J. Min. Metall. Sect. B-Metall. 55 (3) B (2019) 295 - 303

Journal of Mining and Metallurgy,
Section B: Metallurgy

FLUIDIZED BED ROASTING TECHNOLOGY IN IRON ORES DRESSING IN CHINA — A REVIEW ON EQUIPMENT DEVELOPMENT AND APPLICATION PROSPECT

Z.-D. Tang [a, b], P. Gao [a, b, *], Y.-X. Han [a, b], W. Guo [a, b, #]

[a*] School of Resources and Civil Engineering, Northeastern University, Shenyang, P.R. China
[b] National-local Joint Engineering Research Center of High-efficient exploitation technology for Refractory Iron Ore Resources, Shenyang, P.R. China

(Received 20 May 2019; accepted 30 August 2019)

Abstract

Due to the undesirable characteristics of iron ore resources in China, it is necessary to utilize refractory iron ores resources with high efficiency. The mining and mineral processing costs are usually high. The supply of domestic iron ores in China has been in serious shortage for a long time. Therefore, the development and utilization of complex and refractory iron ore resources are extremely urgent. Magnetizing roasting followed by magnetic separation is an important method for the beneficiation of low grade iron ores. More attention has been paid to fluidized bed magnetizing roasting rather than shaft furnace and rotary kiln roasting in recent years. In this paper, the main characteristics of fluidized bed magnetizing roasting technology and the development process of its application in the beneficiation of refractory iron ores are introduced. The research status of several typical fluidized bed roasting processes and equipment in China are also summarized. Moreover, the application prospect of the technology for efficient utilization of low grade hematite, siderite, and limonite ores, as well as iron containing tailings, is analyzed.

Keywords: *Fluidized bed magnetizing roasting; Complex and refractory iron ores; Development process; Application prospect*

1. Introduction

Fluidization refers to a physical phenomenon in which solid particles are imparted with fluid properties when the former are suspended by a rising gas or liquid [1-4]. Due to its distinctive advantages for the chemical reaction process, including large contact areas between gases and solids, high rates of heat and mass transfer, uniform bed temperature, and non-mechanical agitation of the reacting species, the fluidized bed technology is widely applied in industries such as coal gasification and combustion, petroleum catalytic cracking, chemical production, material preparation, and biomass utilization [5-10].

Early in the 1950-1960s, fluidized bed roasting technology became a focus of global public attention, which was studied in the UK, the USA, Canada, Italy and other countries [11]. A fluidized bed magnetizing roasting plant that can process 1000 tons of pyrite per day was built in Follonica, Italy. Through this technology, from an iron ore concentrate assaying 65% Fe, 95% recovery rate can be achieved, and the SO_2 for acid production can be obtained as well [12]. In addition, The United States designed a multi-layer fluidized bed magnetizing roasting plant with an annual processing capacity of 200,000 tons [13]. In recent years, however, due to the abundant high-quality mineral resources, the complex refractory iron ores have basically not been utilized in foreign countries. Therefore, few pertinent studies have been reported on the fluidized bed magnetizing roasting.

In 1958, the famous fluidization expert Mr. Mooson Kwauk adopted the technology for magnetizing roasting of lean iron ores [14]. Since then, the pioneering practice of fluidized bed magnetizing roasting technology in the mineral processing field of complex refractory iron ores has been developed. Fluidized bed roasting is known to be a very effective step for low-grade iron ores beneficiation when conventional methods such as froth flotation, gravity concentration, and direct magnetic separation are deemed to be unfit. By this

*Corresponding authors: *gaopeng@mail.neu.edu.cn; #meguowang@163.com*

https://doi.org/10.2298/JMMB190520051T

roasting, the weakly magnetic iron minerals (mostly hematite, limonite, and siderite) are converted into the magnetic form, which is suitable for easy beneficiation by magnetic methods. Compared with the shaft furnace and rotary kiln roasting, the advantages of the fluidized bed magnetizing roasting are as follows: (1) Since the particles are suspended in the gas phase, the particles are in a better dispersed state. Thus, the gas and solids can be fully contacted and the quality of roasted product is uniform and stable; (2) The fluidized bed magnetizing roasting technology has high reaction rate, high heat transfer rate, high mass transfer rate, and low heat consumption. Especially in the alumina industry, by contrast with the traditional rotary kiln, the heat consumption of the fluidized bed roasting is reduced by more than 30%; (3) Due to the uniform bed temperature and stable airflow distribution, the roasted products are homogeneous; (4) As a consequence of the absence of moving parts within the reactor, the operation can be controlled easily [15].

