Accretion Control in Sponge Iron Production Kiln using Fuzzy Logic

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Abstract

Sponge iron is the product generated by direct reduction of iron ore with aid of either carbon or natural gas under controlled temperatures and pressures within a rotary kiln. However the performance of rotary kilns is usually adversely affected by the formation of accretion. This accumulation of sintered solid particles which form rings along the length of the kiln hinders material flow, lowers productivity and life span of the kiln. To maintain the quality of sponge iron and improve on performance of rotary kilns, there is need to minimize accretion build up in the kiln. However due to the nonlinear nature of the reduction process dynamics, it is difficult to control accretion build up in the kiln. This paper proposes the control of accretion build up through the application of Fuzzy Logic control. The controller receives partial and imprecise data from field instruments and is able to maintain product quality under dynamic process conditions. MATLAB Fuzzy-Toolbox was used to model and simulate the design. A comparison is made between the designed Fuzzy system and the PID controller. Simulation results show that it is possible to reduce accretion build up from 27 % when using PID controller to 14.6 % with the use of Fuzzy control.

Keywords: Accretion, Fuzzy Logic, Kiln, Sponge iron

1. Introduction

Rapid growth in technology has resulted in increased demand for high quality products. This has called for high performance control systems for industrial applications to produce high-tech products. The complexity of a processing plant determines the type of control strategy to be implemented. Sponge iron production process requires accurate monitoring and control of the process parameters. The performance of rotary kiln sponge iron based processes is normally affected by accretion build up along the kiln linings. Accretion build up is the accumulation of semi-molten material which form rings along kiln lining. These rings narrow the kiln diameter thereby hindering efficient material flow and effect lowering production rate and performance of the kiln. PID controllers have been implemented to control process parameters for minimizing accretion build up. However, due to the nonlinear nature of the sponge iron production process, there are some short-falls in the performance of these conventional controllers. Processes that are characterized by nonlinear dynamic behaviour call for different approach to the use of modern automatic control techniques so as to achieve consistent operation, accuracy, speed, better product quality, reduced operating costs and increased safety. Fuzzy logic (FL) has become one of the most successful techniques for developing sophisticated control systems. The motivation of using such control techniques is that FL addresses complex applications perfectly as it resembles human decision making with an ability to generate precise solutions from certain or approximate information [Nwodoh and Ejimofor (2010)]. Though fuzzy logic controllers have the capability of mimicking the human expert reasoning through measuring and processing inexact and imprecise data [Nwodoh and Ejimofor (2010), Karray and De Silva, (2004)], there are still some challenges encountered in using these controllers alone due to limitations in adaptation capabilities to random changes in both known and unknown process parameters. The essence of fuzzy control is to build a model of human expert capable of controlling the plant without thinking in terms of the mathematical models [Ross *et al,* (2002)]. While conventional approaches require accurate equations to model real-world behaviors, fuzzy design can accommodate the ambiguities of real-world human language and logic [Nwodoh and Ejimofor (2010]. The fuzzy sets and fuzzy rules can be formulated in terms of linguistic variables, which help the operator to understand the functioning of the controller in terms of *IF, THEN* control

rules [Karray and De Silva, (2004), Bryan and Bryan, (1997)]. The main objective of this study is to develop an accretion control system by using Fuzzy Logic control and maintain the kiln parameters at recommended working ranges.

2   KILN BASED SPONGE IRON PRODUCTION PROCESS

Rotary kilns are found in many processes that involve processing of solids. This study focuses on sponge iron kiln based process. The chemical process involved in making sponge iron removes oxygen from iron ore by using a reducing agent in the form of non-coking coal [Patra *et al,* (2005)]. The reduction process is carried out in an inclined horizontal rotary kiln, which rotates at a programmed speed. A temperature profile ranging from 700^0C-1050^0C should be maintained along the length of the kiln at different zones. As the material flows down due to rotary action and gravity, the ore is reduced. The kiln is divided into two zones; the pre-heating zone and the reduction zone. For direct reduction in the inclined rotary kiln, iron ore and coal pass through the inclined kiln in a counter current direction to the oxidizing flue gases in the freeboard. The volatile particles of the coal from the bed material are burnt, over the entire length of the kiln with a controlled amount of air from kiln shell air fans and center burner fan, thereby providing the necessary heat required for the metallization process. The overall process requires retention time of approximately 8 to 9 hours inside the kiln depending on the capacity of the kiln, during which iron ore under goes reduction process and discharges to a rotary cooler for indirect cooling to a temperature below 100°C before coming out into the finished product circuit, [Patra *et al,* (2005), Prasad *et al*, (2006)].

