Effect of Recycling Blast Furnace Flue Dust as Pellets on the Sintering Performance

N. A. El-Hussiny, M. E. H. Shalabi
Central Metallurgical Research and Development Institute (CMRDI),

Abstract:
The Egyptian Iron and Steel Company generates a great amount of blast furnace flue dust. The recovery of metals and carbon from this flue dust becomes a very important demand due to the increase of the price of coke breeze and the decrease of the primary source of metals. At the same time, it make the environment more safe by decreasing pollution. Introducing these dust fines in the sintering process proves to be very harmful for different operating parameters. Thus, this study aims at investigating the production of pellets resulting from these fines, using molasses as organic binder and its application in sintering of iron ore. The sintering experiments were performed using flue dust as pellets as a substitute of coke breeze. The results revealed that, sintering properties such as inter strength increases with using the flue dust pellets, while productivity of both the sinter machine and sinter machine at blast furnace yard decreases. Also the vertical velocity of the sinter machine and the weight loss during the reduction of produced the sinter by hydrogen decrease.

Keywords: Blast furnace flue dust, Pelletization, Iron ore, Sintering process.

1. Introduction

Production processes in iron and steel industry involve the formation of large amounts of by-products. These by products cause large volumes of waste streams. The recovery of metals from these by-products, for example dusts and sludges, becomes more and more important as legal requirements demand a thorough utilization, existing landfill capacities as well as the scarcity of primary resources and in the long term the rising prices of metals make such utilization economically attractive [1].

One solution for further reuse of waste materials, such as ferrous and/or carbon containing dusts, is the injection into various metallurgical aggregates to use for burning, fluxing etc. [2]. A number of technologies have been developed to allow better utilization of iron bearing steel plant fines in primary operations. Methods ranging from simple agglomeration techniques to new hot metal production processes for treating the dust materials to recycling in iron and steel making operations. These processes involve thermal, hydrometallurgical and physical beneficiation methods [3].

Pelletization is one of the agglomeration processes which converts the fines into pellets of suitable size. Binders are important for holding the fine particles together during the pelletization process. Either organic or inorganic binders can be used. Organic binders burn or volatilize during movement of the flame front. Owing to the comparatively high prices of

*) Corresponding author: shalabimeh@yahoo.com
binders the only interest becomes feasible is that of using waste products such as molasses that is both cheap and locally available [4-8].

In an integrated iron and steel plant, one of the most important thermal operations is sintering of raw iron ore, mostly hematite (Fe₂O₃). In the sintering process, a mixture of iron ores, coke, lime or limestone, and iron bearing residues (e.g. blast furnace flue dust, mill scale, scrap and other waste material recycled from within or outside the steel plant) is heated at high temperatures and sintered into a porous, calibrated feedstock acceptable to the blast furnace. Almost all types of ferro wastes available in iron and steel works can be utilized in appropriate proportions to produce quality sinters [9].

Approximately 6.7% of the total energy consumed in iron and steel production is required for sinter operation [10, 11]. As a result of the growth of iron and steel industry all over the world, prime coking coal with adequate properties that yield metallurgical coke is becoming increasingly difficult to procure, and hence this trend is becoming progressively more severe and therefore more expensive [12].

Most research work in the sintering area includes energy consumption and productivity process control. Significant reductions in energy have already been achieved in sintering plants as a result of improving raw materials characteristics of ores and coke breeze as size and composition [13]. Sintering of BOF dust without coke breeze (fuel) was investigated by the sintering pot test. The coke breeze-less sintering has an advantage in investment, as a sintering machine is more economical than a rotary kiln or other reduction facilities [14].

The blast furnace flue dust is a mixture of oxides expelled from the top of the furnace, whose major components are iron oxides and coke fines. The yield of iron in blast furnace dust depends upon the quantity of iron oxide present in the flue dust [15]. Being able to be utilized, economically, such iron oxide fines have the potential to add significant benefits to the iron industry [16].

The Egyptian Iron and Steel Company generates a great deal of blast furnace flue dust (20000–30000 t year⁻¹), a typical analysis of which shows that it contains 33·30% carbon and 27-20% Fe [17].

