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Study the effect of catalyst (THERMACT-BF) on reduction behavior of iron-ore

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ABSTRACT

Iron ore is the raw material used to make pig iron, which is one of the main raw materials to make steel. 98% of the mined iron ore is used to make steel. Coke is used as a reducing agent in smelting iron ore in a blast furnace The carbon monoxide produced by its combustion reduces iron oxide (hematite) in the production of the iron product. But there is a problem associated with iron and steel industry firstly: increasing in the cost of coke (coking coal) and their quality and secondly: the reduction of iron oxide with coke in blast furnace is done completely or not which directly affected the production of pig iron. In this paper we describe about a catalyst (THERMACT-BF) after addition of catalyst on iron ore with hard coke. We found that coke quality increased. The degree of reduction of iron oxide with coke also increased as well as production of pig iron increased. The study of the catalyst THERMACT – BF on hard coke with iron ore it was observed that the efficiency of reduction of Iron Ore and Coke increased on addition of THERMACT-BF in the Blast furnace without any ill effect on the system.

Keywords: Thermact-BF, Iron Ore, coke, Blast Furnace, Reduction.

INTRODUCTION

The Iron ores are usually rich in iron and vary in color from dark grey, bright yellow, deep purple, to rusty red. The iron itself is usually found in the form of magnetite (Fe_3O_4,72.4% Fe), hematite (Fe_2O_3, 69.9% Fe), goethite (FeO(OH), 62.9% Fe), limonite (FeO(OH).n(H_2O)) or siderite ($FeCO_3$, 48.2% Fe). Ores carrying very high quantities of hematite or magnetite (greater than ~60% iron) are known as "natural ore" or "direct shipping ore", meaning they can be fed directly into iron-making blast furnaces. Iron ore is the raw material used to make pig iron, which is one of the main raw materials to make steel. 98% of the mined iron ore is used to make steel [1].

Production of steel through the conventional blast furnace and basic oxygen furnace route requires good quality coking coal, which India has limited reserve. Coke making is extremely problematic [2,3]. While coking coal reserves are 15 percent only. Therefore, evolution of a technology for the reduction of iron ore using abundantly available non coking coal was contemplated, giving birth to Direct Reduced Iron Technology (DRI) .Sponge Iron is the main product obtained by Direct Reduction Process. Iron Ore (Hematite) and non-coking coal are prime raw material for the production of Reduced Iron .These are charged into a rotary kiln/furnace in requisite proportion along with some limestone/ dolomite [4,5,6,7,8,9,10,]. Using pre-reduced ore as a raw material in the blast furnace is effective in increasing the blast furnace productivity and decreasing the reducing agents rate [11]. On iron oxide direct reduction with carbon they showed that the reaction proceeded in two stages:1) The reduction of an oxide to a sub –oxide or to a metal: and 2) the generation of carbon monoxide according to the bourdourd reaction . Specially,

hematite was reduced to magnetite, then to wustite, and finally to metallic iron. Carbon dioxide produced by the reaction subsequently react with solid carbon to produce more carbon monoxide. The regeneration reaction was found to control the overall reaction rate. [12].

The reduction of iron oxide is a gas–solid reaction, which has been extensively studied in the process conditions test, energy saving and reducing consumption [13-17]. The knowledge about the reduction characteristics and fundamental mechanisms is investigated from several aspects. Rao investigated the reduction kinetics of a mixture of hematite and carbon powders in the temperature range of 850～1087°C, and the isothermal weight loss of the samples was determined as a function of time. Precipitated iron oxide samples were characterized using temperature-programmed reduction in H_2 [18,19]. Pineau et al. discussed the reduction of Fe_2O_3 by H_2 in the temperature range of 220～680°C and the reduction of Fe_3O_4 by H_2 in the temperature range of 210～950°C. Ding et al. applied thermogravimetry to estimate the kinetics of isothermal reduction of the carbon bearing pellets in the temperature range of 1000～1400°C. The reduction roasting of chromite overburden with $CO/CO_2/N_2$ gas mixture in the temperature range of 700～750°C has been studied 20, 21,22,23]. Luo et al. Presented a novel iron making technology using biomass and iron oxide. The effects of briquettes composition, reduction temperature, reaction time and reducing gas composition on the quality of metallic iron were discussed [24]. It have been reported that the chemical composition and physical properties of the ore, the temperature and time of reduction besides some additives all of which can affect the reducibility of iron oxides (Stephenson and Smailer, 1980; Bryk and Lui, 2004; Lee *et al.,* 1997 and Lu and Huang, 2003) [25]. It can be seen that addition of BaCo3 to the coal considerably increases reduction degree. Researcher has pointed out the catalytic effect of $BaCO_3$ on the reduction process [26]. The reduction of iron oxide by solid carbon overall reduction is governed by the availability of reducing gas (CO) which produce by gasification of carbon in accordance with the reduction (CO2 + C = 2CO) which is commonly known as the Boundouard reaction (Biswas, 1981) Rao and Han (1984) reported that the rate of the carbothermic reduction of iron oxides is markedly improved by the addition of alkali oxides catalysts. The catalyst promotes the gasification reaction and ensures adequate supply of reducing gas, which in turn enhances the rate of reduction. Anhydrous alkali carbonate in a powder form of sodium, potassium and calcium of reagent grade were used as additives. coke reduction additive Na_2CO_3, K_2CO_3 and $CaCO_3$ system have effective influence of the reducibility of the ore. The degree of reduction has been found to increase with increasing additive amount and temperature within the selected experimental range and conditions [27].

M/s. Abhitech Energycon Ltd. have introduced recently developed thermo-active combustion catalysts THERMACT-BF for improving the combustion and reduction efficiency in the blast furnace to manufacture good quality of metal with less consumption of fuel [28].

This paper describes the effect of THERMACT-BF on the reduction behavior of iron ore in the blast furnace.

EXPERIMENTAL SECTION

The following experiments were conducted to investigate the performance and efficacy of THERMACT-BF on reduction behavior of iron ore with hard coke.