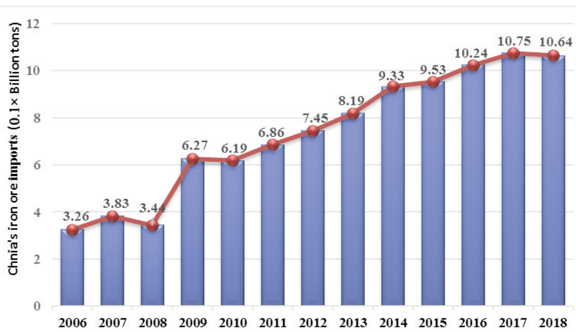

Figure 1. *China's iron ore imports in the past period*

The iron and steel industry is a crucial basic industry of the Chinese national economy, a supporting industry for realizing industrialization and an intensive industry in technologies, capital, resources and energy. China is a big developing country with a comparatively large demand of iron and steel in economic development which will continue for several more decades. Accordingly, iron ores, the supportive resource for China's steel industry, belong to the strategic mineral resources. Although the total reserves of iron ore resources in China are huge, the distribution of iron ore resources is more dispersed, with more lean mines and very few rich mines. Most ores are difficult to mine, the cost of mining is high, and the actual output cannot meet the production needs of domestic steel mills; therefore, domestic steel producers have to choose to import large quantities of iron ores. With the rapid increase in iron ores imports, there is also a growing dependence on foreign iron ores, as shown in Fig. 1 [16]. In 2018, China's iron ore dependence on foreign countries rose to more than 90%. In the past three consecutive years, the imported iron ores remained at a high level with above 1 billion tons per year. As a result, if the relevant governments at the source of imports restrict the export of iron ores to China in the future, the steel industry will face a difficult situation, which would in turn pose a huge threat to the safe operation of the national economy [17-20].

According to the statistics, the complex refractory iron ores account for a high proportion of China's iron ore resources, while the total reserves of typical hard-to-use iron ore resources such as siderite, limonite, and fine-grained ore are more than 20 billion tons [21]. As Fig. 2 shows, these resources are widely distributed in Liaoning, Gansu, Shaanxi, and Sichuan provinces, etc [22]. Owing to the fine grain size and complex mineral composition of such iron ore resources, it is hard to obtain better technical and economic indicators by conventional mineral processing technology; therefore, most of them have not yet been exploited for industrial development. In spite of the fact that a small part of the resources have been developed, the beneficiation process is complicated and expensive, and the recovery rate can only reach 60% to 65% [23]. Based on these facts, a great deal of research has been carried out by researchers on the efficient utilization of complex refractory iron ore resources using fluidized magnetizing roasting technology, which greatly shortens the roasting time, improves the roasting efficiency, and reduces the cost of beneficiation. Furthermore, it would be beneficial to promote the self-sufficiency rate of iron ore and get rid of the shackles of foreign mining giants [24-28].

In this paper, the main characteristics of fluidized bed magnetizing roasting technology and the development process of its application in the beneficiation of complex refractory iron ores are

Figure 2. *The distribution of complex refractory iron ores in China*

introduced. The research status of several typical fluidized bed roasting technologies and equipments in China are also summarized. Moreover, the application prospect of the technology is analyzed for efficient utilization of low grade hematite, siderite, limonite, and iron containing tailings.

2. Development of fluidized bed magnetizing roasting technology in iron ores

In 1958, the Institute of Chemical Metallurgy of the Chinese Academy of Science started to apply the fluidized magnetizing roasting to utilize the low-grade refractory iron ores in China. The systematic laboratory and scale-up experimental studies on Anshan hematite deposit, Bayan Obo iron ore deposit, and Jiuquan siderite and specularite deposits were carried out. Meanwhile, great separation results were achieved. Based on that, the fluidized magnetizing roasting technology received a strong support from the state. In early 1966, a 100 t/d fluidized bed magnetizing roasting semi-industrial test equipment was established at the Ma'anshan Institute of Mining Research. And then, this technology was applied to several complex refractory iron ore deposits, where they obtained good beneficiation indicators as well. Take the JISCO fine ore as an example: through the fluidized roasting with the temperature range of 552-570 °C, the fine ore containing 13.06% Fe was promoted to an iron ore concentrate assaying 61.89% Fe with 93.82% recovery, while the iron grade of the tailings was 7.38% [29].

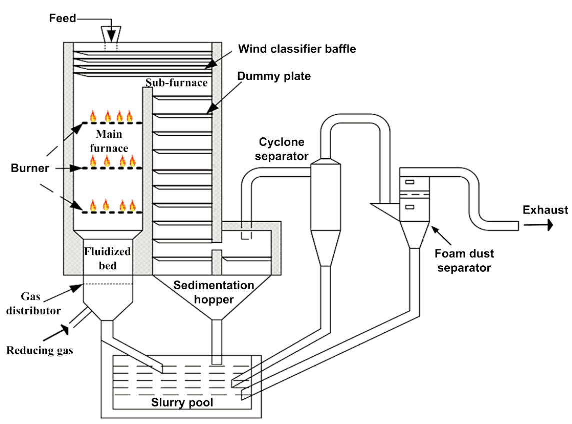

***Figure 3.** The diagram of Anshan-type fluidized bed roaster*

In the 1960s, on the basis of the above test equipment, the Anshan Iron & Steel Company developed a "reverse U" type two-phase fluidized roaster with a handing capacity of 700 t/d, as presented in Fig. 3 [30]. The ores fed at the top are naturally classified into two categories by the airflow in the furnace. The separated fine-grained particles enter the sub-furnace with the gas flow for reduction roasting, while the coarse-grained particles fall down the main furnace, where the particles are heated in the upper dilute region and reduced by the rising reducing gas in the bottom dense boiling bed. The roasted coarse products would drop into the slurry pool through an overflow pipe above the gas distributor and cool with the water quenching. Correspondingly, the roasted fine products discharge into the slurry pool through the sub-furnace and the sedimentation hopper. The detailed operating conditions are displayed in Table 1.

