ISSN 2176-3135

DEVELOPMENT AND APPLICATION OF PELLET INDURATION MODEL[1]

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Abstract

The relevance of pellet production to ironmaking industry is rising every year, following the rise in production of pellet feed. Among the pellet induration systems, the traveling grate furnace (TGF) is the most important, particularly in Brazilian market. The paper presents a software that allows one to simulate it, evaluating product and process characteristics. The simulation follows a deterministic, fundamental-based mathematical model of the TGF, which considers the gas network, predicts pellet properties and energy consumption and productivity of the process. The mathematical model is composed by two coupled sub models: a model of pellet induration concerning the physical and chemical phenomena that occurs in the bulk of the pellet bed and a gas flow model which solves the gas flow between the different zones of the furnace. The user interacts with the model through a graphical interface. The software is applied to a particular case and the results are discussed.

Key words: Pellet induration; Numerical simulation; Traveling grate.

1 *Technical contribution to the 6th International Congress on the Sicence and Technology of Ironmaking – ICSTI, 42nd International Meeting on Ironmaking and 13th International Symposium on Iron Ore, October 14th to 18th, 2012, Rio de Janeiro, RJ, Brazil.*

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ISSN 2176-3135

1 INTRODUCTION

The increasing use of pellets in blast furnaces, expansion of direct reduction and depletion of iron ore reserves are some of the factors that push for investments in new pelletizing plants and a better performance of the existing ones.

One of the tools that may be used for studying and proposing improvement in operational parameters of an induration plant is the mathematical modeling. Since 1970, several authors have proposed first principle models and implemented them numerically.[1-5]

The modeling of TGF may be seen as two coupled sub models: pellet bed model and gas network model. The first one deals with phenomena that take place inside the pallet car – thermal exchange between gas and pellets, pellet reactions and pellet quality development. The latter describes and solves the flow distribution on the gas network that is set up by the TGF ducts, fans, valves and pellet bed. Some of the previously proposed models tackled the TGF focusing only the pellet bed, assuming some of the furnace conditions as inputs (pressure drop in bed pellet, e.g.) and having the fired pellet composition and quality as main results. Although useful, this kind of model does not bring much information about the process energy and fuel consumption, nor links the pellet quality to furnace operational aspects. Other models have comprised both scopes (pellet bed and gas network), computing also the gas distribution over the ducts that link the furnace zones. This approach requires a great deal of plant data and modeling about fans, valves, burners e possible gas leakages that may occur.

The present work discusses the development and results of a comprehensive model (pellet bed and gas network) which simulates TGF pellet bed and gas network.

2 MATERIALS AND METHODS

The Pellet Induration Model (PIM) represents the second stage of a two-year project which goal is to deliver a complete model for the TGF. In the first stage of the project, a numerical model of a pot grate (pilot scale indurator furnace) was developed, obtaining good agreement with published experimental data.[6] At the current development stage, the model is able to consider both pellet bed and gas network phenomena. This allows the user to study the interaction between what happens inside the pellet bed and the operational process parameters.

An overview of the PIM is shown in Figure 1. The PIM is a two-dimensional, steady state first principle model of the TGF. The pellet bed height is divided in several elements (dz) at same time that each zone is divided in dx elements.

The focus of the present paper is the modeling of furnace gas network. The details of the pellet bed model that has been employed in the current work has been already published by the authors previously.[6]

