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# Concentration and Microwave Radiated Reduction of Southeastern Anatolian Hematite and Limonite Ores—Reduced Iron Ore Production

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## Abstract

The concentration of low grade iron ore resources was evaluated by washing and reduction. The advanced concentration methods for low grade limonite and hematite iron ores of South Eastern Anatolian resources required such specific methods. The followed column flotation and magnetic separation, microwave radiated reduction of hematite slime and limonite sand ore were investigated on potential reducing treatment. The bubbling fluidized bed allows more time to the heat radiation and conduction for reducing to the resistive iron compounds. Furthermore, heavy limonite and iron oxide allowed sufficient intimate contact coal and biomass through surface pores in the bubbling fluidized bed furnace due to more pyrolysis gas desorption. Bubbling bath porosity decreased by temperature decrease. This research was included reduction in microwave of poor hematite and limonite ores in the microwave ovens, but through smaller tubing flows as sintering shaft plants following column flotation and scavenging operation. Two principle stages could still manage prospective pre reduction granule and pellet production in new sintering plants. There is a lack of energy side which one can produce reduced iron ore in advanced technology plants worldwide. However, for the low grade iron ores such as limonite and sideritic iron ores it was thought that microwave reduction technique was assumed that this could cut energy consumption in the metallurgy plants.

**Keywords:** microwave radiation, iron waste slurries, reducing bath, bubbling bath, concentration treatment, sorbent bath, ferrite, waste ferrite, limonite slurries, microwave activation, reducing treatment, iron ore composts

## 1. Introduction

In 2017 1.63 billion tons of steel was produced in the world as given in **Table 1** and first share of that was China with 631 million ton first and even highest consumption with 736,8 million tons of pig iron and the other share countries were sequentially classified as Japan, USA, India and Russia. Iron ore production in the same years was also reached 2162 billion tons as given in **Table 2**. In the first ranks in iron ore production was first state Australia, Brazil, China, India and Russia was competed

Thousand tons	2015	2016	2017
European Union (28)	166,115	162,024	168,305
Turkey	31,517	33,163	37,524
Other European	35,778	37,601	42,203
CIS	101,552	102,108	100,933
North America	110,938	110,638	115,761
South America	43,899	40,220	43,693
Africa	13,701	13,099	15,053
Middle East	29,429	31,480	34,475
Asia	1,112,873	1,123,948	1,123,948
Oceania	5717	5837	5985
World	1,620,001	1,626,954	1,690,479

**Table 1.**  
*Crude steel production [world steel association, 2019].*

Million tons	2015	2016	2017
European Union (28)	27,825	30,187	30,675
Turkey	9994	7520	6226
Other European	15,407	11,072	9526
CIS	195,298	189,064	177,906
North America	112,451	107,590	113,838
South America	448,122	465,811	465,590
Africa	93,760	90,559	85,657
Middle East	39,370	43,280	55,087
Asia	283,527	316,758	336,879
Oceania	814,403	861,521	887,365
World	2,030,164	2,115,842	2,162,524

**Table 2.**  
*Iron ore production [world steel association, 2019].*

by even scrap trade. In these years in the world 88,664 million tons of reduced iron (**Table 3**), about 101 million tons scrap and sponge iron was imported [1, 2].

Iron ore reserves in our country distributed in Divriği, Bingöl, Kayseri regions. Besides these ores Kesikköprü, Balıkesir and Adapazari different types of iron ore reserves are available. The low quality iron ore was extracted and mixed a certain weight rate amount with high quality ores evaluated in sinter making [3].

Iron ore is used in iron and steel plants. Turkish iron ore reserves can be absolute ore deposits 115 mill tons, apparant iron ore deposits 950 mill tons, potential iron ore deposits 432 millions determined in three groups as tons. Substantially expressing our country’s iron ores as low quality, high titaniferrous iron ore is a serious mistake. Low grade iron ore deposits occurred in mainly Sivas, Malatya and Erzincan [4, 5].

In 2019, the recent years by Erdemir Plant of OYAK, in Turkey, produced pig iron in 4 iron blast furnaces used high grade (63% Fe total) imported iron ores mixed with at high rate over 5/1 local iron ores evaluated [4, 5]. Hence, this

Thousand tons	2015	2016	2017
European Union (28)	659	702	703
CIS	5436	5820	7200
North America	10,621	8644	9618
South America	2680	1691	1722
Africa	4025	4019	6152
Middle East	28,906	29,816	33,194
Asia	23,654	27,638	30,075
Oceania	5717	5837	5985
World	75,982	78,331	88,664

**Table 3.**  
*Direct reduced iron ore production [world steel association, 2019].*

evaluation of low grade explored iron ore deposits prompted. The limonite ore deposits contained low grade Fe such as 25–42% Fe in South Eastern Anatolia needed enrichment for evaluation in blast furnaces after sizing suitable for use. Low grade hematite ore was concentrated to over 65% Fe grade by gravity and magnetic separation. The advanced methods were searched for low grade iron ore potential to evaluate. But some of the ore undesirable by integrated impurities and low iron content. It was partially operated in certain periods. An important part of these resources contains limonitic and sideritic iron ores and below 44% Fe as low grade hematite river sands. The limonite ore deposits range between 19 and 44% Fe. Low grade hematite ores 20% Fe grade could be evaluated in India and China. The limonite ores are enriched and pelletized [4, 5].

The pelleting plant projected in Divrigi contained a concentrator and pelleting facility established at a capacity of 1 million hematite ore. Regarding our iron ore qualities over undesirable contents such as Ti and Mn the resources was not projected in evaluation as long years since no study conducted on behalf of preparation cost and mining cost of iron ore.

