EJONS
International Journal on Mathematic, Engineering and Natural Sciences
(Uluslararası Fen, Mühendislik ve Doğa Bilimleri Dergisi)
https://ejons.org/index.php/ejons
e-ISSN: 2602 - 4136
Research Article
Doi: https://doi.org/10.5281/zenodo.10814424

Recycling Iron - Microwave Reduction of Poor Iron Ore Slime/ Limonite Sand and Foundry Waste Iron Slime by Bio Char

Yıldırım İsmail TOSUN [1,*]

[1] Şırnak University, Engineering Faculty, Mining Engineering Department, Şırnak, 73000, Turkey

*Sorumlu Yazar e-mail: yildirimismailtosun@gmail.com

Article Info

Received: 22.02.2024
Accepted: 14.03.2024

Keywords

Microwave radiation,
İron waste slurries,
Reducing bath,
Concentration treatment,
Sorbent bath,
Limonite slurries.

Abstract: The microwave-assisted reduction of iron slime waste and poor iron ore is carried by sequentially concentration and reduction. A suitable advanced method is required for low-grade limonite and hematite iron ores of Şırnak, and Eastern Anatolian iron ores, in Turkey. The low-grade limonite resources are widely disseminated in the region, containing 47-80% $Fe_2O_3.H_2O$, and goethite sands containing 25-30% Fe_2O_3. Benefaction from iron slimes, wet poor iron waste of foundries, and poor iron ore provides the recycling of iron and even other valuable metals such as tin, chromium, cobalt, and nickel. The microwave-assisted reduction is carried by sequentially following concentration and pre-reduction. An optimized reduction method is required for low-grade limonite and hematite iron ores of Şırnak, and Eastern Anatolian iron ores, in Turkey.
In this study, the poor limonite ores of Şırnak, the following gravity concentration, and microwave reduction in bubbling bed were studied in sequential batch processes.

How To Cite: Tosun, İ. Y.(2024). Recycling Iron - Microwave Reduction of Poor Iron Ore Slime/ Limonite Sand and Foundry Waste Iron Slime by Bio Char EJONS International Journal on Mathematic, Engineering and Natural Sciences, 8(1):135-148.

1.Giriş

Iron ore reserves of Turkey were located in Divriği, Bingöl, Kayseri regions. Besides those resources, Kesikköprü, Balikesir, and Adapazarı showed different types of low grade iron ore resources are available. In the Southeastern Anatolian region, Bitlis, Şırnak, Hakkari had at disseminated locations with the low quality iron ore deposits explored as a certain amount for utilizing in ironmaking (Kermen,2019).

Erdemir Plant İsdemir Plant of OYAK, Ereğli, and İskenderun of Turkey, produce raw cast iron and steel in 4 iron blast furnaces and 2 EAF using imported iron ores and imported scrap steel feed [6-8]. Hence, the evaluation of poor cheap iron ores is required for the preparation and concentration units in the country (Yıldız,2010). The limonite ore deposits contained low-grade Fe such as 25-42% Fe in Bitlis, Eastern Anatolia and Şırnak, Hakkari provinces of South Eastern Anatolia were excavated and traded in the region. However, for this poor iron ore usage, a suitable enrichment prior to evaluation in blast furnaces should be managed after certain size classification. The preparation followed magnetic separation and microwave accelerated ore reduction using charcoal became an advantageous process using coal gas fluidized bed-reducing treatment (Tosun,2019).

The bubbling bed managed shorter gas solid reactions period and higher reduction efficiencies compared to packed bed reduction in microwave. Hence, the radiated heat following to bubbling gas heat transfer radiation and conduction to bubbling granule bath below 1 m/s for reducing to iron oxide, even for the refractive crystalline iron ore minerals (Tosun, 2018). The poor limonite and siderite ores allow longer dissociations, sequentially oxidation by carbon dioxide gas of char and reduction by reducing carbon monoxide gas of char and biomass char. The higher amount of surface areas of bio-char in the bubbling fluidized bed furnace manage much more char gas desorption for reduction. The bubbling column bath was proposed in this study. The porosity of bath was reaching to 60 % of total bath volume in order to efficiently reduce the reducing char gas at the temperatures of 700 ^{o}C in the column bath. The temperature of bath increased to 800 ^{o}C with use microwave pre-treated poor iron ores and certain amount of slime iron addition in the mixture.

1.1. Iron Ore Pelleting and Sintering

The iron ore is first of all concentrated. The hematite liberalization from locked gangue mineral is needed by crushing and grinding till the fine size is below 100-micron size. The fine concentrate is pelletized at a high grade and used in the EAF or reduced to sponge iron instead of scrap (WSI, 2019).

The fine sized such as below 1mm is not suitable for Blast furnace iron making. (WSI, 2019) The fine iron ores are pelletized into 12-16 mm balls or the iron concentrate at 1-8mm size is sintered. Pelleting is an enlargement method using a drum for balling fine enriched iron ores with almost 1% bentonite binder at 8-10 % moisture (JSI, 2019). Then, 12-16 mm classified balls are fired in the furnace for high strength regarding the ASTM standard over 250 kg/cm2, and 65% total Fe grade is wished. (Table 1)(TÇÜD, 2020)

Table 1: Blast furnace Iron making requires the chemical and physical properties of the pellet

Chemical Content		**Physical characteristics**	
Fe	65.5	+ 16mm	3.0%
SiO_2 + Al_2O_3	4.20	+ 8 mm - 16 mm	92.0%
P	0.05	- 5 mm %	4.0
S	0.01	Drum index, + 6.3 mm	94.0%
MgO + CaO	1.25	Wear index, - 5 mm	5.0%
Ti	2.0	Compress strength, kg/pellet	250
Mn	2.0	Bulk density, g/cm^3	2.1
Na_2O	0,15		
K_2O	0,15		
Basicity	0.30		

The chemical content of pellets is important for sponge iron production. The general chemical and physical properties of pellets used in Sponge iron are given in Table 2 (TÇÜD,2020).

Table 2: The required reduction and physical properties from pellets for the Production of sponge iron.