2.1 RELATED WORK ON CONTROL STRATEGIES IN KILN BASED PROCESSES

Some of the sponge iron rotary kilns are still under manual and open loop control with human operator observing the burning status of the different zones of the kiln. As a result, it is difficult to maintain consistent product quality and energy consumption is high. In addition, the kiln liner wears out rapidly and the kiln production rate is low. PID controllers have been used as control technique in sponge iron plants, however the random changes of the process variables has posed some limitations to this control strategy. Due to complicated working conditions including heat transfer, fuel consumption, material aggregation which makes a rotary kiln a nonlinear system, many researches have been done so as to get the maximum output of rotary kiln process. Garikayi *et al,* (2013), applied FL strategy in trying to minimize accretion in sponge iron kilns. Also a neuro-fuzzy techniques have been implemented by [Fallahpour *et al,* (2008)] in parameter control in a Cement manufacturing kiln. Other advanced control strategies including fuzzy control [Holmblad and Østergaard (1995)], intelligent control [Jarvensivu *et al,* (2001)] and predictive control have been introduced into process control and monitoring of rotary kilns. An advanced Reinforcement Learning-Based Supervisory Control Strategy for Alumina Rotary Kiln Process is highlighted in [Zhou *et al,* (2008)]. All the researches that were done basing on kiln control aim at improving the kiln performance by process parameter control. Thus this study's main goal is to design a FL control strategy for kiln accretion control through process parameter control thereby improving kiln performance. In developing optimization systems based on intelligent systems, Ross *et al,* (2002)], suggests that one should first understand the process and know what to achieve then characterize the various forms of uncertainty and finally develop mathematical models to quantify them.

2.2 ACCRETION IN ROTARY KILNS

It has been observed that some material adhere to the refractory coating inside the kiln after continual operation of the kiln for several days. Accretion build up or ring formation in the kiln is normally caused by the deposition of low melting complex compounds on the refractory wall of the rotary kiln which gradually increases in thickness and takes shape of a circular ring. This narrows the kiln diameter which ends up hindering material flow in the kiln and hence low rate of production and a short campaign period are experienced [Garikayi *et al,* (2013), Boeteng, (2008), Dash *et al,* (2007), Sarangi and Sarangi, (2011)]. Some accretion can also form because of the agglomeration of fines nearer to the charge end or because of sintering of sponge iron due to extreme temperatures and low carbon/iron ratio at the charge end of the kiln [Sarangi and Sarangi, (2011)]. It is therefore necessary to minimize the causes attributed to the formation of semi-molten masses in the rotary kiln during production that leads to accretion. Figure 1 shows cross-section of kiln showing accretion build up.
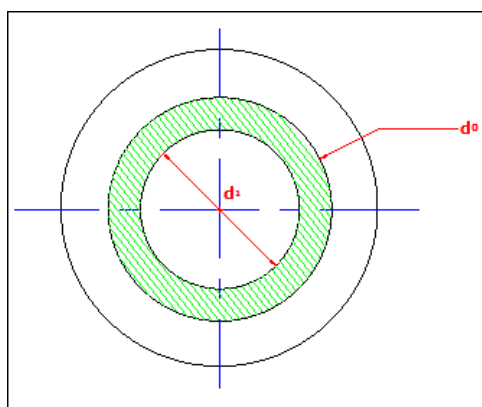
Figure 1 Kiln cross-section showing accretion

$$a_b = \frac{d_0 - d_1}{d_0} \times 100 \qquad [1]$$

Where d_0 is the initial kiln diameter, and d_1 is the kiln diameter after the accretion has built up.