India ranked first reduced iron ore use in world steel production with integrated iron and steelmaking waste gases in established in the direct reduction facility [5].

In Turkey, imported scrap at 9 million used for 22 million tons EAF iron and steel making instead of concentration and pelleting our low grade ores. Reduced iron ore pellet plants in India [6–9]. produced 36.9 million tons in 2019 and varied total ore production of 232 million tons. Vertical gas shaft furnaces were commonly used in evaluation of reduced low grade hematite sands followed pelleting and imported low grade ores in this country directed to horizontal grate for production reduced sinters on grate-reduction using coal gas or steel making flue gas. Although reduced pellets were high grade 85% Fe total ore produced, sponge iron production was not commonjust 3 million tons.

The most effective and cost-effective technologies are needed for iron ore products in today’s modern technologies. Turkish pig iron industry needs direct reduced iron ore products and related technologies and high quality at lower cost with various types of local iron resources should be investigated.

Şırnak and Hakkari region asphaltite coal combusted and ash discarded in the boiler bottom contains 15% limonite at fine sand size below 2 mm from furnace [10]. The rivers and some local land soil contained below 22% Fe grade hematite at slime size of below 150 micron simply excavated as river sand and exported to Iran. In this study this low quality hematite and limonite ores were evaluated for steel-making reduced iron ore [11–13]. The gravity concentration was affective in limonite

and hematite sands. The Humphrey spirals were also used in the washing of Şırnak asphaltite coal bottom ash. The limonite sands gave high Fe yields in the low intensity magnetic separation and especially in the washing of the hematite sands in the coal ash widely [12]. In the high load density and high ash coals Humphrey spirals and magnetic separation was specific performances of concentration selectively at 82% during the washing was observed to increase the amount of high grade iron ore concentrates.

## 2. Flotation-magnetic separation of low grade limonite ores

In this investigation, a comparison was done between the use of poor limonite and hematite ores containing 15% limonite of the regional coal boiler bottom ash discarded as municipal waste 120 thousand tons per annum. The column flotation tests of 44% hematite using collector making hydrophobic by oleic acid and frothing agent of pine oil for long height stable frother to float limonite and hematite slimes at there stages scavenging flotation. The scavenging column flotation was nedded for long period of flotation of hematite slimes and losing high slime content at high grade froth performances [12–16]. The amount of collector and pH changed from 2 to 5 kg/t and from 8 to 11, respectively. The test results showed reduced limonite and hematite recoveries of 63% and 45%. The less amount scavenger yield resulted better (70–85%) limonite recoveries.

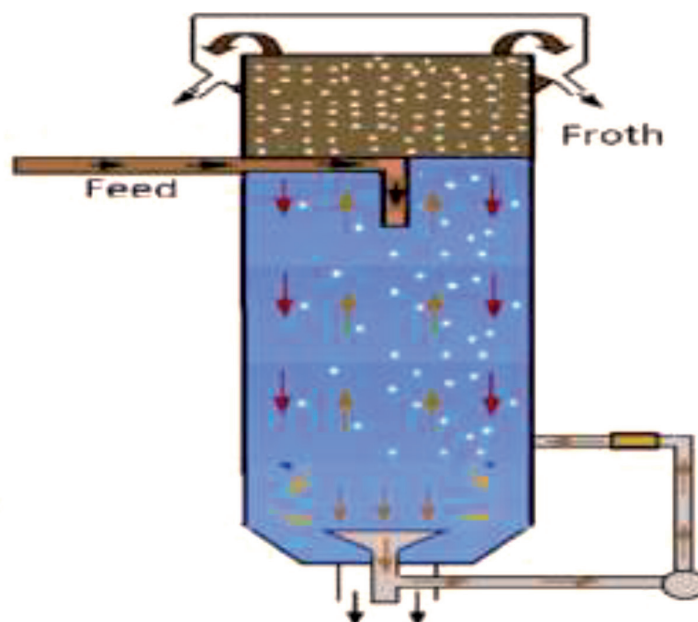
In the tests of reduced iron ore production reductive roasting at 1000°C with coal fine for different times, ranging 40 min, and 80 min for the limonite pellets [17–23] were converted to reduced iron ore and the properties of the reduced iron ore showed the optimum conditions of concentration. The burned asphaltite coal in reductive roasting showed that high volatile gases amount and flue gas quantity and temperature provided by microwave affected on reductive roasting of limonite slimes to direct reduced iron ore.

The flotation routes of iron ore can be classified into five major groups, i.e. cationic flotation of iron oxide, cationic flotation of quartz, anionic flotation of iron oxide, anionic flotation of quartz [24–31]. Despite the variety of flotation route for iron ores, currently, the reverse cationic flotation route widely used in the iron ore industry. The two anionic flotation methods developed by Hanna Mining and Cyanamid, i.e. direct anionic flotation and reverse anionic flotation routes, are also being used in the iron ore industry.

Tosun discussed that at the three stages of scavenging hematite slime flotation, the flotation rate of the slime suspension at 10% solid weight rate shows very low viscosity. The wash water has little effect on the froth flow. Consequently, the only froth length at 30 cm scale in the column of 1.5 m will be sufficient to 4 cm diameter column scale. Following Floatex density separation, this Outec air sparged column flotation as shown in **Figure 1** is similar to froth happens in the free fall of an 100 micron slime hematite in a positive base flow [12]. The scavenging froth time increases approximately by growing particles load of froth heavily with time at the early stages of the scavenging process. After the theree stage scavenging, The Outotec flotation column [32] use need some relatively long time, the maximum concentration of the air sparging decreases and the positive base flow effects high grade froth making. The collector cations are either stuck onto the bubble. The suspension of limonite particles caused hard water [33, 34].

