Simulation of Rotary Kiln Used in Sponge Iron Process Using ANN

Anil K. Poonia and Shabina Khanam, *Member, IACSIT*

***Abstract*—In the present study, estimation of actual output parameters is carried out for a sponge iron production process by designing a Multilayer Perceptron model that uses a momentum learning algorithm. For this purpose data of temperature profile of rotary kiln are collected from typical sponge iron plant, which correlate four air inlets and twelve temperatures measured at different lengths of the kiln. Four different topologies are proposed for this data set to optimize the regression coefficients (R2). Firstly, these topologies are used to identify optimum value of output parameters based on value of R2. These values of output parameters meet the process requirements. Further, a better option is found to compute actual input parameters correspond to desired output. The analysis shows that to get desired output the input parameters are varied maximum by 38.9% in comparison to input parameters used in the industry.**

***Index Terms*—Sponge iron process, rotary kiln, temperature profile, artificial neural network.**

I. INTRODUCTION

Sponge iron is the metallic form of iron produced from reduction of iron oxide below the fusion temperature of iron ore (1535°C) by utilizing hydrocarbon gases or carbonaceous fuels as coal. The reduced iron having high degree of metallization exhibits a 'honeycomb structure', due to which it is named as sponge iron.

It is seen that the growth of sponge iron industry in last few years is unremarkable and today India is the largest producer of sponge iron as it covers 16% of global output. Sponge iron is used as feedstock and a recognized alternative to steel scraps in iron and steel making processes.

With the availability of raw materials, high demand of sponge iron and less payback period, sponge iron industry has emerged as a profitable venture. However, due to lack of proper integration techniques, non-optimal process parameters, high energy consumption and old running process technology, the industries are facing a setback in market. Amongst these draw backs the problem of proper integration technique and high energy consumption are addressed by many investigators [1]-[7].

However, the optimization of process parameters based on the desired output of the industry remains untouched. These parameters include temperature profile inside the main units of the process which is kiln and production rate as well as % metallization of iron ore. These parameters depend on air, iron ore and coal flow rate which may be regulated to suit the desired output of the process. For this purpose one may use manual practice to see the outcome when one input parameter is varied. It is clumsy and cumbersome approach which requires considerable experimentation to set the optimum parameters. Thus, an easy methodology to optimize the process parameters is considered in the present work with artificial neural network (ANN). In this work, ANN based topologies are developed and discussed to know actual temperature profile in rotary kiln. It appears that no such study is available in the literature.

II. ROTARY KILN

Rotary kiln is cylindrical in shape and is 80m long having 4.2m internal diameter. This is the reactor of the process where reduction as well as combustion reactions are carried out. The role of kiln is to convert the raw material (iron ore, coal and dolomite) into the sponge iron [8]. Detail reaction mechanism of the process is discussed below:

There are two reduction reactions. First reaction converts iron ore to iron oxide which further reacts with CO to produce metallic iron (Fe) which is called sponge iron. These two reactions are exothermic in nature. Thus, overall process is exothermic.

$$Fe_2O_3+CO = 2FeO+CO_2 \quad (1)$$

$$FeO+CO = Fe+CO_2 \quad (2)$$

In the process four combustion reactions are involved amongst which first reaction (Eq.3) is endothermic and others (Eqs. 4 to 7) are exothermic in nature.

$$C+CO_2 = 2CO \quad (3)$$

$$2CO+O_2 = 2CO_2 \quad (4)$$

$$C+O_2 = CO_2 \quad (5)$$

$$2C+O_2 = 2CO \quad (6)$$

$$2H_2+O2 = 2H_2O \quad (7)$$

Kiln is made up of special alloy of boiler plate and is of 25mm thick. It is supported by three rollers which are placed along the length of the kiln. It is rotated by girth gear with 4.3 rpm. It is connected with the transfer chute, which is a closed rectangular duct. Inside layer of it is covered

Manuscript received February 24, 2013; revised May 15, 2013.

A. K. Poonia is with Dept. of Chemical Mechanical Engineering, National Institute of Technology, Raipur-492010, Chhattisgarh, India (e-mail: ak_poonia@rediffmail.com)

S. Khanam is with Dept. of Chemical Engineering, Indian Institute of Technology, Roorkee-247667, Uttarakhand, India (e-mail: shabinahai@gmail.com)

DOI: 10.7763/IJET.2014.V6.673

is a closed rectangular duct. Inside layer of it is covered with the refractory brick to control the heat transfer of the kiln discharge material at this junction. Its primary function is to transfer the material coming out from the discharge end of the kiln to rotary cooler. It is sealed in such a manner that puffs cannot come out and air cannot be sucked inside even if the system is working at the discharge mode.