***Table 1.** Detailed operating conditions*

Parameters	Reference value
Main furnace pre-tropical temperature (°C)	450-500
Combustion zone temperature (°C)	830-870
Dilute phase section of sub-furnace temperature (°C)	710-850
Exhaust temperature (°C)	600
Reduction gas consumption (m^3/h)	2000-2500
Heating gas consumption (m^3/h)	800-1500
Air consumption (m^3/t)	3000-5000
Coal gas pressure (kPa)	23-24
Calorific value (MJ/m^3)	7.5

Industrial trials were carried out on the Qidashan hematite deposit, while a high quality iron concentrate with a grade of 57.6-64.7% and recovery of 87.1-96.2% was obtained [31]. Though iron grade and recovery can be greatly improved by this Anshan-type fluidized bed roaster, several problems such as the slow process of reduction and uneven quality of the reduced products exist. Moreover, no further research was performed due to the Cultural Revolution after 1966.

In recent years, the international iron ore prices have increased significantly. At the same time, domestic iron ores are in a serious shortage due to poor endowment, difficulty in utilization, and high cost of mining. This status quo not only has a serious impact on China's steel industry, but also poses a great threat to the safe operation of the national economy. Therefore, it is urgent to pursue efficient utilization of complex refractory iron ore resources in China. Based on the above background, the treatment of refractory iron ores by magnetizing roasting has been re-emphasized. According to the type of roasting reactor, magnetizing roasting can be divided into shaft furnace roasting, rotary kiln roasting and fluidized bed roasting. Among them, compared with the shaft furnace roasting and the rotary kiln roasting, fluidized magnetizing roasting has become a research hotspot due to its outstanding advantages of high heat and mass transfer efficiency.

The scientific research team leded by Yongfu Yu, a well-known mineral processing expert in China [32-38], proposed the concept of flash magnetizing roasting and designed a reaction device of conveying bed combined with multi-stage cyclone separators, as presented in Fig. 4. The roasting process is as follows: Ore feeding is added from the first stage (C1) standpipe, then heated by the rising hot air stream and carried into the cyclone preheater (V1). The preheated materials flow through the gas-solid cyclone separator and enter the second-stage (C2) standpipe from the dipleg. Subsequently, the materials are heated by hot gas and raised to the cyclone preheater (V2) with another gas-solid separation, the materials enter the third-stage (C3) standpipe through the dipleg, and then are entrained into the cyclone preheater (V3) by the gas. The materials and the hot gas flow undergo a three-stage heat exchange, causing the materials to be heated to about 550-650 °C during the process of the overall downward movement. Next, the materials arrive at the reaction furnace (R) of the fourth stage (C4), rapidly heating up and being reduced once in contact with the flue gas of 950-1000 °C; accordingly, the iron minerals are converted into magnetite. Meanwhile, the roasted ores are carried into the fourth-stage cyclone (V4) for gas-solid separation, and drain into the concentrate room, where the materials are directly water quenched without contacting air. Additionally, the flue gas from the fourth-stage cyclone (V4) is recirculated into the preheating system, and the heat is exchanged in reverse contact with the materials from top to bottom. Finally, the gas is discharged from the top of the first-stage preheater (V1) to the exhaust gas treatment system or employed as a return air.

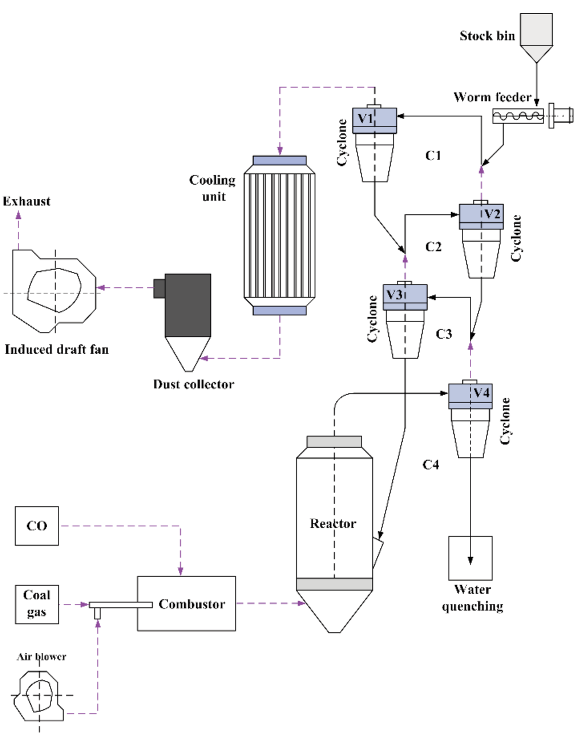

Figure 4. *The diagram of flash magnetizing roaster*

The flash magnetizing roasting technology was applied to the Daxigou siderite deposit, Wangjiatan siderite deposit, Jielong siderite deposit, etc., and the separation results are summarized in Table 2. It is clear that various types of refractory iron ores can achieve an iron grade of 57-61% and 79-95% iron recovery rate by this technology, and a demonstration project of 600,000 tons/year was built in Huangmei, Hubei. If the large-scale engineering application of the technology and equipment is realized, it will promote the development of complex refractory iron ores in China and open up a new way for utilizing these kind of iron ores resources.