Once accretion has been formed in the kiln, it acts as a secondary dam which interferes with the charge movement resulting in poor material flow, increased back spillage at the inlet, decrease in effective diameter thereby, reducing the working volume resulting in decrease discharge rate and finally stoppage of the kiln operation if 30% of kiln internal diameter is surpassed [Sarangi and Sarangi, (2011), Srivastava *et al,* (1988)]. It also adversely effects on the kiln availability and economy of the process; thermocouple temperature measurement becomes difficult thereby, making the control of the kiln temperature and consequently air profile virtually impossible.

2.3 SPONGE IRON PRODUCTION PROCESS PARAMETERS

Kiln performance is influenced by many parameters which include temperature, kiln pressure, kiln inclination and speed, raw material characteristics, feed rate and burden composition, coal slinging and heat transfer, kiln gas atmosphere, quantity of char in the kiln discharge.

This paper focuses on the control of kiln temperature profile in reduction zone and the kiln pressure so as to regulate rate of accretion build up in the kiln. Although other parameters have a direct effect on accretion formation and product quality, their effects were considered to be negligible for the formulation of this design.

3 PROPOSED FUZZY LOGIC CONTROL STRATEGY

The basic structure of the proposed design of kiln accretion control consists of kiln Shell Air Fan damper valve, a hydraulic actuated cylinder stack cape and fuzzy logic control system. The Shell Air Fans are mounted along the length of the kiln of which they are seven for a 42m long 100TPD kiln. The Shell Air fans provide air for combustion inside the kiln thus a closed loop control strategy was proposed in this design. The damper acts as an actuator to control the amount of air entry in to the kiln, thus regulating both temperatures and pressure inside the kiln. The Stack cap is connected to the pressure loop, in such a way that when kiln pressure is very high it opens and releases pressure to the outside environment. K-type thermocouple temperature sensors were used to measure temperature where Honeywell-ST 3000 pressure transmitters were used in observing kiln pressure. The sensors with amplification transmitter unit are connected with the fuzzifier of the fuzzy logic control system. There are three outputs of defuzzifiers: displacement angle of damper opening (degrees), displacement of stack cap cylinder and Accretion (%). Figure 2 shows the block diagram of the proposed structure.
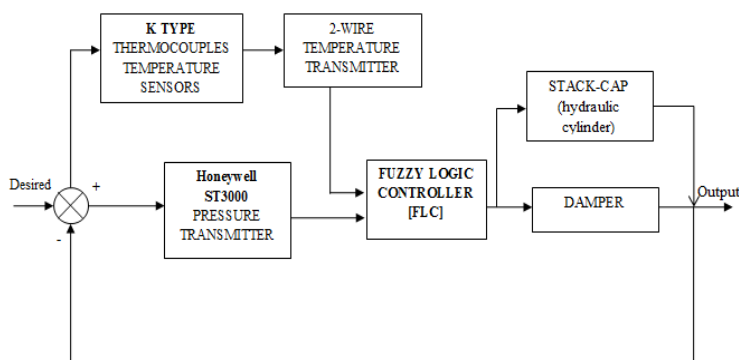
Figure 2 Block diagram of designed structure

3.1 FUZZY LOGIC ALGORITHM

In this study, the fuzzy control linguistic rule base has been used to program the fuzzy control application. The input information consists of real process variables measured from the plant. The output variable which is a result of transformation being performed by the rule base of the fuzzy is in the form of correcting variables. The main components of fuzzy control comprise of the fuzzifier, linguistic rules base, the inference and the defuzzifier. This algorithm is used to design the fuzzifier, inference engine, rule base and defuzzifier for the accretion control system according to the control strategy of the processing plant to achieve the quantity and quality of the desired needs to maintain the kiln performance high.