The accessories of rotary kiln are followings: Girth Gear is spur type big gear whose width is about 400 mm. Gear is meshed with two numbers of pinion placed both sides of gear. Three numbers of rollers, made up of high wear resistance Stainless Steel, supports the kiln. Alignment of the kiln is checked by pushing or pulling the support roller. One thruster slides along the length of the kiln up and down and the sliding is controlled by hydraulic cylinder.

The schematic of rotary kiln is shown in Fig. 1 where temperatures T-1 to T-12 are noted through 12 thermocouples which are placed along the length. The values measured through thermocouples give temperature profile in the rotary kiln. Around the periphery of the kiln air is injected through positions AT-1, AT-2, AT-3, MF-1 and MF-2. At AT-1 to AT-3 positions three blowers are attached. At MF-1 and MF-2 two blowers are placed to each inlet. Thus, total seven blowers are placed which provide air along the length of the kiln. To produce sponge iron, iron ore and coal are used as raw material. In the kiln coal is injected from feed side, which is called feed coal as well as discharge side, which is called injected coal. Injected coal is fed as fines, medium and coarse coal pneumatically however, feed coal is fed as coarse coal. This is due to process requirement as discussed in the work of Prasad [8]. The sponge iron is produced in the form of lumps as well as fines. The production of sponge iron depends on metallization of iron ore.

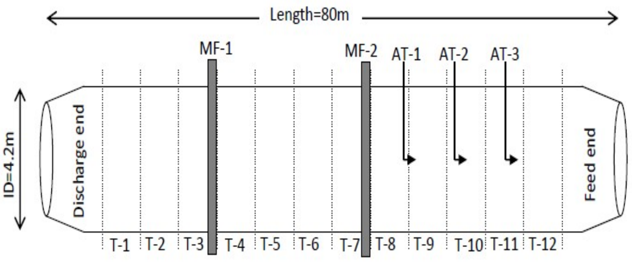

Fig. 1. Schematic of rotary kiln

For the present work data of a typical industry of 527 T/day production capacity is collected for 25 days. The data of temperature T-1 to T-12, AT-1 to AT-3 and MF-1 and MF-2 are referred as Data-1. Due to limitation of pages of the paper data of 10 hours of day one is shown in Table I. It should be noted from Table I that air flow rate is shown through different numbers such as 20, 19, 43, etc. These numbers are % of damper opening. Damper opening of 1% gives air flow rate around 600 m^3/h.

TABLE I: TEMPERATURE PROFILE IN ROTARY KILN (DATA-1)

Temperature profile (°C)												Air inlet (%of damper opening)				
T-1	T-2	T-3	T-4	T-5	T-6	T-7	T-8	T-9	T-10	T-11	T-12	AT-1	AT-2	AT-3	MF-1	MF-2
1098	1090	1085	1076	1075	1057	1061	1007	935	898	811	773	16	20	13	43	20
1100	1092	1087	1078	1061	1047	1044	1000	931	896	813	770	17	20	13	43	20
1076	1068	1063	1060	1061	1045	1051	1011	923	915	816	766	17	20	13	43	20
1076	1068	1063	1053	1060	1056	1075	1011	938	923	816	784	18	20	14	43	20
1050	1042	1037	1034	1056	1061	1062	1029	943	927	831	770	18	20	14	44	20
1040	1032	1027	1035	1055	1062	1070	1030	940	934	844	775	18	20	14	45	20
1059	1051	1046	1026	1060	1066	1065	1039	965	934	867	793	18	20	14	46	21
1054	1046	1041	1029	1059	1060	1074	1041	967	963	869	795	18	20	14	47	21
1075	1067	1062	1048	1073	1073	1076	1048	978	965	876	796	18	20	14	48	21
1086	1078	1073	1055	1083	1089	1082	1070	986	960	865	791	18	20	13	48	21

III. ANN TOPOLOGY

In the design of ANN structures, it is important to find a right structural organization of the network that will predict the industrial data in the best possible manner. The modification in a structure is basically done by varying randomization, number of hidden layer as well as number of epochs. However, the number of neurons in the input and output layers are already fixed as per the number of inputs and outputs parameters the ANN addresses. Generally, number of hidden layers of the network is chosen by trial and error as no accurate method has been developed so far to predict it for a given problem. In the present work different topologies of ANN structures are identified and reported in Table II. The topologies shown in Table II are trained using Multilayer Perceptron (MLP) method and Tanh as activation function. For this purpose a part of data (usually two third) is used for training and the remaining is used for testing. These topologies are solved with 1000 epochs. The topology with best value of R^2 is further refined to train and test with increased epochs such as 2000, 3000 and 5000.