Table 2. *Magnetic separation results via flash magnetizing roasting [32-38]*

Ore type	Fe /%	Yield/%	Recovery/%
Siderite ore from Daxigou, Shannxi	＞56	38-40	＞80
Siderite ore from Jielong, Chongqing	58.76	62.30	86.05
Siderite ore from Wangjiatan, Kunming	59.13	59.58	90.74
Limonite ore from Baozipu, Kunming	59.50	57.40	92.06
Limonite ore from Huangmei, Hubei	60.70	50.93	94.49
Limonite ore from Tiekeng, Jiangxi	60.27	61.92	94.31
Oolitic Hematite from E'xi, Hubei	58.53	61.75	81.22
Siderite, Limonite from Daye, Hubei	60.16	70.96	93.04
Siderite, Limonite from Baotou, Inner Mongolia	57.81	41.60	79.07
Hematite, leaching residue from Lingbao, Henan	60.15	52.85	90.13

Based on the suspension preheater of the cement industry, Xu et al. [39-41] developed a new process and equipment for the high solid-gas ratio suspension magnetizing roasting of iron ores, as exhibited in Fig. 5. The semi-industrial suspension magnetizing roasting test was carried out on the Daxigou siderite tailings with the TFe of 15.10%. At the same time, a magnetic separation concentrate with the iron grade of 53.30% and iron recovery of 70.50% was obtained under a weak oxidizing atmosphere with an oxygen content of 1.0% at 740 °C. Similarly, under a weak reducing atmosphere with the CO content of 1.0% at

800 °C, the gold tailings containing 27.30% iron was treated via this equipment followed by a three-stage grinding-magnetic separation process, resulting in a magnetic concentrate assaying 55.60% Fe with a recovery of 81.90%. Although the high solid-gas ratio suspension magnetizing roasting process achieved good results in the semi-industrial roasting tests of iron ores, no subsequent industrial applications have been reported until now.

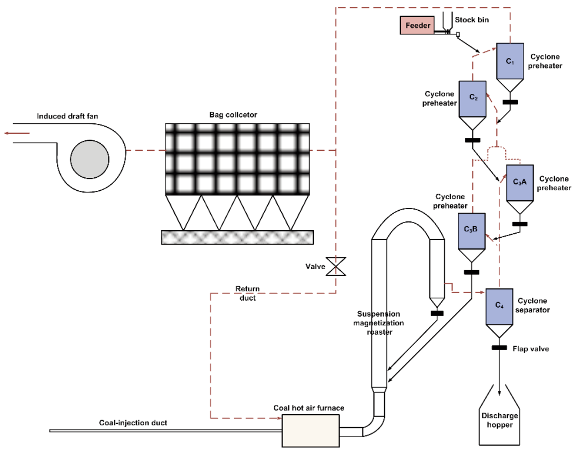

Figure 5. *Schematic diagram of high solid-gas ratio suspension magnetizing roaster*

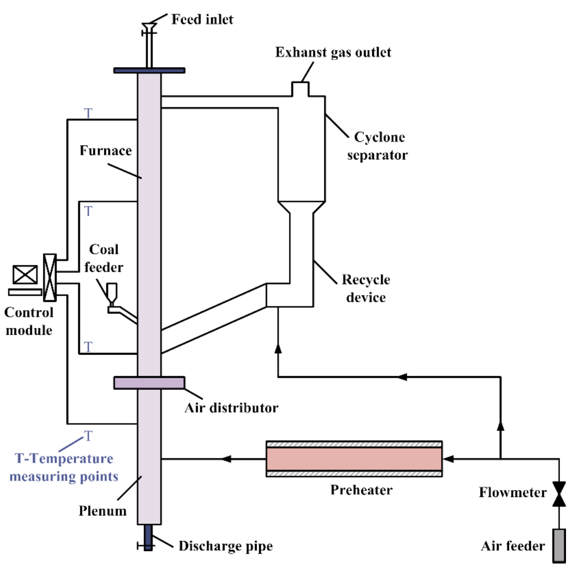

Figure 6. *Schematic diagram of circulating fluidized bed test bench*

Zhejiang University [42-44] proposed a new technology combining coal-fired power generation and magnetizing roasting, employing iron ores as the bed material of a circulating fluidized bed boiler. Through the circulating fluidized bed apparatus shown in Fig. 6, the magnetizing roasting-magnetic separation test was carried out on an Oolitic hematite with an iron grade of 47.20%, and the effects of roasting temperature, roasting time, roasting atmosphere, gas flow rate and magnetic field intensity on the separation results were investigated simultaneously. Under the grinding fineness of around 80 wt.% passing 45 µm, a high-quality iron concentrate assaying 56.60% Fe with a recovery rate of 77.79% was gained [42]. With the similar approach, a refractory low-grade iron ore containing 9.63% Fe from Xinjiang could be promoted to an iron ore concentrate assaying 46.25% Fe with 25.52% recovery at a roasting temperature of 850 °C for 10 minutes, employing a mixed gas of CO and N_2 (CO volume fraction of 10%) as the reducing agent [44]. It can be observed that the circulating fluidized bed technology can effectively reduce hematite to magnetite and obtain a better result, but it is uneconomical to treat the low-grade ores [45].

Based on the previous studies and experience of the fluidized magnetizing roasting, the Institute of Process Engineering of the Chinese Academy of Sciences [11] first compared the energy consumption of various stages during the entire roasting process and found that the sensible heat brought by the ores accounted for 70-80% of the total energy consumption. Accordingly, lessening this kind of heat loss is the critical part to reducing the energy consumption of the whole process. As far as we know, the methods for reducing the sensible heat loss of the roasting process mainly include: (1) recovering the sensible heat of the roasting ores by heat exchange; (2) reducing the sensible heat loss by lowering the temperature of the roasting ores. Since the sensible heat recovery of high-temperature roasting ores is difficult to achieve, they decided to focus on the latter method of reducing energy consumption. After a period of exploration, a low-temperature fluidized magnetizing roasting process was proposed [1].

