AGGLOMERATION PROCESS PRODUCTIVITY INCREASING BY A SINTER MIX PREHEATING

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ABSTRACT

To increase the productivity of the agglomeration process, preheating of the charge is proposed. A series of industrial experiments was carried out on the sinter machine No. 1 of the sinter department of JSC “Ural Steel”. The dynamics of the sinter mix temperature during the technological stages of its preparation from pelleting to loading on pallets was studied, depending on a water temperature change during pelletizing. It was defined that for the winter working of the sinter department of JSC “Ural Steel” the water temperature increase which supplied of the pelletizer to moistening, for every 10°C, facilitates an increase in the temperature of the sinter mix on the pallets by 1.5 - 2.0°C. Therefore, for stable sinter mix production with a temperature higher than 55°C, it is necessary to supply a pelletizer with water, which temperature is at least 85°C. To implement the proposed technology, it is necessary to equip the sinter machines with water-heating recuperative heater, installed above the sintering machine behind the ignition hood and using heat, radiated from the surface of the sinter.

Keywords: pelleting, sinter mix temperature, sinter cake, water heater.

INTRODUCTION

A prerequisite for the highly-productive work of sintering machines and the production of high-quality sinter cake is the supplying of a well-pelletized sintering mixture with an optimum content of carbon and moisture, homogeneous in chemical composition, with a minimum amount of fines and a temperature not lower than the “dew point”. Therefore, the increased attention is always paid to the issue of sinter mix preparation [1 - 23].

The sinter mix temperature is one of the key parameters of the sintering mixture quality, which determines its behavior during the sintering process and the results of the sintering process. Sintering of mixtures with a temperature above the “dew point” occurs without the formation of an overwetting zone. This ensures a high permeability of the sinter batch layer, improves the thermal conditions of sintering, increases the productivity of a sintering machines and the quality of the sinter [19 - 21]. Therefore, the sinter mix heating before sintering is an indispensable element of modern sintering technology. The sinter mix at the sintering plants is usually preheated by a sinter returns, (natural, blast furnace, etc.) or by steam supplied to the pelletizer, and using burnt limestone [10].

At present, JSC “Ural Steel” the sinter mix preheats with a hot return, which is fed into the sinter mix before mixing with a temperature of 350 - 400°C. An additional source of heat is the exothermic lime quenching reaction, which is used to improve pelleting at a rate of up to 30 kg/t. As a result, the sinter mix temperature during loading on the sintering machine is 52 - 61°C in summer and 41 - 52°C in winter (at an average value of 47°C).

The lower temperature of the sinter mix during winter makes impel us to limit the height of the sintered
layer (up to 250 mm) and a quantity of fine-grained concentrates (ore concentrates) in it (up to 60 %). This is the main reason for the reduced productivity of the sintering plants [22 - 24]. Therefore, the additional heating of the sinter mix is a good resource for improving the technical and economic parameters of sintering production.

EXPERIMENTAL

At the sinter mix pelletization according to the technology operating at JSC “Ural Steel”, it is moistening at 3.5 - 4.5 % (just after mixing) to 7 - 8 % by technical water with a temperature of 5 - 30°C (depending on the period of the year). At a pelletizer capacity of 150 tons per hour, the water consumption for humidifying the charge is up to 6 tons per hour (up to 40 liters per ton of sinter mix). The water has a high enough heat capacity of 4,187 kJ/kg/K, so it can be used for additional heating of the sinter mix. Calculation of the heat balance of the sinter mix showed that when water is consumed in the pelletizer 40 l/t, water with a temperature of at least 85°C (except hot return and burnt limestone at a rate of 30 kg/ton) must be used to stabilize the sinter mix preheating up to 55°C. At the same time, an increase in the water temperature for every 10°C ensures an increase in the sinter mix temperature by 1.5 - 2.0°C.

To heat the water supplied to the pelletizer, we propose to use the sinter cake heat, emitted from the surface of the sintering machine working part. For the utilization of sinter heat, radiated from its surface, it is necessary to equip sintering machines with recuperative water heaters. We place it above the sintered cake surface behind the ignition hood, where the surface temperature is maximal (up to 1200°C).