3.1.1 FUZZIFICATION

Temperature and pressure were considered the two input variables in to the fuzzy input block function. Within these inputs block functions, two trapezoidal and three triangular membership functions were used covering a scale range of 900 ℃ to 1100 ℃ for the temperature input and 0.2 to 0.7mBar pressure input. **Temperature input variable:** Using the fuzzy sets, the operation of fuzzy controller is to determine the angle of displacement (degrees) of damper valve for each pressure level to control the rate of accretion build up in the kiln. The membership function of temperature comprise of five fuzzy labels that was defined by linguistic terms: Low (LO), Medium Low (MLO), Medium (M), High (H) and Very High (VH) as shown in Figure 3.
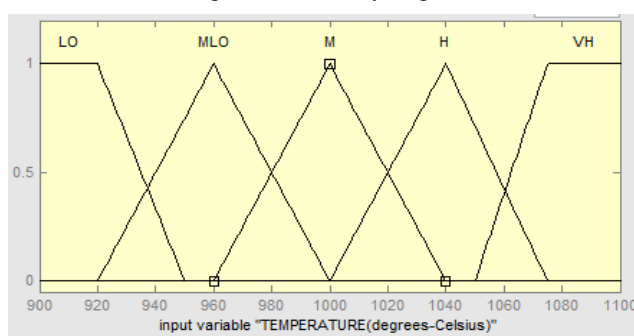

Figure 3 Membership Functions for Temperature

Pressure input variable: Also for the level of pressure the operation of fuzzy controller is to determine the angle of displacement of damper valve opening and closing for each temperature value to control the rate of accretion build up in the kiln. The membership function was divided into five levels, Very Low (VLO), Low (LO), Medium (M), High (H) and Very High (VH). The input membership functions for pressure are represented in Figure 4.
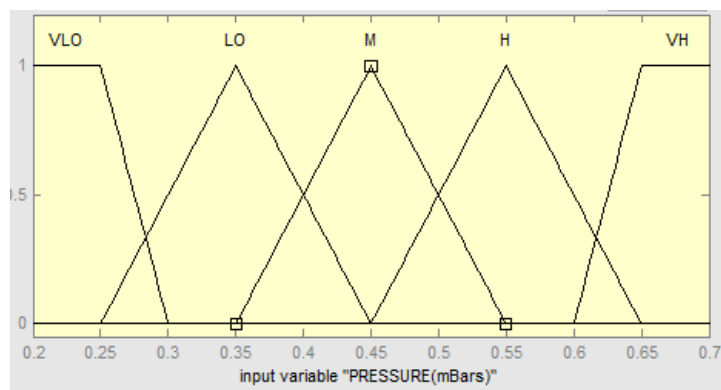
Figure 4 Membership Functions for Pressure

3.1.2 FORMULATION OF RULE BASE

Lists of intuitive rules that govern the accretion control system were made. Contrasting to the conventional control method which uses a mathematical model, the rules are developed in linguistic form of IF –THEN statements. Table 1 shows the 25 rules that were formulated. The rules can be read as shown by few examples here:

IF (TEMPERATURE is LO) and (PRESSURE is VLO) THEN (Damper-opening is Closed) (Stack Cape-opening is Open) (Accretion is Low

TABLE 1 Fuzzy Rule Base

INPUT VARIABLES		OUTPUT VARIABLES		
TEMPERATURE (degrees Celsius)	PRESSURE (mBar)	DAMPER-OPENING(degrees)	STACK-CAP OPENING(m)	ACCRETION %
LO	VLO	Closed	Open	Low
LO	LO	Closed	Open	Low
LO	M	M-Close	Medium	Low
LO	H	Medium	Medium	Low
LO	VH	Medium	Closed	Moderate
MLO	VLO	Closed	Open	Low
MLO	LO	M-Close	Open	Low
MLO	M	Medium	Medium	Moderate
MLO	H	Medium	Closed	Moderate
MLO	VH	Medium	Closed	Moderate
M	VLO	Closed	Open	Low
M	LO	M-Close	Open	Moderate
M	M	Medium	Medium	Moderate
M	H	Open	Closed	Moderate
M	VH	Open	Closed	High
H	VLO	M-Close	Open	Moderate
H	LO	Medium	Open	Moderate
H	M	Open	Medium	Moderate
H	H	W-Open	Closed	High
H	VH	W-Open	Closed	High
VH	VLO	M-Close	Open	Moderate
VH	LO	Medium	Open	Moderate
VH	M	Open	Medium	High
VH	H	W-Open	Closed	Very High
VH	VH	W-Open	Closed	Very High