Swelling index	**max. 15%**
Reduction	93%
After reduction, kg/pellet	50
Basicity	0.30

1.2. Waste Iron Ore, Slime, and Blast Furnace Plant Waste Steel Slime

Cement plants and blast furnace ironmaking and steel-making plants in Turkey produce waste iron ore slimes which cannot feed to the furnaces because of the inability to furnace ironmaking operation or unable to recycle in the ironmaking furnace costs causing fouling the gas flows and the stockpiles in our country reach to totally 100 million tons in decades. The poor limonitic and siderites iron ores and titaniferous ore fines contain the chemical components given in Table 3 below reaching higher stockpiles and evaluated in cement plants below 1-4 mm (SIMA,2020).

Table 3: The chemical properties of poor iron ore fines and Blast furnace Ironmaking and Steelmaking slime and dust wastes

Chemical Content	Ereğli Çelik Metal Şlam	Sideritic Ore Hekimhan	Stream Kızılsu Sand	Limonitic Ore Uludere	İtabaric Ore Uludere
Fe	45	35.5	19.0%	45.5	23.0%
$SiO_2 + Al_2O_3$	4	24.20	32.0%	4.20	32.0%
P	2	0.15	2.0	0.05	0.5
S	0,01	0.01	0.01%	0.01	0.01%
MgO + CaO		7.5	44.0%	11.25	5.0%
Ti	1	1.0	0,50	1.0	1,5
Mn	1	1.0	1.1	1.0	2.1
Na_2O		0,15	1,1	0,1	2,1
K_2O		0,15	1,2	0,1	1,2
Basicity		0.30	0,5	1.70	0,1

1.3. Iron Ore ConcenFollowingnd following Reduction

The sintering or pelleting of iron ore is necessary for the preparation of high qualities over the reduction of undesirable contents such as Ti and Mn in the bleached resources. Some poor iron ores need magnetic concentration projected in evaluation. However, concentration units increase the cost on behalf of preparation cost over the mining cost of iron ore (Anonymous, 2020, Anonymous 2017).

The preparation cost using the flotation method developed directs anionic flotation or reverse anionic flotation commonly used for poor hematite iron ore. (Yıldız 2018; Tosun 2018) Wet magnetic separation is commonly used for hematite muds to high-grade iron ores before pelletization. 12 mm pellet was suitable high quality feed into blast furnaces in India (Anonymous, 2017; Anonymous 2020).

In Turkey, imported scrap at 19 million tonnes reduced cast steel in EAF, and about 12 million tons of iron ore was converted to cast iron in iron-making BF instead of concentrating and pelleting our local low-grade limonitic iron ores. Direct reduced ore plants in India had capacities of 4 million tons. The direct reduction method of iron ores for steelmaking has become increasingly important. The reduction is a result by primarily of natural gas, coal gas, coke gas, shale gas, and liquid fuels such as fuel oil used as reducing, especially over 600ºC.(Machida et al. 2009, Kumar 2009, Fine et al. 1970, Melcher 1963). DRI hot charging directly to the arc furnace at temperatures needs low energy requirements. The DRI ores are easily converted crude steel in EAFs, and economic with 100% DRI feed bringing it to scrap melting hot working (Subhasisa 2009, Small 1981, Ramachandra Rao 2006, Anonymous, 2017, Anonymous 2020).

The magnetic wet concentration following direct reduced iron ore is preferred in common sense for high-quality iron ore at lower cost with various types of local iron resources. Even impurities are discarded in the following concentration unit by wet magnetic separation. Vertical shaft furnaces were used in sufficiently reduced pellet production. The evaluation of reduced low-grade hematite sands followed reduced pelleting in India (Anonymous, 2017, 2020). The low-grade iron ores in subjected to grate reduction as sinters by coal gas or steel-making flue gas. Since the final pellets are high grade, the final pellets containing 85% Fe total are proposed to produce sponge iron production.

The char, coke fine, and coal gas are used in reduction managed by reacting gas of CO over 30% over almost 600 ^{o}C as seen in Figure 1 over 1000^{o}C temperature. The temperature profile changes in fluidized bed reactions. Therefore bubling bed reaction is successful in long-reducing iron ore reactions by char and char gas.(Vogtenhuber et al. 2019, Roetzel et al. 2020,) The fractional reduction of iron ore granules by CO gas of char is managed by Equation 1. (8-10] The Frossling Equation defines the mass transfer coefficient and reduction rate determined as Equation 2 -5.

1/3 Fe2O3+ 3CO/H2=2/3Fe3O4 = 2FeO= 2/3 Fe+3CO2/H2O (1)

$$k_f = \frac{D}{d}(2 + 0{,}55\ Re^{1/2}S^{1/3}) \quad (2)$$

$$D = 3{,}7104.10^{-5}T^{1{,}75} \quad (3)$$

$$p_{H2} = 2{,}2656.10^{-5}T^{0{,}75} \quad (4)$$

Reaction equilibrium constant K of Equation (1)

$K_{reduction} = p_{H2O/CO2}{}^3 a_{Fe/FeO} / p_{H2O/CO2}{}^3$; **K=**$e^{(18{,}76-20{,}52.10^3/RT)}$ and forward kinetic rate constant coefficient (k_{ri}) at i fractional diffusion model k_r

$$k_r = e^{(5{,}67-9{,}92.10^3/RT)} \quad (5)$$

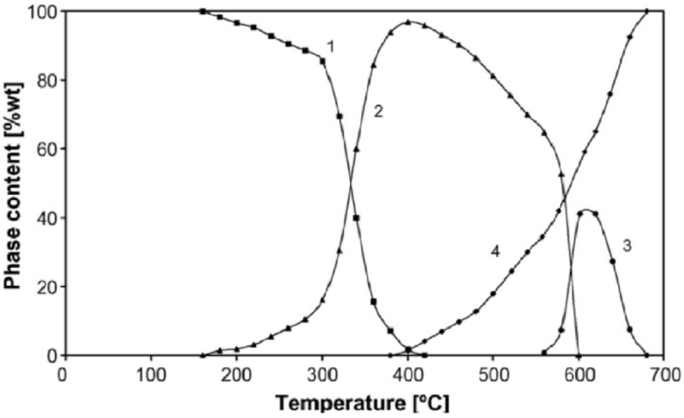

Figure 1: Distribution of Fe-FeO by 2%H_2 gas regarding temperature in Iron Ore Reduction (1) Fe_2O_3; (2) Fe_3O_4; (3) FeO; (4) Fe

2. Materials and Method

2. 1. Ore Preparation: Gravity Concentrating, Wet Magnetic Separation, Pneumatic Jet Flotation and Column Flotation