When designing an experimental water heater, we took into account requirements for its placement - instead of a heat shield (length 3.2 mm) installed after the ignition hood (its length 4.8 mm). In addition to reducing the construction and installation costs, this installation option provides the maximum flow of thermal radiation from the surface of the sinter cake. As a result, the overall dimensions of the water heater were 3.4 m in width (with a pallet car width of 2.8 m) and 3.2 m in length, and the distance from the heat-sensing (working) surface of the water heater to the level of the pallet car boards is 800 mm. In the manufacture of the water heater, steel pipes were used according to DIN 2448 with an external diameter of 76.1 mm made of steel St 37.2 (DIN 2458 - St 37.2 - 76.1 x 5.6), which were available in the factory. As a result, the experimental water heater is a serpentine heat exchanger having one water flow circuit, which consists of 21 turns. The heat-absorbing surface of an experimental water heater is made of steel pipes, through which water is supplied to moistening the sinter mix. The scheme of the installation of a recuperative water heater is shown in Fig. 1.

Technical characteristics of the experimental radiation water heater are: length - 3.2 m; width - 3.4 m; height of the location of the heat-sensing surface - 800
mm from the level of the pallet car boards; material - pipe DIN 2448 - St 37.2 - 76.1 x 5.6; number of heating spiral turns - 21 pcs.

After installation of the experimental water heater on the sintering machine, the water temperature was measured at its working flow rate of 6 tons per hour. At the initial water temperature at the inlet to the water heater 15 - 17°C, the outlet temperature was 85 - 90°C. When the heat capacity of water is 4,187 kJ/kg/K, the amount of heat that is additionally supplied to the pelletizer with water is 1.71 - 1.88 GJ/h. Then, when the pelletizer productivity is 150 tons per hour and the heat capacity of the sintering mix is 0.85 - 0.90 kJ/kg/K [10], additional heat with water (1.71 - 1.88 GJ/h) will increase the temperature of the sinter mix by 12.7 - 14.8°C (without taking into account heat losses).

The sintering surface temperature along the length of the water heater varied from 1200 to 680°C during the experiment (an average of 940°C). Examples of typical thermograms of the sinter cake surface at the outlet of the ignition hood and after the water heater are shown in Fig. 2. Thus, with the degree of the agglomerate surface blackness under the water heater of 0.95 and the radiation surface area of 8.96 m² (at the width of the pallet car 2.8 m), the amount of heat emitted from the surface of the sinter cake will be 3.76 GJ per hour. With hourly heat removal from the water heater 1.71 - 1.88 GJ, the degree of absorption of heat emitted from the surface of the sinter cake is 45 - 50 %.

To estimate the effect of water temperature on the heating of the sinter mix, measurements of the sinter mix temperature were made at four points:
- on the feeding conveyor before the pelletizer;
- at the exit from the pelletizer;
- in the intermediate bin;
- on the pallet car of the sintering machine.

The scheme of the water heater location and the sinter mix temperature measuring is shown in Fig. 3.

Measurements of the sinter mix temperature were carried out using the Flir T640 infrared thermal imager. Prior to the experiments, the thermal setting was conducted by adjusting the coefficient of sinter mix radiation. The experimental value of the radiation coefficient of the sinter mix wet was fitted in laboratory for a sinter mix with a moisture content of 7.5 %, preheated to 60°C.

Fig. 2. (a) Examples of typical thermograms of the sinter cake surface at the outlet of the ignition hood.

Fig. 2. (b) Examples of typical thermograms of the sinter cake surface after the water heater.

Fig. 3. Scheme of the water heater location and the sinter mix temperature measurements.
RESULTS AND DISCUSSION

The industrial tests of the water heater were carried out for a month on the sinter machine No. 1 of JSC “Ural Steel” (sintering area 84 m$^2$). In the experimental period, the sinter machine worked with a constant composition of raw materials. The sinter mix was batched for obtaining of the sinter with a basicity (CaO/SiO$_2$) of 1.7 and with an Fe content of 50%.

During the experiment, the sinter mix samples were taken before and follows pelletizer at fixed parameters of the sinter machine: rarefaction in the wind-box collector; temperature in the wind-box collector; speed of sintering belt movement.

The moisture and the granulometric composition were determined in the samples of the sinter mix. The results were compared with the “baseline”, which was collected during the operation of sinter machine No. 1 before the installation of an experimental water heater.

The averaged data of the moisture and granulometric composition of the sinter mix are listed in Table 1.

The sinter machine working conditions and the sinter mix temperature are given in Table 2.

Examples of typical thermograms are shown in Figs. 4 - 7.

