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USE OF PROCESS MODELS TO ESTIMATE CO_2 EMISSION REDUCTION FOR TOP GAS RECYCLE FURNACE

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Abstract

The blast furnaces contribute to a major part of the CO_2 emissions in an integrated steel plant. A top gas recycle (TGR) furnace, which is essentially a modified blast furnace system, has been suggested by ULCOS for consideration of reduction of CO_2 emission from a blast furnace type of point source. This furnace is operated with an oxygenated blast and the top gas is passed through vacuum pressure swing adsorption (VPSA) unit to reject the major amount of CO_2 and the CO-rich gas is recycled back either through tuyere or, both tuyere and shaft. The predictions made pertain to assumed burden specifications which have been the subject of a recent publication. These describe how attainable carbon rates and CO_2 emission can be predicted subject to constraints of Raceway Adiabatic Flame temperature and thermal reserve zone temperature. In this paper, an attempt has been made to construct Pareto Fronts for minimizing carbon rate and net CO_2 emissions at given coal rate injection and recycle gas circulation through tuyeres only. The data was categorized by the net downstream energy available. The optimal carbon rates show a variation and need to be governed by choice of input operating conditions of the blast, recycle gas volume and temperature by the plant. It is brought out that when the available downstream energy is to be maximized, it may not be possible to attain the lowest CO_2 emissions. An identical trend in productivity is also observed. For attaining high values of downstream energy, the productivity shows a decreasing trend with higher CO_2 emissions.

Key words: Iron making, top gas recycle furnace (TGR), CO_2 emission, process model

1. INTRODUCTION

Due to the pressure of environmental issues, steel producers are very much conscious about reducing the CO_2 emissions. Many different programmes like ULCOS, COURSE-50 etc. are being run to mitigate such environmental problems of global warming and climate change. For CO_2 reduction, Top Gas Recycle Blast Furnace (TGR-BF) is one such potential solution as suggested by ULCOS (Ultra Low CO_2 Steelmaking) (Danloy et al., 2008; Van der stel et al., 2013). TGR-BF is an oxygenated blast furnace along with recycling of top gas after passing through a CO_2 separation unit like VPSA (Vacuum Pressure Swing Adsorption) to reject the major amount of CO_2 and the CO-rich gas is recycled back either through tuyere or, both tuyere and shaft. TGR-BF has drawn attention of many researchers due to its promising advantages in terms of reduction in CO_2 emission along with reduced carbon rate. However, the consequences of its implementation in the integrated steel plant are not yet reported. In the recent publication, the authors have made predictions to estimate the carbon rate, CO_2 emission and downstream energy available based on the input blast and recycle gas parameters under the constraints of raceway adiabatic flame temperature and thermal reserve zone temperature (Sahu et al., 2014). Randomly selected input process parameters were used for the cases discussed in this publication,

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and different output parameters were estimated as per the developed model. It was not possible to work out a solution space for the various outputs when a chosen output parameter was held constant. It was desirable to examine the solution space under constraint of a given value of downstream energy. For example, a requirement to ensure a given downstream energy which plays an important role in any integrated steel plant needs to be examined vis-a-vis the emissions of CO_2.

During the current rework, a complete set of data (around 135 data points) has been regenerated from the model to consider the whole decision space and to reach at its optimised values under feasible range of blast furnace operating conditions. One new parameter i.e. productivity has also been incorporated in the model, to meet the real world challenges of operation requirements, which is defined on the basis of fixed superficial velocity and calculated bosh gas volume from the model.

2. OPTIMIZATION APPROACH

The approach of generating the data points was solely based on the constant heat loss conditions of blast furnace to predict the coke rate and top gas analysis. The generated data points were used to construct neural networks for predictions of output parameters like carbon rate, CO_2 emission, productivity, RAFT, TRZ and downstream energy, which are shown schematically in figure 1. The details of various ranges of input, output and constant parameters are summarized in table 1 and 2. The generated networks fitted very well except the TRZ network whose slope of fitness line found to be 0.96.