The objective of this work represents possible utilization of blast furnace flue dust from the Egyptian Iron and Steel Company after pelletization in a disc pelletizer using molasses as a binder material through sintering process as a substitute of coke breeze due to its high price.

2. Experimental

2.1. Materials

Coke breeze was provided by the Egyptian Coke Co., whereas the Egyptian Iron and Steel Company supplied their ore, blast furnace flue dust and limestone. Tabs. I-III show the chemical composition and sieve analysis of raw materials. Molasses which is used as a binder in granulation process was obtained from El-Hawamdia Sugar Co.

X-ray diffraction of the iron ore and blast furnace dust as shown in Figs. 1 and 2 indicate that iron ore mainly consists of hematite and limonite while the main phases in the blast furnace flue dust are Hematite (Fe₂O₃), Magnetite (Fe₃O₄), Silica (SiO₂), Calcite (CaCO₃) and carbon respectively.
**Tab. I** Chemical composition of main components of raw materials

<table>
<thead>
<tr>
<th>Components</th>
<th>Iron Ore, %</th>
<th>Blast furnace flue dust, %</th>
<th>Limestone, %</th>
<th>Coke Fines, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe&lt;sub&gt;total&lt;/sub&gt;</td>
<td>50</td>
<td>32.98</td>
<td>-</td>
<td>2.24</td>
</tr>
<tr>
<td>SiO&lt;sub&gt;2&lt;/sub&gt;</td>
<td>9.1</td>
<td>1.76</td>
<td>1.1</td>
<td>3.2</td>
</tr>
<tr>
<td>Al&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;3&lt;/sub&gt;</td>
<td>2.1</td>
<td>3.66</td>
<td>0.8</td>
<td>2.0</td>
</tr>
<tr>
<td>CaO</td>
<td>1.9</td>
<td>7.59</td>
<td>54.7</td>
<td>0.7</td>
</tr>
<tr>
<td>MgO</td>
<td>0.4</td>
<td>1.08</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>P&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;5&lt;/sub&gt;</td>
<td>0.4</td>
<td>0.24</td>
<td>-</td>
<td>0.04</td>
</tr>
<tr>
<td>MnO</td>
<td>3.8</td>
<td>1.92</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Na&lt;sub&gt;2&lt;/sub&gt;O</td>
<td>0.4</td>
<td>1.12</td>
<td>-</td>
<td>0.02</td>
</tr>
<tr>
<td>K&lt;sub&gt;2&lt;/sub&gt;O</td>
<td>0.6</td>
<td>0.81</td>
<td>-</td>
<td>0.1</td>
</tr>
<tr>
<td>ZnO</td>
<td>0.4</td>
<td>3.01</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>F.C</td>
<td>-</td>
<td>30</td>
<td>-</td>
<td>84.8</td>
</tr>
<tr>
<td>CO&lt;sub&gt;2&lt;/sub&gt;</td>
<td>-</td>
<td>-</td>
<td>42.8</td>
<td>-</td>
</tr>
</tbody>
</table>

**Tab. II** Sieve analysis of Blast furnace flue dust

<table>
<thead>
<tr>
<th>Sieve diameter, mm</th>
<th>Blast furnace flue dust, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.35 mm + 0.316 mm</td>
<td>3.33</td>
</tr>
<tr>
<td>-0.316 mm + 0.25 mm</td>
<td>8.37</td>
</tr>
<tr>
<td>-0.25 mm + 0.125 mm</td>
<td>58.87</td>
</tr>
<tr>
<td>- 0.125 mm</td>
<td>29.23</td>
</tr>
</tbody>
</table>

**Tab. III** Sieve analysis of iron ore

<table>
<thead>
<tr>
<th>Sieve diameter, mm</th>
<th>Iron ore, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>- 5 mm + 4.7 mm</td>
<td>23.1</td>
</tr>
<tr>
<td>- 4.7 mm + 3 mm</td>
<td>8.7</td>
</tr>
<tr>
<td>-3 mm + 2 mm</td>
<td>11.4</td>
</tr>
<tr>
<td>- 2 mm + 1 mm</td>
<td>15.8</td>
</tr>
<tr>
<td>- 1 mm + 0.5 mm</td>
<td>11.6</td>
</tr>
<tr>
<td>- 0.5 mm + 0.2 mm</td>
<td>15.2</td>
</tr>
<tr>
<td>- 0.2 mm + 0.1 mm</td>
<td>4.6</td>
</tr>
<tr>
<td>- 0.1 mm</td>
<td>9.5</td>
</tr>
</tbody>
</table>