2.1 Sample Preparation

Sampling of hard coke and iron ore was done as per the procedure prescribed in IS:436(Part-II) and crushed in 200 Mesh. The coke and **THERMACT-BF** ratio was maintained 1:6000 . The sample of iron ore for TGA and for reduction studies was prepared in 73:27 ratio for Iron Ore Coke and **THERMACT-BF** was added in the ratio of 1:6000 of coke.

2.2 Proximate Analysis

Proximate analysis of **THERMACT-BF**, hard coke with and without **THERMACT-BF** was conducted using compositional analysis method prescribed for inherent moisture, ash, volatile matter and fixed carbon in IS:1350 (Part-1) 1984. The 300 g sample for investigation were prepared as per the method prescribed in IS:436(part1/Section 1)-1964 and IS:436(Part II)-1965. The results are shown in Table 1 & 2.

Table 1: Proximate analysis of THERMACT-BF

Moisture (%)	Volatile Matters (%)	Ash (%)	Fixed Carbon (%)
6.50±0.5	17.10±0.5	10.48±0.5	65.92±0.5

Table 2: Proximate analysis of coke with and without THERMACT-BF

Hard Coke				Hard Coke + THERMACT-BF			
Moisture (%)	Volatile Matters (%)	Ash (%)	Fixed Carbon (%)	Moisture (%)	Volatile Matters (%)	Ash (%)	Fixed Carbon (%)
3.12±0.2	1.98±0.2	13.0±0.5	81.90±0.5	3.10±0.2	2.00±0.2	13.23±0.5	81.67±0.5

2.3 Gross Calorific Value

Constant volume in oxygen saturated with water vapor, the original material and final products being at approximately 25 ^{o}C. The results of investigation are given in Gross Calorific value of both the samples was studied using bomb calorimeter and method prescribed in IS: 1350 (Part-2) 1984. The gross calorific value at constant volume is the one usually used in the characterization of energetic materials especially in case of coal and coke. It is assumed that all the heat produced is available, including the heat of condensation of any steam, resulting from the combustion of hydrogen of the fuel, to water at room temperature. Number of heat units liberated when a unit mass of the fuel is burnt at Table 3.

Table 3: Calorific value of hard coke with and without THERMACT-BF

Gross Calorific Value (Kcal/kg)			
Hard Coke		Hard Coke + THERMACT-BF	
Air Dried Basis (adb)	Dried Basis (db)	Air Dried Basis (adb)	Dried Basis (db)
6314	6461	6432	6504

2.4 Compositional Analysis

The compositional analysis of iron ore was done using chemical analysis method. The results of iron ore are shown in Table 4 & 5.

Table 4: Compositional analysis of iron ore

Sr. No.	Constituents	Percentage (%)
1.	Fe (Total)	64.23
2.	Fe_2O_3	91.34
3.	Al_2O_3	2.64
4.	SiO_2	1.32
5.	TiO_2	0.08
6.	MnO	0.02
7.	Loss on Ignition	4.60

Table 5: Effect of THERMACT-BF on ash and moisture analysis of iron ore and coke composite composition

Iron Ore +Coke				Iron ore +Coke + THERMACT-BF			
Moisture adb (%)	Moisture db (%)	Ash adb (%)	Ash db (%)	Moisture adb (%)	Moisture db (%)	Ash adb (%)	Ash db (%)
1.00	1.32	71.48	72.20	0.92	1.14	70.33	70.98

2.5 Thermo Gravimetric Analysis (TGA)

Thermo gravimetric analysis (TGA) is a thermal analysis technique which measures the amount and rate of change in the weight of a material as a function of temperature or time in a controlled atmosphere. TGA measurements are used primarily to determine the composition of materials and to predict their thermal stability up to elevated temperatures. However, with proper experimental procedures, additional information about the kinetics of decomposition and in-use lifetime predictions can be obtained.

CONSTANT HEATING RATE TGA

The constant heating rate, or conventional TGA, approach is based on the Flynn & Wall method which requires three or more determinations at different linear heating rates, usually between 10 and 25 ^{o}C/minute.

The approach assumes the basic Arrhenius equation.

$$\left[\frac{d\alpha}{dt}\right] = Z\exp\left(-Ea/RT\right)(1-\alpha)^n$$

Where:
α = fraction of decomposition
T = time (seconds)
Z = Pre-exponential factor (1/second)
Ea = activation energy (j/mole)
R = Gas constant (8.314 j/mole K)
n = reaction order (dimensionless)

The effect of THERMACT-BF on the thermal behavior of coke and iron ore was studied using Thermo Gravimetric Analyzer (TGA Model TG-50 and TA Processor TC-11 Mattler). The Differential Thermo gram (DTG) of coke with THERMACT-BF at 10, 15, 20, 25 and 30^oC were run and impact of THERMACT-BF on the ignition temperature, peak temperature, combustion behavior and residual matters were studied. The photograph 1 shows the TGA and Figure 1-3 shows the Differential Thermogram (DTG) as an example for THERMACT-BF, Coke, Coke+ THERMACT-BF, Iron ore + Coke and Iron Ore + Coke + THERMACT-BF respectively. The Table 6-8 shows the results at different heating rates. The reduction behavior of iron ore in presence of coke with and without THERMACT-BF was also conducted in isothermal as well as dynamic condition.