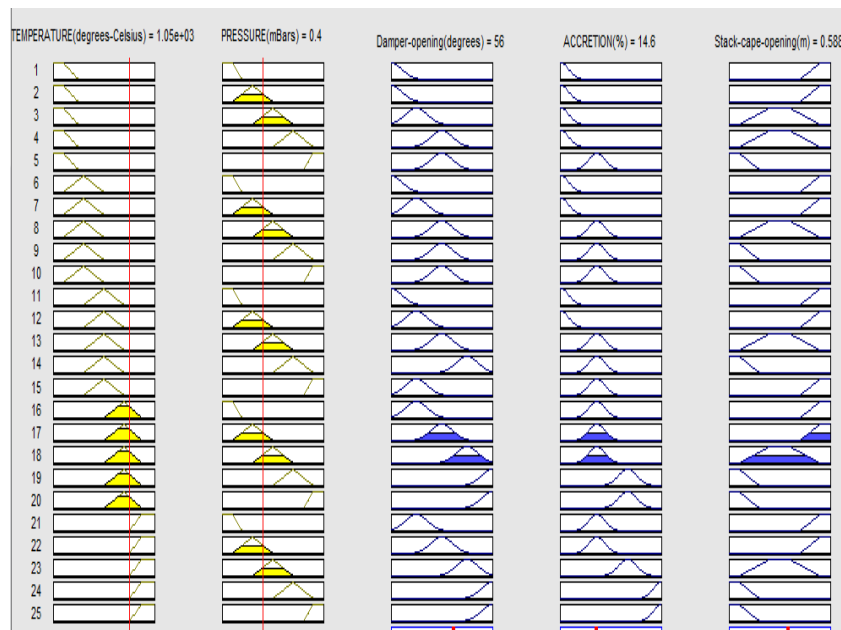Figure 5 represents the Rule Viewer of the formulated control rules modelled with MATLAB.

Figure 5 Fuzzy Model Rules

3.1.3 DEFUZIFICATION

A Mamdani-type fuzzy inference system (FIS) was considered in this study. The "center of gravity" or the "centroid" method of defuzzification was chosen, since it weighs the effect of each input variable towards the calculation of the output [Nwodoh and Ejimofor (2010), Karray and De Silva, (2004)]. Input fuzzy sets and rules are converted into an output fuzzy set, and then into a crisp output for controlling the damper, stack cape and accretion percentage. Through the firing of control rules, an output value is decoded by the deffuzifier component to give a crisp value.

Damper-opening output variable: the fuzzy output Gaussian membership function was defined into linguistic variable representing the required degree of damper valve opening: Closed, Medium-Close (M-Close), Medium (M), Open, and Wide-Open (W-Open).
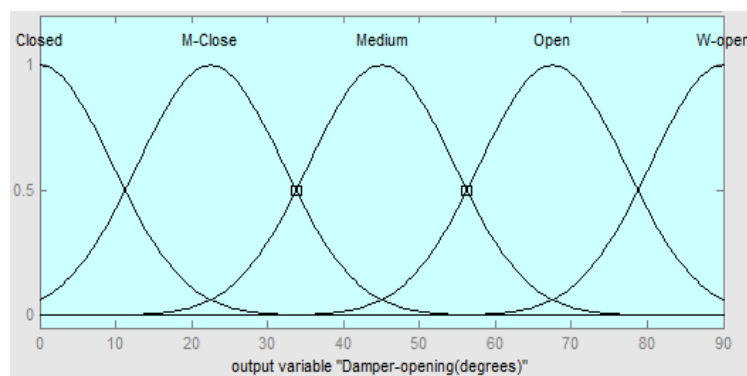

