49	13.21	15.29	0.50	71.00
6	13.50	15.95	0.95	69.60	13.23	15.37	0.49	70.90
7	15.24	15.88	0.98	67.90	14.55	15.57	0.43	69.45
8	15.49	16.22	1.07	67.22	13.95	15.64	0.45	69.96
9	14.91	15.01	1.31	68.77	13.45	14.88	0.60	71.07
10	16.20	18.52	1.29	63.99	14.42	15.18	0.59	69.81
11	13.97	15.85	1.01	69.17	13.60	15.42	0.47	70.51
12	15.86	15.21	0.99	67.94	13.74	14.85	0.46	70.95
13	16.42	18.04	0.94	64.60	14.86	15.18	0.39	69.57
14	16.92	18.98	1.25	62.85	14.73	15.12	0.51	69.64
Average	15.28	16.62	1.02	67.07	14.15	15.29	0.48	70.07

This is more essential for removal of oxygen from iron ore and also reduced the consumption of coke in the manufacturing of pig iron.[31,32]

The effect of additive on iron ore products after sintering in sinter plant was studied for their composition (Table 2). Compositional analysis of sinter cake results indicated significant changes on iron metallization after addition of additive. The iron metallization increased with additive from 48.61 to 51.89% and decreased FeO from 12.26 to 9.28%. Increase in Fe and decrease in FeO contents provide an indication of improvement in the quality of sinter production.[33] The content of CaO, SiO_2, Al_2O_3, MgO and FeO were 14.21, 10.79, 3.72, 1.89 and 12.26%, respectively without additive and 10.90, 8.31, 2.79, 1.47 and 9.28%, respectively with additive. Reduction of CaO, SiO_2, Al_2O_3, MgO and FeO improves the properties of sinter with respect to strength, quality, good flowability, viscosity and desulphurization in sinter formation, which exhibited improvement of quality of sinter.[34] Further, reduction of SiO_2 reduces the magnetic content of the sinter consequently the reducibility enhances.[35] Overall un-agglomerated material was reduced by the use of additive.

Present study optimized the dose of additive and coke ratio as 1:1000 (Tables 3, 4 & 5 and Fig. 1a, 1b & 2). The efficacy of pig iron was studied to understand the techno-economic comparison to evaluate the saving of the coke per ton of hot metal production. It is found that consumption of hard coke

Table 2 — Chemical compositional analysis of sinter with and without additive

Sr. No.	Sinter without additive CaO (%)	SiO_2 (%)	Al_2O_3 (%)	MgO (%)	FeO (%)	Fe (%)	Sinter with additive CaO (%)	SiO_2 (%)	Al_2O_3 (%)	MgO (%)	FeO (%)	Fe (%)
1	11.50	9.50	4.15	2.01	13.88	49.70	10.21	6.98	3.01	1.78	8.58	50.95
2	14.65	9.88	3.06	1.93	12.38	48.81	9.24	7.88	2.92	1.35	7.98	52.15
3	13.57	8.94	3.03	1.80	12.52	50.16	12.89	7.84	2.90	1.40	10.22	52.16
4	18.96	12.49	4.29	1.93	10.09	45.02	11.20	8.82	2.96	1.39	9.67	52.25
5	14.52	10.23	3.12	1.83	12.53	48.68	11.29	8.89	2.90	1.41	10.12	52.02
6	14.44	10.54	3.25	1.87	12.21	48.86	10.96	8.49	2.79	1.63	10.09	51.02
7	14.56	11.02	3.95	1.89	12.32	47.44	12.52	7.52	3.02	1.66	7.53	52.06
8	14.59	10.59	4.12	1.88	11.98	48.65	11.23	8.98	2.58	1.60	9.48	53.14
9	13.89	11.61	3.88	1.87	13.11	48.05	11.84	8.63	2.85	1.42	9.32	50.65
10	14.09	9.97	4.11	1.92	12.31	49.50	10.97	8.56	2.74	1.34	9.28	52.63
11	13.88	11.65	3.51	1.89	13.08	48.25	11.16	8.69	2.75	1.32	10.04	52.45
12	12.98	12.04	3.21	2.04	12.88	49.02	10.24	8.44	2.61	1.33	9.97	52.48
13	13.50	11.20	4.18	1.82	11.49	48.95	9.02	8.40	2.88	1.53	8.84	50.12
14	13.81	11.40	4.22	1.83	10.95	49.55	9.96	8.25	2.21	1.50	8.81	52.51
Average	14.21	10.79	3.72	1.89	12.26	48.61	10.90	8.31	2.79	1.47	9.28	51.89