**Fig. 1.** X-ray diffraction of iron ore.
2.2 Experimental

2.2.1 Production of the pellets

The pellets were prepared in a disc pelletizer with a diameter of 400 mm, collar height 100 mm, angle of inclination 52°, disc rotating speed 17 rpm and residence time 10 min. Blast furnace flue dust fines (200 gm) were fed to the pelletizer. The predetermined amount of water with or without molasses was then sprayed onto the rolling bed of material in the disc pelletizer. At the end of the tests, a pellet sample was collected and screened to collect the (2.8 - 7 mm diameter) fraction which was taken as a measure of the productivity of the pellet.

\[ P_p = \frac{W_1}{W_2} \times 100 \]

Where:  
- \( P_p \) is the productivity of the pellets (2.8 - 7 mm size), %.
- \( W_1 \) is the weight of the pellets (2.8 - 7 mm size), g
- \( W_2 \) is the weight of the charge fed to disc pelletizer, g

The produced green pellets were dried in air for three days, to ensure the evaporation of water used during the pelletization process. The average compressive strength of dried pellets is controlled by compressing at least 10 pellets (5 pellets of 2.8 – 3.5 mm, and 5 pellets of 3.5 - 7 mm diameter) between parallel steel plates up to their breakage. The mean value of the tested pellets gives their compressive strength. This test is carried out on a platform balance with weight indication by means of a pointer. The pellet to be tested was placed on the lower steel plate of the balance and is gradually compressed with a steel plate while the pointer position is observed. The pellet breakage was indicated by the jumping back of the pointer. The maximum weight load observed corresponds to the compressive strength of the pellet. The dried granules were then subjected to use in sinter mix [18].

2.2.2. Sintering experiments

Sintering experiments were conducted in a laboratory down draft sinter pot (its diameter and height were 125 and 340 mm respectively, with capacity 5 kg). Air flow was
provided by two fans in series which were capable of producing a suction pressure in excess of 12 kPa. The raw material (iron ore) was mixed with limestone, 30% of the charge sinter return, 6% coke breeze (1-3 mm) (the amount of coke breeze as reducing agent from the total dry charge used in sintering plant in Egyptian Iron and Steel Company) or coke breeze (1-3 mm) with blast furnace flue dust pellets (2.8-7 mm) as a substitute of coke breeze as a reducing agent (i.e. the carbon content in the charge must be equal to the carbon content in 6% coke breeze), 2% calcium chloride added for dezincification of blast furnace flue dust, and amount of water (9.5 % of the charge) was added after thorough of raw materials. The sinter charge basicity (CaO of the iron ore, blast furnace flue dust, coke breeze and limestone / SiO₂ of the iron ore, blast furnace flue dust, coke breeze and limestone) = 0.9 was kept constant throughout all experiments.

The green charge was loaded over the sinter hearth layer (0.5 kg sinter 10 to 12 mm size the green raw mix was then ignited with a gas flame for a period of 1.5 min. The ignition was done under suction pressure of 5.88 KPa, while sintering was performed under a suction pressure of 11.76 kPa. The sintering time was determined by the time elapsed from the start of ignition until the exhaust gas temperature reached its maximum value. At the end of the sintering experiment the produced sinter was dropped on to a steel plate laid on concrete and then the sinter cake was screened over a sieve of 7 mm size to determine the productivity of the sintering machine as calculated from the formula [18]:

\[ P = 14.4 \times K \times \phi \times V \text{ton}/(m^2\text{.day}) \]  

Where \( K \) is the percentage of ready made sinter from the charge (above 7 mm), \( \phi \) is bulk density of the charge, ton/m³, \( V \) is vertical velocity of sintering machine \( (V = \frac{H}{T}) \) m/min. \( H \) is the height of the charge in sinter pot (340 mm), and \( T \) is the time of sintering, min.