TABLE II: THE TOPOLOGY FOR DIFFERENT ANN STRUCTURE

Networks Tested for present work	Randomization	No. of Hidden Layers
TOP-1	1	1
TOP-2	2	1
TOP-3	2	2
TOP-4	2	3

IV. Results and Discussion

The data of temperature profile of rotary kiln with variation in air inlet to it (Data-1) are analyzed using topologies, TOP-1 to TOP-4. For these networks the average values of regression coefficient, R^2, are shown in Table III. The average value of R^2 is computed using R^2 values of individual temperatures, T-1 to T-12. Table III shows that R^2 is maximum for topology, TOP-2, which is predicted with 1000 epochs.

TABLE III: Values of Average R^2 for Data-1

Topology	R^2 values
TOP-1	0.09
TOP-2	0.289
TOP-3	0.256
TOP-4	0.28

When topology, TOP-2, is trained with 2000, 3000 and 5000 epochs the value of R^2 is increased to 0.299 for 2000 epochs. In fact, for Data-1 R^2 value is also not significant which may be due to large variation in input data. For example temperature T-1 varies from 1100 to 925◦C which is 18.9%. Similarly, air inlet at position AT-1 varies by 25%. Such large variation in data may be due to variation in quality of iron ore and coal, accretion formation in kiln, etc.

The sensitivity analysis of topology, TOP-2 with 2000 epochs, is shown in Fig. 2, which indicates that parameter T-9 and T-10 are least sensitive to the input parameters of the system. Fig. 2 also shows that the values of T-1 to T-12 are not affected by AT-2 as value of AT-2 is not varying in the data set as shown in Table I. Thus, for further analysis parameters, T-9, T-10 and AT-2 are dropped. The revised data is used to analyze topology, TOP-2 with 2000 epochs, where average value of R^2 is improved to 0.3475. The actual network outputs of T-1 to T-12 for 10 hours of one day are shown in Table IV. Thus, thermocouples around the kiln may be regulated for these values. In fact, the value of maximum temperature in actual network output is 1092°; however, it was 1100° in the Data-1. This meets the process requirement as accretion formation inside the kiln starts at 1100°C. It is caused by low melting eutectic compounds of the FeO, SiO_2, and Al_2O_3 in combination with CaO or MgO from desulphurising agent used in the process. The study of accretions showed that these compounds could form even at temperatures around 1080^0C. Further, softening temperature of coal ash drops by 40-80^0C in the presence of FeO from the ore feed. It is, therefore necessary to ensure that the gas temperatures inside the kiln are kept within 1100-1120^0C. The temperatures in actual network output data is 1092^0C which is less that 1100^0C.

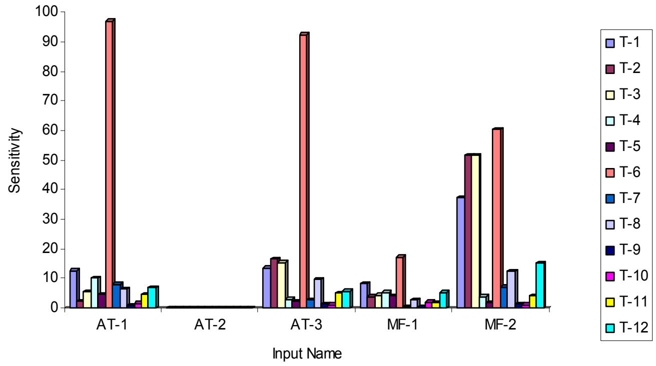

Fig. 2. Plot of sensitivity analysis of Data-1

TABLE IV: The Actual Network Output Values of Temperatures in Rotary Kiln

T-1	T-2	T-3	T-4	T-5	T-6	T-7	T-8	T-11	T-12
1005	998	992	1037	1075	1113	1067	1043	846	781
1005	998	992	1037	1075	1113	1067	1043	846	781
1066	1062	1057	1067	1075	1072	1078	1040	842	747
1089	1087	1079	1062	1072	1052	1075	1052	852	761
1004	991	990	1040	1072	1120	1073	1038	851	786
1019	1014	1008	1060	1075	1209	1080	1053	852	785
1051	1042	1038	1062	1069	1090	1071	1040	846	744
1077	1072	1059	1066	1070	1001	1071	1059	851	757
1077	1072	1059	1066	1070	1001	1071	1059	851	757
1004	991	990	1040	1072	1120	1073	1038	851	786