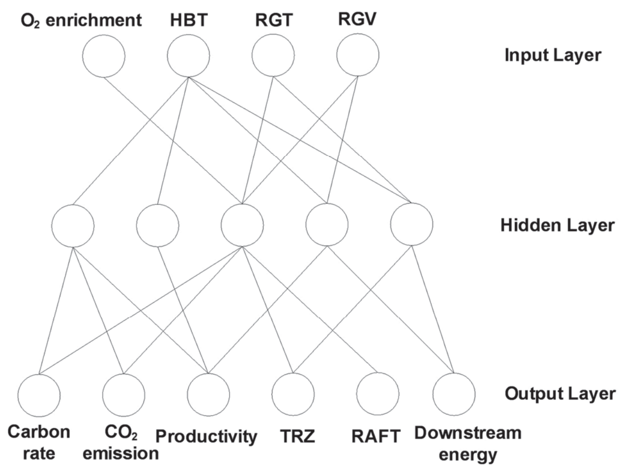


Fig. 1. *Schematic of neural network generated for this study*

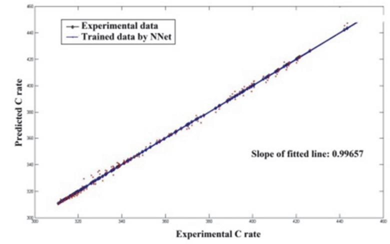
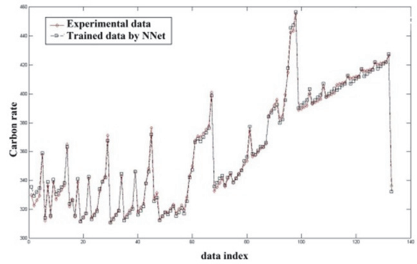
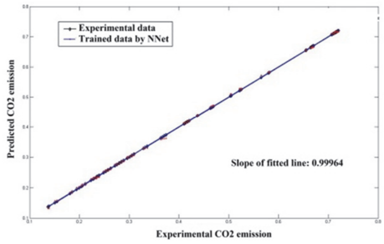
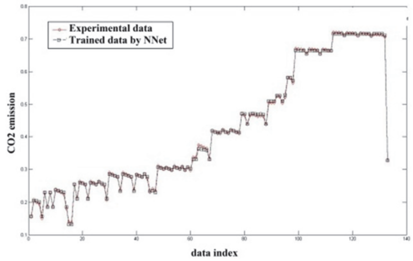
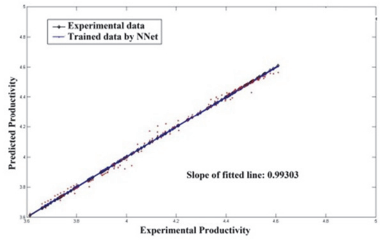
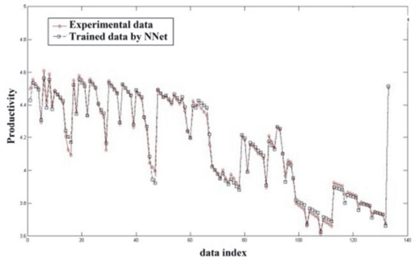
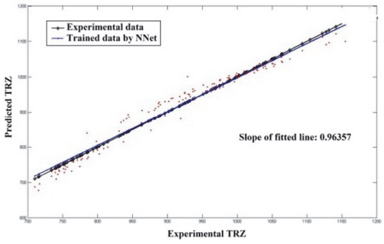
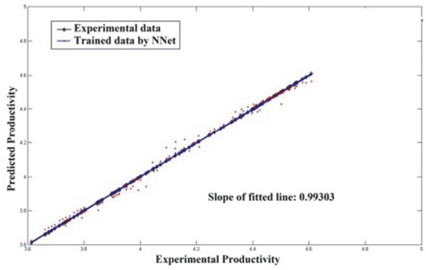
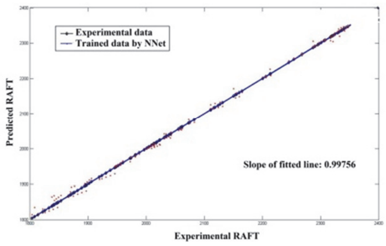
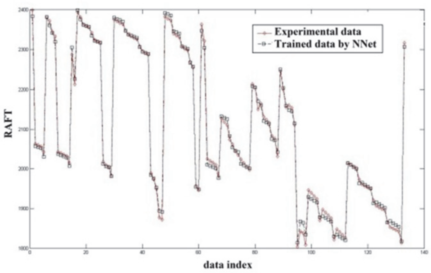
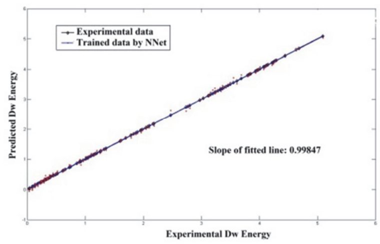
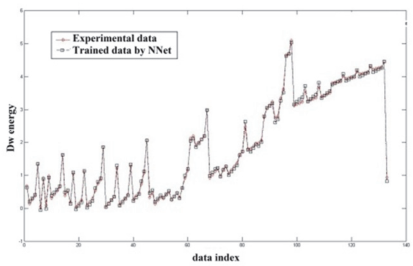
The generated network is used for the present study of optimization. This paper describes about the two multi objective optimization situations of TGR-BF which is described as: 1) *min-min problem of carbon rate and CO_2 emission and,* 2) *max-min problem of productivity and CO_2 emission,* under the constraints of *RAFT, TRZ temperature and downstream energy*. The above objectives are conflicting to each other as they do not lead to any unique optimal solution. Pareto optimal fronts are constructed by joining all the optimal points.