The analysis of the iron test sample ores is given in Table 4. The river sands of Kızılsu, Şırnak contained approximately 17% iron and about 25% hematite observed as red mud, with a high amount of limestone sand carried to the Tigris stream along 5 km. The river slime should be processed by flotation instead of magnetic separation due to 100-micron size reaching over 76% weight rate. In this study, the concentration is based on the concentration of poor limonite and hematite ores at slime size below 100 microns. The column flotation and magnetic separation have attracted considerable interest in iron ore concentration. The method of column flotation and conventional flotation with reagents, collector using oleic acid and frothing reagent,(Yang 1988, Feuerstenau et al 1970, Feuerstenau et al 1967) long height stable frother to carrying longer poor ultrafine in the scavengers. The scavengers are necessary for a long period of flotation of ultrafine hematite particles. For this reason, high ultrafine particle content results in less iron froth. The optimized addition values of the oleate collector and pH changed from 1 to 4 kg/t and from 7 to 9, respectively. The research results showed low froth grade with high recoveries of 62% and 55%. The three-step scavenger yields better results of 70% to 85% Fe recoveries (Figure 2). The proposed magnetic and flotation concentration unit for poor limonitic iron ores as illustrated in Figure 3 and Figure 4 comprised a Humprey spiral Density Separator (HDS) following a column flotation, jet sparged-air flotation and gravity separation which preferred separation of different densities of hematite slime at heavier sink matter.

Table 4: The chemical analysis values of various limonite ores, in calcareous formations of Şırnak province

% Component	Şırnak Kızılsu Hematite Sand	Şırnak Limonite Sand	Şırnak Hematite	Ortaköy Hematiy	Şırnak Şenoba Limonite
SiO_2	3,53	9.42	2,4	7,4	**24,1**
Al203	2,23	6,53	1,1	1,1	**12,6**
Fe2O3	49	44.8	57,4	47,4	**34,1**
CaO	3,48	9,23	1,1	3,1	**9,1**
MgO	2,20	2,28	1,3	2,3	**4,6**
K_2O	0,41	0,53	0,1	0,2	**3,3**
Na_2O	0,35	0,24	0,1	0,1	**1,1**
Ignit Loss	46,19	26,11	1,3	2,3	**21.4**
S03	0,32	0,21	0,2	0,1	**0,2**

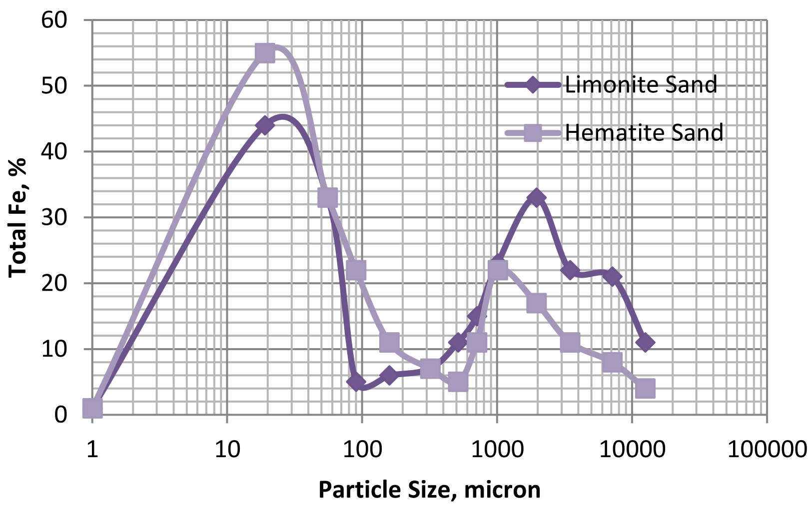

Figure 2: Fe distribution in low-grade Şırnak hematite and Şırnak Limonite ores used in concentration tests.

Figure 2 describes Table 1 hematite distribution versus sand size distribution. The main dense fraction was below 100 microns for whole wastes and poor iron ores.

The Fe grade is 21,3 % for Kızılsu stream slime at 1mm size on based total sand feed. The limonite ores of Ortaköy and Beytüşşebap, Şırnak were 41,3% Fe grade in the lump and crushed size containing about 50 % limestone distributed in the region widely. The sybaritic iron ores occur as poor hematite ores containing 15% limonite or Sphalerite ZnS/PbS in the Hakkari and zinc-bearing lateritic iron contained some 34% hematite.

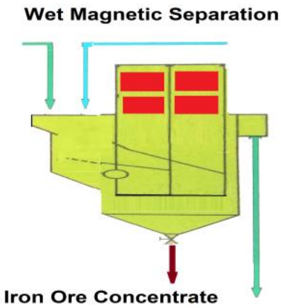

Figure 3. Column flotation and Magnetic Separation of Iron ore Slime

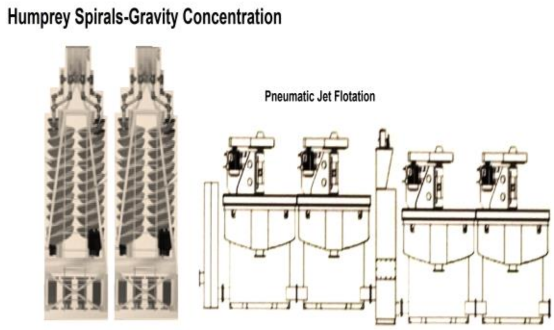

Figure 4 Humprey Spiral and Jet Flotation Separation of Iron Ore Sand

Figure 5. Şırnak Hematite Ore Lump

Figure 6 Şırnak Limonite Iron Ore Sand

2.2. Bubbling Bed Reduction by Asphaltite Char/Wood Char Fine of Low-Grade Limonite Ores

In the tests iron ore slimes and waste boundaries fines mixed following concentration as seen in Figure 7. The tests of microwave radiated treatment are practiced in lab-type microwave TGA reduction by char till 1000^{o}C with coal and biomass char for different times, ranging from 40 min, and 80 min for the original poor ore pellets. The reduction of poor limonitic ore and iron foundry dust mixture resulted that high volatile gas content reducing temperature. The limonitic iron slime in the mixture was suitable for the microwave-affected reduction of limonite and iron waste slime at 10 % weight rate mixtures to directly reduce iron ore. (Figure 8)

Figure 7: Reduced hematite ore and distribution.