Although the reverse cationic flotation route has become the most popular flotation route in iron ore industry, the direct flotation of iron oxides still appears desirable for some low grade iron ores that contain a vast amount of quartz. Oleic acids





**Figure 1.**  
*Outec column flotation equipment.*

as fatty acids provided high froth limonite loadseven at low dosage in the range of 0.45–0.67 kg/t [34, 35]. Reagent conditioning was affected significantly the direct froth load. The longer conditioning time can reduce reagent consumption below 50%. High conditioning time periods over 20 minutes was also found beneficial to the direct hematite flotation [36–44].

The adsorption of fatty acids on limonite plays a key role in the direct flotation route. In the literature, it is generally accepted that fatty acids adsorb on the surfaces of limonite through chemical bonding. Based on infrared studies, established that oleic acid/sodium oleate chemisorbs on limonite [39, 40]. Using the technique of micro electrophoresis, demonstrated the chemisorptions of oleic acid and lauric acid on hematite [40]. It is also confirmed chemisorption of lauric acid on hematite surfaces [44]. In addition to chemisorption, fatty acids can also adsorb on mineral surfaces through surface precipitation [37, 38].

The collector as hydroxamates that shows similar effect to fatty acids in solution [39] is used successfully in the laboratory as collectors for hematite, limonite and goethite flotation, with better performance than fatty acids [40, 41]. The adsorption mechanism of hydroxamates on limonite was classified as classical chemisorptions [35, 36].

In the reverse cationic flotation, the depressant of iron oxides that is widely used is typically corn starch. Corn starch is not soluble in cold water and must be put into solution in a process known as gelatinization.

## 2.1 Washing with the column flotation

Column flotation of iron ore is preferred as well yield preparation selective floated in the microbubbles [34, 43]. Microbubble froth washing in the form of foam zones may be possible to obtain cleaner product [24, 25]. Particularly, for difficult washable vertical column is a method used successfully in flotation at high rates [40]. Particle size and type of coal as the flotation column can easily affect efficiency. However, operating parameters, especially the foam height of the column unit, the wash water is added, and the bias ratio is flammable operating parameters affect efficiency [34–39].

Other froth principles laid cyclonic column flotation cell (S-FCMC) provided a foam zone comprising inclined channels (FCMC) it proved to be effective in column frothing used. The froth product in the column has a third zone of the less froth sediment removed [37].

The application of column cells in the mineral processing industry has gone from virtually zero in 1983 to wide acceptance in 1990 [35–37]. The major operating difference between column flotation cells and mechanical flotation cells is the lack of agitation in column flotation which reduces energy and maintenance costs [34]. The practice of froth washing in direct flotation increases concentrate grades without significant recovery losses [34]. In the reverse flotation of iron ores, froth washing was found effective in reducing the loss of fine iron oxide particles to froth. It was reported that the cost of installing a column flotation circuit is approximately 25% - 40% less than an equivalent flotation circuit of mechanical flotation cells [36].

## 2.2 Magnetic separation Following reduction

Reduction in retort furnace and Shaft furnaces were commonly used in iron ore reduction processes depend on numerous factors including coal rank in carbonization, the volatile gaseous matter of coal such as presence of hydrogen, carbonyl gas and reduction rate [45–53]. Hydrate and carbon dioxide removal was stabilizing the mass desorbance, the settings of optimal diffusion conditions including structure defects (nitrogen, phosphorus, sulfur, etc.). The temperature, oxygen content of coal, optimization of carbonmonoxide concentration ratios acted the adsorption-desorption balance, the residence time and the spatial distribution of molecules in iron ore pores among other factors determining the efficiency of reduction. as factors affecting the rate and extent of char to CO motion much dependent on the site activation, its desorption properties and ore porosity.

The limonite reducing capacity of the microwave heated [54–62] column samples according to output reduced iron sand, char shale fine washed away and time sequential experiments and reduction limits were high, but high clay contents in limonite sand provided low performans washing and clay have efficiently reduced Fe yield. Samples for this microwave heat treatment at low temperatures at 900°C provided certain properties of the hematite material of high reducibility capacity and not dispersed in the wet state [63–83].