Table 3 — Raw material input and pig iron production without additive

Sr. No.	Coke (Kg)	Iron Ore (Kg)	Sinter (Kg)	Iron Ore + Sinter (Kg)	Iron Ore in Sinter + IO (%)	Pig Iron in (MT)	Pig Iron in (Kg)	Iron in Iron Ore + Sinter (%)
1	114600	69500	214350	283850	0.24	150.00	150000	52.84
2	147200	104700	271000	375700	0.27	204.65	204650	54.47
3	129100	64400	231200	295600	0.21	163.56	163560	55.33
4	137600	82950	227100	310050	0.26	180.60	180600	58.24
5	97920	60400	162100	222500	0.27	98.55	98550	44.29
6	112500	68400	211250	279650	0.24	135.20	135200	48.34
7	135610	93450	229250	322700	0.28	183.23	183230	56.78
8	112000	67500	210500	278000	0.24	134.50	134500	48.38
9	96520	61400	163200	224600	0.27	123.45	123450	54.96
10	140500	79800	269900	349700	0.22	201.10	201100	57.50
11	116000	72200	223400	295600	0.24	153.20	153200	51.82
12	76500	41200	170431	211631	0.19	85.10	85100	40.21
13	150100	82600	281550	364150	0.22	203.03	203030	55.75
14	78450	39379	168739	208118	0.18	84.50	84500	40.60
Average	115665	69767	218263	288031	0.24	146.25	146250	50.77

IO = Iron Ore, S = Sinter, M = Moisture, MT = Metric Ton, Kg = Kilogram

Table 4 — Raw materials input and pig iron production with additive

Sr. No.	Coke (Kg)	Iron Ore (kg)	Sinter (Kg)	Iron Ore + Sinter (Kg)	Iron Ore in Sinter + IO (%)	Pig Iron (MT)	Pig Iron in (Kg)	Iron in Iron Ore + Sinter (%)
1	67000	31492	146190	177682	0.17	87.21	87210	49.08
2	87388	46309	208182	254491	0.18	132.24	132240	51.96
3	94422	48518	221367	269885	0.18	140.40	140400	52.02
4	96200	49250	222100	271350	0.18	143.45	143450	52.86
5	116200	71800	224100	295900	0.24	170.35	170350	57.57
6	78550	41600	223527	265127	0.15	138.99	138990	52.42
7	81869	41144	211149	252293	0.16	129.32	129320	51.25
8	65751	25182	149993	175175	0.14	86.80	86800	49.55
9	142300	80400	271100	351500	0.22	215.50	215500	61.30
10	122300	66700	208900	275600	0.24	148.35	148350	53.82
11	96500	58500	191300	249800	0.23	128.20	128200	51.32
12	93240	57020	161020	218040	0.26	114.70	114700	52.60
13	91643	42953	214335	257288	0.16	133.80	133800	52.00
14	89586	51200	205005	256205	0.20	133.20	133200	51.98
Average	90986	48825	197684	246509	0.19	129.95	129950	52.71

IO = Iron Ore, S = Sinter, M = Moisture, MT = Metric Ton, Kg = Kilogram

Table 5 — Saving of coke with additive

Sr. No.	Description	Coke (Kg)
1	Coke consumption per ton of pig iron without additive	791
2	Coke consumption per ton of pig iron with additive	700
3	Coke saving per ton of pig iron with additive	91
4	Coke consumption saving per day	1763
5	Coke consumption saving in 14 days	24679