TGA Parameters of Differential Thermogram (DTG)

Sr. No.	Step Analysis Parameters	Screen Parameters
1.	Dyn/ISO 1 or 2	1
2.	Autolimit 0 or 1	1
3.	Start Temperature ^oC	25
4.	End Temperature ^oC	800
5.	Baseline type	1
6.	Plot cm	10
7.	Plot Mode	2091
8.	Mole Mass Gas	0
9.	Mol Mass Init.	0
10.	Sample ID. No.	As per the sample Taken
11.	Rate of Heating ^oC/Minute	10, 15, 20
12.	Weight mg	As per the sample taken
13.	End Screen Temperature ^oC	795-797.3

Photograph 1: Thermo Gravimetric Analyzer (Model TG-50, Mattler)

Table 6: Results of DTG of THERMACT-BF

Sr. No.	Rate of Heating (°C/Min.)	Peak-1	Peak-2	Residual Matter
1	10	ST 28.7 PT 72.7 ET 171.7 Loss % 13.215	ST 171.7 PT 527.3 ET 729.0 Loss%72.098	Temp. 797.3°c δm mG 2.665 δm % 14.523
2	20	ST 29.0 PT 93.0 ET 177.0 Loss % 14.050	ST 177.0 PT 549.0 ET 793.0 Loss % 74.410	Temp. 795.3°c δm mG 3.200 δm % 12.559
3	25	ST 28.8 PT 100.0 ET 178.8 Loss % 13.553	ST 178.8 PT 568.8 ET 793.7 Loss % 68.155	Temp. 794.2°c δm mG 4.600 δm % 18.018

Table 7: Results of DTG of Hard coke + THERMACT-BF

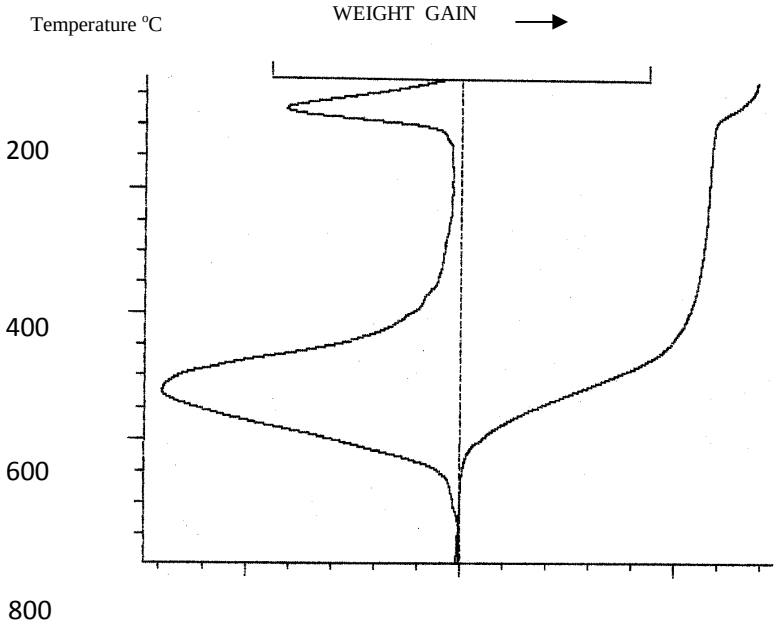
Sr. No.	Rate of Heating (°C/Min)	Peak-1	Peak-2	Residual Matter
1	10	ST 28.7 PT 43.3 ET 344.0 Loss % 4.215	ST 344.0 PT 699.7 ET 795.0 Loss % 84.224	Temp.797.3 °C δm mG 1.890 δm % 11.382
2	15	ST 28.8 PT 51.3 ET 276.3 Loss % 3.905	ST 276.3 PT 733.8 ET 793.8 Loss % 70.915	Temp.796.5°C δmmG 4.740 δm % 24.358
3	20	ST 25.0 PT 53.0 ET 401.0 Loss % 4.510	ST 401.0 PT 789.0 ET 793.0 Loss % 55.032	Temp.795.3 °C δm mG 7.080 δm % 39.921

Table 8: Results of DTG of Iron Ore + Hard coke

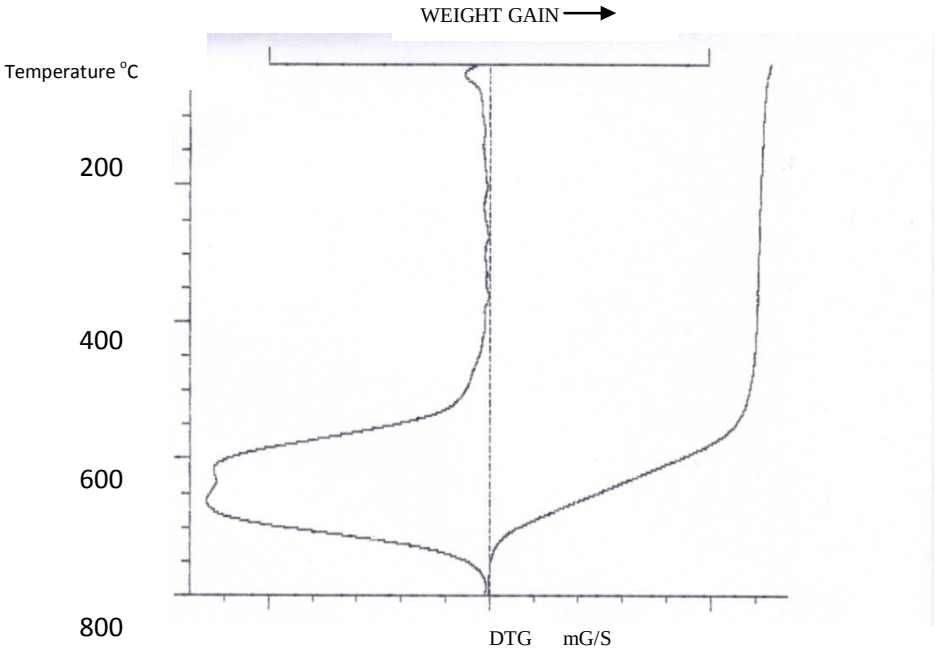
Sr. No.	Rate of Heating (°C/Min.)	Peak-1	Peak-2	Peak-3	Residual Matter
1	10	ST 25.0 PT 43.3 ET 380.7 Loss% 8.7098	ST 380.7 PT 630.0 ET 795.0 Loss% 28.375	No third peak	Temp.797.3 °C δm mG 12.570 δm % 62.740
2	15	ST 48.8 PT 67.5 ET 240.0 Loss% 2.1193	ST 240.0 PT 285.0 ET 375.0 Loss% 2.4188	ST 375.0 PT 663.8 ET 795.0 Loss % 25.962	Temp.796.5°C δmmG14.720 δm % 67.818
3	20	ST 29.0 PT 53.0 ET 237.0 Loss% 4.7189	ST 237.0 PT 285.0 ET 373.0 Loss% 2.3012	ST 373.0 PT 721.0 ET 793.0 Loss% 25.430	Temp. 795.3 °c δm mG 11.550 δm % 67.288

