

## Air pollution prevention using Cleaner Production and Burning Optimisation

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### Introduction

Energy consumption in Romania is highly energy intensive in terms of energy use per unit of output. The policies promoted in the 1970s and 1980s resulted in an industrial base, which is characterized by energy intensive heavy industries and *environmental problems*, but in the last years, the Romanian companies are aware that they need **to reduce specific energy consumption and level of atmospheric pollution**.

In the Romanian Iron and Steel Industry there are many **re-heating and holding furnaces**, which are important consumers of gaseous fuel, especially natural gas, but also COG (Coke Oven Gas), BFG (Blast Furnace Gas) and others. The specific fuel consumption is, in average, with 30-40% larger than the one for similar equipment in the EU countries, and the level of chimney emissions is also higher. For this reasons, we started to promote specific tools to improve the burning control, thermal efficiency and to reduce air pollution impact of the re-heating and holding furnaces in the Romanian Iron and Steel Industry, using EU - Best Practice methods and the most appropriate and cost - effective energy efficiency technologies and techniques available in industry.

The management of the Iron and Steel Works SIDEX SA Galatzi (which is one of the greatest steel producer in the Central-Eastern Europe with its capacity of 3.2 million tonnes of steel/year), and of the Iron and Steel Works Industria Sarmei Campia Turzii – ISCT (with a capacity of 0.8 million tonnes of steel/year) are committed to facilitate the penetration of energy efficiency and relevant know-how to improve the burning control, and to **maximise the thermal efficiency and minimise the atmospheric emissions**.

So, in this context, to reduce emissions in Iron and Steel Works in Romania especially, but not only in this branch, and to obtain ISO 14001 certification, have been started in 1998 a Cleaner Production (CP) demonstrative project at IS Campia Turzii (ISCT). In the *first stage* of this project, the principles of **M&T (Monitoring and Targeting)** was applied; the regular tracking and analysis of fuel consumption and production data helped us to identify changes in energy and environmental performance. In the *second stage*, with the support of the first stage achievements, we started to implement the *Best Practice technologies and techniques* for the control and **optimisation of the burning process**, making use of **mathematical modelling and neural network for burning process and atmospheric dispersion**, parameters control and air-fuel ratio control.

## 1 Cleaner Production Projects in Romanian Iron and Steel Industry

The CP concept strictly refers to cleaner practices for pollution prevention and its minimization at source. There is a connection between CP strategy and Environmental Management System (EMS) implementation according to ISO 14001, on the one hand, and energy efficiency of technological processes, on the other hand.

The first CP project from Romanian Iron and Steel Industry emphasized this connection. This project is still started at ISCT in 1998 by means of a programme financed by Know How Fund and Department for International Development (DFID) from United Kingdom. For this project, UK advisers from renowned companies (FSC, ETSU and Ridgeway) have worked together with Romanian experts from Metallurgical Research Institute Bucharest (ICEM) and also ISCT.

This project aims *three directions*:

- **waste minimization;**
- **energy efficiency;**
- **EMS implementation according to ISO 14001.**

Both **waste minimization and energy consumption reduction** are **methods for reduction of pollutants at source**; hence they are methods recommended by CP practice. The project leads to the selection of CP options, that were actually implemented at ISCT and the establishment of some procedures, manuals and case studies, that are the basis, both for *Environmental Management System (EMS) implementation at ISCT and for obtaining accreditation according to ISO 14001*. Also, it is important to notice the advanced phase for accreditation<sup>1,2</sup>.

It was elaborated three manuals, including all methods and procedures, obtaining as a result of activities at ISCT during 2 years, and two case studies. The results are important both ISCT activities and subsequently development of some CP projects at others Romanian Iron and Steel works. In these case studies are presented the **significant energy savings, obtaining both in the short and the long term and the air pollution prevention measures**.