In 2008, in cooperation with the Qujing Yuegang Iron & Steel Company in Yunnan provice, a 100 kt/a industrialization demonstration project was developed, while the continuous stable operation was

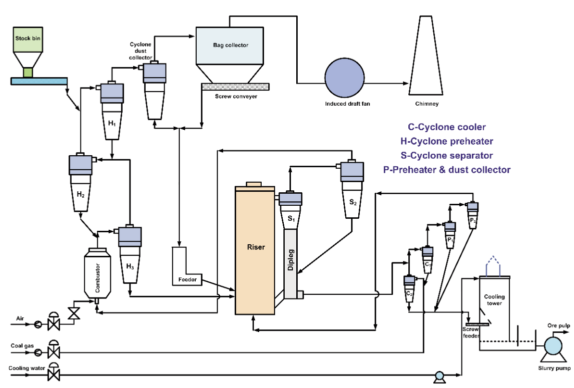

Figure 7. *Schematic of the low temperature fluidized magnetizing roasting system*

realized in 2012. The process flow diagram is shown in Fig. 7. For the beneficiation of a limonite ore with 33% Fe from Yunnan, through the magnetizing roasting-magnetic separation, good technical indexes of iron concentrate with a TFe grade above 57% and iron recovery rate 93-95% were obtained at the roasting temperature of 450 °C. In terms of the above-mentioned engineering demonstration, a complete set of technology for low temperature fluidized magnetizing roasting of refractory iron ores was initially developed; furthermore, the industrialization promotion is currently underway [45, 46].

In summary, fluidized magnetizing roasting is a considerable means to efficiently utilize complex refractory iron ore resources. After years of development, the core technology of fluidized magnetizing roasting-magnetic separation has been gradually improved and completely qualified for industrialization. As a result, it is of great significance to promote the development and utilization of refractory iron ore resources such as limonite, siderite and sedimentary metamorphic hematite [47]. However, once the above fluidized magnetizing roasting technology were applied to the complex refractory iron ores, the following three problems existed.

(1) Due to the inconsistent nature of iron minerals, the reactions of different minerals under the same reduction conditions are not synchronized, and the weakly magnetic iron minerals cannot be fully reduced to ferromagnetic Fe_3O_4, or may be over-reduced to non-magnetic FeO, even to iron silicate (Fe_2SiO_4, $FeA1_2O_4$), which is extremely difficult to be reduced, resulting in an undesirable separation index.

(2) The heating and reduction of iron ores are carried out in the same furnace chamber, leading to difficulty in regulating and controlling the reducing atmosphere.

(3) The latent heat is not recycled during the cooling process of the roasting iron ores, causing a great waste of energy.

In response to the problems existing in the prior technologies, a new concept of “peroxidation–regenerative reduction–reoxidation” suspension magnetizing roasting was proposed by Northeastern University (NEU) [48-60]. Further, a new type of suspension roasting pilot-scale test equipment has been successfully developed. The schematic diagram of the iron ore suspension roaster is shown in Fig. 8.

As can be seen, the iron ore suspension magnetizing roaster mainly consists of a cyclone preheater, a suspension heating chamber, a gas-solid cyclone separator, a U-type reduction chamber, a cooling unit, and a dust pelletizing system. The iron ores were fed in by a worm feeder, preheated and fluidized by hot flue gas from the gas-solid cyclone separator. Next, the iron ores flowed through a

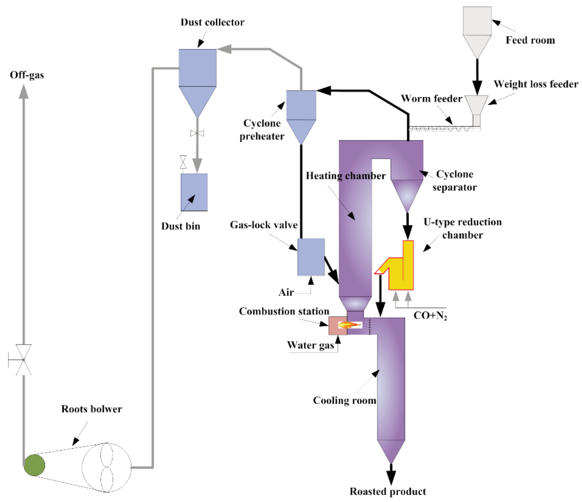

Figure 8. *Schematic diagram of the iron ore suspension roaster*

cyclone preheater and a gas-lock valve, and then entered into the suspension heating chamber, while the heat of ores was constantly accumulating. The hot gases (about 700-900 °C) produced by the combustion of water gas simultaneously heated and entrained the iron ore powder to the gas-solid separator where siderite ($FeCO_3$) and limonite (Fe_2O_3•nH_2O) were thermally oxidized or decomposed to hematite (Fe_2O_3). Then, the heated iron ores (about 600-750 °C) flowed downward into the U-type reduction chamber under the action of gravity. Correspondingly, hematite (Fe_2O_3) was reduced to magnetite (Fe_3O_4) quickly by reducing gas (CO/H_2) in the range of 450-600 °C. After reduction roasting, the mixed gas transported the iron ore powder to the cooling unit where partial magnetite (Fe_3O_4) was re-oxidized to ferromagnetic maghemite (γ-Fe_2O_3) by air with a temperature of 200-350 °C. Meanwhile, the preheated air with the residual reducing gas entered into the heating furnace and burnt to heat the iron ore, achieving an efficient recycling of heat and excess tail gas. Finally, the strongly magnetic iron minreals could be successfully recovered by magnetic separation. The entire roasting system was operated under a negative pressure condition, and the driving force was provided by the the roots bolwer. This techlogy is considered to be energy-saving, safe and environmentally-friendly.