Figure 6 Membership Functions for Damper-opening

Stack Cap-opening output variable: the Stack cap opening was determined by pressure values inside the kiln, thus the opening was actuated by a hydraulic cylinder displacement. Linguistic labels used for the membership function are Closed, Medium and Open
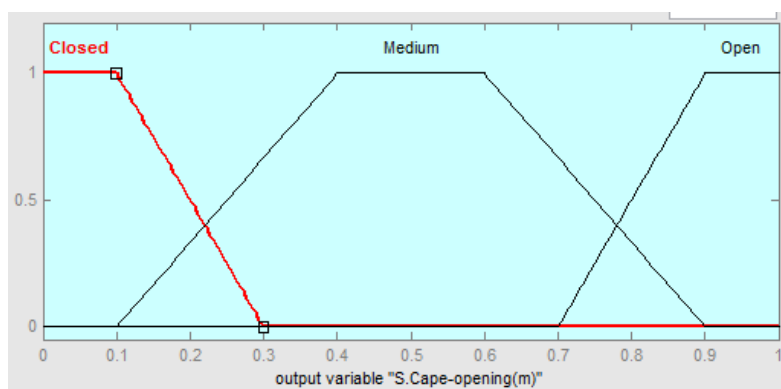
Figure 7 Membership Function for Stack Cap-opening

Accretion output variable: accretion build up is determined by the temperature and pressure values which are being controlled by the opening of the Shell Air fan damper valve and the Stack cap. The membership functions of Accretion consist of four fuzzy logic ranges that were defined using the linguistic terms: Low, Moderate, High and Very High.
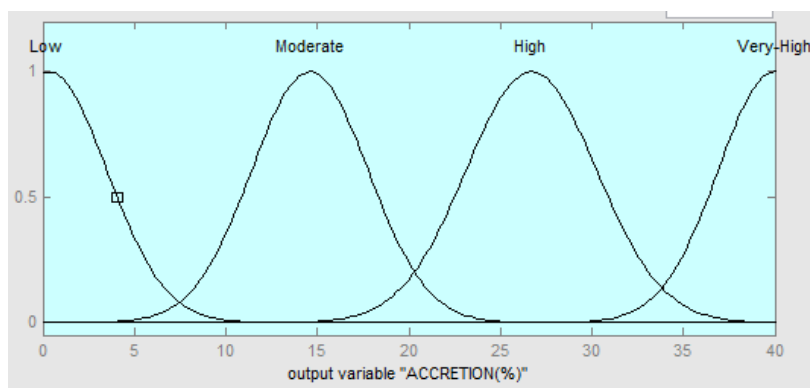

Figure 8 Membership Functions for Accretion

4 RESULTS AND DISCUSSIONS

This system was simulated for the given range of input variables. Simulation results are presented in MATLAB graphic viewer. The study showed that the possible rate of ring formation is 14.6% using the desired process parameters at the reduction zone of temperature 1050^0C and kiln outlet pressure of 0.4mBars. The study also revealed that reduction temperatures can be increased to 1100^0C and kiln outlet pressure of 0.35mBar, accretion percentage of 14.6% can be maintained. Although accretion can be reduced below 14.6%, the study suggests that temperature values of 950^0C to 1050^0C must be maintained in the reduction zone so as to maintain high product quality.
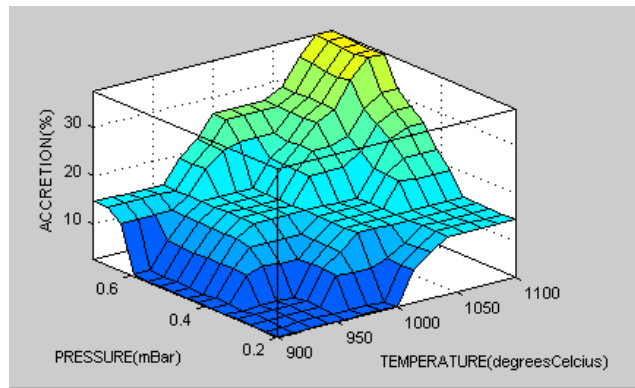
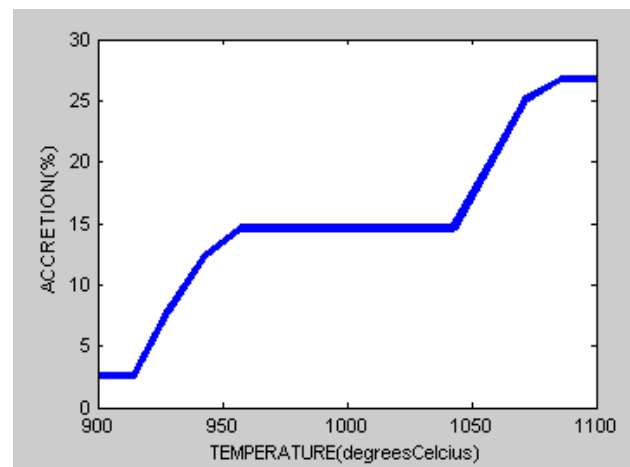Figure 9 Plots between Pressure-Temperature & Accretion