In the first phase, specific energy consumption vs. production charts and «best fit» linear regressions were obtained based on specific methods – M&T (Monitoring and Targeting). Thus, there were identified reasons of the significant deviations from appropriate curves and from standard values. Based on these information in the second phase it carried out improvements for equipment by means of low and no cost measures, such as: production programme improvement, **burning optimisation**, thermal losses through nozzles, untightness, etc.<sup>3</sup>. After consumption data processing, it was possible to evaluate (by means of calculation or estimations) economic benefits (4 millions USD / year at ISCT).

## 2 Burning Optimisation using Mathematical Modelling

One of the primary methods of *reducing polluting gaseous emissions* established by ICEM and used at ISCT and SIDEX Galati is based on the correlation between environmental process indicators and combustion parameters. These relations representing the *transfer functions* of the process are: the energetic and environmental transfer function  $K_{ee}(t)$  associated to the energetic and emission factor (mg pollutants / MJc) and the transfer function  $F_{Br}(t)$ .

The transfer functions are defined by the relations:

$$K_{ee}(t) = \frac{E(t)}{P_t(t)} = \frac{E(t)}{D_c(t) \cdot Q_{inf}} \quad (1)$$

$$F_{Br}(t) = \frac{V_{fg}(t)}{Q_c(t)} \quad (2)$$

where:

E = amount of pollutants evacuated by stack (kg / h);

P<sub>t</sub> = thermal power of combustion installation (kW);

D<sub>c</sub> = flow rate of fuel (kg / h for solid and liquid fuel; Nm<sup>3</sup> / h for gaseous fuel);

Q<sub>inf</sub> = low calorific power (kJ / kg or kJ / Nm<sup>3</sup>);

V<sub>fg</sub> = flue gas volume evacuated by stack (Nm<sup>3</sup> fg);

Q<sub>c</sub> = heat amount produced by fuel in the burner (Q<sub>c</sub> = P<sub>t</sub> · t).

Two methods for the determination of the transfer function have used experimental and analytical method. In the case of *experimental methods*, for each combustion installation type it has been assessed for the following parameters curves type (emission concentration as a function of flow rate of fuel), depending on air excess, combustion temperature, fuel composition, viscosity (for the liquid fuel). *The analytical method* is structured on a mathematical model and calculation program in order to determine energetical and environmental indicators in function of combustion parameters.

The input data of the program are constants (thermo - physical constant) or variables (structural and functional combustion parameters of the installation):

*Thermophysical constants*: low calorific power, equilibrium constant, specific heat coefficients;

*Structural parameters*: burner type, recycling degree of waste gas, method of recycling exhausted gas;

*Function parameters*: nature of the used fuel, chemical analysis of the fuel, fuel temperature, air excess coefficient, concentration of oxygen in the air, waste gas evacuation temperature, fuel flow rate.

The output data of the program:

*Energetical parameters and indicators*: combustion air flow rate, process temperature, temperature of chamber, fuel specific consumption;

*Environmental parameters and indicators*: waste gas emission compounds, emission concentration for each type, waste gas flow rate, temperature of evacuated gas;

*Transfer parameters of combustion process*: emission factor relative to the unity of fuel amount, energetic and ecological emission factor and conversion factor.

### 3 Atmospheric Dispersion Modelling using Neural Network

The concepts for the Neural Networks and their uses for process modelling and process control have been detailed in many recent paper<sup>4</sup>. The computer algorithms that make up a «neural network» are based on biological neurons and their interactions. A computerized neural network is made up individual elements called processing elements that are modeled the biological neurons. In computerized neural networks the weighting that occurs via growth in biological networks is accomplished via mathematical weighting.

Using a software based on neural networks, it has been achieved dispersion modelling of atmospheric pollutants:

- in a point (x, y) for one and more sources;
- for a surface splitted in a rectangular network, where the points are known.

### *3.1 Modelling in a point for one source*

The neural network model estimates the function  $f(x, y, Q, d, H, v, T_e, u, S, T_a)$  that calculates pollutants concentration from one source.