ISSN 2176-3135

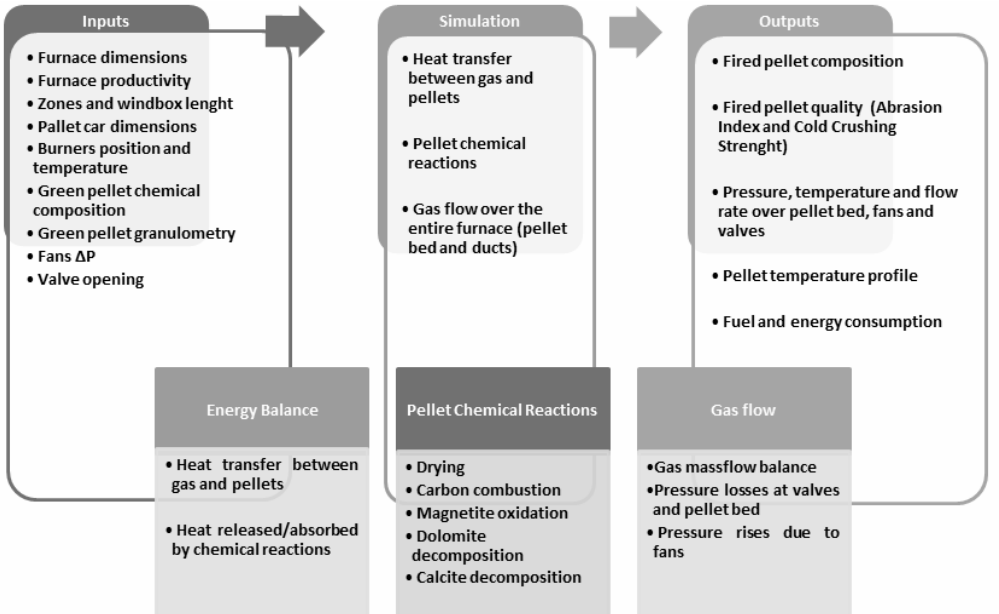

Figure 1. Overview of Pellet Induration Model.

2.1 Gas Network Analysis

One of the main aspects of the TGF is the energy recovery, which happens recirculating the gas from one furnace zone to another. In general, two main recovery loops are present: from the cooling zone to the firing zones and drying zones and from the firing zones to the drying zones. The air is impelled the furnace by fans and valves allow the operator to mix the gas streams with atmospheric air or other furnace streams. A schematic diagram of the TGF is shown in Figure 2. Arrows entering valves and fans represent air intake while arrows pointing outward represent gas discharge to atmosphere.

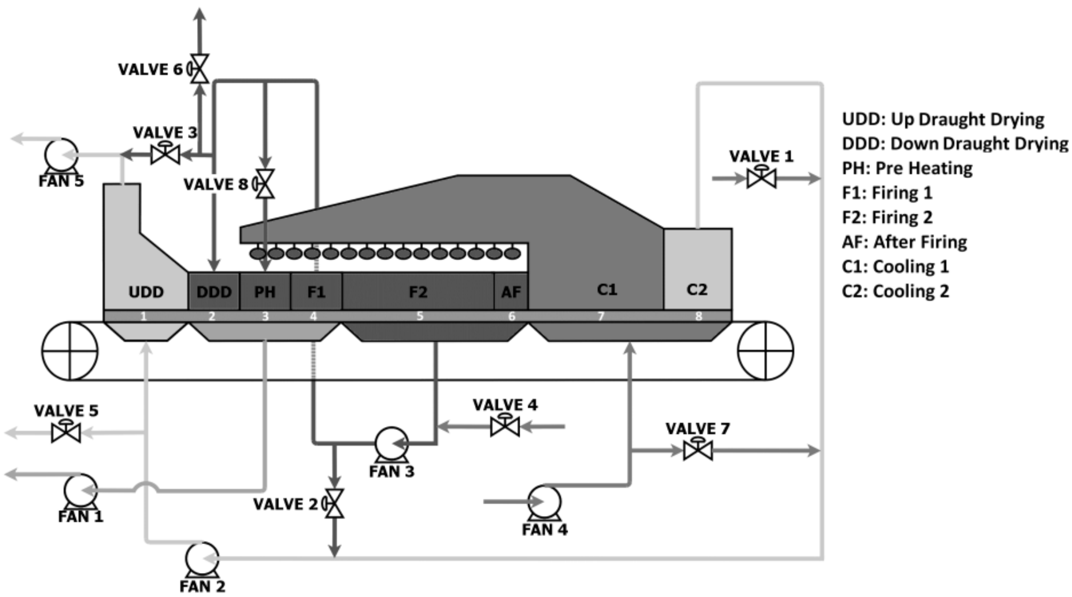

Figure 2. Schematic diagram of TGF.