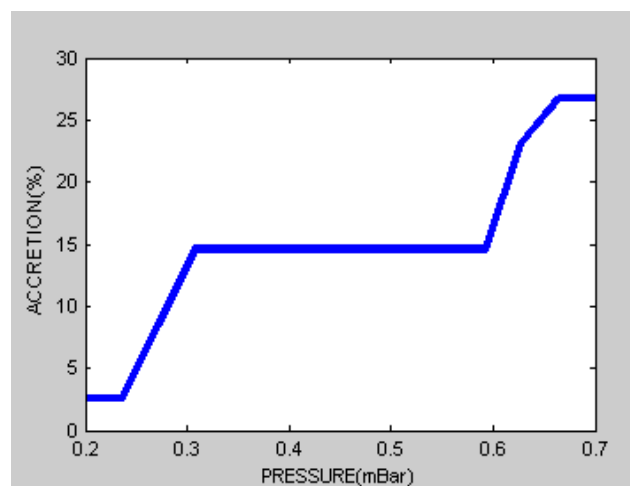Figure 10 Effect of temperature on Accretion formation

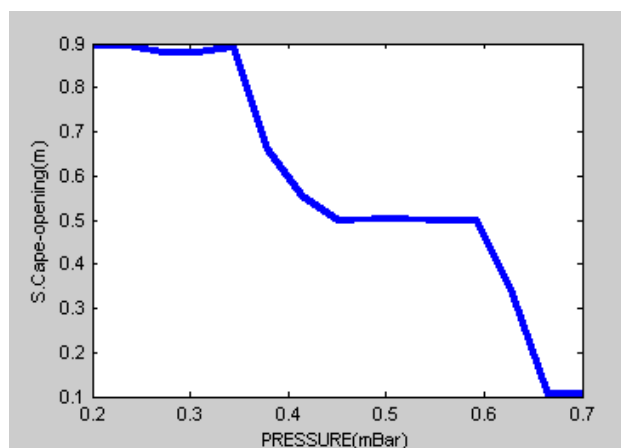Figure 11 Pressure effect on Accretion formation

Figure 12 Pressure effect on Stack Cap-opening

If kiln temperature is to be raised to 1100^0C, it results in high pressure build up inside the kiln as the damper opening will be very high, thus increases in accretion build up. To moderate high pressure build up in the kiln, the Stack Cap opening and closing loop was linked to the pressure control loop. The study has revealed that temperatures above the recommended 1050^0C cause a sudden increase in ring formation inside the kiln thus there is need to maintain the reduction zone temperatures within the recommended temperatures. Also temperatures above 1100^0C will result in sudden increase in accretion build up as sponge iron approaches its melting point and the coal fines and other minerals will be melting. The results also showed that pressure range of 0.3mBars-0.6mBars managed to maintain accretion rate of 14.6% as highlighted by Figure 11. The recommended kiln operating pressure range from the Sponge iron plant is 0.29mBars-0.58mBars, thus the designed system falls within the recommended values.

5 CONCLUSIONS

The simulation results of the design were compared to the experimental results done using PID control. The Fuzzy logic control results showed that it is possible to reduce accretion build up rate from 27 % to 14.6 % for a 100TPD capacity kiln. This shows that Fuzzy Logic controller performs better than a PID controller. These results can improve plant availability. However to validate these simulation results, these need to implement the Fuzzy logic control in the actual operation of the Sponge iron kiln. This study revealed results which are based upon temperature and pressure as the main causes of accretion build up inside a Sponge Iron kiln since other parameters effect on accretion build up were assumed negligible. Though the fuzzy controller proved to work well, there is need to implement closed loop control on the control system of temperature and pressures since the current conventional control loops at the plant are open control loops. The design managed also to introduce a control damper valve replacing the manually driven dampers. The benefit of the fuzzy controller is that it managed to implement the reasoning and the experience of the process engineer thus able to handle the tasks which were normally implemented by the engineer.