The function inputs are: horizontal plan of the distance from source to the calculation point ( $x$ ), vertical projection of the distance from source to the calculation point ( $y$ ), pollutant flow rate ( $Q$ ), stack diameter ( $d$ ), stack height ( $H$ ), jet velocity at pollutants discharge ( $v$ ), effluent output temperature ( $T_e$ ), air currents velocity at 10 m height ( $u$ ), stable conditions, according to Pasquill ( $S$ ) and ambient temperature ( $T_a$ ).

It has been considered that the physical characteristics of the stack and the output temperature of the effluent are not modified, and these are: diameter  $d = 0.5$  m, height  $H = 30$  m,  $T_e = 323$  K. Also, stable conditions and ambient temperature are constant:  $S = D$  class (neutral),  $T_a = 293$  K. The variable input values are: wind velocity for 10 m height,  $u = 5 \dots 6$  m/s with step 0.2 m/s; jet velocity at pollutants discharge,  $v = 4 \dots 8$  m/s with step 2 m/s; pollutant flow rate  $Q = 5000 \dots 10000$  m<sup>3</sup>/h with step 500 m<sup>3</sup>/h.

The output values (pollutants concentrations values for the chosen point) for the inputs data set has been calculated by means of Gaussian dispersion model. The network has been configured with 3 neurons for input level and 1 neuron for output level, based on the vector of the inputs – outputs values. It has been made several attempts for network teaching in order to establish the hidden layers and the neuron numbers for each layer. Average modelling error for this neural network is 1.09% and maximum error is smaller than 5.55%, meaning a very good estimation of the process for the whole teaching field. The testing has been achieved with the input values, the network not being taught. The test has been realised with 2805 input – output data values for the whole teaching field. In this case the average error is 0.94%, and the maximum error is less than 5.55%. It is observed that for this case, the network has estimated dispersion function very well. This means that for each point from the teaching field, the neural network is covered. Both results indicate that for wind velocity between 5 – 6 m/s, for pollutants outputs velocity between 4 – 8 m/s and for pollutant flow rate between 5000 – 10000 m<sup>3</sup>/h, the software will calculate concentration value in one point with average error about 1% and maximum error 5.55%.

### *3.2 The modelling in a point for more sources*

The modelling with neural networks can be made for more pollutant sources. In this case, the calculation of pollutants concentration in a chosen point is achieved by means of summing up all sources in that point.