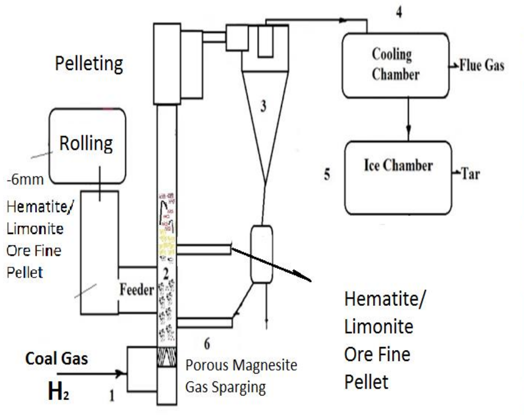

Figure 8: Experiment bubbling tube in TGA, balance measuring reduced weight of hematite sand.

In the reverse flow reduction cycling process is realized by fractional reduction or alkali fouling. The physicochemical reduction fundamentals of iron ore are still not fully understood and the reduction of fraction is seen in Figure 9 at different core theories arisen.

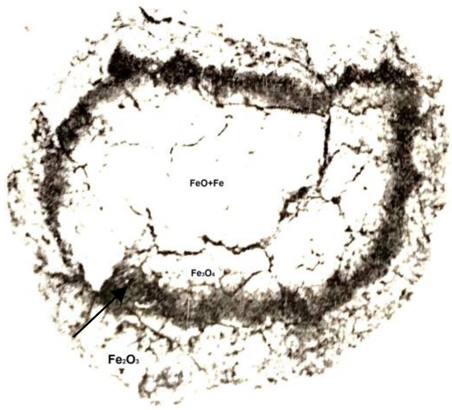

Figure 9: Reduced hematite sand ore and core fractional unreduced magnetite layer

Heat conduction was efficient for the metallic intermediate phase for iron matters in microwave radiation. (Roetzel, et al. 2020, Welty et al. 2015, Machida 2009, Kumar 2009) In the microwave process, it is commonly resulted temperature increases on the iron metal layers vibrate more vigorously, (Amenkwah 1992, Amenkwah 1995, Hutcheon et al. 1995, Jacob et al 2009, Kelly and Rowson 1995, Kingman et al 1999, Lu et al 2007, Ma and Pickle, 2003, Marland et al 2000). Thus reductive microwave causes the breaking of the intermolecular reducing carbon and hydrogen bonds and allowing desorption of water. In the iron ore reduction, thermal refractive phase hazards of sintering may happen in the hot reduced ore (Rehder 1983, Snall 1981). The associated energy cost in reduction heating in comparison of reduction refractive ores with the refractive matter of cluster much less is known about corn reduction (Tosun 2018).

2.3. Microwave Reduction by Char

Char and waste iron slime were so efficient in microwave reduction reaction in iron ore processing and thermal heat conduction has become effective as microwave heat (Amenkwah 1992, Amenkwah 1995, Hutcheon et al. 1995, Jacob et al 2009, Kelly and Rowson 1995, Kingman et al 1999, Lu et al 2007, Ma and Pickle, 2003, Marland et al 2000) and the associated reducing gas heating at low energy cost in heating. In comparison with conventional char reduction matter, certain reduction weight decrease is known about 40-50 % rate.

2.3.1. Microwave Reduction of Hematite/Limonite Sand in Retort

30 gr samples were ground to -0,1mm in ball mill from –0,3mm feed size. The pressed pellets with char and waste iron slime at -0,1mm grain size fractions were subjected to TGA direct reduction. The studied sample compositions and test results as weight decreases are illustrated in Figure 10.

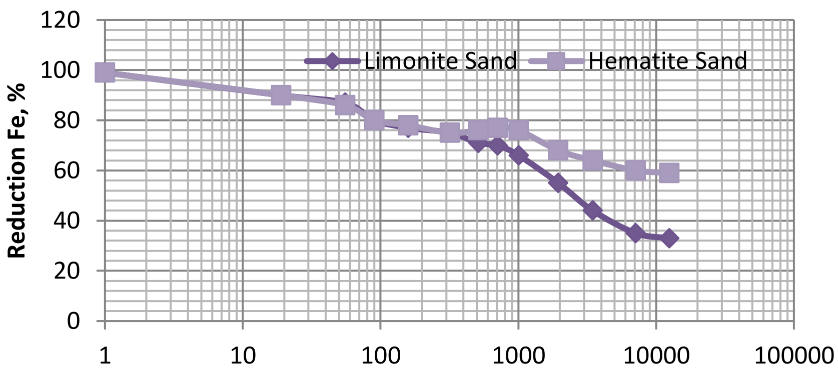

Figure 10: Particle Size effect on iron ore reduction % for low-grade hematite/ limonite ore in Şırnak

Table 5: The distribution of Hematite and Limonite regarding Particle Size and retort char content in reducibility in an hour.

Screen Size	Char Weight,%	Limonite Sand Reduction,%	Hematite Sand Reduction,%	Şırnak Limonite Reduction,%	Şırnak Hematite Reduction,%	Ortaköy Hematite Reduction,%
+ 10	44	43,4	40,3	20,3	43,3	33,3
+ 5	38	74,6	70,0	50,0	74,0	56,0
+ 3	33	71,3	68	58	78	58
+ 1	25	77,5	75	65	85	65
+0,6	23	73,2	75	65	85	65
+0,1	23	74	73	63	76	63
-0,1	23	76	77	67	87	57

A 1-liter Quartz bubbling tube cell for reduction experiments was used to yield iron slime and limonite sand mixture reduction. The reductive bubbling at 6 min and cold starting 5 min in direct resistant heating carried for 2min extra at 20% volume solids. The bubbled reduced limonite sand was agitated in a mixing gas bottom bed. The poor limonite flotation tests used sand 1000 g and coal and wood char 400 gr into sand mixed.

According to the results of the reduction made by one class; -0,1 mm grain obtained by calculating the cumulative classes test results are given in Figure 10. Limonite and iron slime mixture fine grade and reduction yields given in these TG reduction rate values are described in Figure 2 with the curve slope.

The iron slime and Limonite concentrate mixture can be reduced to a char weight ratio of 58.2%. 59.7% iron grade limonite can be reduced in a weight ratio of 68.2% total iron reduction. This identifies that wood char is determined to be effective (Table 5.)

26.3% by weight of the sand reduced is observed with the 57.5% yield of limonite recovered as given 28.4% as given in Table 5.