The TGF gas flow system may be seen as a network of pressure elements (pellet bed, fans and valves) and sources/sinks of mass (inlets, leakages and outlets). This approach allows one to describe it as a graph and, consequently, build

ISSN 2176-3135

its matrix representation. Employing Kirchoff Laws, it is possible to compute the gas mass balance and solve the system.(7) As the pressure drops across the pellet bed depends on the gas flow and vice-versa, the interactive nature of the system calls for an iterative computation process.

Some simplifying hypotheses were assumed in the gas network analysis:

- The furnace is in steady-state;
- The pressure increase due each fan is an input;
- Leakages are neglected;
- Pressure losses in ducts are neglected.

Thus, the elements in the gas network are pellet bed, fans and valves. The pressure in each element was computed by the following rules:

- Pellet bed: pressure loss computed by Ergun's Equation;(7)
- Fans: pressure increase of each fan is an input to the model;
- Valves: pressure loss computed by Equation 1, where C_V accounts for valve coefficient and G for gas flow rate.

$$\Delta P_V = C_V \cdot G^2 \qquad \text{Equation 1}$$

Once the model has a method to compute the pressure of each element, the application of first and second Kirchoff's Laws build the algebraic system that describes completely the mass and pressure balance over the network. The solution of this system is carried by the Newton nodal method.(7)

2.2 Fuel Consumption

Along with fans pressure, the model requires the gas temperatures above the PH, F1, F2 and AF zones as boundary condition, where burners are present. The model considers that the gas that is recovered from other zones has its temperature raised to the boundary condition temperature. The difference between the incoming gas temperature and the boundary condition temperature allows one to compute the amount of fuel that is burnt in firing zones (Equation 2). T_{in} accounts for the incoming gas temperature, T_{out} for the boundary condition temperature and Cp for the gas specific heat.

$$E_{burner} = \int_{Tin}^{Tout} G \cdot Cp \cdot dT \qquad \text{Equation 2}$$

2.3 Coupling with Pellet Bed Model

The presented model was coupled with the previously developed model of pellet bed phenomena. Figure 3 shows the flowchart for the coupled model. It may be seen that the interaction between the sub models takes place when the gas flow is updated. In this update, the pressure of each gas network element is computed taking in account the thermal phenomena that was simulated by the pellet bed sub model. Also, Figure 3 shows that the user interaction with the model happens through a Graphical User Interface (GUI).

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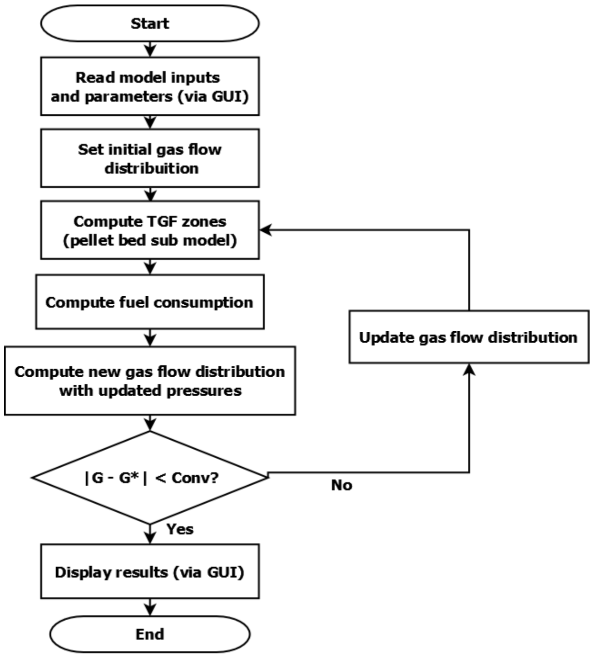

Figure 3. Flowchart of the PIM.