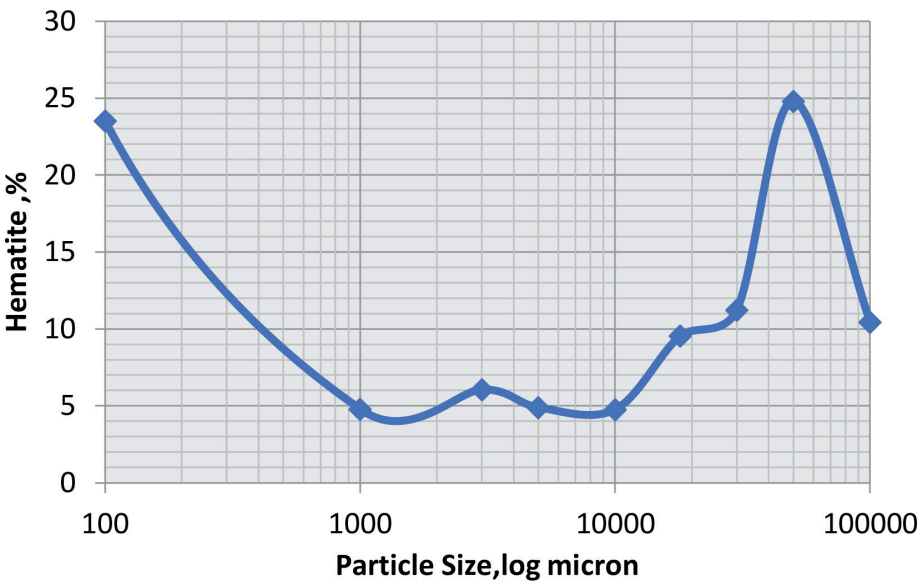
## 3. Material and methods

### 3.1 Gravity washing and floatation

The bottom ash of Avgamasya vein asphaltites represent approximately 67% of the production is carried out from the coal mines has been reduced to 120 kg sample cone reduced by up to 18 mm-fours under the hammer. Nuts are widely washed coal ash and high sulfur coal to be sold as industrial fuel asphaltites is intended to be sold. Optimum bottom ash flotation plant is determined by standard testing results performed. In the experiments, the bottom ash of Avgamasya vein asphaltites was crushed and screened prior to represent flotation samples and distribution of fractional ash is given in **Table 4**. **Figure 2** describes **Table 1** hematite distrubition versus ash size distribution. Higher sized ash contained more hematite. The sand size had lower content of hematite. Especially the range below 10 mm contained remnant about 21,3% hematite of total ash feed. The limonite percentage was 21,3% in the total bottom ash distribution. It showed uniform distribution of the hematite content in all fractions.

Screen Size	Ash Weight, %	Hematite, %	Hematite Yield, %	Limonite, %	Limonite Yield, %
+ 10	10,44	13,44	1,40	38	26
+ 5	4,8	14,6	0,70	16	22
+ 3	1,23	11,23	0,13	3	23
+ 1.8	5,54	15,54	0,86	2	24
+ 1	7,75	17,75	1,37	1	26
+0,6	13,82	13,82	1,90	2	30
+0,3	15,55	15,55	2,41	4	28
+0,1	13,74	16,74	2,30	9	32
−0,1	27,13	17,13	4,64	25	31
Total	100		15,75		27,16

**Table 4.**  
The distribution of hematite at bottom ash regarding particle size and hematite yield content in ash.



**Figure 2.**  
Content distributiobn values in hematite yields in different size grain fraction against size.

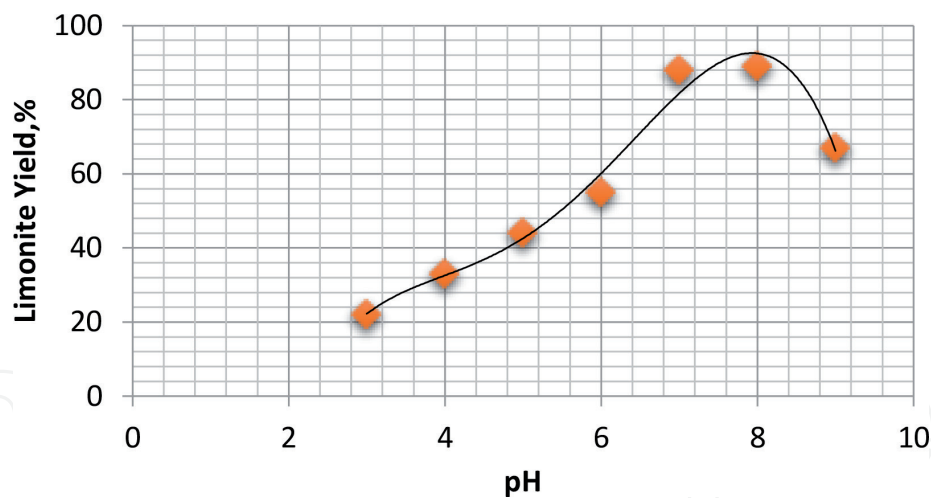
### 3.2 Flotation of hematite/limonite in oleate

30 kg samples were ground to −0,1 mm in ball mill and 1 kg representative samples were used in the study represent −0,3 mm size of −0,1 mm separated flota- tion tests for grain size fractions were subjecte direct flotation made by oleic acid. In the direct flotation test; oleic acid at neutral pH solution were used as collector. − 0,1 mm fraction used in this study were studied in similar way.

1 liter Denver laboratory flotation cell for clean conventional flotation tests were used to produce concentrated hematite and limonite concentrates. The condition- ing 5 min and frothing 10 min in conventional flotation carried for 2 min extra at 20% weight solids. The flotation cell was agitated in a mixing speed 1500 rpm. Limonite flotation tests used oleic acid 1000 g /ton and frother pine oil 400 g /t to be conditioned.

According to the results of the flotation made on pH effect on Limonite at size classed; −0,1 mm grain obtained by gravity concentrated classes test results as given in **Figure 3**.





**Figure 3.**  
*Test values in limonite yields in- 0.3 mm grain fraction against pH.*

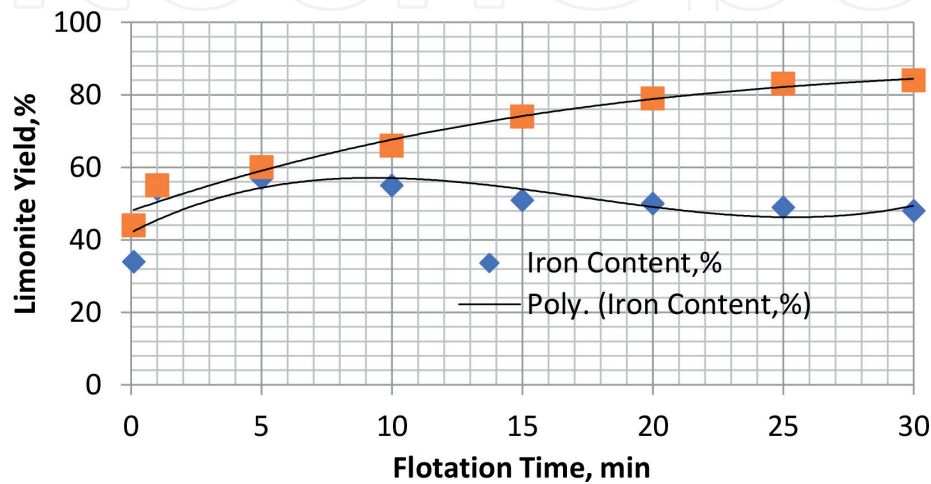
Limonite yields were illustrated in **Figure 1** with the curve.