Table 9: Results of DTG of Iron Ore + Hard coke + THERMACT-BF

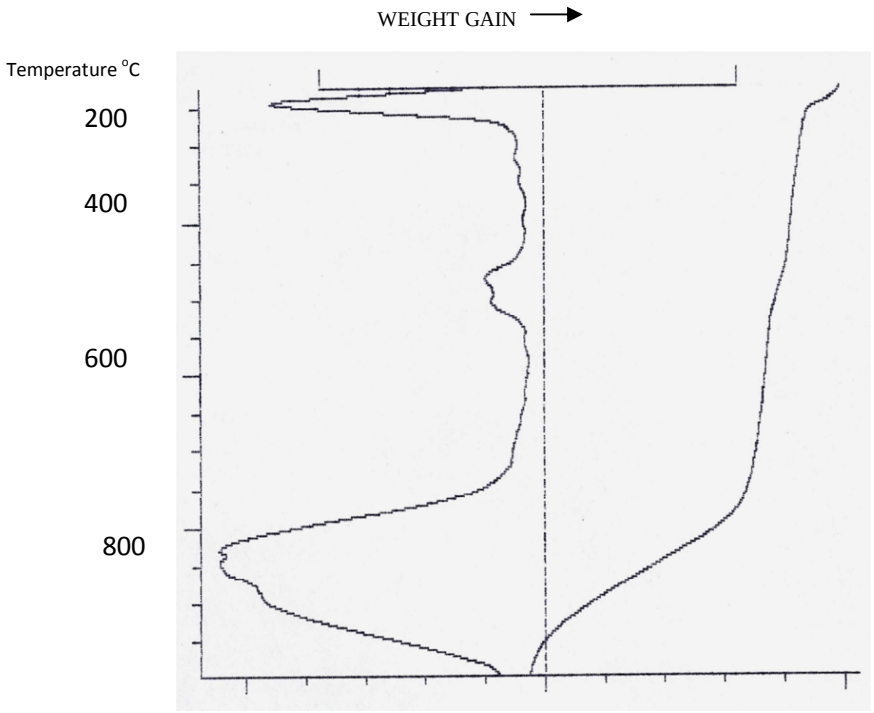
Sr. No.	Rate of Heating (°C/Min.)	Peak-1	Peak-2	Peak-3	Residual Matter
1	10	ST 28.7 PT 47.0 ET 179.0 Loss% 4.7786	ST 179.0 PT 281.7 ET 347.7 Loss% 2.243	ST 347.7 PT 630.0 ET 795.0 Loss% 28.457	Temp.797.3°C δmmG 16.490 δm % 64.326
2	15	ST 28.8 PT 51.3 ET 208.8 Loss% 5.253	ST 208.8 PT 283.8 ET 355.0 Loss%2.3133	ST 355.0 PT 655.0 ET 790.0 Loss%30.160	Temp.796.5 °C δm mG 12.800 δm% 61.687
3	20	ST 25.0 PT 53.0 ET 189.0 Loss%5.0105	ST 189.0 PT 297.0 ET 365.0 Loss% 3.0420	ST 365.0 PT 669.0 ET 793.0 Loss% 9.0665	Temp.795.3 °C δm mG 10.040 δm % 59.887



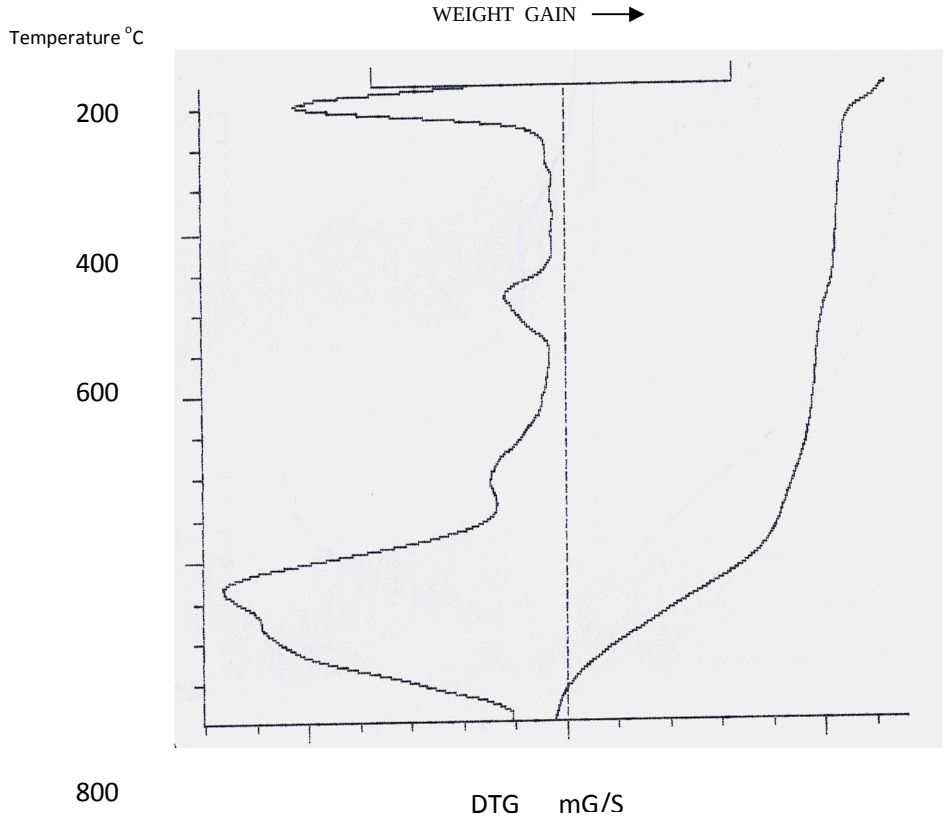
STEP		STEP		RESIDUE	
START TEMP. °C	29.0	START TEMP. °C	177.0	TEMPEPRATURE °C	795.3
PEAK TEMP. °C	93.0	PEAK TEMP. °C	549.0	δm mG	3.200
END TEMP. °C	177.0	END TEMP. °C	793.0	δm %	12.559