3. Results and Discussion

3.1 Asphaltite /Wood Char Fine Reduction

The Biomass and coal char or coal can be used in reduction with some weighing as high as 10 %. The iron slime and limonite mixture, just iron sand slimes on the reduction rate of 46.3% constituting 2 mm pellet size reduction yields are obtained. This is thought to be caused by slime cover reduced content. However, river sand slime is efficiently reduced by biomass wood char. The total result of the reduction test; was 77.5% at 22% weight reduction with an efficiency of 29.4% as seen in Figure 11.

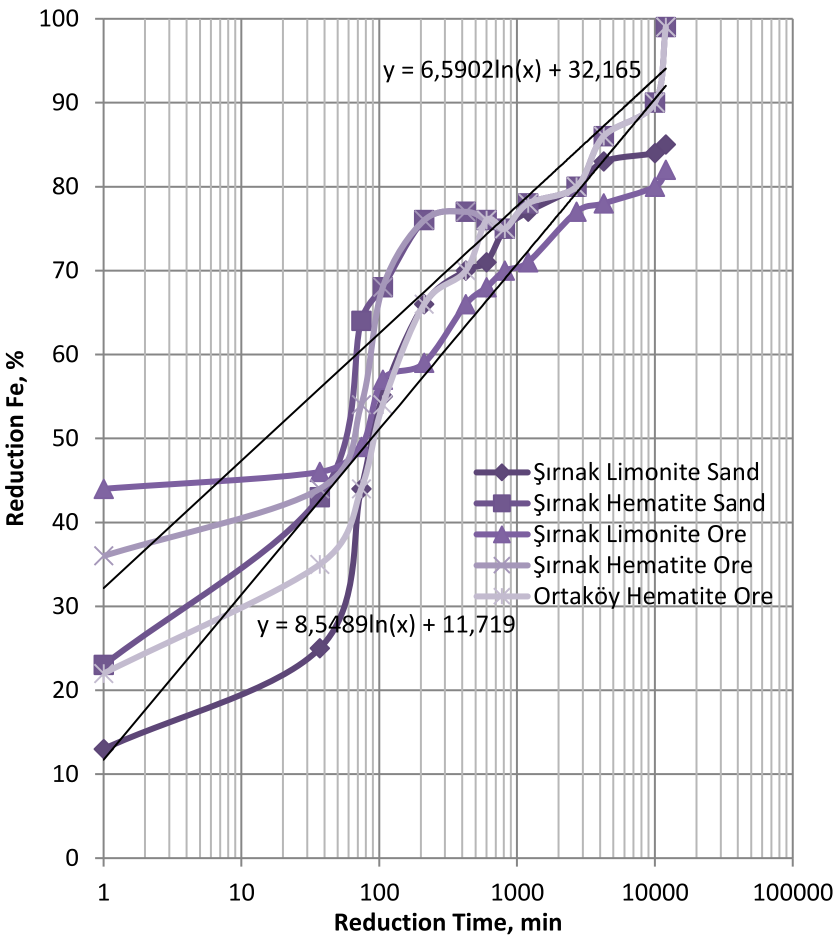

Figure 11: Reduction Time effect on iron ore reduction % for low-grade hematite/ limonite ore in Şırnak

-0.1 mm the concentrated samples are reduced by char in TGA and then magnetic separation in the laboratory resulted in a higher Fe grade of 85% with 76 iron performance in the river sand evaluation(Figure 11)

3.2. Reduced Iron Ore Magnetic Separation and Hot Pressing

The iron waste slime, char shale fine sand returned to away by dry low intense permanent magnet magnetic separation and time-sequential reduction step were high. The high clay contents in limonite sand provided low yields and clay content efficiently reduced Fe concentration grade in magnetic separation. Samples for this microwave reduction treatment at low temperatures at 900 C provided high-quality concentrates from the reduced hematite sand of high metal content at 85%Fe at a high yield of 77% and limonite sand ores were not dispersed in the 80% iron content at 67% yield and results as given in Figures 12.

The iron fine is used as reductive matter and other iron wastes use an increase in demand due to outflow in the iron and steel foundries or machining. Fractional shell reduction easily happens in bubbling granule beds affected by microwave for the identified. The other iron waste potential sources should be determined. The reductive porous bed was critical for heating purposes. The iron waste mixtures with poor iron ores on fullness should be investigated and suitable properties for bubbling compost reduction. This study improved the iron ore reduction in the microwave-assisted bubbling bath heating process. This study used microwave-reduction heat-absorbed hematite samples taken from the local area. By applying the reductive coal gas CO atmosphere in the process, the standard semi-metallic iron and wustite output was suitable for industrial microwave radiation fractionally emitted through hematite. The reduced matter production was possible.

The spatial distribution of bubbling bath pores in the reduction, the factors determining the efficiency of reduction was affecting the rate and extent of reduction fractional and much dependent on the time and pore site activation, its CO diffusion properties, and granule's porosity.

3.3. Bubbling Reducing Activation

The high performance in fluidized reducing gas-solid contact increased the kinetics for reducing solid char mixtures in the reduction columns. The char/air mixture was over 1/3 volume rate than occasionally exposed to poor limonite ores. The gas content increased high stability based on char content and high reduction performance.

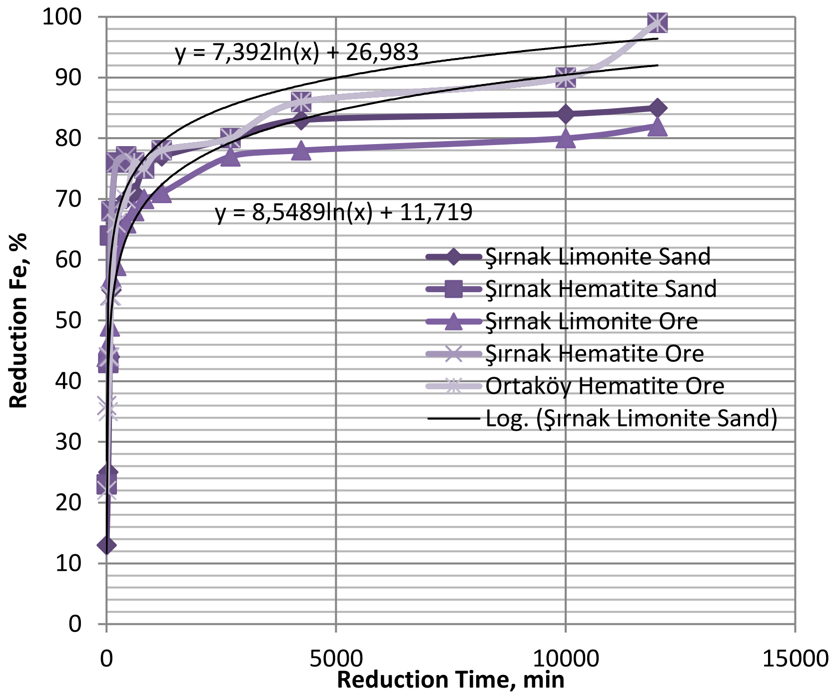

Figure 12: TGA analyses of the samples were carried out in Bubbling Bed in Microwave Radiated Tube