Limonite concentrate can be floated in a weight ratio of 58.2%. 59.7% iron grade limonite can be floated in a weight ratio of 68.2% concentrations at pH 8 (**Figure 3**). 26.3% by weight of the limonite sand floated with the 57.5% yield of limonite. The sand could be recovered as given 28.4% as given in **Figure 5**

Crusher-run coal can be washed with some weighing as high as 17.9% when the limonite and ash slimes on limonite flotation for 42.3% constituting 0.02 mm grain size flotation yields were obtained. This is thought to be caused by iron ore slime Fe content. However, limonite sand and slime have also been coupled in parallel as limonite product. The cumulative result of the mixed obtained from the test; 76.5% side with an efficiency of 28.4% can be recovered as slime product is seen from **Figure 4**.

**3.3 Washing with the column flotation followed FDS**

The Floatex Density Separator (FDS) is a water sparged-bed gravity separator which is used to separate different density of hematite ores at heavier specific gravity. Both the size below 0,5 mm and density have substantial effective on the concentration of limonite and hematite. The FDS was attracted considerable interest in iron ore concentration. The macropictures of samples are shown in **Figures 5** and **6**.



**Figure 4.**  
*Test values in limonite yields in- 0.3 mm grain fraction against flotation time.*



**Figure 5.**  
*The macropictures of Şırnak limonite.*



**Figure 6.**  
*The macropictures of Şırnak hematite.*

The separator consists of an upper tank with a square cross-section and a lower conical section [30]. Representative of  $-0.5$  mm samples are concentrated and then concentrate hematite of FDS reduced to grinding  $-100$  mikro at controlled size grinding. The representative model, 1,6 m glass column 3 cm in diameter laboratory column cell flotation cell (**Figure 1**) used in the column flotation unit of limonite slime flotation.

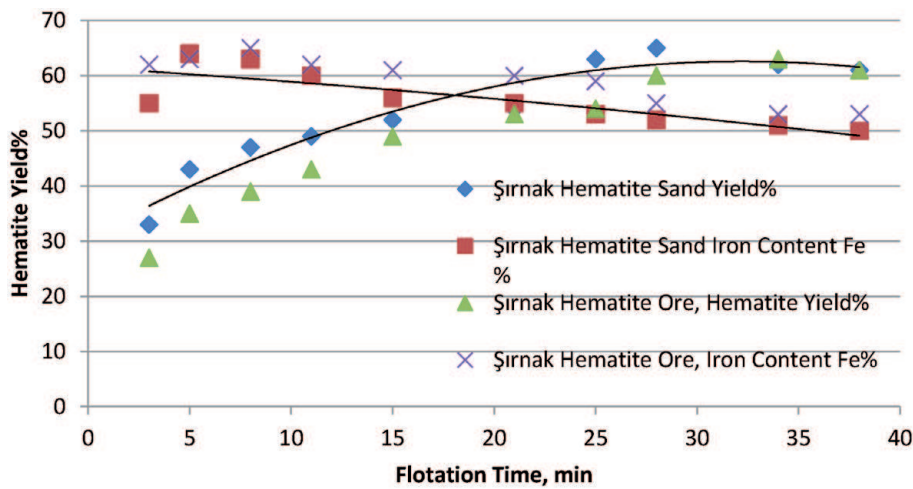
The reagents used in conventional flotation column flotation tests were also performed in the column tests. In the column flotation tests oleic acid 1000 g / ton pine oil 400 g / t were conditioned foam height is kept constant at 30 cm. Zero Bias ratio is used to concentrate hematite ore and limonite sands. The flotation time was used for 3 min and 35 min time condition coal in tests. 10% solid/liquid ratios of 200 ml/min the wash water rate were used in the experimentation.

Column flotation tests results from limonite concentrate, shale waste can be taken as sink bottom product and limonite yield equilibrium distribution is given in **Table 5**. Accordingly ( $-100$ microns) mm grain size in bottom ash is mixed with slime limonite can be as 60.60% in cumulative yield will be thrown when recovered limonite is contained, 54.3% iron content of the ash and bottom tailings contained 4% iron as waste (**Figure 7**).

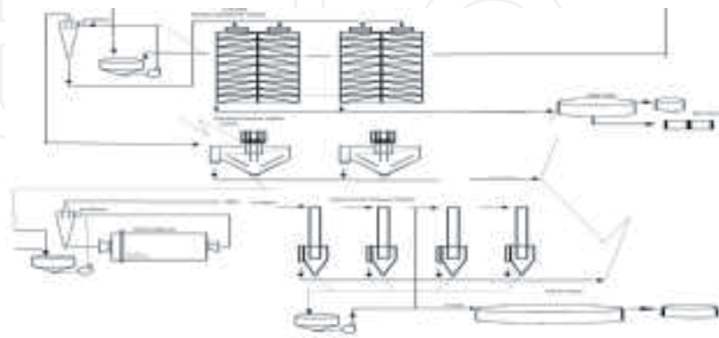
Column Flotation efficiency of limonite products produced from the results of tests of the direct flotation to 77% of limonite yield has fallen 64% value.

