Available online at www.sciencedirect.com
ScienceDirect

JOURNAL OF IRON AND STEEL RESEARCH, INTERNATIONAL. 2016, 23(5): 434-441

Intelligent Control of Grate-kiln-cooler Process of Iron Ore Pellets Using a Combination of Expert System Approach and Takagi-Sugeno Fuzzy Model

Gui-ming YANG, Xiao-hui FAN, Xu-ling CHEN, Xiao-xian HUANG, Zong-ping LI
(School of Minerals Processing and Bioengineering, Central South University, Changsha 410083, Hunan, China)

Abstract: Grate-kiln-cooler has become a major process of producing iron ore pellets in China. Due to the diversity of the raw materials used and the multi-device multi-variable characteristics, this process still encounters with control problem. An attempt was proposed to deal with this issue. The three-device-integrated feature of the process was firstly analyzed to obtain control strategy, and then an intelligent control system using a combination of expert system approach and Takagi-Sugeno (T-S) fuzzy model was developed. Expert system approach was used to diagnose and remedy the abnormal conditions, while T-S fuzzy model was used to stabilize the thermal state. In the construction of T-S fuzzy rules, antecedents were identified by fuzzy c-mean clustering algorithm incorporated with subtractive clustering algorithm, and consequent parameters were identified by recursive least square algorithm. The control system was applied in a Chinese pelletizing plant and the application results demonstrated its effectiveness of stabilizing the thermal states within three devices.

Key words: intelligent control; grate-kiln-cooler; expert system; fuzzy model; iron ore pellet

Iron and steel industry has developed dramatically in the past two decades in China. In 2014, Chinese annual production of pig iron surpassed 700 Mt, accounting for 60.3% of global production. At present, iron ore pellets only occupy less than 20% of blast furnace burdens in China, and the ideal percentage is acknowledged to be 30%; thus, a growth potential in the future can be expected. Processes of producing iron ore pellets mainly include vertical shaft furnace, moving grate and grate-kiln-cooler. The last process has become a major process in China recently due to the advantages such as large handling capacity, multiple fuel capacity and good adaptability to various materials.

Optimizing a group of manipulated variables to maximize economic benefits is a goal for engineers to pursue. For grate-kiln-cooler process, optimization can be achieved by numerical simulations. Separate models of traveling grate[1-3], rotary kiln[4,5] and circular cooler[6,7] have been reported. Even though these models are beneficial to optimize the process in a level-2 control system, they are more suitable for design and operation guidance rather than on-line control. The control of rotary kiln has been intensively investigated since rotary kilns are ubiquitous fixtures of the metallurgical and chemical industries (e.g. cement clinkering, limestone incineration, and coal pyrolysis)[8-10]. Despite these reports, grate-kiln-cooler process still encounters with control difficulty due to the diversity of the raw materials used and the multi-device multi-variable characteristics.

Pellet production is a process of complicated physical-chemical reactions with pure hysteresis, nonlinearity and strong coupling characteristics. Moreover, the three-device-integrated feature, that is, the variation of mass flow or heat flow within one device, will influence the thermal states of the others, which increases the difficulty in controlling the entire process. Up to now, control strategy of the entire process has not been specified and the intelligent control system considering the integrated feature has not been reported in details.

Artificial intelligence is an effectual tool. In this paper, an attempt to control the grate-kiln-cooler process was proposed using a combination of expert system approach and Takagi-Sugeno (T-S) fuzzy model.

Foundation Item: Item Sponsored by National Natural Science Foundation of China (51174253)
Biography: Gui-ming YANG, Doctor Candidate; **E-mail**: csuygm@sina.com; **Received Date**: July 13, 2015

