International Journal of Mineral Processing 140 (2015) 26–31

Contents lists available at ScienceDirect

International Journal of Mineral Processing

journal homepage: www.elsevier.com/locate/ijminpro

Simultaneous energy saving and production rate improvement in pelletizing process by solid fuel addition

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ARTICLE INFO

Article history:
Received 24 June 2014
Received in revised form 2 March 2015
Accepted 28 April 2015
Available online 1 May 2015

Keywords:
Pelletizing process
Solid fuel
Secondary hematite
Deep bed practice
Energy saving
Anthracite

ABSTRACT

Generally, in pelletizing process, the magnetite ore is oxidized to hematite during induration as an exothermic reaction; thereby the magnetite ore requires less energy compared to hematite ore. This form of heat generation inside the pellet is much more efficient than the transferred one from hot gases heated by external burners. This mechanism leads to higher production rates with lower total energy consumption. In order to achieve these improvements, different amounts of anthracite as the solid fuel (0 to 0.95 wt.%) were added to the initial mixture of hematite (60%) and magnetite (40%) ores. The portion of hematite was reduced to magnetite phase by anthracite, and then the produced magnetite re-oxidized again to secondary hematite. Afterwards, the studies of mechanical and reducibility behaviors of pellets were performed by the tumbler/abrasive indexes and the Linder experimental tests. Furthermore, the microstructural evaluation was carried out by scanning electron microscope (SEM). The results demonstrated that by anthracite addition to the mixture, the production rate was significantly increased (more than 30%) while the natural gas consumption was reduced at least 35%. Moreover, based on the strength and reducibility analyses, the anthracite addition up to 0.78% (as an optimal amount) caused considerably to the betterment of fired iron ore pellet properties.

1. Introduction

In the last decades, the access to higher production rates parallel to energy consumption decrease has become the main interest of steel industries (Hasenack et al., 1985; Langley, 1986; Li and Zhu, 2014; Xu et al., 2014; Porzio, 2013). Considering that pelletizing is a key stage of iron-making procedure that can influence on reduction process and the amounts of required energy for induration steps, the modifications of its conditions can be valuable. Typically, the pelletizing efficiency depends on some parameters such as compositions of raw materials, addition of specific matters, and the induration procedure's changes (Aubrey and Ketter, 1967; Beal, 1968; Hutter, 1977; Sharma, 1992; Jiang et al., 2008). In general, the increase of pelletizing bed depth in firing step is one of the most important techniques to improve the yield capacity of pelletizing. Accordingly, the following equation shows the effect of some parameters on pelletizing process (Meyer, 1980).

$$P = K.(F/A)[H/\Delta P]^n \quad (1)$$

where P, F, A, H, and Δp are the heat permeability, gas flow rate (m^3/min), surface of pelletizing bed (m^2), bed depth (cm), and pressure drop of gas flow (mbar), respectively. Thus by assumption of laminar gas flow rate ($n = 1$), the amount of pressure drop can be expressed as subsequent equation.

$$\Delta P = K\ .(F.H)/(A.P) \quad (2)$$

Moreover, the amount of pressure drop in each firing machine depends on some technical parameters like the potency of air suction fans that have negligible tolerance in this research. According to the limitation of pressure drop variations, in order to increase bed depth, the enhancement of permeability or/and the decreasing of gas flow flux density are absolutely necessary. In fact, the elevation of P amount and the reduction of the flow rate are the main effective strategies to increase bed depth that can lead to production capability augmentation. Furthermore, in the fixed rate of firing conveyor, the amount of gas flow rate is proportional to the hot gas volume that is required in the firing process. In addition, while the gas flow rate has a fixed quantity the increase of bed depth can cause the gas volume to decline (per unit volume of pellet); so the required energy to the pellet firing should be provided through other mechanisms. Obviously, the required energy in firing the magnetite pellet is lesser than the required amount for hematite pellet firing process (Jiang et al., 2008; Meyer, 1980; Seaton et al., 1983; Loo, 1991; Elhajjar and Shams, 2014; Shams and El-Hajjar, 2013a, 2013b). Consequently, the higher amounts of

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http://dx.doi.org/10.1016/j.minpro.2015.04.023
0301-7516/

magnetite in pelletizing initial mixtures can lead to the increase of the bed depth due to the lower required thermal energy to pellet firing (Jiang et al., 2008; Meyer, 1980; Li et al., 2009). On the other hand, because of raw materials and economical restrictions, the utilization of magnetite ores as initial materials has some limits. Although by increasing the pelletizing bed's thickness can cause the growth of the production capacity, there are some technical limitations to consider. In another consideration, the final composition of pelletizing process is completely hematite. There are two kinds of hematite, the primary hematite from ores and the secondary hematite that is the result of magnetite re-oxidation (Meyer, 1980; Applyby and Shaw, 1985). The kinds and amounts of hematite have sensitive influences on subsequent processes because of the better secondary hematite reducibility (Meyer, 1980). The addition of solid fuels to raw materials is one of the approaches for bed depth augmentation and evolution of secondary hematite (Applyby and Shaw, 1985; Hohensee, 1983; Haque et al., 1992; Yang et al., 1995). In fact, during induration process, the solid fuels cause the reduction of the atmosphere creation, and thereby reducing the hematite of raw materials to magnetite phase; hence in the incipient firing stage (temperature above 1000 °C), the composition of pellets would be completely magnetite and behaves similarlt to 100% magnetite pellets induration regime (Meyer, 1980; Yang et al., 1995; Srivastava and Sharma, 1988; Huang and Loo, 1993; Janowski and Sadowski, 1996). Although, recently the solid fuel addition in composite pellets using their released heat from re-oxidation of magnetite to hematite in various pelletizing processes, especially in rotary kiln furnaces, has attracted a lot of researchers' attention (Hasenack et al., 1985; Jiang et al., 2008; Li et al., 2009; Hohensee, 1983; Chakravorty et al., 1991), the studies about solid fuel utilizations in pelletizing process by Dwight Lloyd machine method have been rarely done.