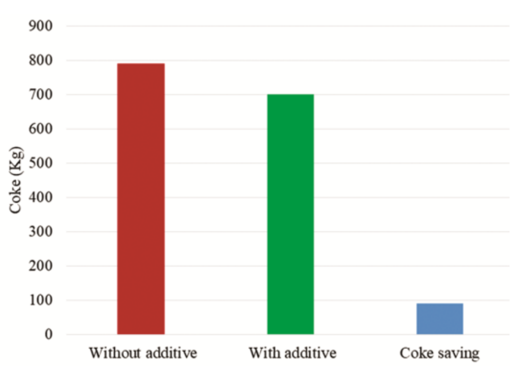

Fig. 2 — Coke consumption per ton of pig iron and coke saving with additive

per metric ton of hot metal without additive was 791 kg, however, with additive coke consumption reduced to 700 kg which leads to 91 kg saving of coke per ton of hot metal production. Additive significantly reduced the hard coke consumption resulting per day saving of coke by 1763 kg. The experiment of 14 days trial in pig iron plant resulted in the saving of 24679 kg of coke along with improved good quality of pig iron. The duration of batch maturing time was reduced by 8–10 minutes. The result revealed that production increased by 1.94%. It showed saving of time, reduced consumption of coke and greater production of pig iron. It is opined that additive plays an important role in the iron ore reducibility and enhancement of quality of pig iron our observation was in conformity with the other workers.[22,26,36]

The composition and impact of additive on composition of pig iron are given in Table 6. Result showed the trends of impact of additive upon chemical constituents of pig iron. The values of pig iron compositional analysis for C, Si, Mn and S content were 3.78%, 1.90%, 0.30%, and 0.24% without additive and 3.34 %, 1.26%, 0.23%, 0.08% with additive respectively. Addition of additive decreased C, Si, Mn significantly which lead to energy efficient and improvement of pig iron quality.[34] Reduction in sulphur from 0.22% to 0.08% showed that additive accelerate the reaction, desulphurization simplifies the process and lowers the cost of agglomeration and smelting [37,38] which lead to quality product of the pig iron.

The result of composition of slag is given in Table 7. Result indicated significant changes in the composition of slag during pig iron production. FeO content was 1.21% without additive and it is reduced to 0.82% after addition of additive. The CaO and SiO_2 content enhanced from 33.97% and 32.05 to 35.60% and 32.89 respectively after addition of additive. Similarly other important chemical constituents such as, Al_2O_3, MgO and MnO which were 22.31, 6.39 and 0.46%, respectively have increased to 22.94, 6.86 and 0.55% with additive in slag formation. Increase in CaO and SiO_2 enhances the reducibility of the Iron

Table 6 — Chemical composition analysis of pig iron with and without additive

	Pig iron without additive				Pig iron with additive			
Sr. No.	C (%)	Si (%)	Mn (%)	S (%)	C (%)	Si (%)	Mn (%)	S (%)
1	3.90	2.22	0.35	0.23	3.38	1.21	0.26	0.08
2	3.86	1.43	0.36	0.31	3.26	1.17	0.22	0.07
3	3.73	1.80	0.33	0.15	3.33	1.28	0.25	0.06
4	3.75	1.92	0.29	0.17	3.42	1.27	0.23	0.09
5	3.73	1.87	0.27	0.21	3.26	1.32	0.24	0.08
6	3.81	1.44	0.31	0.26	3.35	1.23	0.25	0.09
7	3.65	1.45	0.32	0.38	3.49	1.33	0.23	0.11
8	3.78	2.12	0.28	0.19	3.65	1.25	0.21	0.07
9	3.90	2.48	0.32	0.25	3.20	1.30	0.25	0.08
10	3.68	1.98	0.30	0.22	3.45	1.25	0.24	0.07
11	3.74	1.74	0.29	0.24	3.46	1.31	0.26	0.11
12	3.75	1.61	0.31	0.29	3.21	1.29	0.25	0.09
13	3.69	2.40	0.25	0.20	3.25	1.30	0.21	0.06
14	3.95	2.20	0.25	0.27	3.15	1.26	0.20	0.08
Average	3.78	1.90	0.30	0.24	3.34	1.26	0.23	0.08