1 Process Description

The typical schematic figure of grate-kiln-cooler process for iron ore pellets is shown in Fig. 1. The drying, preheating, roasting and cooling of pellets are accomplished in three devices. Traveling grate is generally divided into four sections according to the temperature level, namely up-draught drying (UDD), down-draught drying (DDD), tempered pre-heating (TPH) and pre-heating (PH). Green pellets charged from feed end move horizontally along with the grate plate while hot gas flows vertically to conduct cross-current heat exchange in four sections respectively. Physical and chemical phenomena occurring in traveling grate mainly include: evaporation of pellet moisture, oxidation of magnetite, desulphurization, decomposition of dolomite or limestone, pellet shrinkage, etc. Pre-heated pellets discharged from PH section are then roasted in the rotary kiln where pellets move forwards and circumferentially due to the kiln inclination and rotation. Pulverized coal or natural gas is injected into the kiln by burner blower and burns with the aid of primary air, supplying heat for the whole system. The heat exchange within the kiln can be viewed as counter-current. Circular cooler is generally selected as cooling equipment in large-scale pellet production due to its small footprint and high efficiency. It is commonly divided into three zones to attain hot gas of different temperatures (some plants divide it into four zones and the waste gas of last zone is exhausted to the air). Cooling air flows through wind-box, grate plate, pellet bed and vessel hood successively from the bottom to the top while pellet bed moves circumferentially along with trolley. To optimize energy consumption, off-gas from Zone 1 is re-circulated to rotary kiln, while off-gas from kiln end is re-circulated for pre-heating and down-draught drying of iron ore pellets through PH exhauster and DDD exhauster. Off-gas from Zone 2 is re-circulated to TPH through TPH exhauster while off-gas from Zone 3 is re-circulated to UDD.

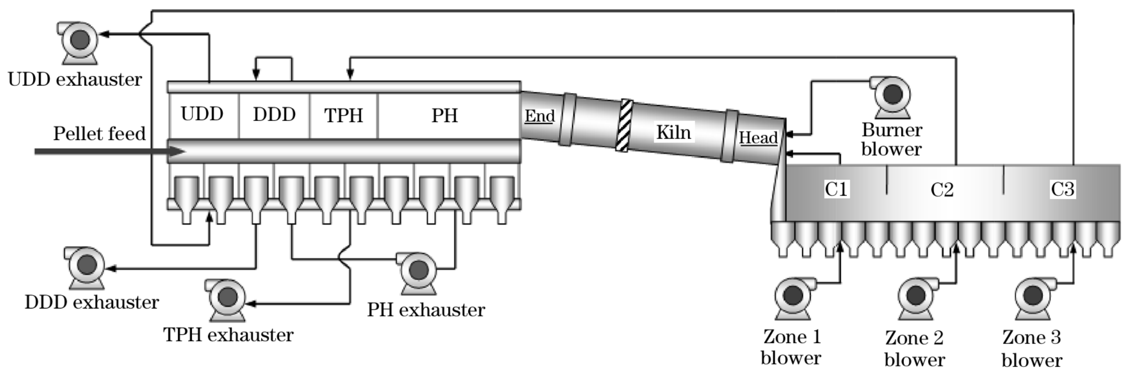

Fig. 1 Schematic diagram of grate-kiln-cooler process

Thermal process of iron ore pellets involves numerous measured variables in the pelletizing plant. A rough selection of measured variables is conducted based on the cognition of domain experts and field operators. These preliminarily selected variables are all available from field DCS (distributed control system) and listed in Table 1. In addition, important binary variables such as the opening of bypass valves (connect the wind-box to gas hood in traveling grate), cold blast valves (set besides the gas pipe of exhausters to introduce cold air) and release valves (set upon gas hoods for emergency emission) are selected to deal with abnormal conditions.

2 Proposal of Control Strategy

A main task of controlling grate-kiln-cooler process is to guarantee the pellet strength. According to the pellet consolidation mechanism[11], adequate residence time and heating temperature are the foundation of the qualified products. Residence time, which relates to the moving speed of three devices, is generally determined by the production plan. Since it is a common practice not to adjust the moving speed at the given productivity, the main controlled variables are thermal states within three devices. To maintain normal production, the control constraints specified by designers or field technicians should be acknowledged. The constraints are mainly used to identify and remedy the abnormal conditions. When production becomes normal, the operating target turns to stabilize the thermal state and optimize the process parameters. State variables and manipulated variables, and their inherent correlations should be acquired. Based on the understanding