After that sinter cake above 7 mm was dropped four times from a height of 2 m (shatter test, sinter strength) then the out sinter after the shatter test was screened over a 7 mm sieve Sinter strength \( (S_s) \) was calculated as the percentage of (above 7 mm) sinter after shatter test related to the ready made sinter strength [19].

\[ S_s \% = \frac{W_3}{W_4} \times 100 \]  

Where: \( S_s \) is the sinter strength, %
\( W_3, W_4 \) represent the weight of sinter (above 7 mm) after and before shatter test respectively.

The productivity of the sinter machine at blast furnace yard \( (P_{B.F}) \) was calculated according to the following equation [19]:

\[ P_{B.F} = P \times S_s \]  

Where: \( P_{B.F} \) = the productivity of the sinter machine at blast furnace yard, ton/m².day.
\( P \) = the productivity of sintering machine, ton/m².day
\( S_s \) = shatter index (sinter strength) above 7 mm, %

### 2.2.3. Reduction of the produced sinter

The reduction of the produced sinter is done by hydrogen (flow rate 1.5 l/min), temperature 900 °C, and reduction time 90 min.

\[ \% \text{ weight loss} = \left(\frac{W_S - W_f}{W_S}\right) \times 100 \]  

Where; \( W_S \) = starting weight of the sinter sample.
\( W_f \) = final weight of the sinter sample after reducing for 90 min.
3. Results And Discussion

3.1. Effect of molasses addition on the properties of green and dried pellets

The effect of using different amount of molasses (5-9 % molasses), with a constant amount of water (11 %) on the properties of produced pellets were studied where the following conditions were kept constant (residence time in the disc pelletizer 10 min, disc rotating speed 17 rpm, inclination angle of disc pelletizer 52°). Results illustrated in Fig. 3 indicated that as the amount of molasses increases up to 7% the productivity of the produced pellets increases, then it decreases. This is due to the increase of the viscosity of liquid with increasing the amount of molasses dissolved in water. Also it is clear that increasing the percentage of molasses increases the compressive strength of the dried granules. This may be attributed to the fact that increasing molasses addition leads to an increase in the contact points between the particles of flue dust fines and a decrease in the distance between them so the compressive strength of dried granules increases [20]. Whereas the decrease in productivity by increasing the molasses content above 7 % is probably due to the formation of large granules having size bigger than 7 mm.

![Graph showing productivity and compressive strength vs. amount of molasses added](image)

**Fig. 3.** Effect of the amount of molasses added on the properties of produced flue dust pellets (2.8-7mm) containing 11% water and constant inclination angle of disc pelletizer 52°.

3.2. Effect of varying the amount of water added on the properties of green and dried pellets under constant amount of molasses (7%).

Fig. 4 illustrates the effect of the amount of water added on the quality of the produced pellets under the following constant conditions (residence time 10 min, disc rotating speed 17 rpm, inclination angle of disc pelletizer 52°, and 7% amount of molasses added). It is clear that the productivity of pellets (2.8-7 mm size) increases with increasing the amount of water until it reaches its maximum value at 15% water. This may be attributed to the fact that increasing the water content from 11 to 15 %, leads to an increase in the coalescence mechanism and the liquid capillary bridges between the particles of flue dust fines until 15% water. Beyond 15% water the charge becomes stickier [18, 21]. Whereas the compressive strength of dried pellets relatively decreased with increasing the amount of water added. This may be due to the decrease of the viscosity of liquid with increasing the amount of water, and the rate of liquid evaporation from pellet pores with drying.
3.3. Effect of changing the inclination of disc pelletizer on the properties of green and dried pellets under constant amount of molasses (7%) and water (15%).