Char gas flow occurred through gas reduction of the iron slimes over the coal char at 40% provided reducing the temperature at 750°C. The microwave radiation increased the reduction temperature to 800°C for iron ore reductions over hematite as shown in Figure 12.

The reduced pellet is 4.02 g/cm3 by microwave TGA reduction showed a clear reduction weight decrease. The better appearance of the hematite reduction with char was contaminated by the clay content of output with the ferrite pellet and slag formation in the furnace material. Finally, magnetic separation reduced contamination so the reduction weight showed a reduced iron grade of the sample (Table 6).

Table 6: The chemical composition and physical properties of reduced ores in the experiment

Ore Type	chemical composition and	Total Fe %	bulk density g/cm3 and	strength of briquets kg/cm2	Reducibility,%	Reduction Rate
Şırnak Limonite Sand	CaO:2,1-2.8%; SiO2:5.18; P≤0.1%;S≤0.1%,	Fe2O3:4,5%;Fe:85.3;	2.8~3.2	230	78	0,7
Şırnak HematiteSand	CaO:1.16%; SiO2:5.18%; P:0.05%; S:0.02%	Fe:74.3%;				0,8

Şırnak hematite ore	CaO:2,1-2.8%; SiO2:5.18 P≤0.1%;S≤0.1%,	Fe2O3:4,5%;Fe:85.3;	2.8~3.2	230	78	0.6
Şırnak Limonite Ore	CaO:2,1-2.8%; SiO2≤10%; P≤0.1%;S≤0.1%,	Fe2O3:4,5%;Fe:85.3;	2.8~3.2	230	78	0,77
Ortaköy Hematite Ore	CaO:2,1-2.8%; SiO2≤10%; P≤0.1%;S≤0.1%,	Fe2O3:4,5%;Fe:85.3;	2.8~3.2	230	78	0,78
Iron OxideSlime		90,9 Fe	7,5	357		

TGA Analysis uses approximately 30 g of limonite samples till a temperature range of 800-1000 ° C at a heating rate of 5 ° C / min. The temperature ranges. The weight change is recorded in the TG analysis as given in Table 6. The limonite pellet weight change was 24 % with 65% iron mass at 900 ^{C}, respectively. This is due to the pellet adsorbing higher conductive heating.

In the TGA curves, the logarithmic regressed reduction values following the microwave-radiated poor iron ores of river sands and limonite resulted in the increasing iron ore grades and yield contents at 70-80 %. The hematite, and coal char waste iron slime pellets revealed that the total mass losses at 900^{o}C were 31.9% weight reduction and 77.75% iron mass.

4. Conclusions

In the three-stage microwave cycling reduction test measurements made found that 1730 g Fe/kg in limonite/asphaltite char decreased to 530g Fe /kg in the last column output. Likewise, the reduced limonite ore iron grade increased to 76% Fe as final magnetic separation was obtained after 10min concentration by a low permanent magnet and Fe yield was at 47% of the final performance. The proposed flow sheet for poor iron resource evaluation is illustrated in Figure 13. HBI with iron slime is offered as seen in Figure 14.

The iron slimes and reduced mixture iron pellets are concentrated and briquettes at 20 % waste iron slime or without iron slime. The briquettes gave advantageous iron content, and high-quality feed for steelmaking in EAF plants and casting foundries. The other side in steelmaking is low impurity scrap feed and reduced iron contents limed. The common EAF needed iron scraps and iron slimes with reduced high-grade quality ores in steel ladles. There are lack of local miners to produce directly reduced iron ore fluxed which are working at slag making. The microwave reduction method used in this study proved that investing in high-quality iron-making and steelmaking feed.

Due to the iron content of Şırnak limonites and hematite sands microwave reduction can be as effective as conventional reduction. The iron reduction rate in an hour time was also determined not low sufficiently. as well as limonite reduction product can be 56%. The reduction of limonite reaches 87% in the microwave reduced time of 3 hours to 68% of the sand disposed.

The iron waste as iron foundry muddy fine content in the limonite mixture sand is suitable for sponge iron production so the sponge iron will provide higher benefits in terms of reducing costs, even easy transport, and environmental protection. The waste iron resources at suitable grade can be evaluated in iron recycling and high capacity recycling for iron making and manufacturing.