STEP		STEP		RESIDUE	
START TEMP. °C	28.7	START TEMP. °C	344.0	TEMPEPRATURE°C	797.3
PEAK TEMP. °C	43.3	PEAK TEMP. °C	699.7	δm mG	1.890
END TEMP. °C	344.0	END TEMP. °C	795.0	δm %	11.382



STEP		STEP		STEP		RESIDUE	
START TEMP. °C	29.0	START TEMP. °C	237.0	START TEMP. °C	373.0	TEMPEPRATURE °C	795.3
PEAK TEMP. °C	53.0	PEAK TEMP. °C	285.0	PEAK TEMP. °C	721.0	δm mG	11.550
END TEMP. °C	237.0	END TEMP. °C	373.0	END TEMP. °C	793.0	δm %	67.288



STEP		STEP		STEP		RESIDUE	
START TEMP. °C	28.7	START TEMP. °C	179.0	START TEMP. °C	347.7	TEMP. °C	797.3
PEAK TEMP. °C	47.0	PEAK TEMP. °C	281.7	PEAK TEMP. °C	630.0	δm mG	16.490
END TEMP. °C	179.0	END TEMP. °C	347.7	END TEMP. °C	795.0	δm %	64.326

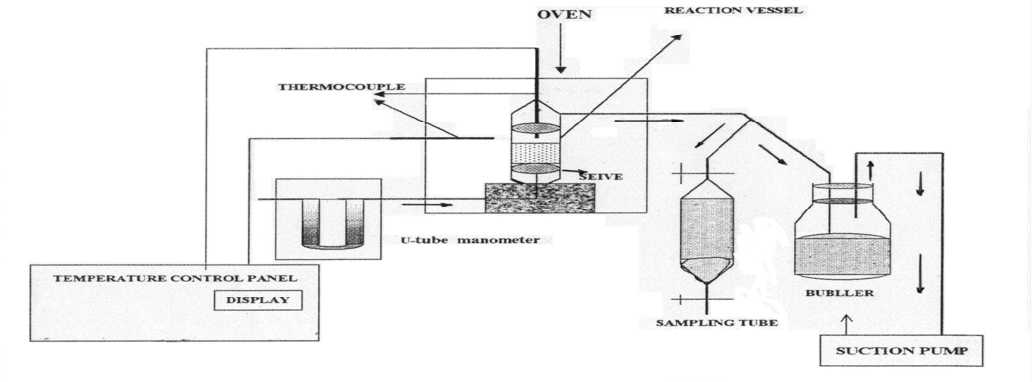


Figure 5: Set up for Thermal decomposition study

6. Gas Evolving at Elevated Temperature

100 g grinded sample of Hard coke, Hard coke+ THERMACT-BF, Iron Ore + Hard Coke and Iron Ore + Hard Coke+ THERMACT-BF were kept in the reactor and heated at elevated temperature in specially designed experimental set-up (Figure 5 & Photograph 2-3). Air samples were collected from the discharge of the reactor at

temperature 950 ^{o}C. The collected sample were analyzed by Gas Chromatograph to determine the gases given off by the products during reduction of the iron ore. Table 10-11 showed the results of gases evolved during combustion of coke and reduction of iron ore with and without THERMACT-BF. Figure 6-9 showed the GC graph for gases evolved during burning of coke and reduction of iron ore with and without THERMACT-BF.

Description of the set-up

The device consists of a microprocessor based programmable rate of heating electrical furnace having a heating chamber of Dimension 450 x 400 x 400 mm internal cross section. A reaction vessel in 150mm length and internal diameter 37.5mm made of 4.mm thick brass was fitted vertically in the heating chamber. The Lower end of reaction vessel is connected with a flow meter through a tube while upper end is connected with air sampling arrangement and a suction pump for establishment of airflow in the vessel. The internal arrangement inside the vessel are such that known weight the sample is placed over a wire net less than 0.2mm pore size and packed with glass wool. The purpose of the wire net is uniform distribution of air velocity inside the vessel to measure temperature of the sample a sensitive thermocouple is inserted in the vessel. The system has facility for heating at constant temperature or heating at known rate. In the system bath temperature and sample temperature are instantaneously displayed on programmable control panel.

The sample was charged carefully in the reaction vessel and remaining arrangements were made as shown in Figure 5 above. After making the arrangements leak less, flow rate of air in the range of 0.1 to 0.4 m/min (80 – 90 cc/min) inside the vessel was established with the help of suction pump and a flow meter connected with opposite end of reaction vessel. Thereafter air bath was tightly closed and sample was heated at rate 5^{o} C /min by a programmable heating coil.

Photograph 2: Experimental set-up for determination of gases at elevated temperature