% Component	Şırnak Kızılsu Hematite Sand	Şırnak Limonite	Şırnak Şenoba Limonite
SiO <sub>2</sub>	3,53	4	11,14
Al <sub>2</sub> O <sub>3</sub>	2,23	6,5	8,61
Fe <sub>2</sub> O <sub>3</sub>	49,1	53	54,9
CaO	23,48	5,23	9,18
MgO	2,2	2,18	4,68
K <sub>2</sub> O	0,41	0,53	3,32
Na <sub>2</sub> O	0,35	0,24	1,11
Ignition Loss	16,19	26,11	38,43
S <sub>03</sub>	0,32	0,21	0,2

**Table 5.**  
The chemical analysis values of various limonite ores, in calcareous formations of Şırnak province.

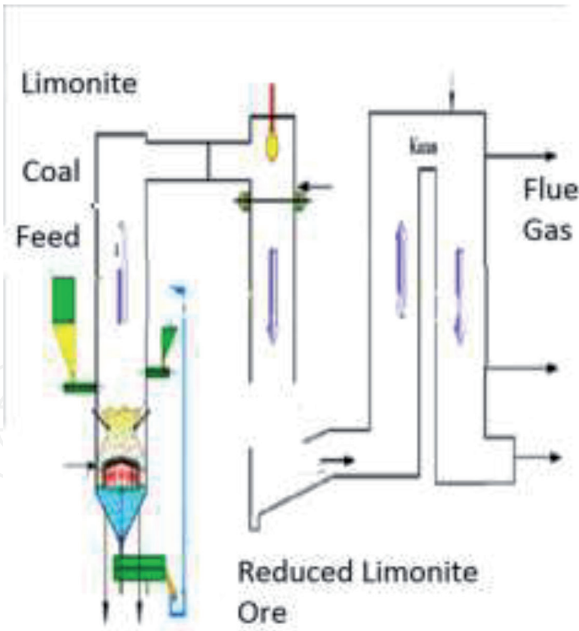


**Figure 7.**  
Hematite yields in- 0.1mm grain fraction column flotation tests of Şırnak Hematite Sand and Ore at pH 8.



**Figure 8.**  
Proposed Limonite concentration plant.

Flotation test results produced for the limonite product yields from 77–64% of the iron content has fallen 45% value (**Figure 8**). As shown in **Figure 5** The iron contents produced from test results of 42% decreased to value of 37% for the column flotation of bottom ash. The product yield is lower compared to other methods.

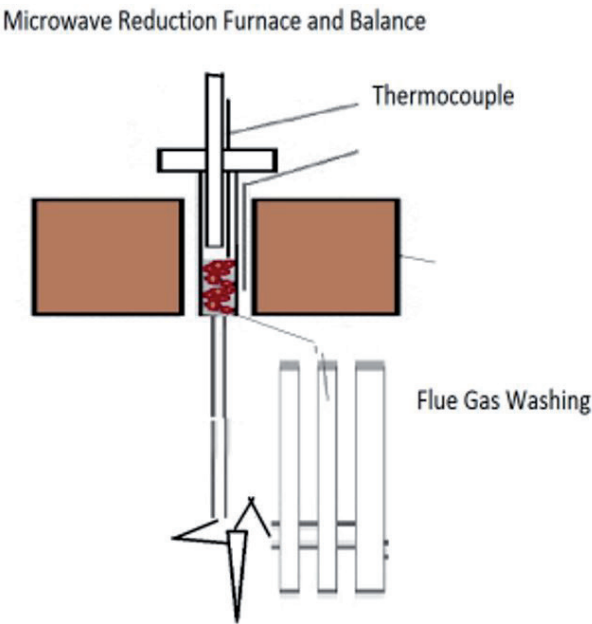


**Figure 9.**  
*Schematic view of vertical shaft bubbling reduction with recycled by microwave heating technique.*

**3.4 Reducing bubbling Teatment**

Reduction was carried out in 5000 ml tubes by adding 75 gr limonite to 1900 ml of bubbling bath. For a homogeneous bubbling suspension limonite coal asphaltite mixture was first subjected to cold start treatment in a 5 minutes microwave radiation (**Figure 9**).

After the hot temperature gas limonite suspension was allowed to stand for 30 minutes after being bubled so that the reduced particles and ashes were collected and settled cyclone output. At the end of the period, suspended limonite concentrate was reduced by cycled method and was magnetically separated from ashed matter fine.



**Figure 10.**  
*TGA analyzes of the samples were carried out in Bubling bed in microwave radiated tube.*

The layout of the reducing cycle was somewhat simpler than that of the limonite slurry: there was no gas reducing column towers connected to the ashed contaminated bubbling compost, and the reducing unit contained one single microwave radiation column can be used to perform the three separation magnetized flow phases: roughing, scraping and cleaning. The variation of the third cycle washed was also limited recycled by microwave act (**Figure 10**).

## 4. Results and discussion

The current use of absorbent hematite and new areas of use increase in demand due to outflow. Absorbant matter beds must be fully identified, potential sources should be determined, absorbant purpose on fulness should be investigated and suitable properties for absorbent compost production. This study was improved reduction in microwave processes. This study used for microwave reduction heat absorbant hematite samples taken from the local area. By applying the reductive atmosphere processes, The standard semimetallic materials was suitable for industrial microwave radiation emitted through hematite for reduced matter production was possible.