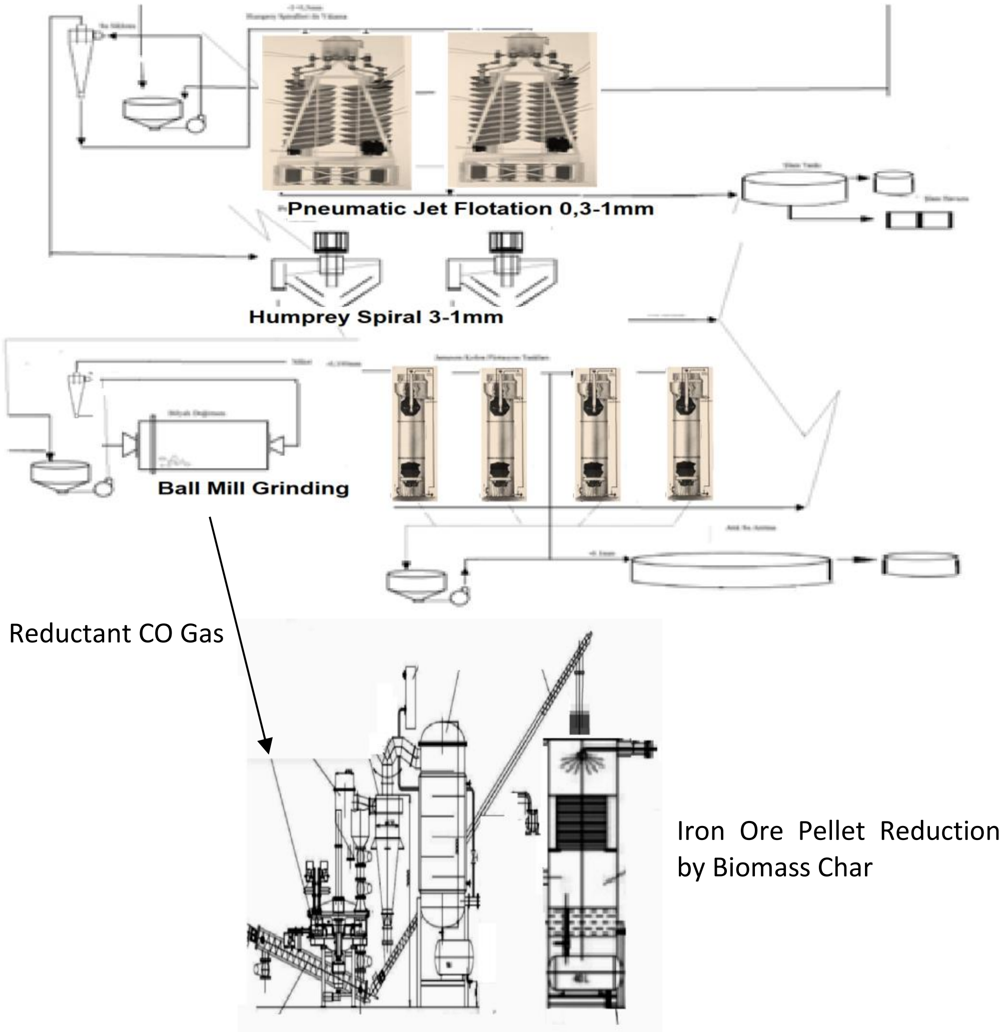

Figure 13: The concentration, reduced and HBI ore production plant and waste iron slime evaluation

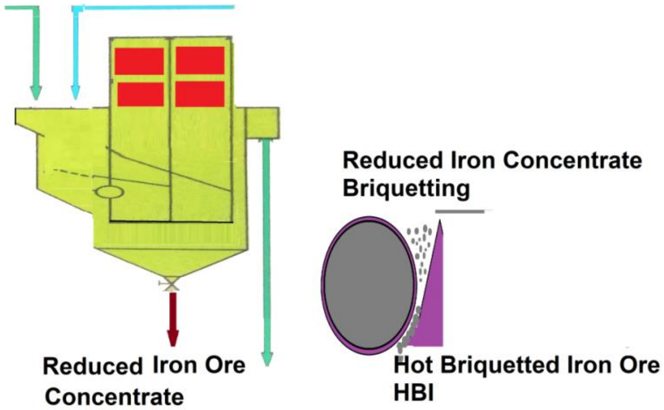

Figure 14: The magnetic concentration of reduced iron ore and HBI briquetting with waste iron slime production plant and waste iron slime evaluation

In the proposed design of the limonite reduction plant, reduced iron and HBI were partly capable of high-grade metallic iron grade in the plant, as reduced iron (-10 mm) 150 000 tons, industrial 85% metallic iron grade with iron slime addition to HBI. HBI reduced iron ore produced by using waste slime (-0.5 mm) of 20,000 tons. Instead of the sponge iron ore, the HBI reduced iron production facility is proposed as given in Figure 14. The microwave-radiated reduction and briquette with char/limonite ores and even waste iron composites may be advantageous for EAF steelmaking.

Kaynaklar

Anonymous, (2020). Can 10% Royalty Reduction In Iron Ore Give Fillip To Atmanirbhar Bharat?, Outlook Magazine, https://www.outlookindia.com/website/story/india-news-can-10-royalty-reduction-in-iron-ore-give-fillip-to-atmanirbhar-bharat/360757

Anonymous, (2020). Indian iron ore pellet makers raise supply concerns, Argus Media, https://www.argusmedia.com/en/ news/ 2133647-Indian-iron-ore-pellet-makers-raise-supply-concerns,

Amankwah, R.K., Pickles, C.A. (2005). Microwave calcination and sintering of manganese carbonate ore. Canadian Metallurgical Quarterly 44 (2), 239–248.

Amankwah, R.K., Pickles, C.A., Yen, W.T. (2005). Gold recovery by microwave-augmented sanding of waste-activated carbon. Minerals Engineering 18 (2), 517–526.

DeVaney, F.D. (1985). Iron Ore. In: Weiss, N.L. (Ed.), SME Mineral Processing Handbook, American Institute of Mining, Metallurgical and Petroleum Engineers, New York.

Chen TT, Dutrizac JE, Haque KE, Wyslouzil W, Ksandyap S. (1984). The relative transparency of minerals to microwave radiation. Canadian Metallurgical Quarterly, 123, 3, s. 349–51.

Datta A K; Nelson S O (2000). Fundamental Physical Aspects of Microwave Absorption and Heating in Handbook of Microwave Technology for Food Applications. CHIPS Publications, USA

Fuerstenau, M.C., Miller, J.D., Gutierrez, G. (1967). Selective flotation of iron ore. Trans. AIME 238, 200-203.

Fuerstenau, M.C., Harper, R.W., Miller, J.D. (1970). Hydroxamate vs. fatty acid flotation of iron oxide. Trans. AIME 247, 69-73.

Fine, M. M.; Melcher, N. B.; Bernstein, N.; Woolf, P. L. & Reuss, J. L. (1970). Prereduced Iron Ore Pellets: Preparation, Properties, Utilization, United States Bureau of Mines Reports, USBM Bulletin 651,

Haque KE. (1999). Microwave energy for mineral treatment processes—a brief review, 1999, International Journal of Mineral Processing, 57, 1, s.1–24.

Hutcheon, R.M., De Jong, M.S., Adams, F.P. (1992). A system for rapid measurement of RF and microwave properties up to 1400 _C. Journal of Microwave Power and Electromagnetic Energy 27 (2), 87–92.

Hutcheon, R.M., De Jong, M.S., Adams, F.P., Lucuta, P.G., McGregor, J.E., Bahen, L., (1992a). RF and microwave dielectric measurements to 1400 _C and dielectric loss mechanisms. In: Materials Research Society Symposium Proceedings (Microwave Processing of Materials III), vol. 269, pp. 541–551.