The present work is focused on the effect of anthracite solid fuel employment (with different amounts) on the properties of green and fired pellets, and the reduction conditions of pellets in Dwight Lloyd straight grate machine.

2. Materials and methods

In this research, a series of tests and studies were conducted to determine the optimum parameter amounts for usage of solid fuel in pelletizing process. Based on literature, these studies include the general property evaluation of used concentrates, fired and green pellet property assessment i.e. strength mechanisms, porosity, Linder reducibility tests, and the microstructural analyses. The mixed hematite (60%) and magnetite (40%) concentrates were used to produce oxide pellets. Furthermore, 0.7 wt.% of bentonite was added to the mixture as an adhesive agent. Water content (moisture) was also adjusted by infrared dryer and added in ratio of 8 wt.%, and finally according to practical testes, the various amounts of solid fuel have been used. The chemical composition and some physical properties of these raw materials and fired pellets are presented in Tables 1 and 2, respectively. Moreover, the chemical analyses and physical properties of anthracite that has been used as a solid fuel are shown in Table 3.

Upon completion of raw pellet production, the green pellets are sieved by +10 mm screen and placed in the pilot pot grate; subsequently, according to the defined thermal cycle, they were dried, fired and then cooled. The amount of the produced green pellet in disk (with a diameter of 80 cm) was 65–70 kg. The firing process was done at 1250 °C as a maximum temperature in the top section of pot grate for 7 min. After the induration process, some laboratory tests i.e. cold compression strength (CCS), porosity amount, tumbler index and abrasive index (according to ISO-3271 standards) were performed. Reduction properties of the pellets have been studied by well known Linder experimental tests. The amount of samples for the Linder tests was 500 g. In order to carry out these tests, the mixtures of 500 g dried pellet and 200 g coke were placed in the reduction furnace for 5 h while the rotating rate was 30 rpm. Furthermore, the reduction and metallization degrees were calculated according to the theoretical equations that are presented in related sections. Moreover, the FeO concentration in each section was determined by applying the X-ray diffraction (XRD) method. In addition, in order to accurately evaluate reduced and oxidized pellets, the studies of microstructural properties were carried out by scanning electron microscope (SEM (JEOL JSM-6340 F)).

Table 2
Chemical compositions and basicity of fired pellets with 0.78% anthracite in different bed depth samples.

Bad depth	Chemical composition (%)									Basicity
	FeO	SiO_2	Al_2O_3	TiO_2	CaO	MgO	P	S	Fe_{Total}	
30 cm	0.75	1.86	0.27	0.16	0.76	0.69	0.03	0.00	67.31	0.41
35 cm	0.65	1.99	0.33	0.19	0.76	0.46	0.04	0.00	67.27	0.38
40 cm	0.23	2.02	0.33	0.20	0.76	0.51	0.05	0.00	67.21	0.37
45 cm	0.30	2.00	0.34	0.20	0.80	0.41	0.04	0.01	67.30	0.40

3. Results and discussion

3.1. Physical and mechanical properties of pellets

As mentioned previously in this work, anthracite is used as a solid fuel and its specifications are presented in Table 1. In order to achieve the optimum state of performance i.e. at least 80% efficiency of hematite reduction to magnetite, the different amounts (0, 0.78, 0.88, and 0.95 wt.%) of anthracite have been added in initial mixtures. Fig. 1 shows the variations of porosity amounts and CCS of pellets as a function of anthracite percentages. Accordingly, by increasing the anthracite up to 0.95 wt.% (approximately equal to 100% reduction of hematite to magnetite), the porosity percentage is increased in the range of 21 to 25% owing to the porosity creation instead of consumed anthracite (Meyer, 1980; Clout and M., 2003). On the other hand, the growing of anthracite amounts is caused to CCS decreasing due to the gradual increasing of porosities. In addition, it can be seen that the decrease of CCS has various slops in each part of anthracite elevation; in fact, by variations of anthracite in the range of 0 to 0.78 wt.%, the amount of CCS is decremented only by about 3%, whereas it is equal to 40% in the range of 0.78 to 0.95 wt.%. Based on these results, it can be concluded that the 0.78 wt.% anthracite is the optimum amount of solid fuel in order to achieve the acceptable mechanical properties (Jiang et al., 2008; Applyby and Shaw, 1985; Hegdi et al., 1990).

In addition, the variations of created FeO percentage and oxidation degree of fired pellets with 0.78 wt.% anthracite as a function of bed

Table 1
Chemical compositions and some physical properties of raw materials.

Raw material	Chemical composition (%)												Physical properties	
	FeO	SiO_2	Al_2O_3	TiO_2	CaO	MgO	P	S	Fe_2O_3	Na_2O	Fe_{Total}	K_2O	Particle size	Surface area
Hematite	10.34	1.94	0.35	0.28	0.39	0.15	0.06	0.03	N.D.	N.D.	67.58	N.D.	80% (−40 μm)	N.D.
Magnetite	13.65	1.06	0.18	0.08	1.16	0.92	0.04	0.08	N.D.	N.D.	68.42	N.D.	80% (−40 μm)	N.D.
Mix (60%H + 40%M)	11.66	1.58	0.28	0.2	0.69	0.32	0.05	0.05	N.D.	N.D.	67.92	N.D.	80% (−40 μm)	2525 cm^2/g
Bentonite	N.D.	66	15.7	0.6	3.3	2	N.D.	N.D.	3	2	N.D.	1	83% (−45 μm)	2670 cm^2/g

N.D.: not detectable in these analyses.