### 4.1 Bubbling reducing activation

#### 4.1.1 Coal gas and bath sand particle size

A major reason is that the retention time in fixed film processes is longer than in solid–gas processes. This allows more time to the carbonization far cracking to the desorbed persistent compounds. Furthermore, high rank coals allows an sufficient intimate contact between surface pores and gas atmosphere in the furnace due to more gas desorptions [55–56].

#### 4.1.2 Bubbling bed porosity

The bubbling fluid matter was simulated for reduction solid air mixtures on sands. The sand/air mixture was more than occasionally exposed to limonite sand to air. The air fluid was comprised of a unique high-stability base plus high-performance oxidation inhibitor/stabilizer (**Figure 10**).

Initially, most of the limonite flow occurred through chemical reduction of the iron oxides over the hematite where the coal combustion temperature was in the combustion phase below 950°C that reducing gas lasts approximately in 5–13 mins. The gas removal efficiency from asphaltite coal was 40–90% reported during the temperature range at 950°C. Following the combustion at 800°C iron ore reductions over hematite was started as shown in **Figure 9**.

### 4.2 Bubbling bed reducing treatment

Bubbling reduction design of fluidized bed made an advantage of reducing ore and eliminating the effects of microwave convection. The balance and gas flow measuring ensuring the heat power and temperature measurement is made in a magnetic field of known cycled flow and that the heat losses in the system minimized under both magnetic heating [67–83].

We report on this study of the hematite and limonite compound in terms of iron oxide weight stability. Microwave thermal stability in column layers radiated thermal activation determined 800°C temperature value of the limonite and hematite in



Material	The Chemical composition	The Bulk density g/cm <sup>3</sup>	Microwave Activity	Reduction Rate at 30 min CO flow
Ferrite pellet	CaO:2,1–2.8%; SiO <sub>2</sub> ≤ 10%;Fe <sub>2</sub> O <sub>3</sub> :45 ~ 65%; P ≤ 0.1%;S ≤ 0.1%,	2.8 ~ 3.2	Weak	75%
The sintered ore	CaO:1.16%; SiO <sub>2</sub> :5.18%;Total Fe:54.3%;P:0.05%; S:0.02%	2.4 ~ 3.0	Strong	85%
The iron oxide powder	total iron is 55%, Oxide	4.8 ~ 5.2	Strong	65%
Limonite slime, oxide	total iron oxide 70.02%, silica 1.55% .	3.6 ~ 4.3	Weak	65%

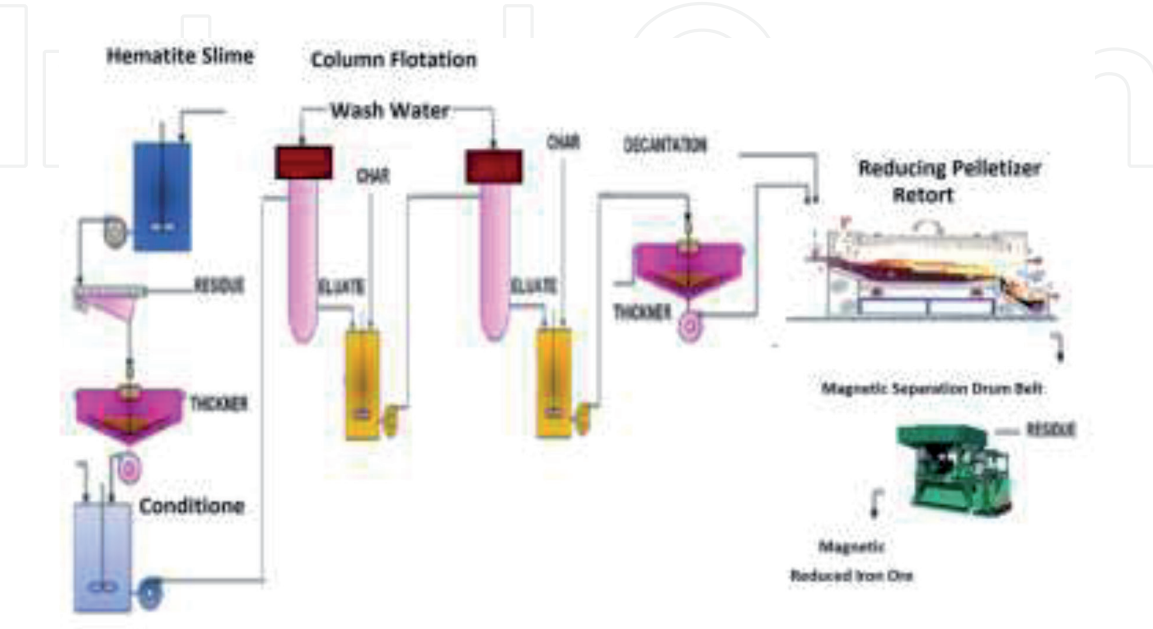
**Table 6.**  
*Microwave activity, chemical composition and physical properties of iron materials in the experiments.*

this chemical compound in a crystal structure of diamagnetic grains can be emitted at an optimum temperature of 980°C.