Based on this innovative process and equipment, the suspension magnetizing roasting laboratory and semi-industrial tests have been conducted on iron ore resources domestically and overseas [48-59], such as the Ansteel eastern tailings, Donganshan iron ore, JISCO fine ore, tailings and lump ore, and Sierra Leone iron ore. The results are summarized in Table 3. It can be seen that for different types of refractory iron ore resources, the iron grade and recovery can be greatly improved by this new kind of technology,

Table 3. *Main pilot test indexes via NEU's new technology (“-” represents unused resources) [48-60]*

Iron ores	Raw ore grade /%	Present separation process		NEU's new technology	
		Iron grade /%	Recovery /%	Iron grade /%	Recovery /%
Donganshan iron ore	31.63	63	60–65	66.60	79.72
JISCO lump ore	34	59–60	70–75	60.50	91.36
JISCO fine ore	32.50	50–53	65–67	60.67	76.27
Ansteel eastern tailings	10.60	-	-	65.69	55.33
Sierra Leone iron ore	54	-	-	64–65	95–98
Hubei oolitic hematite	46.31	-	-	58.32	85.69
Donganshan direct flotation tailings	43.53	-	-	60.52	78.68

espeically for the JISCO fine ore assaying 32.50% Fe. With the treatment by the process of PSRM technology, a high-quality iron concentrate with an iron grade of 60.67% and recovery of 76.27% was obtained. Compared with the current high intensity magnetic separation process, the concentrate iron grade and recovery rate are increased by more than 10%.

In view of the good results and the industrial feasibility, Jiuquan Iron & Steel Company invested 480 million yuan to build a suspension roasting and dressing production line with an annual processing capacity of 1.65 million tons of fine ore. The production line was initially completed at the end of 2017, and it is currently in the stage of commissioning production, as shown in Fig. 9 [60]. Once the project is officially put into production, it is estimated that the annual benefit will exceed 100 million yuan, which would provide a demonstration for the efficient utilization of iron ore resources in China and the world.

3. Conclusion and outlook

For years, China's iron ore reserves have been far from able to meet the requirement of the rapid development of the steel industry. With the depletion of rich iron ore reserves, the efficient utilization of complex refractory iron ores has become a focus of public attention. However, due to poor endowment, it is difficult to obtain better technical and economic indicators by conventional physical beneficiation methods. After a series of studies, a consensus has been reached that fluidized bed magnetizing roasting is considered the most effective and promising method.

In this paper, the main characteristics of fluidized bed magnetizing roasting technology and the development process of its application in the beneficiation of refractory iron ore were introduced. The research status of several typical fluidized bed roasting technology and equipment in China were also summarized. Although both the laboratory and the semi-industrial tests have achieved good indicators, only the suspension magnetizing roasting technology has developed an industrial production line which is currently in the stage of commissioning production, indicating that it still has a long way to go to realize the industrial application. Furthermore, it is expected that this technology would have broad prospects in the following two aspects once industrilized:

On the one hand, it can realize the efficient utilization of hematite, siderite, limonite ore, and iron tailings in China. Among the iron ore resources in China, 13% of the primary iron ores that cannot be effectively beneficiated by conventional dressing methods are mostly in an unusable state. Besides, due to running a high steel production but low grade of

Figure 9. *Industrial iron ore magnetizing suspension roasting equipment*

raw ores in China, a large amount (up to 60%) of iron ore tailings is generated. The newly developed fluidized magnetizing roasting technology is expected to play a vital role in the utilization of these iron ore resources, and it is estimated that more than 10 billion tons of iron ore resources can be revitalized.

On the other hand, it can greatly improve the recovery of complex refractory iron ores in China. Since the iron ores are characterized as “poor, fine, and miscellaneous” in China, the beneficiation process is complicated and high-cost, while the recovery rate can only reach 60-65%. Once these iron ores are treated by fluidized magnetizing roasting technology, the recovery rate would be increased by more than 15% compared with that of the existing process, which acts as a major breakthrough in the efficient utilization of complex refractory iron ore. Furthermore, it is of great significance to reduce the external dependence of China's iron ore and promote the sustainable, healthy and coordinated development of China's steel industry.

Acknowledgements

The authors are grateful for the financial support provided to this project by the National Science Foundation of China (Grant No. 51674065 and 51734005) and the Liao Ning Revitalization Talents Program (XLYC1807111). Zhidong Tang thanks the China Scholarship Council (201806080081) for a visiting Ph. D scholarship. In addition, Zhidong Tang thanks Huan Liu (Memorial University of Newfoundland, Canada) for her linguistic assistance during the preparation of this manuscript.