Fig. 5 illustrates the effect of changing the inclination angle of disc pelletizer on the quality of the produced pellets under the following constant conditions (residence time 10 min, disc rotating speed 17 rpm, 15% water and 7% amount of molasses added). It is clear that the productivity of pellets increases with increasing the inclination angle until 60°. This may be attributed to the fact that at small angles the feed materials are found to be in a rest position in the disc. The feed charge would not be lifted by friction at inclination angle greater than 60° and hence the productivity was reduced at angle 67° [18]. The compressive strength of the dried granules increases with increasing the angle until 60 due to an increase in the contact points between the particles and a decrease in the distance between them.

Fig. 5 Effect of change of the inclination angle of disc pelletizer on the properties of produced flue dust pellets (2.8-7mm) containing 7% molasses + 15% water.
3.4. Effect of using blast furnace flue dust pellets as a substitute of coke breeze on the sintering performance

Sintering experiments were carried out by adding 6% coke breeze (the amount of coke breeze as reducing agent from the total dry charge used in the sintering plant in Egyptian Iron and Steel Company) or coke breeze with blast furnace flue dust pellets as a substitute for coke breeze (i.e. the carbon content in the charge must be equal to the carbon content in 6% coke breeze), along iron ore charge with water 9.5 %, sinter returns 30%, firing time 1.5 minutes, and basicity (CaO / SiO₂) = 0.9. All experiments were repeated 3 times and average values have been reported.

3.4.1. Effect of using blast furnace flue dust pellets on the sinter strength

Fig. 6 shows the effect of using blast furnace flue dust pellets on the strength of the produced sinter. From this figure, it is clear that the sinter strength increased with increasing flue dust pellets and decreasing coke breeze content in sinter charge. This may be attributed to increasing the amount of melt in charge with increasing the amount of flue dust pellets added.

![Fig. 6. Relation between the amounts of coke breeze added to sintering charge and the strength of sinter produced. (Notes : Total amount of carbon content added to the sinter charge from flue dust pellets and coke breeze is fixed and equal to the carbon content in 6% coke breeze).](image)

3.4.2. Effect of using blast furnace flue dust pellets on the sintering speed

Fig. 7 shows the effect of using blast furnace flue dust pellets (2.8-7 mm) on the vertical velocity of sinter machine. From this figure, it is clear that the vertical velocity of sinter machine decreased with increasing flue dust pellets and decreasing coke breeze (1-3 mm) content in sinter charge. This may be attributed to the fact that the internal heat of the sinter mainly depends on the amount and the size of the coke breeze particles. Larger particles burn slowly, thereby prolonging the combustion time, and this leads to the thermal
inhomogeneity. The flue dust pellets added as a substitute of coke breeze have larger size than coke and more amount of melt, which leads to an increase in the combustion time and a decrease in the vertical speed of machine [19, 22].

**Fig. 7.** Relation between the amounts of coke breeze added to the sintering charge and vertical velocity of the sintering machine. (Notes: Total amount of carbon content added to the sinter charge from flue dust pellets and coke breeze is fixed and equal to carbon content in 6% coke breeze).

### 3.4.3. Effect of using blast furnace flue dust pellets on the productivity of sinter machine and productivity of the sinter machine at blast furnace yard

Fig. 8 illustrates the effect of using blast furnace flue dust pellets on the productivity of sinter machine and productivity of the sinter machine at blast furnace yard. It is clear that the productivity of sinter machine and productivity of the sinter machine at blast furnace yard decrease in case of using blast furnace flue dust pellets. This is due to decreasing the vertical velocity of sintering process as shown in Fig. 7.

**Fig. 8** Relation between the amounts of coke breeze added to the sintering charge and productivity of the sintering machine and productivity of the sintering machine at B.F. yard. (Notes: Total amount of carbon content added to the sinter charge from flue dust pellets and coke breeze is fixed and equal to carbon content in 6% coke breeze).
3.4.4. Effect of using blast furnace flue dust pellets on the amount of fluxing materials used in sintering process

The experimental results of the flue dust effect on the amount of fluxing materials added to the sinter charge are illustrated in Fig. 9 from which it is clear that, the amount of limestone used in the sintering process as a fluxing material decreased with increasing the amount of blast furnace flue dust pellets used through the sinter mix. This may be due to the fact that the blast furnace dust contained calcite (CaCO$_3$) phase which dissociate during sintering process giving CaO. The produced CaO acts as a fluxing material leading to decreasing the amount of limestone used in the sintering process.