Photograph 3: Sample holder for burning of sample at elevated temperature

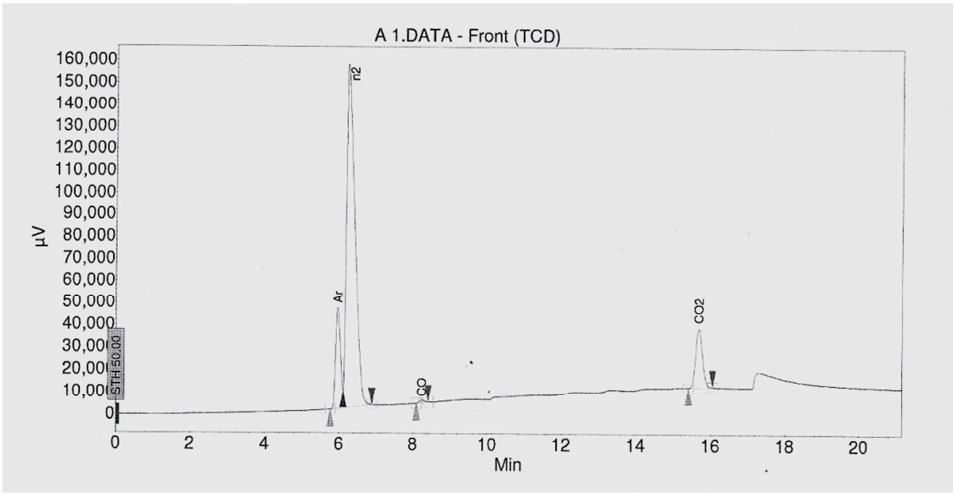


Figure 6: GC graph for Hard Coke

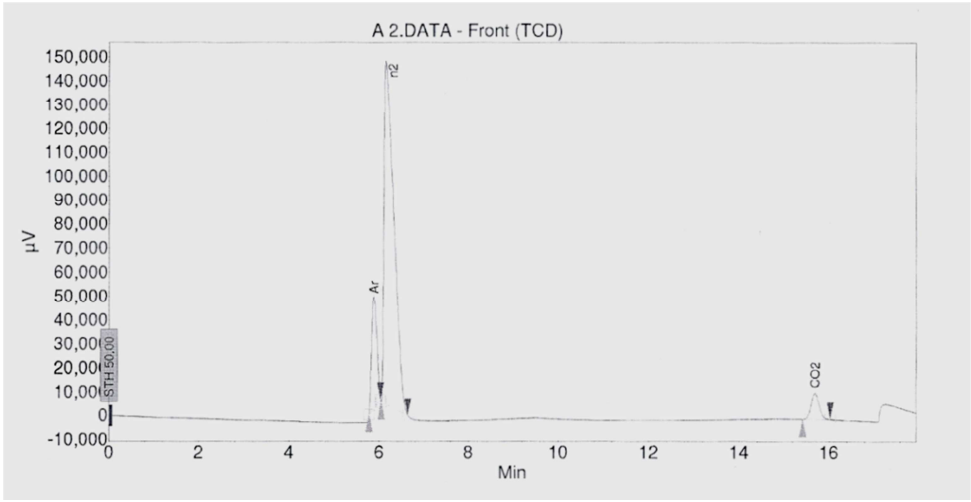


Figure 7: GC graph for Hard Coke + THERMACT-BF

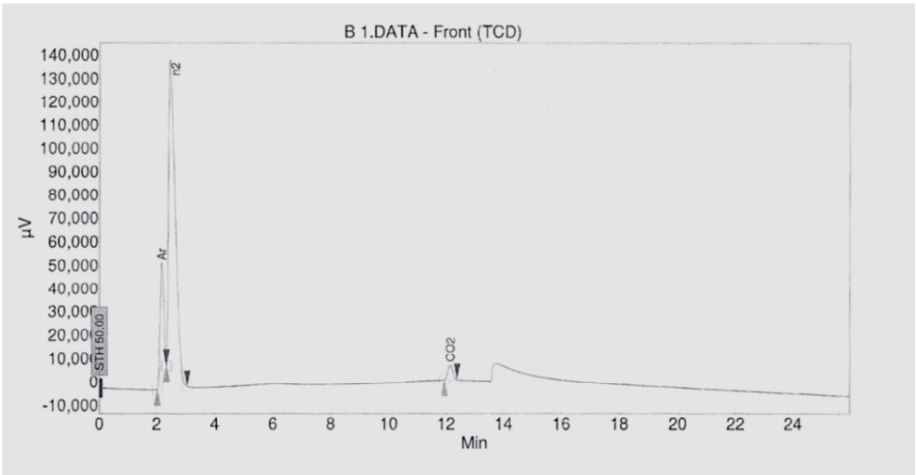


Figure 8: GC graph for Iron ore + Hard Coke

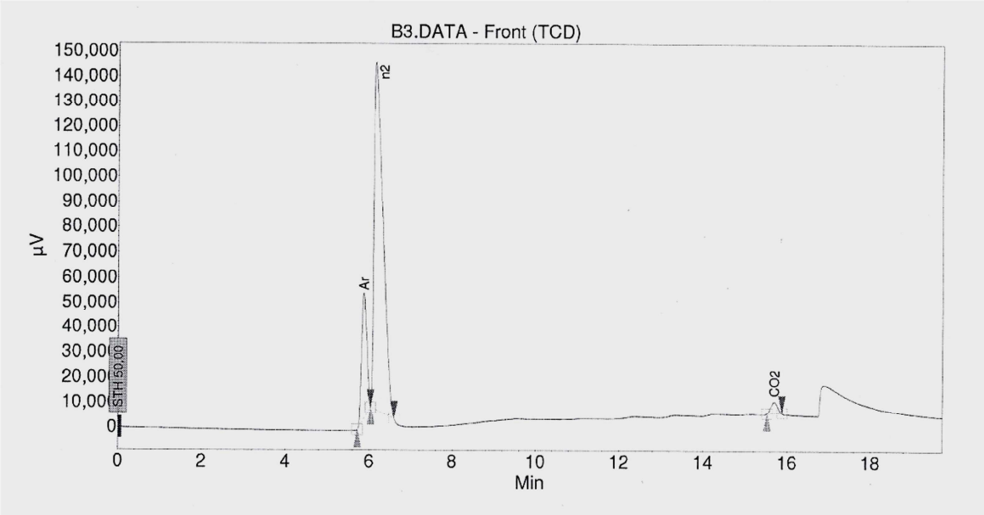


Figure 9: GC graph for Iron ore + Hard Coke + THERMACT-BF

Table 10: Gas evolving from Hard coke (with and without THERMACT-BF)

Hard Coke				Hard coke + THERMACT-BF			
Ar	N_2	CO	CO_2	Ar	N_2	CO	CO_2
12.40	81.10	0.28	2.34	11.60	73.28	NIL	1.00

Table 11: Gas evolving from Iron ore + Hard Coke (With and without THERMACT-BF)

Iron Ore + Coke				Iron Ore + Coke + THERMACT-BF			
Ar	N_2	CO	CO_2	Ar	N_2	CO	CO_2
12.71	69.78	NIL	0.52	13.15	69.96	NIL	0.36

2.7 ***Reduction Behavior***

Generally, iron manufacturing involves reducing its ore to either sponge iron or pig iron. Sponge iron is prepared by a direct reduction method, which uses a reducing gas produced from natural gas or coal. Pig iron is produced using a blast furnace technique that uses iron ore and hard coke (reducing agent) as raw materials.