Reference

[1] C.Q. Hu, Y.F. He, D.F. Liu, S.Y. Sun, D.Q. Li, Q.S. Zhu, J.G. Yu, Rev. Chem. Eng., (2019) 1-40.

[2] K.S. Lim, J.X. Zhu, J.R. Grace, Int. J. Multiphase Flow, 21 (1995) 141-193.

[3] Vinod Kumar V., Raghavan V. R., 2011 National Postgraduate Conference, Malaysia, 2011.

[4] E.C. Fox, R.P. Krishnan, C.S. Daw, J.E. Jones Jr, Energy, 11 (1986) 1183-1200.

[5] B. Özkaya, A.H. Kaksonen, E. Sahinkaya, J.A. Puhakka, Water Res., 150 (2019) 452-465.

[6] T. Fouilland, J.R. Grace, N. Ellis, Biofuels, 1 (2010) 409-433.

[7] M. Saidi, H.B. Tabrizi, J.R. Grace, Adv. Powder Technol., 30 (2019), 1121-1130.

[8] F. Winter, B. Schratzer, Fluidized Bed Technologies for Near-Zero Emission Combustion and Gasification, 2013, 1005-1033.

[9] R.X. Cai, X.W. Ke, J.F. Lyu, H.R. Yang, M. Zhang, G.X. Yue, W. Ling, Clean Energy, 1 (2017) 36–49.

[10] M. Rüdisüli, T.J. Schildhauer, Serge M. A. Biollaz, J.R. Ommen, Powder Technol., 217 (2012) 21-38.

[11] H.Z. Li, M. Kwauk, CIESC Journal, 64(2013) 52-64. (in Chinese).

[12] M. Borcraut, 1008938.1962-07-05.

[13] W. Georg, H. Joseph, W. Herbert. 1127925. 1960-10-22.

[14] H.Z. Li, Chin. J. Process Eng., 18(4) (2018) 657-668. (in Chinese).

[15] J.W. Yu, Y.X. Han, Y.J. Li, P. Gao, Miner. Process Extr. Metall. Rev. 36 (4) (2015) 249-257.

[16] Y.X. Han, P. Gao, Y.J. Li, Y.S. Sun, Metal Mine, 45(12) (2016) 2-8. (in Chinese).

[17] J.F. He, C.G. Liu, P. Hong, Y.K. Yao, Z.F. Luo, L.L Zhao, Powder Technol., 342 (2019) 348-355.

[18] J.F. He, L.T. Zhu, X.Z. Bu, C.G. Liu, Z.F. Luo, Y.K. Yao, Chem. Eng. Process., 138 (2019) 27-35.

[19] W.B. Liu, W.G. Liu, B.Y. Wang, Q. Zhao, H. Duan, X.D. Chen, Powder Technol., 355 (2019) 700-710.

[20] W.B. Liu, W.G. Liu, B.Y. Wang, H. Duan, X.Y. Peng, X.D. Chen, Q. Zhao, Miner. Eng., 142 (2019).

[21] Y.X. Han, Y.S. Sun, Y.J. Li, P. Gao, Metal Mine, 2 (2015) 1-11. (in Chinese).

[22] G.R. Li, Volodymyr Shatokha, IntechOpen, 2018.

[23] M. Wang, Q.M. Peng, H.F. Yu, Beijing: Geological Publishing House, 2016. (in Chinese).

[24] Z.D. Tang, Y.X. Han, P. Gao, E.L. Li, Powder Technol., 345 (2019) 64-73.

[25] Y.S. Sun, X.R. Zhu, Y.X. Han, Y.J. Li, J. Clean Prod. ,206 (2019) 40-50.

[26] J.W. Yu, Y.X. Han, Y.J. Li, P. Gao, Int. J. Miner. Process., 168 (2017) 102-108.

[27] P. Gao, Z.D. Tang, Y.X. Han, E.L. Li, X.L. Zhang, Powder Technol., 343 (2019) 255-261.

[28] Z.D. Tang, P. Gao, Y.S. Sun, Y.X. Han, Adv. Powder Technol., 30 (10) (2019) 2430-2439.

[29] Q.S. Zhu, H.Z. Li, CIESC Journal, 65(7) (2014) 2437-2742. (in Chinese).

[30] M. Kwauk, Scientia Sinica, 22 (11) (1979) 1265-1291.

[31] J. Zhu, Beijing: Metallurgical Industry Press, 208: 43-64.

[32] X.Y. Liu, Y.F. Yu, W. Chen, Metal Mine, 10 (2019) 84-85. (in Chinese).

[33] Z.L. Feng, Y.F. Yu, G.Y. Liu, Metal Mine, 9 (2009) 58-60. (in Chinese).

[34] L.Q. Luo, Y.F. Yu, Y.J. Shang, China Mining Magazine, 11 (2009) 84-87. (in Chinese).

[35] H.Q. Zhang, Y.F. Yu, Z.Y. Peng, Iron & Steel, 44 (7) (2009) 11-14. (in Chinese).

[36] L.F. Luo, Y.F. Yu, W. Chen, Mining and Metallurgical Engineering, 29 (3) (2009) 26-28. (in Chinese).

[37] Q.L. Wang, W. Chen, Y.F. Yu, Conservation and Utilization of Mineral Resources, 3 (2010) 73-76. (in Chinese).

[38] R.B. Zuo, Y.H. Li, Modern Mining, 555(7) (2015) 193-195. (in Chinese).