The X-ray fluorescence analysis of the produced sinter shows that, the chemical composition of the produced sinter using flue dust pellets is Fe$_{\text{total}}$ = 51.97%, Fe$_2$O$_3$ = 74.24 %, SiO$_2$ = 8.52 %, CaO = 7.9 %, Al$_2$O$_3$ = 1.494 %, ZnO = 0.131, MgO = 0.638% , Na$_2$O = 0.1625 % and K$_2$O = 0.074%. , while the chemical composition of produced sinter using coke breeze only is Fe$_{\text{total}}$ = 50.456%, Fe$_2$O$_3$ = 72.08%, SiO$_2$ = 8.1%, CaO = 7.4%, Al$_2$O$_3$ = 0.8%, ZnO = 0.120 %, MgO = 0.12% , Na$_2$O = 0.13 % and K$_2$O = 0.012%. From the previous analysis, it is clear that the amount of ZnO in the case of using flue dust pellets reached 0.131. This is due to the use of CaCl$_2$ as a dezinking agent, while in the case of using coke breeze only ZnO reached 0.120 %.

![Fig. 9](image)

Fig. 9 Relation between the amount of coke added to the sintering charge and the amount of fluxing materials added to the sintering charge. (Notes: Total amount of carbon content added to the sinter charge from flue dust pellets and coke breeze is fixed and equal to carbon content in 6% coke breeze).

Fig. 10 illustrates the X-ray analysis of the produced sinter in each case of using coke breeze only or blast furnace flue dust pellet. Hematite and magnetite are the main minerals of the produced sinter, and the amount of magnetite in the case of the use of flue dust pellets is more than in the the case of using coke breeze.
3.4.5. Effect of using blast furnace flue dust pellets on the percent weight loss during the reduction of the produced sinter

Fig. 11 illustrates the effect of using blast furnace flue dust pellets on the weight loss of the produced sinter due to the reduction. From the figure, it is clear that the percentage of weight loss decreased with increasing the blast furnace flue dust pellets in the sinter mix. This may be due to the fact that the magnetite (Fe₃O₄) phase which is less reducible than hematite (Fe₂O₃) increases in the sinter mix with increasing the amount of flue dust pellets in sinter charge according to X-ray diffraction of flue dust (Fig. 10), and this needs more coke to reduce.
4. Conclusions

The most suitable pellets (2.8 - 7 mm) of blast furnace flue dust fines are produced in disc pelletizer at angle of inclination 60°, disc rotating speed 17 rpm and residence time of pellets on pelletizer 10 min. The results show that pellets with the highest mechanical properties were obtained with 7 wt % molasses and 15% water addition. Using blast furnace flue dust pellets in the sintering process of an iron ore improves the mechanical properties of the produced sinter, while the vertical velocity of the sinter machine and the productivity of both sinter machine and sinter machine at blast furnace yard decrease. XRD analysis of the produced sinter indicates that hematite and magnetite are the main minerals of sintering in case of using coke only or flue dust pellets only. Using blast furnace flue dust pellets in the sintering process of an iron ore leads to decreasing the amount of fluxing material used in the process.

5. References

Садржај: Египатска компанија за гвожђе и челик генерира велике количине отпадне прашине из високе пећи. Добијање металла и угљеника из ове прашине је све битније због раста цене кокса и смањења примарних извора метала. У исто време се смањује зagaђење околне. Увођење ове прашине у процес синтеровања има велики негативан утицај на различите параметре операције. Из овог разлога тема овог рада је проучавање утицаја производње испресака од ове прашине коришћењем моласе као органског везива и њихова примена у синтеровању руде гвожђа. Синтеровање је вршено коришћењем испресака прашине уместо кокса. Добијени резултати су показали да се коришћењем испресака прашине увећава унутрашња јазина узора као се продуктивност машине за синтеровање и високе пећи умањује. Такође се смањује вертикална брзина машине за синтеровање и губитак масе током редукције производа хидрогеном.

Кључне речи: Прашина из високе пећи, пелетизација, руда гвожђа, процес синтеровања.