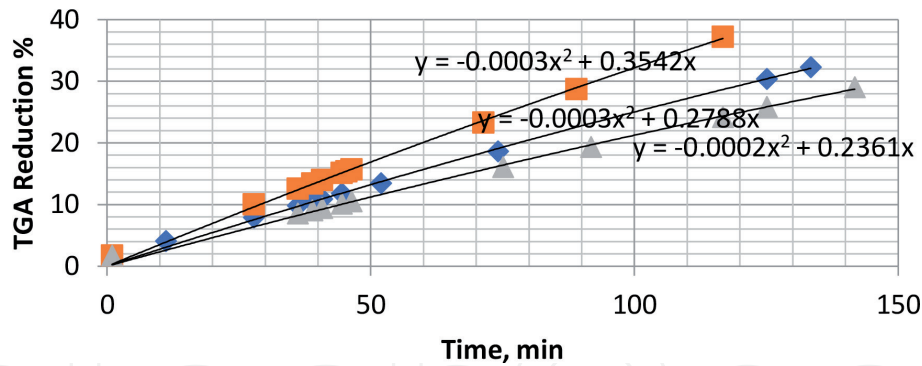
The microwave reduced chemical composition and physical properties of FeO formation material in reduced matter showed as **Table 6**. The bulk density average value of the ferrite pellet is 3.02 g/cm<sup>3</sup> by reduction. In order to better application of the hematite ferrite pellet the melting point of the ferrite pellet and slag formation material of reducer was compared. The finally the hematite sample put into microwave furnace at the temperature of 1350°C and time of holding temperature was 2 minutes. The reduced sintering state of sample was immediately observed after cooling.

**4.3 Concentration reduced ore and model method**

The iron oxide groups showed that the limonite quality will enhance the quality of direct reduced iron ore quality as high iron grade. Further reductive roasting provides much higher metal conversion. The concentration model using Retort furnace and coal char was seen in **Figure 11**.



**Figure 11.**  
*Concentration and reduced iron ore production by retort pelletizing bed in retort furnace.*



**Figure 12.**

*TGA analyzes of the samples were carried out in Bubbling bed in microwave radiated tube.*

#### 4.4 TGA analysis

Analyzes were performed using approximately 300 g of limonite samples at a temperature range of 800–1000° C at a heating rate of 10° C / min. The temperature ranges and mass loss values obtained from the TG analysis are given in **Figure 12**. The limonite samples reduced 65% iron yield at 805°C, 899°C and 980°C, respectively. The limonite reduction was effective due to the core heat adsorbed on autonomous heating particle core by radiation.

In the TGA curves, the reduction rate values of the microwave activated limonite samples were determined to be lower than those of the native sample due to the increasing iron ore contents at 72–81%. The hematite, coal char shale and limonite samples revealed that the total mass losses at 1000°C were 31.9%, 47.75% and 38.15%, respectively.

#### 5. Conclusions

In the pH measurements made, the pH value of 7,3 in washing limonite finally at the last washing column flotation decreased to iron yield lower to 53%, depending on the concentration of salt content of slurries in the foam water.

In the three stage microwave cycling reduction test measurements made with found that 730 g Fe/kg in limonite/asphaltite char decreased to 530 g Fe /kg in last column output. Likewise, the reduced limonite ore iron grade increased to 76% Fe as final magnetic separation obtained after 10 min concentrating by low permanent magnet and Fe yield was at 47% of final performance.

The reduced iron ore pellets or sinters provided high quality steelmaking feeds in plant facilities. The other side in steelmaking is low impruty scrap feed and reduced iron contents. In our country, Iskenderun EAF needed this quality ironmaking reduced iron ores in steel ladles. There is lack of local miners to produce direct reduced iron ore and fluxing limed pellets which are working at ironmaking. The microwave reduction method use in this study proved that investing in high quality ironmaking and steelmaking feed.

Due to the low iron content of Şırnak limonites and hematite sands this effective method showed that retort reduction and magnetic separation following column flotation might be effective as bubble bed reduction. The total iron yield was also determined as 72% at not reduced sufficiently, as well as limonite product can be 56%. The recovery of limonite was 87% in the limonite flotation plant. The recovery in column flotation can be reduced to 68% of the bottom ash disposed.

Limonite content of the bottom ash was suitable for evaluation in sponge iron production so that the sponge product will provide benefits in terms of reduced

costs as well as transport and environmental protection. The lower grade value can be both beneficial in recovery and capacity for industrial iron produced.

In the proposed design of the microwave direct reduction following limonite flotation plant, reduced iron ore product was capable of total iron grade of 81% in the plant, as reduced iron (12–10 mm) 350,000 tons, industrial 80% iron grade may produced with microwave radiation and char use (–10 / -0.5 mm) of 20,000 tons, as the magnetic separated 165,000 tons of reduced iron was able to be produced in proposed model in **Figure 8**.

Iron ores fines as limonite and hematite sands slime was finely concentrated by column flotation then managed efficient reduction by bubbling bath at 25% porosity at temperature of reducing at 900°C. It was determined that so great extent reducing rate 64% at 20 minutes and 72% of iron recoveries was found by a porous bubbling bath over 47–55% weight rate of limonite was optimized for reduction. The more efficiently conducted heat reduced more a low amount limonite with below iron weight rate of 35%.

This research was included primitive microwave ovens, but that smaller tubing flows reduction in microwave as sintering tube plants without any complicated equipment for operation. Two principle stages could still manage prospective pre reduction granule and pellet production in new sintering plants: improvement of preparation of limonite ores of minus 5 mm retort reduction process as well as optimization of the retort coal gas reduction quality. A second stage was principle microwave reduction tube passage has prevailed during the last reduction because of hematite core was becoming higher temperature CO reduction due to the act of the microwave radiation over core of particles This process was beneficial for using low quality coal gas and not needing sintering on the issue of energy and environmental dust emission ways., Due to the produced granules was efficiently used in electrical arc furnaces for scrape steel and other mixture demands, in the steel plant operators improve scrape and dust controls in hot metal pouring. Approx. 5% of the total pig iron production was originated from the pre reduced iron ores of total 35 million tons of pig iron production in EAF technology, which highly struggle on recover waste gas energy and dust, toxic emissions. This technology may improve dust control by stick hot matter in hot pouring process.


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