#### *The configuration of the neural network resulted for this case:*

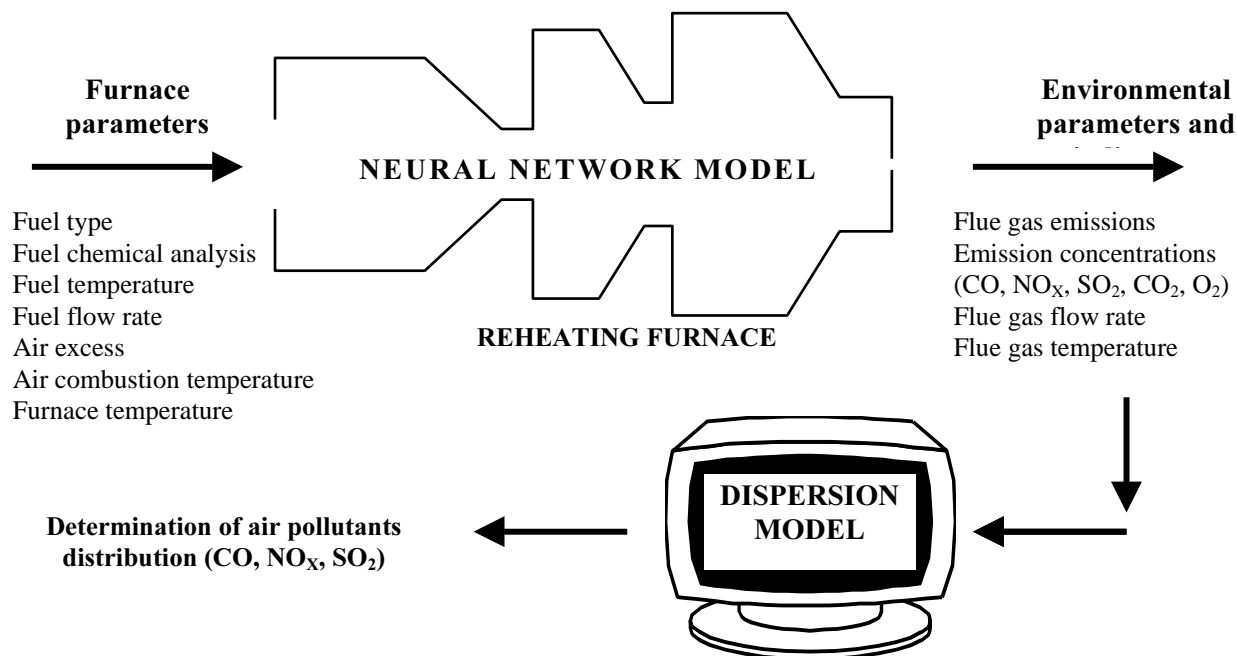
- an input layer with 8 neurons (according to wind direction frequency, emission pollutant concentration for 4 sources, wind velocity, Pasquill atmospheric stability classes, ambient temperature);
- an output layer with 1 neuron (according to emission concentration for the chosen point);
- a hidden layer with 25 neurons (after the successive attempts for obtaining of an smaller error).

After finishing of teaching process, the errors for each output vector are very small (under 0.268%).

## **4 Burning Optimisation using Neural Network**

The neural modelling advantage of a burning process, as soon as the network has taught the process with an pre-established error, can be used for the analysis and fast detection of gradually or suddenly modification of process function, before obtaining the final results<sup>5</sup>.

Thus, it has been considered a reheating furnace from SIDEX Galatzi, where burning process suffers modification of input parameters and where it is important to know the way how these variations influence atmospherical emissions resulted (Fig. 1). For a better representation, it has been chosen 4 situations according to the 4 options of fuel uses: methane (1), bigas: methane + coke oven gas (2), coke oven gas (3), bigas: methane + blast furnace gas (4).