The experimental data show that an increase in the water temperature from 17.6 to 86.9°C (by 69.3°C) made it possible to increase the sinter mix temperature at the outlet from the pelletizer by 10.5°C. At a pelletizer productivity of 150 tons per hour and the heat capacity of the sintering mix in it is 0.85 - 0.90 kJ/(kg K), the increase in the heat content of the sinter mix in the trial period was 1.34 - 1.42 GJ per hour. An additional amount of heat with water at a flow rate of 6 tons/hour and a heat capacity of 4,187 kJ/(kg K) is equal to 1.74 GJ per hour. That is, the assimilation of additional heat entering the pelletizer with heated water amounted to 76.9 - 81.4 %. Thus, the experimental results are confirmed by the possibility of hot water using for the sinter mix additional heating: an increase in the temperature for every 10°C gives an increase in the sinter mix temperature by 1.52°C.

The increasing of the sinter mix temperature practically did not affect the quality of pelletization - the

<table>
<thead>
<tr>
<th>Sinter mix material parameters</th>
<th>Base period</th>
<th>Experimental period</th>
<th>t*</th>
</tr>
</thead>
<tbody>
<tr>
<td>The temperature of water to moisten, °C</td>
<td>17,6</td>
<td>86,9</td>
<td>173,70</td>
</tr>
<tr>
<td>+10</td>
<td>5,16</td>
<td>4,88</td>
<td>1,52</td>
</tr>
<tr>
<td>5-10</td>
<td>8,15</td>
<td>10,11</td>
<td>6,63</td>
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<td>3-5</td>
<td>9,35</td>
<td>10,02</td>
<td>0,95</td>
</tr>
<tr>
<td>1-3</td>
<td>24,13</td>
<td>25,60</td>
<td>1,69</td>
</tr>
<tr>
<td>0-1</td>
<td>53,21</td>
<td>49,39</td>
<td>4,24</td>
</tr>
<tr>
<td>Moisture before pelletizing, %</td>
<td>3,50</td>
<td>3,70</td>
<td>1,84</td>
</tr>
<tr>
<td>Average pellet size of sinter mix, mm</td>
<td>2,38</td>
<td>2,53</td>
<td>1,71</td>
</tr>
<tr>
<td>+10</td>
<td>12,30</td>
<td>11,80</td>
<td>1,66</td>
</tr>
<tr>
<td>5-10</td>
<td>12,70</td>
<td>11,96</td>
<td>2,46</td>
</tr>
<tr>
<td>3-5</td>
<td>19,34</td>
<td>18,62</td>
<td>1,57</td>
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<td>1-3</td>
<td>35,69</td>
<td>39,15</td>
<td>5,94</td>
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<tr>
<td>0-1</td>
<td>19,97</td>
<td>18,47</td>
<td>3,26</td>
</tr>
<tr>
<td>Moisture after pelletizing, %</td>
<td>7,60</td>
<td>7,30</td>
<td>1,95</td>
</tr>
<tr>
<td>Average pellet size of sinter mix, mm</td>
<td>4,08</td>
<td>3,99</td>
<td>1,67</td>
</tr>
</tbody>
</table>

* calculated values for the parameters $t$-test (critical value of $t$-test at a significance level $\alpha = 0,95$ and including 200 degrees of freedom is $t_\alpha = 1,96$).
fraction of fines decreased by 1.5 % while the average diameter of the granules decreased from 4.08 to 3.99 mm. Comparison of the calculated values of the Student’s criteria with the critical value shows that the differences observed in Table 1 of the average values of the mean diameter of the granules and humidity of the sinter mix are not statistically significant. A significant difference is observed only for the content of individual fractions in the sinter mix, such as 5 - 10 mm, 1 - 3 mm and 0 - 1 mm. Thus, during the pilot-industrial tests, there was no significant effect of sinter mix temperature on the pelletization results.

The increase in the sinter mix temperature led to reduction in the vacuum of the wind-box collector by 0.27 KPa (5 % rel.), and the temperature in the pressure manifold increased by 12.5°C. These changes indicate an improvement in the gas permeability of the sintered layer, which is explained by the elimination of the