A multi objective genetic algorithm based evolutionary neural network is used here to construct the objective functions. Subsequently, the optimization technique is carried out using a predator-prey algorithm, whose details can be found elsewhere (Agrawal et al., 2010; Mitra et al., 2011).

Table 1. *Various input-output parameters of TGRBF used in the optimization*

Input Parameters	Units	Range	Remarks
O_2 enrichment	%	15-79	
Hot Blast Temperature	^oC	25-1200	
Recycle Gas Temperature	^oC	25-1200	
Recycle Gas Volume	Nm^3/thm	100-600	
Output Parameters			
Carbon rate	kg/thm		Minimize
CO_2 emission	t-CO_2/thm		Minimize
Productivity	thm/day/m^3		Maximize
TRZ	^oC	700-1200	Constraint
RAFT	^oC	1900-2100	Constraint
Downstream energy	GJ/thm		Constraint
Constant Parameters		Values	
PCI	kg/thm	200	
Humidification	gm/Nm^3 blast	60	
Top Gas Temperature	^oC	100	
HM Temperature	^oC	1425	
Slag Temperature	^oC	1500	
Top eta CO	%	44	
Top eta H_2	%	50	
Overall Heat Loss	GJ/thm	0.5	

Table 2. Network fitness of various output parameters

Output Parameters	Fitness	Generated Network
Carbon rate		
CO_2 emission		
Productivity		
TRZ		
RAFT		
Downstream energy		

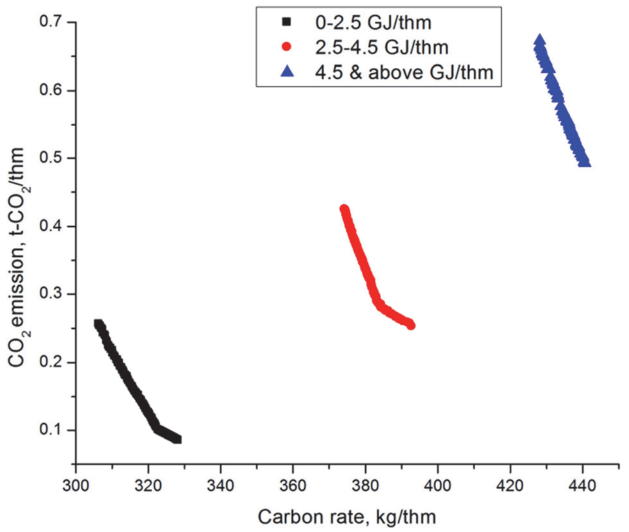


Fig. 2. *Pareto-fronts for minimizing carbon rate and net CO_2 emissions at given PCI rate*

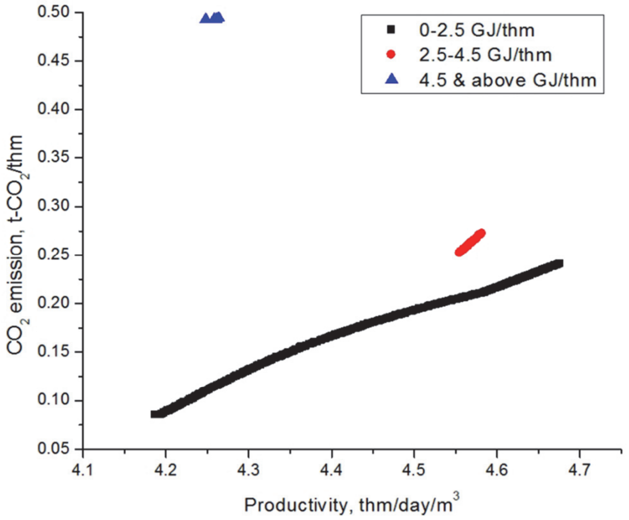


Fig. 3. *Pareto-fronts for maximizing the productivity and minimizing net CO_2 emissions at given PCI rate*

