THE THERMOVISION MEASUREMENT OF TEMPERATURE IN THE IRON-ORE SINTERING PROCESS WITH THE BIOMASS

Jaroslav Legemza 1)*, Mária Fröhlichová 1), Robert Findorák 1)
1) Department of Ferrous Metallurgy and Foundry, Faculty of Metallurgy, Technical University of Kosice, Slovakia

Received: 10.12.2013
Accepted: 18.04.2014

*Corresponding author: e-mail: Jaroslav.Lagemza@tuke.sk, Telephone number: +42155 602 3155, Department of Ferrous Metallurgy and Foundry, Faculty of Metallurgy, Technical University of Kosice, Slovakia

Abstract
Sintering is thermal process used in the iron and steel industry to transform fine particles of iron ore and concentrate into porous product known as sinter. Sinter is input material for the blast furnace process. In the sintering process fuel is in the form of coke breeze (or in the form various types of biomass) used for production of iron-ore sinter. Temperature measurement and monitoring is very important in the iron sintering process. Temperature can be a very good indicator of the behavior of the sintering process. The present work contains the findings, which were obtained from analysis of the results, obtained by experiments with the laboratory sintering pan. The simulation conditions on this laboratory sintering pan are sufficiently close to those present in the sintering layer. This paper primarily presents temperature measurement in iron sintering process with infrared thermography. During the sintering, the laboratory sintering pan was monitored by thermovision camera and movement of the combustion zone in direction of airflow was recorded. The information provided by the measurement system can be used to control many parameters of the sintering process (homogeneity and dimension of combustion zone, temperature profile in sintering bed, etc.). The experiment results were analyzed and summarized in the present paper.

Keywords: sintering process, laboratory sintering pan, infrared thermography, temperature control

1 Introduction
Sintering is an agglomeration process in which iron ore fines and other products such as coke fines (or biomass) and basic materials are mixed and fired at a temperatures 1200 – 1350 °C. This process produces a solidified porous material known as sinter. Sinter composition usually depends on chemical composition of input materials, carbon content, oxidation potential of the gaseous phase and temperatures in the sintering bed [1-5]. Under operational conditions the agglomeration process is performed on agglomeration (sintering) belts which operate on the principle of ignition of the agglomeration charge using a burner, creating and applying the sucking air underpressure across the sintering bed (in which the burning of fuel, heat transfer and oxidation-reduction processes take place) and the gradual cooling of the produced agglomerate in the cooling section of the agglomeration belt [1, 2]. In the iron and steel industry most processes require accurate temperature measurement and control. Temperature
measurement and monitoring is a mandatory requirement for most steps in iron and steel manufacturing [6]. Measuring, monitoring and controlling iron and steel temperature throughout the manufacturing process ensures that materials meet product specifications, preventing defects in the final product [7, 8]. Temperature can also be used to detect objects, where images taken in the visible spectrum are not adequate [9]. Thus, temperature measurement and monitoring during and after the sintering process are critical to achieve optimal results in the quality of iron bearing sinter [10]. Also, temperature measurement is crucial to control productivity, energy consumption, and safety. Temperature measurement is already present in sintering machines because it is a required feedback value for the models that control the process. Temperature is normally measured using thermocouples installed under the sinter cars used to move the mixture forward during the process. Some experimental works are based on infrared thermography. The most common machine used for sintering is the Dwight-Lloyd machine [11]. Fig. 1 shows a schematic representation of the sintering process using this type of machine. The camera used in the system is at the discharge end of the sintering process. The position of the camera can be seen in Fig. 1.

![Sintering process using a Dwight-Lloyd machine](image)

**Fig. 1** Sintering process using a Dwight-Lloyd machine [11]

**Fig. 2(a)** shows an image taken from this position in the visible spectrum. This image shows the flame front in the material, although in images taken in the visible spectrum, the position is barely appreciable. In contrast, **Fig. 2(b)** shows an infrared image taken from the same position, where the flame front can be seen much more clearly. These images show why it is necessary to use infrared thermography. Temperature measurement with infrared devices is largely affected by the emissivity of the material. Emissivity calibration is especially complicated in low emissivity objects, such as polished steel or aluminum, because small variations in emissivity lead to large variations in the resulting temperatures. However, in objects with high emissivity, such as a sintering mixture, slight variations in the chosen emissivity value cause only minor changes in the resulting surface temperatures.
The camera used in the system presented in paper [12] is installed in a window of the sintering machine, well above the sinter cooler. Thus, the acquired images show a top view of the sinter during cooling, as can be seen in Fig. 3.

Next in the research in Japan [13], the movement of the combustion zone from upper to lower during the sintering process was observed using a silica glass tube in the pot test. Fig. 4 shows the time-dependent change and progress of the movement of the combustion zone during the sintering. Additional studies were realised in papers [14, 15].
Experimental materials and methods

For the experiments, iron ore, iron concentrate, dolomite, limestone, coke breeze, and sawdust from oak-wood were used. In the experiments following parameters of sintering charge were considered: ($Fe_{total} = 44\%$, basicity = 1.6, moisture = 10\%, content of fuel = 3.8\%). The process of simulating the laboratory production of agglomerate under laboratory conditions of Department of Ferrous Metallurgy and Foundry in Košice has been divided into two stages – a cold stage and a hot stage. The cold stage included the preparation and processing of individual charge components, their agglomeration, formation of test heaps, pre-pelletization and determination of their moisture and air permeability. The hot stage included the heating of the pan, loading the pre-pelletized mixture into the laboratory-scale sintering pan, ignition of the surface of the charge using a burner and high temperature sintering. The sinter batch was charged as micropellets into the laboratory sintering pot (LSP), Fig. 5. After ignition the sintering process have been carried out while maintaining the constant underpressure of 5 kPa. Airflow measurements were made in the offgas passage where the hot exhaust gas has been cooled. Thermocouples were installed at 100 mm, 200 mm and 300 mm depths through the sinter bed.