The actual network outputs of Data-1 can be achieved in the process by adjusting input parameters. However, it is not known a priory that how each input parameters must be set to get actual output. For this purpose one should observe output parameters with varying values of input parameters. It is a cumbersome approach which requires considerable experimentation to set the optimum input parameters. Thus, a better option is to find out actual input parameters correspond to desired output. For this purpose desired output of Data-1 are considered as input parameters. Consequently, the input parameters of Data-1 are assumed as output parameters. For these cases TOP-1 to TOP-4 are developed. The best values of average R^2 as 0.424 is found for TOP-1 with 1000 epochs. It is found that to get desired output the input parameters are varied maximum by 38.9% in comparison to input parameters used in the industry.

V. Conclusions

The salient features of the study are shown below:

1) The developed MLP neural network capable of estimating important output parameters with average regression coefficient (R^2) ranges from 0.09-0.3475. A methodology has been developed to identify important I/O parameters based on sensitivity analysis.

2) The tested output parameters meet the process requirements.
3) The developed model can be further used to carry out parametric study to find out the optimum value of inputs for a desired output. For this case the average regression coefficient is 0.424.
4) The analysis shows that to get desired output the input parameters are varied maximum by 38.9% in comparison to input parameters used in the industry.

REFERENCES

[1] S. Rani Devi and B. Mazumder, "Recovery of carbon from sponge iron plants - studies on the dust samples," *Environ. Sci. Eng.*, vol. 5, 11-16, 2007.

[2] A. K. Prasad, R. K. Prasad, and S. Khanam, "Development of energy conservations scenarios for sponge iron industry using process integration," *Energy Efficiency*, vol. 4, pp. 321-333, 2011.

[3] B. B. Agrawal, K. K., Prasad, S. B. Sarkar, and H. S. Ray, "Cold bonded ore-coal composite pellets for sponge ironmaking. Part 1 Laboratory scale development," *Ironmak. Steelmak*, vol. 27, 2000.

[4] B. B. Agrawal, K. K., Prasad, S. B. Sarkar, and H.S. Ray, "Cold bonded ore-coal composite pellets for sponge ironmaking. Part 2. Plant trials in rotary kiln," *Ironmak. Steelmak.*, vol. 28, 23-26, 2001.

[5] D. K. Biswas, S. R. Asthana, and V. G. Rau, "Some studies on energy savings in sponge iron plants," *Trans. ASME*, vol. 125, 228-237, 2003.

[6] A. K. Prasad, R. K. Prasad, and S. Khanam, "Design Modifications for Energy Conservation of Sponge Iron Plants," *J. Therm. Sci. Eng. Appl.*, vol. 3, 2011.

[7] V. Kumar and S. Khanam, "Recovery and utilisation of waste heat in a coal based sponge iron process," *Chem. Eng. Process,* vol. 56, pp. 19-28, 2012.

[8] A. K. Prasad, "Application of Pinch Technology for Process Integration in Coal Based Sponge Iron Plant," Ph.D. dissertation, Dept. Mech. Eng., National Institute of Technology Jamshedpur, India, 2011.

Anil K. Poonia is associated with Chemical Engineering Department of NIT Raipur as associate professor. He has completed his Bachelor of Technology and M.Tech of Technology from H.B.T.I. Kanpur, U.P., India. The author is pursuing his Ph.D. from NIT Raipur, Chhattisgarh

He has 13 years of industrial experience at various position in M. P. Oil federation and 10 years teaching experience at U.G. & P.G. level at NIT Raipur.

Shabina Khanam was born in1978 at a town of UP, is working as assistant professor in Chemical Engineering Department of IIT Roorkee. She has completed B.Tech degree from AMU Aligarh, Aligarh, Uttar Pradesh, India in 2000 and M.Tech and Ph.D. degree from IIT Roorkee, Uttarakhand,India in 2002 and 2007. Her major field of study is process integration, energy management and modeling and simulation.

Dr. Khanam is a member of IICHE and IACSIT. She has 5 years' experience in teaching and research. She has published 17 international papers and completed one consultancy project.