Degree of reduction of iron ore with and without THERMACT-BF was studied. The iron ore and hard coke is grinded 200 MESH and pellets using silicate binders and moisture of following compositions were manufactured:

1. Iron ore + hard coke (73:27 ratio)
2. Iron ore + Hard coke + THERMACT-BF (73:27 ratio and THERMACT-BF was added in 1:6000 ratio of coke)

The iron ore pellets were allowed to heat at 250 ^oC and when achieves full strength, the pellets kept at 950 ^OC for two hours for study the reduction behavior. The loss of weight was recorded after 10, 30, 60 and 120 minutes interval. The reduction behavior was measured as degree of reduction using following formulae:

$$DR = \left(\frac{W_1}{TO} \right) x100$$

Where:
DR = Degree of reduction
W_1 = Loss in weight of pellet
TO= Total oxygen content in the pellet

The results of investigation of the reduction behavior of iron ore with and without THERMACT-BF are shown in Table 11 & 12. Chemical composition of reduced material is shown in Table 13-14.

Table 12: Reduction behavior of Iron ore in presence of coke at 950 ^{o}C

Sr. No.	Time (Min.)	Initial weight (g)	Final weight (g)	Loss in weight (%)	Reduction (%)
1.	10	3.0	2.52	16.00	73.80
2.	30	3.0	2.21	26.33	84.15
3.	60	3.0	2.12	29.33	87.73
4.	90	3.0	2.12	29.33	87.73
5.	120	3.0	2.11	29.66	88.14

Table 13: Reduction behavior of Iron ore in presence of Hard coke and THERMACT-BF at 950 ^{o}C

Sr. No.	Time (Min.)	Initial weight (g)	Final weight (g)	Loss in weight (%)	Reduction (%)
1.	10	3.0	2.48	17.33	74.99
2.	30	3.0	2.23	25.66	83.40
3.	60	3.0	2.08	30.66	89.40
4.	90	3.0	2.07	31.00	89.85
5.	120	3.0	2.07	31.00	89.85

Table 14: Chemical composition of the reduced iron ore without THERMACT-BF

	Temperature (^{o}C)	Time (Minutes)	Fe Content (%)	Carbon Content (%)
1.	950	10	45.00	28.0
2.	950	30	47.35	20.0
3.	950	60	51.07	18.0
4.	950	90	52.85	12.0
5.	950	120	52.90	12.0

Table 15: Chemical composition of the reduced iron ore with THERMACT-BF

Sr. No.	Temperature (^{o}C)	Time (Minutes)	Fe Content (%)	Carbon Content (%)
1.	950	10	46.32	26.0
2.	950	30	47.23	24.0
3.	950	60	48.21	18.0
4.	950	90	52.06	14.0
5.	950	120	53.75	12.0

RESULTS AND DISCUSSION

3.1 Proximate analysis

Results shown in Table 1 for proximate analysis of THERMACT-BF revealed that the Moisture, volatile and ash content were 6.5%, 17.10% and 10.48 % respectively. The fixed carbon was 65.92 percent.

Proximate results (Table 2) for hard coke with and without THERMACT-BF indicated that there is no detrimental effect on the composition of the hard coke and hard coke retains their properties upon addition of the THERMACT-BF.

3.2 Calorific Value

Table 3 showed the impact of THERMACT-BF on the calorific value of the hard coke and found that the caloric values were almost similar. The gross calorific value of the coke without THERMACT-BF of air dried basis (adb) and dried basis (db) was 6314 and 6461 kcal/kg respectively. It was 6432 and 6504 kcal/kg respectively upon addition of THERMACT-BF.

3.3 Compositional Analysis of Iron Ore

Iron ore sample was evaluated for composition and effect of coke upon composition with and without THERMACT-BF was also studied using TGA and other conventional methods and found that the total Fe content was 64.23 % (Table 4).

Results shown in Table 5 revealed that residual matters upon burning at 950 ^{o}C was 71.48 and 72.20 % in case of Iron ore + Coke on air dried basis (adb) and dried basis (db) respectively while it was 70.33 and 70.98 % in case of

Iron ore + Coke + THERMACT-BF on air dried basis (adb) and dried basis (db) respectively. Results revealed that THERMACT-BF is not affecting the acceptable composition system required by steel industries.

3.4 Thermo Gravimetric Analysis (TGA)

3.4a THERMACT-BF

Thermo gram shown in Figure 1 indicated that moisture, volatile maters etc. release in between the temperature from 29.0 to 177.0 ^{o}C and peak temperature for the components released was 93.0 ^{o}C. The combustion of THERMACT-BF was occurred in between 177.0 to 793.0 ^{o}C and decomposition peak temperature was 549.0 ^{o}C. The decomposition of the THERMACT-BF was 74.410 percent from 177.0 to 793.0 ^{o}C. The residual matters in THERMACT-BF was 12.559 percent at 795.3

3.4b Hard Coke+ THERMACT-BF

Thermogram shown in Figure 2 indicated that moisture, volatile matters etc. release in between the temperature from 28.7 to 344.0 ^{o}C and peak temperature for the components released was 43.3 ^{o}C. The combustion start temperature of Coke was 344.0 ^{o}C. The combustion of Hard coke+THERMACT-BF was occurred in between 344.0 to 795.0 ^{o}C and decomposition peak temperature was 699.7 ^{o}C. The decomposition of the Hard coke+THERMACT-BF was 84.224 percent from 344.0 to 795.0 ^{o}C.

3.4c Iron Ore + Hard Coke

Thermo gram of iron ore + coke in the ratio of 73:27 showed that the composite decomposed in three different temperature zones. In the first temperature zone moisture and volatile matters were released. Second temperature zone showed slight combustion of coke. It may be due early initiation of reduction of iron ore. The third temperature zone is for reduction process of iron ore with combustion of coke. The residual matter showed reduced iron and ash generated from coke burning.