2.4 PIM Implementation

PIM is composed of two modules: solver and GUI. The solver was implemented in Fortran and the GUI was built using JAVA. User inputs some parameters and initial values using the GUI, which calls the solver. After attaining convergence, the solver registers the results in files and the GUI reads and exhibits them to the user.

2.5 Comparison with Plant Data

The model was set to simulate a TGF plant, which is currently in operation. Table 1 shows the zones and pellet input parameters for PIM. Table 2 shows the inputs for fans pressure and valve openings. A total of 92 parameters were set in order to configure the model to the selected case. A hematite pellet with roughly 1 % of fixed carbon was considered.

Table 1. TGF zones grate and pellet inputs

Zones length [m]				Grate width [m]	3.5	Pellet Density [kg/m^3]	2982
UDD	15	F2	27	Green pellet bed height [m]	0.35	Moisture [%]	10.5
DDD	9	AF	6	Heart layer height [m]	0.05		
PH	9	C1	24	Productivity [t/h]	569		
F1	9	C2	12	Average pellet diameter [mm]	11		

Table 2. Model inputs for fans and valves

Fan Pressure [mmH2O]		*Valve Opening (%)*			
1	550	**1**	0	**5**	0
2	480	**2**	100	**6**	0
3	530	**3**	92	**7**	0
4	470	**4**	0	**8**	0
5	105	**5**	0		

The gas network analysis for this TGF plant resulted in a system of 27 equations (11 for mass balance at nodes and 13 for pressure loads balance).

ISSN 2176-3135

3 RESULTS AND DISCUSSION

The comparison of a TGF model results with plant data is often complex since many of the variables computed may have no instrumentation counterpart in practice. During the validation effort, the authors acknowledged several phenomena that can affect the TGF performance which PIM is currently neglecting: leakages into/out the furnace, gas flow between zones, non-uniform bed height, etc. These phenomena are, particular of each plant and depend on each case, what makes modeling them very difficult. Most of the previous models were validated against pot grate data, having as one of the main comparison variable the pellet temperature at different bed heights. Although this variable is also an output of PIM, the authors favored the comparison of model results with data that is acquired in routine operation of TGF. The data for comparison between model and plant was obtained from Fabrica Plant of VALE S.A.

The pressure model results for each zone are shown in Table 3, together with plant data. It may be seen that, in general, there is a good agreement with plant data, with exception of the pressure at hood of C2 zone, where the model obtained a particularly high value. This may point to the existence of some kind of leakage or relief valve that has not been included in the model.

Table 3. PIM and plant average pressure drop, hood pressure and windbox pressure for each zone – NA means “Not available”

	Pressure drop [mmH_2O]		*Hood pressure [mmH_2O]*		*Windbox pressure [mmH_2O]*	
Zone	**PIM**	**Plant**	**PIM**	**Plant**	**PIM**	**Plant**
UDD	615	522	-74	-76	541	446
DDD	581	629	62	78	-519	-551
PH	506	492	-13	-34	-519	-526
F1	506	501	-13	-25	-519	-526
F2	455	411	-13	-21	-468	-432
AF	455	NA	-13	NA	-468	-432
C1	483	572	-13	-11	470	561
C2	409	553	61	8	470	561

The gas temperature at windboxes was also compared with plant data at some specific positions in the furnace (denoted here by the windbox number) where instrumentation was available. This result is seen in Figure 4. It shall be pointed out that the temperature in windboxes 26 to 37 was set as boundary conditions, since their gas input came from Fan 4 (atmospheric).