REFERENCES

Nwodoh T. A and Ejimofor, I.A, (2010), 'Implementation of Fuzzy Logic based Temperature-Controlled Heat Exchanger", *NIGERIAN Journal of Technology*, Vol. 29 No.1, pp. 94-109

Karray, F.O. and De Silva, C. (2004), "Soft Computing and Intelligent Systems Design, Theory, Tools and Applications", © *Pearson Education Limited*, ISBN 0 321 11617 8

Ross, T.J, Booker, J.M. and Parkinson, W.J, (2002), "Fundamentals in Fuzzy Logic and Probability Applications: Bridging the Gap", *ASA-SIAM Series on Statistics and Applied Probability 11*

1. Bryan, L.A. and Bryan, E.A. (1997), "Programmable Controllers Theory and Implementation, Second Edition", *Industrial Text Company Publication*
2. Patra, H.S, Sahoo, B. and Mishra, B.K, (2005). "State of sponge iron units in Orisa Vasundhara", Available:http://vasundharaodisha.org/Research%20Reports/Status%20of%20sponge%20iron%20plant%20 in%20Orissa.
3. Prasad, S.S, Rao, B.K, Kumar, K.R, Sapare, S.G, (2006), "Cleaner Production and Code of Practice in

Sponge Iron Sector", *Information Bulletin, Andhra Pradesh Pollution Control Board, Cleaner Production Cell*, No.129

4. Garikayi, T, Nyanga, L, Mushiri, T, Mhlanga, S, Kuipa, P.K, (2013), "Designing of an Intelligent Fuzzy Logic System for Accretion prevention in sponge iron SL/RN rotary kiln based 100TPD DRI process", *SAIIE25 Proceedings, 9th– 11th of July 2013, Stellenbosch, South Africa* © 2013SAIIE pp. 523_1-523_14

5. Fallahpour, M. A, Fatehi, B, Araabi, N. and Azizi, M, (2008), "A Neuro-Fuzzy Controller for Rotary Cement Kilns", *Proceedings of the 17th World Congress. The International Federation of Automatic Control Seoul*, Korea, pp.13259-13264.

6. Holmblad, L. and Østergaard J, (1995), "The FLS application of Fuzzy logic", *Fuzzy Sets and Systems*, Vol. 70, No. 2-3, pp.135-146, ISSN: 0165-0114

7. Jarvensivu, M, Saari, K. and Jamsa-Jounela, S, (2001), "Intelligent control system of an Industrial lime kiln process", *Control Engineering Practice*, Vol. 9, No. 6, pp. 589-606, ISSN: 0967-0661.

8. Zhou, X, Yue, H and Chai, T, (2008), "Reinforcement Learning-Based Supervisory Control Strategy for a Rotary Kiln Process", *Reinforcement Learning, Cornelius Weber*, InTech, Mark Elshaw and Norbert Michael Mayer (Ed.), pp,312-324, ISBN: 978-3-902613-14-1

9. Boeteng, A.A, (2008), "Rotary Kilns Transport Phenomena and Transport Processes", *Butterworth-Heinemann*, ISBN: 978-0-7506-7877-3

10. K.K Dash, V.K Tiwary and I.N Chakeaborty, (2007), "Refractories Solution to Accretion problem in sponge iron kilns",Technical paper

11. Sarangi, A. and Sarangi, B, (2011), "Sponge Iron Production in rotary kiln", *PHI Learning Private Ltd*, New Delhi, ISBN-978-81-203-4099-2

12. Srivastava, M.P, Bandopadhyay, A, Prasda, K.K, and Chavdhury, B.R, (1988), "Operating Experience of Sponge Pilot-Some aspects", *Trans.IIM*, Vol. 41, No 2, pp. 177-186

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