[39] S.W. Jiu, D.L. Xu, H. Li, Metal Mine, 8 (2008) 33-35. (in Chinese).

[40] L. Zhang, Xi'an University of Architecture and Technology, Xi'an, 2011. (in Chinese).

[41] Y.F. Yao, Xi'an University of Architecture and Technology, Xi'an, 2012. (in Chinese).

[42] G.J. Wang, Zhejiang University, Zhejiang, 2010. (in Chinese).

[43] X.B. Wang, Zhejiang University, Zhejiang, 2011. (in Chinese).

[44] G.J. Wang, Y.Q. Zhu, X.H. Wang, Journal of Zhejiang University (Engineering Science), 45(5) (2011) 885-889. (in Chinese).

[45] C. Chen, Y.C. Liu, Y.S. Zhang, Mining and Metallurgical Engineering, 32(8) (2012) 128-131. (in Chinese).

[46] X.X. Wei, Industrial Furnace, 40(3) (2018) 10-11. (in Chinese).

[47] P. Gao, World Metals, 2015-06-16(B04). (in Chinese).

[48] X.L. Zhang, Y.X. Han, Y.S. Sun, Y. Lv, Y.J. Li, Z.D. Tang, Miner. Process Extr. Metall. Rev. DOI: 10.1080/08827508.2019.1604522 (in Press).

[49] Y.S. Sun, Q. Zhang, Y. Han, P. Gao, G. Li, JOM, 70 (2018) 144-149.

[50] R. Wang, Y.X. Han, Y.J. Li, Metal Mine, 6 (2015) 65-70. (in Chinese).

[51] R. Wang, Y.X. Han, Y.J. Li, Journal of Northeastern University: Natural Science, 36 (7) (2015) 1024-1028. (in Chinese).

[52] S. Yuan, Y.X. Han, P. Gao, Metal Mine, 486(12) (2016) 9-12. (in Chinese).

[53] Z.D. Tang, Y.X. Han, Y.J. Li, Multipurpose Utilization of Mineral Resources, 1 (2018) 106-110. (in Chinese).

[54] J.W. Yu, Y.X. Han, P. Gao, Physicochem. Probl. Mineral Pro., 54(3) (2018) 668-676.

[55] J.W. Yu, Y.X. Han, Y.J. Li, Journal of Central South University (Science and Technology), 49(4) (2018) 771-778. (in Chinese).

[56] Z.D. Tang, P. Gao, Y.S. Sun, Y.X. Han, E.L. Li, J. Chen, Y.H. Zhang, Powder Technol. DOI: https://doi.org/10.1016/j.powtec.2019.09.092. (in Press).

[57] X. L. Zhang, Y. X. Han, Y. S. Sun, Y. J. Li, Powder Technol., 352 (2019) 16-24.

[58] J.W. Yu, Y.X. Han, Y.J. Li, P. Gao, J. Min. Metall. Sect. B-Metall., 54 (2018) 21-27.

[59] J.W. Yu, Y.X. Han, Y.J. Li, P. Gao, Y.S. Sun, Sep. Sci. Technol., 52 (2017) 1768-1774.

[60] Y.X. Han, Y.J. Li, P. Gao, J.W. Yu, J. Iron Steel Res., 31 (2019) 89-94. (in Chinese).

TEHNOLOGIJA PRŽENJA U FLUIDIZOVANOM SLOJU PRILIKOM PRIPREME RUDE ŽELEZA U KINI – PREGLED RAZVOJA OPREME I MOGUĆNOST PRIMENE

Z.-D. Tang [a, b], P. Gao [a, b, *], Y.-X. Han [a, b], W. Guo [a, b, #]

[a*] Fakultet za resurse i građevinarstvo, Severoistočni univerzitet, Šenjang, N.R. Kina
[b] Nacionalno – lokalni istraživački centar za ispitivanje visokoefikasnih tehnologija eksploatacije za rudu železa tešku za izdvajanje, Šenjang, N.R. Kina

Apstrakt

Zbog nepoželjnih karakteristika resursa rude železa u Kini, veoma je važno iskoristiti resurse rude železa koja se teško izdvaja na efikasan način. Troškovi iskopavanja i prerade rude su visoki. Rezerve rude železa u Kini su već duže vreme u manjku i zbog toga su razvoj i upotreba resursa složenih i ruda železa teških za izdvajanje izuzetno važni. Prženje u namagnetisanom polju praćeno magnetnom separacijom predstavlja važan metod za obogaćivanje rude koja sadrži železo niskog kvaliteta. Poslednjih godina se više pažnje posvećuje prženju u namagnetisanom fluidizovanom sloju nego prženju u jamastoj i rotacionoj peći. U ovom radu su predstavljene glavne odlike tehnologije prženja u namagnetisanom fluidizovanom sloju, kao i razvoju primene ove tehnologije u postupku obogaćivanja rude železa teške za izdvajanje. Takođe su prikazani i status istraživanja nekoliko tipičnih postupaka prženja u fluidizovanom sloju, kao i oprema koja se koristi u Kini. Pored toga, analizirana je i mogućnost primene tehnologije za efikasno iskorišćenje rude hematita, siderita i limonita niskog kvaliteta, kao i železa iz jalovine.

Ključne reči: *Prženje u namagnetisanom fluidizovanom sloju; Složene i rude železa teške za izdvajanje; Razvoj postupka; Mogućnost primene*