ISSN 2176-3135

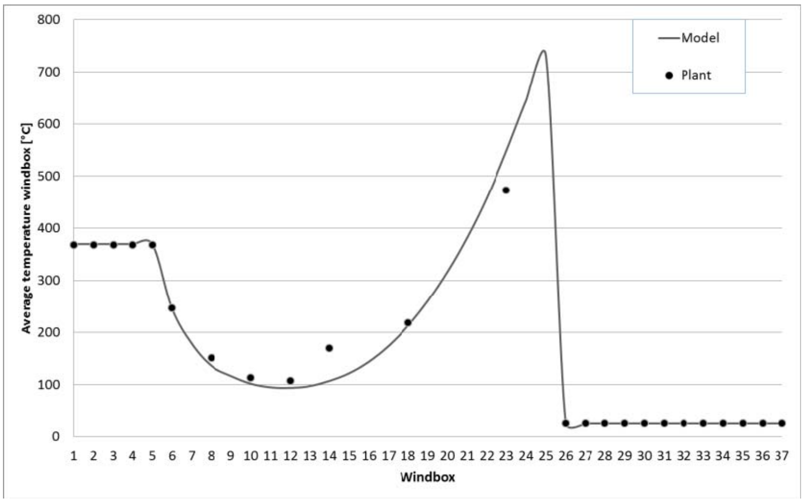

Figure 4. Gas temperature in windboxes.

One important constrain in plant operational practice is the temperature of fans, as excessive temperature may damage these equipment - in particular that of the recuperation fan (Fan 3 in Figure 2). Fans temperatures are measured online in the studied TGF plant and were available to comparison with model results (Table 4).

Table 4. PIM and plant fan temperature

	Fan Temperature [°C]	
Fan	**PIM**	**Plant**
1	143	155
2	370	368
3	365	345
4	25	25
5	134	101

The fired pellet quality (abrasion index and cold crushing strength) is also an output of PIM. Table 5 presents the comparison of the computed pellet quality at the mid height of the bed with the average measured plant values. It is seen that the computed quality at bed middle may provide a good estimative for the average. Yet, it shall be remarked that the quality model embedded in PIM has several parameters that need to be adjusted to each particular case.[8] Nevertheless, even without this proper adjustment, the model is already useful to estimate the pellets quality trend after virtual process changes.

Table 5. Abrasion Index, Cold Crushing Strenght and Maximum Pellet Temperature

	Abrasion Index [%<0.5mm]	*Cold Crushing Strenght [daN/pellet]*
PIM (Middle)	6.6	300
Plant (Average)	6.7	315

Finally, the PIM predictions for energy and fuel consumption at burners are given in Table 6.

Table 6 Gas consumption and thermal energy gas

	PIM	**Plant**
Gas consumption [Nm³/t]	11.5	15
Energy from gas [kcal/t]	116581	129320

ISSN 2176-3135

The comparison between PIM results and plant data showed, in general, good results, in spite of the number of parameters needed for setting the model. During the validation effort, the authors noticed several phenomena that can affect the TGF performance which PIM is currently neglecting: leakages into/out of the furnace, gas flow between zones, non-uniform bed height, etc. These phenomena are particular of each plant and depend on each case, what makes modeling them very difficult. The absence of these does not invalid the model results: as shown, the PIM can attain reasonable results even without them. Thus, once adjusted to a particular plant or to a base case, PIM may be used to understand the dependence between process variables and product quality as well energy consumption.

4 CONCLUSIONS

A complete model of a traveling grate furnace (TGF) was built, comprising both gas network and pellet bed models. The resulting Pellet Induration Model (PIM) is a TGF model which can reproduce plant data with reasonable accuracy. The model was adjusted to a specific operating plant and its results, including bed and windboxes temperature and pressure, fans power and fuel consumption, were compared with collected data, with an overall agreement. The virtualization of TGF offered by PIM allows the user to assess the effect of changes in raw materials and operational parameters without affecting the real plant, estimating both pellets quality trend and energy consumption. Also, it may be employed on training programs for plant operators and process engineers.

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