Hutcheon, R.M., Hayward, P., Smith, B.H., Alexander, S.B. (1995). High-temperature dielectric constant measurement – another analytical tool for ceramic studies. Microwaves: Theory and Application in Materials Processing III, vol. 59. Ceramic Transactions, American Ceramic Society, pp. 235–241.

Jacob J., Chia L.H.L., Boey F.Y.C. (1995) Review—thermal and non-thermal interaction of microwave radiation with materials. Journal of Materials Science, 30, 21, s.5321–7.

Karmazsin, E. (1987). Use of low – and high-power microwave energy for thermal analysis. Thermochimica Acta, 110, 289–295.9th International Exergy, Energy and Environment Symposium (EIS-9), May 14-17, 2017, Split, Croatia

Kelly RM, Rowson NA. (1995) Microwave reduction of oxidized ilmenite concentrates. Minerals Engineering, 8, 11, s.1427–38.

Kılıç Ö. (2009) Mikrodalga ile Isıl İşlem Uygulamanın Kireçtaşı Kalsinasyonuna Etkisi, Madencilik, 48, 3, s 45-53.

Kingman S.W., Vorster W., Rowson N.A., 1999, The influence of mineralogy on microwave-assisted grinding. Minerals Engineering, 3,3, s.313–27.

Raghavan, S., Fuerstenau, D.W., (1974). The adsorption of aqueous octyl hydroxamate on ferric oxide. J. Colloid Interface Sci. 50, 319-330.

Melcher, N. B. (1963). Smelting Prereduced Iron Ore Pellets, JOM volume15, pages298–301(1963)

Machida S, Sato H, Takeda K, (2009). Development of the Process for Producing Pre-reduced Agglomerates, JFE GIHO No. 22, p. 25–31

Kumar, M., S. Ve Patel K.(2009). Characteristics of Indian non-coking coals and iron ore reduction by their chars for directly reduced iron production, Mineral Processing, and Extractive Metallurgy Review, 28,3,258-273

Kermen, H. (2019). Bölüm 1 : Demir-Çelik Sektörü. Türkiye Çelik Üreticileri Derneği, 2018, On birinci kalkınma planı (2019-2023) Ana metal sanayii çalışma grubu raporu,T.C.Kalkınma Bakanlığı, Ankara.

Krishnan, S.V., Iwasaki, I., 1984. Pulp dispersion in selective desliming of iron ores. Int. J. Miner. Process. 12, 1-13.

Lu, T., Pickles, C.A., Kelebek, S., (2007). Microwave heating behavior of a gibbsite type bauxite ore. In: Bekguleryuz, M.O., Paray, F., Wells, M. (Eds.), Proceedings of Symposium on Light Metals in Transport Applications. MetSoc (CIM), Toronto, Ont. Canada, pp. 421–449 (August 25–30).

Ma, J., Pickles, C.A. (2003). Microwave segregation process for nickeliferous silicate laterites. Canadian Metallurgical Quarterly 42 (3), 313–326.

Marland S, Han B, Merchant A, Rowson N. (2000). The effect of microwave radiation on coal grindability. Fuel, 79, 11, s.1283–8.

Metaxas, A.C., Meredith, R.J. (1983). Industrial Microwave Heating. Chapter 10, Peter Peregrinus, London, UK.

SIMA, (2020) Sponge Iron/DRI, http://www.spongeironindia.com/ statistics.php

SIMA, (2017). Sponge Iron Manufacturers Association, New Delhi - DRI Update, http://www.spongeironindia.com/ images/ publications/ DRI%20UPDATE%20-%20December%202017.pdf

Roetzel, W., X. Luo, D. Chen,(2020). Chapter 8 - Experimental Methods for thermal Performance of Heat Exchangers, in W. Roetzel, X. Luo, D. Chen (Eds.), Design and Operation of Heat Exchangers and their Networks, Academic Press 2020, pp. 391–429, https://doi.org/10.1016/B978-0-12-817894-2.00008-X.

Ramachandra Rao T.R. (2006). Direct Reduced Iron Industry in India — Problems and Prospects, Proceedings of the International Seminar on Mineral Processing Technology, Chennai, India. pp. 461 - 463.

Rehder, J.E. (1983). Manufacturing cast iron with pre-reduced iron ore pellets, US Patent no 4401463

Salsman J.B., Williamson R.L., Tolley W.K., Rice D.A. (1996). Short-pulse microwave treatment of disseminated sulfide ores. Minerals Engineering, 9, 1, s.43–54.

Small, M.m(1981). Direct Reduction of Iron Ore, JOM, Volume 33, issue 4, p 71-75

Subhasisa N (2009). Study of Reduction kinetics of Iron ore Pellets by Noncoking coal, MSc Thesis, Department of metallurgical and materials engineering, national institute of technology, Rourkela, India

Tosun Y.I., (2018). Recovery Of Hematite from The Asphaltite Boiler’s Bottom Ash By Column Flotation – Plant Modelling, EJONS International Journal on Mathematic, Engineering and Natural Sciences, Year:2 Volume:(2) Publication Date: June 1, 2018, ISSN 2602 4136, www.ejons.co.uk, pp102-115

Vogtenhuber, H., D. Pernsteiner, R. (2019). Hofmann, Experimental and numerical investigations on heat transfer of bare tubes in a bubbling fluidized bed concerning better heat integration in temperature swing adsorption systems, Energies 12 (2019) 2646, https://doi.org/10.3390/en12142646.

World Steel Association, (2019), World Steel Statistics Japan Steel Institute,2018, Steel Production Report

TÇÜD, (2020) Demir Çelik Üretim İstatistikleri

Welty, J.R., G.L. Rorrer, D.G. Foster (2015). Fundamentals of Momentum, Heat, and Mass Transfer, Sixth ed. Wiley, 2015.

Yang, D.C., 1988. Reagents in Iron Ore Processing. In: Somasundaran, P. and Moudgil, B.M., (Eds.), Reagents in Mineral Technology, Marcel Dekker Inc., New York, pp. 579-644.

Yıldız, N., “Demir Cevheri”, (2010). “Cevher üretimi, zenginleştirilmesi, peletlenmesi, sinter üretimi, sünger demir üretimi, çelik üretimi”, Ertem Basım Yayın Dağıtım San. s 248, ISBN 978-975-96779-3-0,Ankara.