**Figure 1** Overview of provision system for pollutant emissions from reheating furnace.

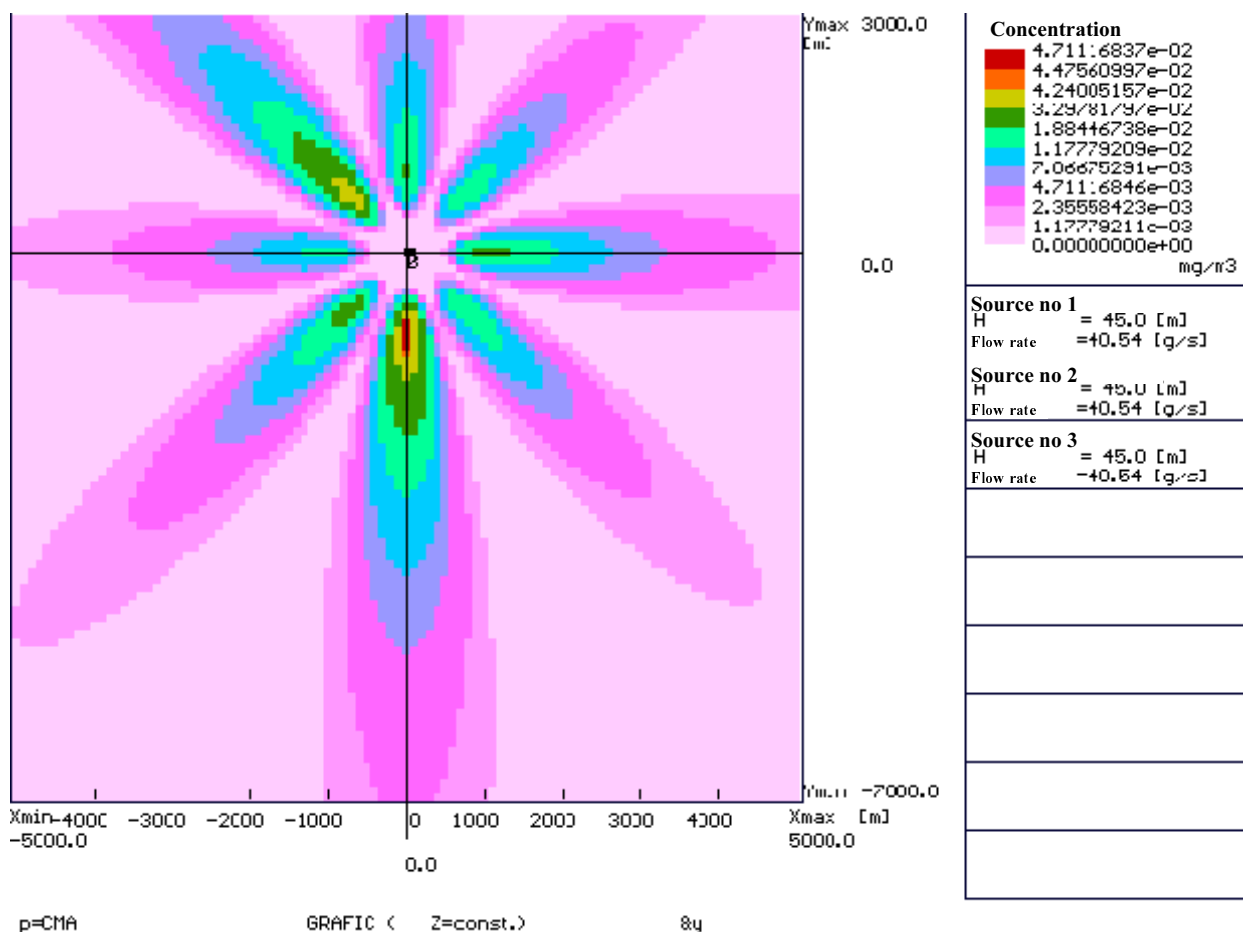
In this way, it can be analysed faster, how the function parameter modifications of the furnace may influence stack emission concentrations (table 1) and how much represent these modifications as imission values (table 2).

**Table 1** Emission concentration values at stack top.

Option	Concentration NO <sub>x</sub> , mg/Nm <sup>3</sup>		Concentration SO <sub>2</sub> , mg/Nm <sup>3</sup>	
	measured	admitted	measured	admitted
methane gas	324,4	500	-	500
methane + coke oven gas	130,6		651	
coke oven gas	612,5		1444,8	
methane + blast furnace gas	98,2		368,6	

**Table 2** Imission concentration values.

Option	Concentration CO, mg/Nm <sup>3</sup>		Concentration NO <sub>x</sub> , mg/Nm <sup>3</sup>		Concentration SO <sub>2</sub> , mg/Nm <sup>3</sup>	
	maximum	admitted	maximum	admitted	maximum	admitted
methane gas	0,00968	6	0,0377	0,3	-	0,75
methane + coke oven gas	0,012		0,0145			
coke oven gas	0,021		0,0732			
methane + blast furnace gas	0,0048		0,0114			



**Figure 2** Yearly average concentration for SO<sub>2</sub>.

These programmes (neural networks + Gaussian model for network teaching) are flexible and permit:

- polluted emission concentration determination from 1 to 18 sources with continuous emissions, momentary and medium values for long term, for any period;
- plume concentration in time and space after an accidental emission;
- pollutants concentration determination, for unstable and stable condition;
- concentration values determination: (a) for variable Z from ground (Z = 0) to other altitude (Z = H); (b) for variable Y: for Z = ct., concentration variation onto Y direction;
- graphical presentation of results into tridimensional shape, where X – Y or X – Z are distances, and the third dimension depends on colour and represents the pollutant concentration.