<table>
<thead>
<tr>
<th>Parameters of the sinter mix batch</th>
<th>Base period</th>
<th>Experimental period</th>
<th>Change, abs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>The temperature of water to moisten, °C</td>
<td>17.6</td>
<td>86.9</td>
<td>+ 69.3</td>
</tr>
<tr>
<td>Sinter mix temperature in the test points (fig. 3), °C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1)</td>
<td>51.6</td>
<td>51.9</td>
<td>+ 0.3</td>
</tr>
<tr>
<td>2)</td>
<td>52.0</td>
<td>62.5</td>
<td>+ 10.5</td>
</tr>
<tr>
<td>3)</td>
<td>52.5</td>
<td>63.4</td>
<td>+ 10.9</td>
</tr>
<tr>
<td>4)</td>
<td>55.6</td>
<td>65.2</td>
<td>+ 9.6</td>
</tr>
<tr>
<td>Rarefaction in the wind-box collector, KPa</td>
<td>5.59</td>
<td>5.33</td>
<td>− 0.27</td>
</tr>
<tr>
<td>Temperature in the wind-box collector, °C</td>
<td>83.7</td>
<td>96.2</td>
<td>+ 12.5</td>
</tr>
<tr>
<td>Actual speed of sintering belt, m/min</td>
<td>1.80</td>
<td>1.80</td>
<td>0</td>
</tr>
<tr>
<td>Normalized speed of sintering belt, m/min *</td>
<td>1.72</td>
<td>1.78</td>
<td>+ 0.06</td>
</tr>
<tr>
<td>Height of sintered layer, mm</td>
<td>250</td>
<td>250</td>
<td>0</td>
</tr>
<tr>
<td>Estimated sintering speed, mm/min</td>
<td>14.33</td>
<td>14.83</td>
<td>+ 0.5</td>
</tr>
<tr>
<td>Sinter yield (+5 mm), %**</td>
<td>74.4</td>
<td>74.2</td>
<td>− 0.2</td>
</tr>
<tr>
<td>Estimated productivity, t/m2/h</td>
<td>1.152</td>
<td>1.189</td>
<td>+ 0.037</td>
</tr>
<tr>
<td>Tumbler index (TI +5mm) in accordance with National Standart of Russian Federation 15137-77, %**</td>
<td>68.6</td>
<td>68.7</td>
<td>+ 0.1</td>
</tr>
</tbody>
</table>

* normalized speed to constant wind-box temperature (100 °C); ** data on sinter plant (consisting of 4 sintering machines).

Fig. 4. Examples of typical thermograms of the sinter mix at the test points 1 (Fig.3) in the “base” (a) and experimental (b) periods.
Fig. 5. Examples of typical thermograms of the sinter mix at the test points 2 (Fig. 3) in the “base” (a) and experimental (b) periods.

Fig. 6. Examples of typical thermograms of the sinter mix at the test points 3 (Fig. 3) in the “base” (a) and experimental (b) periods.

Fig. 7. Examples of typical thermograms of the sinter mix at the test points 4 (Fig. 3) in the “base” (a) and experimental (b) periods.
overwetting zone. An increase in the temperature of the exhaust gases (in the pressure manifold) also indicates an earlier finish of the sintering process and the possibility of increasing the speed of the sintering belt from 1.72 up to 1.78 m/min (by 3.5 %). At the same time, were not observed stable changes in sinter yield and its impact strength in the trial period (Table 2). Therefore, the sinter cake heat use for heating the water supplied to the pelletiser allows us to achieve productivity growth (by 3 - 4 %) as a result of increased gas permeability and sintering rate without deteriorating the sinter strength. In addition, this method of additional heating of sinter mix can also be used to increase the height of the sintered layer. As a result, we can expect an increase in the sinter yield, strength of the agglomerate and, as a result, an increase in productivity.

The advantage of this method of additional heating of the sinter mix is the minimum investment project cost. The estimated cost of manufacturing and installation of an experimental water heater in the conditions of JSC “Ural Steel” does not exceed 10 thousand euros. In addition, this option for heating the sinter mix uses the internal heat of the sintering process itself and does not require additional fuel sources. The only weakness of this method, such as salt settling in the pipelines, can be solved by introducing micro additives into the water, or by replacing the water heater periodically. The water heater stoppage period should be determined by the condition of the heating spiral, which defined by changing the pressure in the pipeline. The last-mentioned, considering the small capital costs of making a water heater is more appropriate.

CONCLUSIONS

Sinter cake heat using for heating the water supplied to the pelletiser to humidify the sinter mix gives us the following advantages:

- to increase the temperature of the sinter mix by 1.5 - 2.0°C for every 10°C the temperature of the water;
- to improve the gas permeability of the sintered layer and productivity of sinter production for the conditions of JSC “Ural Steel” by 3 - 4 % as a result of elimination of the overwetting zone.

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