3. RESULTS AND DISCUSSION

For the bi-objective optimization task, first attempt has been made to minimize the carbon rate and CO_2 emission using the constructed networks of objective and constraint functions, whose results are shown in figure 2. The evolved pareto-fronts were categorized by the downstream energy available. It clearly depicts that the carbon and CO_2 emission will not reach its global minima, if we try to maximize the downstream energy. As we go on decreasing this energy, the carbon rate and CO_2 emission will decrease further. The optimal carbon rates show a variation and need to be governed by choice of input operating conditions of the blast, recycle gas volume and temperature by the plant.

In the series of optimization, next effort has been made to maximize the productivity and minimize the CO_2 emission, whose results are shown in figure 3. An identical trend has been observed in the case of productivity. For reaching the high value of downstream energy, the productivity shows a decreasing trend with higher CO_2 emissions.

4. CONCLUSION

A set of data points generated from the TGR-BF system model were used to construct the neural networks to predict the objective and constraint functions. Subsequently, the two bi-objective optimization tasks: 1) Min-Min problem of carbon rate-CO_2 emission, 2) Max-Min problem of productivity-CO_2 emission, has been done for various ranges of downstream energy. The result shows that downstream energy and CO_2 emission and/or carbon rate, both are conflicting to each other, i.e. maximization of downstream energy leads to increase in carbon rate and CO_2 emission and vice versa. Similar trend was also found in the case of productivity. Hence, an external source of energy (with minimum emission values) needs to be visualized if we want to take the full advantage of TGR-BF, before it is implemented in the integrated steel plant.

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ZASTOSOWANIE MODELU PROCESU DO OCENY ZMNIEJSZENIA EMISJI CO_2 POPRZEZ RECYCLING GAZU GARDZIELOWEGO

Streszczenie

Wielkie piece są głównym źródłem emisji CO_2 w zintegrowanych zakładach hutniczych. Przedmiotem pracy jest recycling gazu gardzielowego (ang. Top Gas Recycle - TGR) sugerowany przez UNCOS (ang. Ultra Low CO_2 Steelmaking), który w znaczny sposób modyfikuje proces wielkopiecowy i zmierza do ograniczenia emisji CO_2. W hutach o ultra niskiej emisji CO_2 ten piec został wybrany jako obiekt, w którym istnieją możliwości redukcji tej emisji. Gaz gardzielowy z takiego pieca, pracującego z dmuchem zawierającym tlen, przechodzi przez niskociśnieniowe urządzenie adsorpcyjne (ang. Vacuum Pressure Swing Adsorption - VPSA) służące do obniżenia udziału CO_2 i tym samym wzbogacenia gazu w CO. Tak przygotowany gaz jest zawracany do dysz lub dysz i szybu wielkiego pieca. Dotychczasowe prace opisane w publikacjach odnoszą się do specyfikacji wsadu. Opisano w jaki sposób można przewidywać możliwe do osiągnięcia zużycia paliwa oraz emisję CO_2, uwzględniając ograniczenia temperatury płomienia i temperatury strefy rezerwy cieplno-chemicznej. W niniejszej pracy podjęto próbę zbudowania Frontu Pareto dla minimalizacji zużycia węgla i emisji CO_2 dla danej prędkości ilości wdmuchiwanego węgla i cyrkulacji gazu tylko przez dysze. Dane pogrupowano względem dostępnej pozostającej do dyspozycji energii. Optymalne zużycia węgla wykazują wahania i powinny być kontrolowane przez wybór wejściowych parametrów dmuchu oraz sterowanie ilością i temperaturą zawracanego gazu. W pracy pokazano, że kiedy dostarczana energia ma być maksymalizowana, uzyskanie minimum emisji CO_2 może nie być możliwe. Podobny trend obserwujemy dla wydajności. Przy wysokich wartości podaży energii obserwujemy spadek wydajności przy wzroście emisji CO_2.

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