Supposing a constant regime of furnace function for a long period of time, besides instantaneous concentration of pollutant emissions, also it can be determined the long term average concentration, similar with daily, trimestrial or yearly average concentration. Thus, yearly average concentration for SO<sub>2</sub> is presented in fig. 2, for the third option (coke oven gas).

The most unfavourable situation is the coke oven gas use as fuel, from point of view of environmental impact. In this case, there are obtained the highest concentrations for CO, NO<sub>x</sub> and SO<sub>2</sub> with the exceeding of admitted values for emissions. But, the use of the methane gas + blast furnace gas mixture leads to the obtaining of the smallest quantities of polluted emissions, so it can be said that this is the most favourable situation for environment.

## Conclusions

The dispersion and neural modelling application for achievement of these provision systems for air pollution levels are very important methods for industrial installations optimisation leading to fast assessments and primary analysis of energy reduction consumption and pollution control scenarios.

They accomplish the main criteria for a technique of energy/environment modelling in case of industrial implementation, being simple and intuitive formulated, modified and maintained. Also, they can integrate all forms of energy, products and pollutants resulted from process and can lead to optimisation of process.

For this application, the advantages of this system are on the one hand the observation of any modification for function data of the furnace, determining the influences referring to environment pollution and on the other hand the accomplishment of energy / environment optimisation for process by means of the establishment of dependence relations between energetical and environmental indicators and burning parameters. Thus, starting from existing situation, by means of atmospheric dispersion neural modelling, it can be prescribed flow rate values for emitted pollutants at stack top and then, with neural model for burning process optimization into furnace, the changing of emissions conditions (parameters furnace adjusting) in order to obtain necessary values for air quality between limits provided by environmental protection norms.

## References

1. Melinte, I., Savin, D., Matei, E., Puscas, C., (2000) 'Cleaner Production Projects (Cleaner Technology and Energy Efficiency) in application in Iron and Steel Industry', *Metallurgy and New Materials Researches* (Bucharest), vol. VIII, pp. 122 – 135, 2000.
2. Melinte, I., Balanescu, M., Pascalin, G., (1999) 'Method to colligate energetically and environmental parameters of burning process', *The situation and tasks of environmental protection in mining and metallurgy* (proceeding – Balaton), pp. 131–136, 1999.
3. Melinte, I., Savin, D., Matei, E., Popescu, L., Puscas, C., (2000) 'The Cleaner Production results in Romanian Iron and Steel Works. Methodology procedures and energy efficiency case studies', *National Scientific Conference* (proceeding - Bucharest), pp. 566 – 574, 2000.
4. Widrow, B., Rumelhart, D., E., Lehr, M., A. (1994) «Neural Networks: Applications in Industry. Business and Science», *Communications of the ACM*, vol. 37, no. 3, pp. 93 – 105, 1994
5. Melinte, I., Cofas, A., Winckelbauer, G., Pascalin, G., (1999) 'New methods for energetically and environmental efficiency of thermal processes in Iron and Steel Industry', *Annual Romanian Metallurgical Society Conference* (Brasov).
6. Cacciamani, C., Nanni, S. & Tibaldi, S., (1994) 'Mesoclimatology of winter temperature & precipitation in the Po Valley of Norther Italy', *International Journal of Climatology*, vol. 14, pp. 777 – 814, 1994.
7. Cox, W.M. & Tikvart, J.A., (1990) 'A statistical procedure for determining the best performing air quality simulation model', *Atmos. Environ.*, vol. 24A, pp. 2387 – 2395, 1990.