Table 7 — Compositional analysis of slag with and without additive

	Slag without additive						Slag with additive					
Sr. No.	CaO (%)	SiO_2 (%)	MgO (%)	Al_2O_3 (%)	FeO (%)	MnO (%)	CaO (%)	SiO_2 (%)	MgO (%)	Al_2O_3 (%)	FeO (%)	MnO (%)
1	34.93	31.98	6.40	21.84	1.26	0.35	35.98	32.40	6.75	22.89	1.04	0.45
2	33.68	31.35	6.19	22.23	1.16	0.64	35.68	32.85	6.86	23.09	0.86	0.72
3	33.69	32.42	6.34	22.23	1.28	0.44	34.74	33.49	6.88	22.83	0.82	0.54
4	32.20	32.70	6.63	22.39	1.50	0.56	35.56	33.55	6.91	22.92	0.95	0.63
5	34.67	32.13	6.55	22.59	1.03	0.43	36.01	32.91	6.89	23.01	0.61	0.55
6	34.65	32.25	6.22	22.41	1.25	0.41	35.20	33.20	6.80	22.99	0.79	0.51
7	34.21	32.84	6.42	22.23	1.27	0.48	35.67	33.33	6.92	22.89	0.92	0.57
8	34.32	33.01	6.23	22.40	1.22	0.46	36.16	33.84	6.80	22.96	0.86	0.53
9	34.64	31.98	6.22	22.30	1.42	0.49	35.01	32.79	6.78	22.84	0.98	0.56
10	33.94	31.05	6.21	22.26	1.38	0.44	34.89	32.01	6.80	23.06	0.90	0.52
11	34.01	32.01	6.32	22.56	1.10	0.51	35.04	32.88	6.86	22.98	0.74	0.60
12	33.92	31.56	6.50	22.62	0.98	0.45	35.01	32.48	6.93	23.02	0.64	0.52
13	33.72	31.66	6.94	22.19	0.91	0.49	37.42	32.34	7.04	22.87	0.59	0.56
14	33.04	31.88	6.36	22.12	1.26	0.42	36.06	32.44	6.87	22.83	0.88	0.49
Average	33.97	32.05	6.39	22.31	1.21	0.46	35.60	32.89	6.86	22.94	0.82	0.55

ore,[26] which indicate increase of finished product quality and product yield.[39] Thus the new developed energetic additive can play an important role in reducibility of the iron ore and resulted into high quality production and saving of coke and time.

Conclusions

On the basis of experimental results with and without addition following conclusions were drawn.

- Additive leads to the decrease in coke moisture by 7.39%, vm (volatile matter) by 52.94% and ash by 8.00%. Fixed carbon, an essential constituent for making pig iron, increased by 4.47% in comparison to without additive leads to reduced coke consumption per ton of hot metal production.
- Additive resulted in reduced consumption of coke by 91 kg/ton of pig iron production. The additive showed positive catalytic effect in the reaction.
- The coke consumption was significantly reduced and per day saving of coke is 1763 kg/day.
- Analysis result of sintered iron ore indicated decrease in CaO, SiO_2, Al_2O_3, MgO and FeO by 23.29%, 22.98%, 25.00%, 22.22% and 24.30%, respectively and Fe (Iron) is increased by 6.74% , it reflects the high reducibility
- The pig iron chemical compositional analysis resulted in a decrease in C by 11.64%, Si by 33.68%, Mn by 23.33% and S by 66.66%. Reduction in sulphur content has sign of improvement in the quality of pig iron.

- The chemical compositional analysis of slag with additive the value are increased by CaO by 4.79%, SiO_2 by 2.62%, MgO by 7.35%, Al_2O_3 by 2.82%, MnO (Manganese II oxide) by 19.56% and FeO is decreased by 32.23%. Slag composition results indicate improvement of productivity and quality of the finished product.
- The additive resulted in an increase in pig iron production by 2%.
- The batch maturing period reduced by 8–10 minutes after addition of additive.

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