In Fig. 6 is shown sintering of agglomeration mixture in laboratory sintering pot. During the sintering, the laboratory sintering pot was monitored by thermovision camera and movement of the combustion zone in direction of airflow was recorded. The movement of the combustion zone from top to bottom during the sintering process was observed approximately 25 minutes.

Fig. 5 The laboratory sintering pan (LSP)
3 Results and discussion

In the first experiment the temperatures (measured by thermocouples) attained at various bed depths during combustion of coke–sawdust mixtures (with 20% replacement of the coke) in the combustion zone reached 920 – 1060 °C. Fig. 7 shows the temperature profile usually observed during iron ore sintering experiments at LSP. The maximum off-gas temperature measured in the sinter pot windbox was approximately 600 °C.

Fig. 7 Bed temperatures profile in experiment 1

Fig. 8 shows the thermo imaging measurement of laboratory sintering pan during the agglomeration process. The thermovision camera was located 5 m from the pan and the temperature profile measurements were made at 1 minute intervals. Fig. 9 shows the relationship between the temperature of the pan surface and temperatures in the sintered layer.
Fig. 8  Infrared images at the sintering process on the laboratory sintering pan (realised in various sintering times)

Fig. 9  The relationship between the temperature of the pan surface and temperatures in the sintered layer

From Fig. 9 it is clear that there is a relatively strong correlation between the temperatures measured in the sintered layer with thermocouples and temperature measured on the surface of the pan by thermovision camera. This correlation increases in the direction of the airflow and is
strongest at 30 cm from the surface of the sintered charge. The movement of the combustion zone in the sintered layer can be monitored by scanned infrared profile. Because of the relatively strong correlation between the measured values, it is possible to consider the future use of thermal imaging for control of the sintering process and for prediction of the maximum temperature of the sintered layer. Fig. 10 shows the infrared temperature measurement of the laboratory sintering pan. The thermovision camera was positioned 2 m from the sintering pan. By changing the distance and position of the camera the temperatures measured on the surface of the sintering pan were by about 80 °C higher than in the previous case (Fig. 8).

Fig. 10 Infrared images (2) at the sintering process on the laboratory sintering pan

In the second experiment the temperatures (measured by thermocouples) attained at various bed depths during combustion of coke–sawdust mixtures (with 20 % replacement of the coke and better permeability of sintering charge) in the combustion zone reaches 1100 – 1230 °C. Fig. 11 shows the temperature profile usually observed during iron ore sintering experiments at LSP. The maximum off-gas temperature measured in the sinter pot windbox was approximately 600 °C. The goal of the second experiment was to determine the temperature on the surface of ignited charge by thermovision camera and homogeneity of the thermal field. The whole process of iron bearing charge sintering and quality of sinter depends on the uniform ignition of the agglomeration charge and sufficient heat input from burner. Fig. 12 shows the thermovision measurement of temperature profile on the surface of the agglomeration charge in laboratory sintering pan. The camera was positioned 2 m from the charge surface. Temperatures on the surface of ignited charge were initially in the interval of about 380 – 540 °C. While these temperatures are lower than the ignition temperature of the coke, it is necessary to consider the fact that in thermal imaging measurement the camera captures an area that is formed not only by burning coke particles, but also by iron ore concentrate particles and basic ingredients. Due to the heterogeneous composition of the agglomeration charge the sensed temperatures are always lower than the combustion temperature of coke itself. In the future, measurement results may help control the process of charge ignition and determine its non-homogeneity. As can be seen from Fig. 12, within about 3 minutes the sintering zone moves to lower levels in the direction of airflow accompanied by increased non-homogeneity of fuel distribution in the sintered layer and more rapid combustion. Fig. 13 shows the infrared temperature measurement on laboratory sintering pan during the second experiment, the thermovision camera was positioned 2 m from...
the sintering pan. In this case, higher temperatures were measured than in the first experiment (Fig. 10), which corresponds to the maximum temperatures measured by thermocouples at particular levels of sintered layer (Fig. 11).

**Fig. 11** Bed temperatures profile in experiment 2

**Fig. 12** Infrared images (3) on the top of the sintering charge in the laboratory sintering pan
Conclusions

When summarizing knowledge gained from the above mentioned experiments, several new findings have been discovered, namely:

1. During iron bearing charge sintering with coke and sawdust the measured temperature in sintered layer were about 900 – 1230 °C. These temperatures are lower than when using coke only. The higher temperatures within this interval were found for sintering charge with higher permeability.

2. By scanning the temperature profile of sintering pan using the thermovision camera it is possible to monitor the movement of fuel combustion zone in the agglomeration layer. Visually determined sintering rate was about 16 mm/min. The calculated sintering rate is 12.5 mm/min.

3. Relatively strong correlation was found between the temperatures measured in the sintered layer by thermocouples and temperatures measured at the surface of the pan by thermovision camera. This correlation increases in the direction of the airflow. Because of relatively strong correlation of the respective measured values, it is possible to consider the use of thermal imaging for control of the sintering process and prediction of the maximum temperatures of the sintered layer in the future.

4. Temperatures on the surface of ignited charge are in the range of about 380 – 540 °C. Due to the heterogeneous composition of the agglomeration charge, sensed temperatures are always lower than the temperature of the combustion of coke itself. Measurement results may help to control the process of charge ignition and determine its non-homogeneity in the future.

References


Acknowledgements

This work was supported by Slovak Research and Development Agency (APVV), Slovak Republic, No. APVV-0405-11.