It was observed from the thermo gram at 10 ^{o}C per minute rate of heating, iron ore reduced in two temperature zones. But at 15 ^{0}C and 20 ^{o}C per minute rate of heating results of thermogram showed that iron ore reduced in four temperature zones with increase in peak temperature (Table 8). The peak temperature at 10 ^{o}C per minute rate of heating was 630.0 ^{o}C and it was 663.8 and 721.0 ^{o}C at 15 and 20 ^{o}C per minute rate of heating respectively. The residual matter which contains the reduced iron and ash generated from the coke burning was 67.818 and 67.288 % at 15 and 20 ^{o}C per minute rate of heating respectively.

3.4d Iron ore +Hard Coke + THERMACT-BF

Thermo gram run for iron ore + Coke and THERMACT-BF in ratio 73:27 with addition of THERMACT-BF in ratio of 1:6000 of coke and results shown in Table 9 showed significant increase of the peak temperature due to addition of THERMACT-BF. at 10 ^{o}C per minute rate of heating the peak temperature of reduction of iron ore was 630.0 ^{o}C. It was significant to note that the peak temperature was increased to 655.0 ^{0}C and 669.0 ^{o}C at 15 and 20 ^{o}C per minute rate of heating respectively. The residual matter occurred 64.326 % in case of 10 ^{o}C per minute heating and it was reduced to 61.687 % and 59.887 % when rate of heating was 15 and 20 ^{o}C per minute. The reduction of the residual matter showed that the Fe_2O_3 is converting into Fe and it may be due to presence and catalytic effect of THERMACT-BF.

Upon comparison of both the system, it was observed that reduction of iron ore in absence of THERMACT-BF required more temperature and for longer period in comparison to Iron Ore reduced with THERMACT-BF. The peak temperature of reduction of iron ore without THERMACT-BF was 721.0 ^{o}C and it was 669.0 ^{o}C when THERMACT-BF was added to the system.

3.5 Gas Characteristics

The results of major gases evolved during the combustion of coke such as Ar, N_2, CO, CO_2 with and without THERMACT-BF shown in Table 10 and Figure 6-7 revealed that there is no toxic gases were observed during combustion of coke with and without THERMACT-BF.

Table 11 and Figure 8-9 showed the gases evolved from the composition prepared from Iron Ore + Coke+ THERMACT-BF inferred that THERMACT-BF does not develop any toxicities in the gases evolved during reduction process of iron ore.

3.6 Reduction Behavior of Iron Ore

3.6a Iron *Ore + Hard Coke*

3.0 g of sample was prepared from Iron ore + Hard Coke in 200 Mesh was subjected to keep at 950 ^{o}C for 10, 30,60, 90 and 120 minutes and loss of weight was observed for libration of oxygen to convert Fe_2O_3 to Fe upon reduction process. In case of Iron Ore + Hard Coke, it was observed that after 10 and 30 minutes weight loss was 16% and 26.33 % respectively and iron ore reduced to 73.80 % 84.15 % respectively. At 60 minutes the reduction of iron ore to produce iron was maximum and it was 87.73 % and there is no significant change in weight loss and reduction of iron ore to Fe at 90 minute. Very little change in weight loss was observed after 120 minutes and reduction of iron ore was 88.14 % (Table 12).

3.6b *Iron Ore +Hard Coke + THERMACT-BF*

3.0 g of sample was also prepared from Iron ore + Hard Coke + THERMACT-BF in 200 Mesh was subjected to keep at 950 ^{o}C for 10, 30, 60, 90 and 120 minutes and loss of weight was observed for libration of oxygen to convert Fe_2O_3 to Fe upon reduction process. The loss in weight after 10 minutes was 17.33 % and reduction of iron ore was 74.99 % and it was more than in case of iron ore + coke. The loss in weight was increased upon increasing the time from 10 minutes to 120 minutes (Table 13). The maximum loss in weight was 89.85 % which is also more than the iron ore + Coke. Maximum reduction of iron ore was achieved after 90 minutes while in case of iron ore + Hard Coke it was after 120 minutes. These results showed the positive catalytic effect of THERMACT-BF upon reduction of iron ore and also showed that time cycle may be reduced due to addition of THERMACT-BF.

3.7 Chemical Composition of Reduced Iron Ore

Results shown in Table 14-15 for chemical composition of reduced of iron ore at 950 ^{o}C with and without THERMACT-BF indicated that after 10 minutes the Fe content was 45.00 % without THERMACT-BF while it was 46.32 % in which THERMACT-BF was added. After 120 minutes Fe content was 52.90 % and 53.75 % for iron ore with and without THERMACT-BF respectively. Increasing of Fe content in the sample reduced in presence of THERMACT-BF showed the catalytic effect of THERMACT-BF on the reduction of the iron ore. Results of carbon content utilized in the reduction of the iron ore also indicated better reduction of iron ore with less consumption of Hard coke.

CONCLUSION

The following conclusions are drawn on the basis of experimental results:

4.1 Based on the kinetic parameters studied, it is observed that the combustion of coke starts at a lower temperature on addition of THERMACT-BF as compared to base sample.

4.2 When the degree of reduction was measured, it was observed that the efficiency of reduction of Iron Ore and Hard Coke increased on addition of THERMACT-BF.

4.3 The activation temperature of reaction of Iron Ore with Hard Coke has reduced on addition of THERMACT-BF. Hence, it can be inferred that reaction(s) are initiating at lower temperature.

4.4 The kinetic parameters of Hard coke as well as iron ore changes positively in relation to activation energy and heat of enthalpy upon addition of THERMACT-BF.

4.5 Gas Chromatographic results for gas evolved upon burning confirm that no harmful gases are evolved on addition of "THERMACT-BF" to Iron Ore and Hard Coke. Hence, it can be inferred that addition of "THERMACT-BF" will not have any detrimental effect on the system.

4.6 There is no detrimental effect on the composition of hard coke with the addition of THERMACT-BF and the properties of hard coke are unaltered.

4.7 The chemical composition of Iron Ore and Hard Coke during reduction is not altered on addition of "THERMACT-BF".

4.8 THERMACT-BF may be useful catalyst for blast furnace.

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