Modelling of the blast furnace internal state with MOGADOR

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MOGADOR is a 2D mathematical model of the blast furnace at steady state. In this project, it is used to get a better insight of the internal state of the BF, as the new types of operation differ greatly from the conventional one. Three important applications for the project are illustrated.

Introduction

The ULCOS blast furnace process consists in recycling most of the top gas after CO_2 removal and reheating. Recycling can take place at main tuyeres and into the stack. To avoid N_2 accumulation due to recycling, the blast is replaced by pure oxygen.

These new operating conditions raise several questions about the behaviour of this huge and complex counter-current reactor. Answers are approached using MOGADOR, a 2-D mathematical model of the blast furnace at steady state.

MOGADOR

Description of the model

As the model has already been presented earlier (1, 2), the description will be limited to the basic principles and to some original features.

MOGADOR (Model for Gas Distribution and Ore Reduction) is a 2-D mathematical model of the blast furnace at steady state.

The input data include notably the complete description of ore and coke layers at stockline, which is calculated by a burdening model. In the present work, the burdening model developed by ArcelorMittal Gent (former Sidmar) is applied (3, 4). The latter model, which applies to a bell-less top, calculates the layers thickness as well as the grain size distribution along the blast furnace radius. The results are in good agreement with the microwave profilemeter measurements (4).

MOGADOR extends the burden distribution inside the whole blast furnace ; it simulates the gas flow through the layered structure, the solids flow, the liquids flow, the heat transfer between the different phases and with the walls, the ore softening and melting in the cohesive zone as well as the main chemical reactions. The work has been restricted to the main phenomena of the blast furnace and some sub-models like liquid flow and softening-melting have been simplified.

The results consist in a complete description of each point of the blast furnace, i.e. the fields of temperature, pressure, velocity and chemical composition of gas, solids and liquids, as well as the wall heat losses distribution.

The determination of the solid flow is based on a potential model taking into account the vanishing of solids by melting and by gasification. The dead man is imposed. The configuration of the layered structure results from this solid flow model (Figure 1).

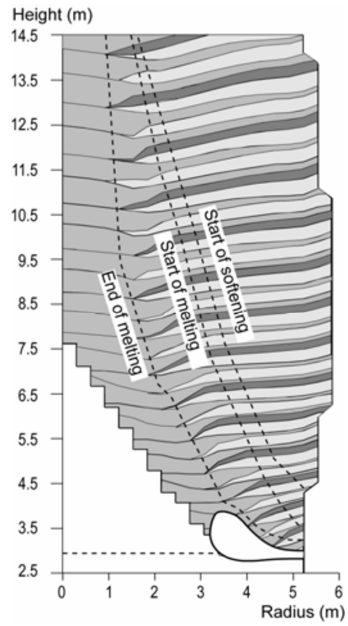

Figure 1. Structure of the cohesive zone calculated by MOGADOR (example)

The layer thickness decreases progressively from the top to the tuyeres as well as the inclination angle of the layers: from 30° at the top, it reaches about 6° in the belly. From the start of melting line to the end of melting line, the ore layers become thinner and thinner, which reflects the melting phenomenon. These results fit very well with the observations made on several dissected blast furnaces, as for example on Hirohata n°1 BF of Nippon Steel (5).

In the gas flow calculations, all the individual layers are taken into account, even if they are thinner than one mesh; this specificity of the model allows improving the precision of pressure and flow rate results.

By optimizing the resolution of the system of equations, it has been possible to improve the convergence speed and hence to decrease significantly the time of calculation which is lower than one hour.

Calibration of the model and comparison with vertical probing measurements

The model has been calibrated with experimental data obtained by vertical probings and by gas tracing at blast furnace B of ArcelorMittal Gent (former Sidmar) (1, 2, 6).

Before running MOGADOR, a global heat and mass balance is applied to the operational data. The main results are compared and fit very well.

The measured vertical profiles of temperature, pressure and gas composition compare rather well with the calculated ones. It is also the case for the horizontal profiles of top gas temperature and composition. Figure 2 presents the shape of the cohesive zone as calculated by MOGADOR for five blast furnace operations corresponding to vertical probings. The upper face of the calculated cohesive zone is compared to the measurements in Figure 3.

Taking into account the difficulties involved both in the measurement and in the modelling work, the results of the model fit rather well with the measurements.

Adaptation of the model to the industrial use

ArcelorMittal Gent developed an interface allowing an automatic acquisition of the data of blast furnace B required by the mathematical model. These data are 24 hours averages. They include the top gas pressure, the temperature, the flow rate and composition of the gas issued from the raceway and the chemical analysis of sinter, coke and hot metal. The coke base, the charge weight and the composition of the charging cycle enter the burdening model, which calculates the complete burden distribution and geometry at the blast furnace top.

The model can be run under different modes. The automatic mode is running on the average data of last 24 hours. The manual mode allows running the model on the 24-hour average data of any preceding day. The detailed mode provides more detailed results and supplementary diagrams for the process analysis.

The results are displayed on a PC screen. The results simulating the operation of the preceding day are available at the morning meeting where the operational decisions are taken regarding the plant management. They are also stored automatically in a database.

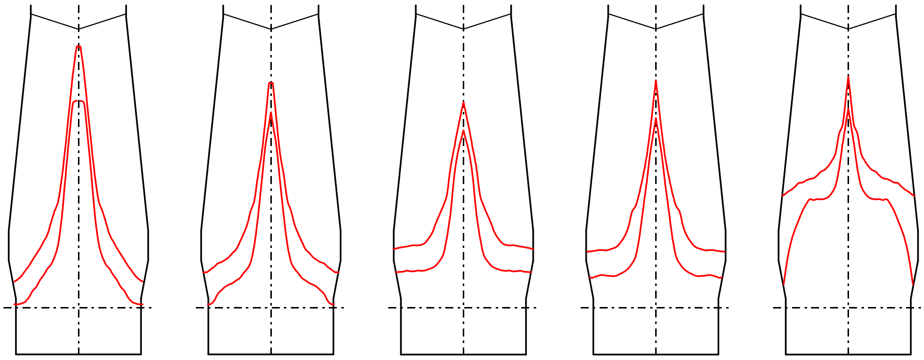

Figure 2. Calculated shape of the cohesive zone (Oct. 96, May 98, Oct. 00, June 01, July 01)

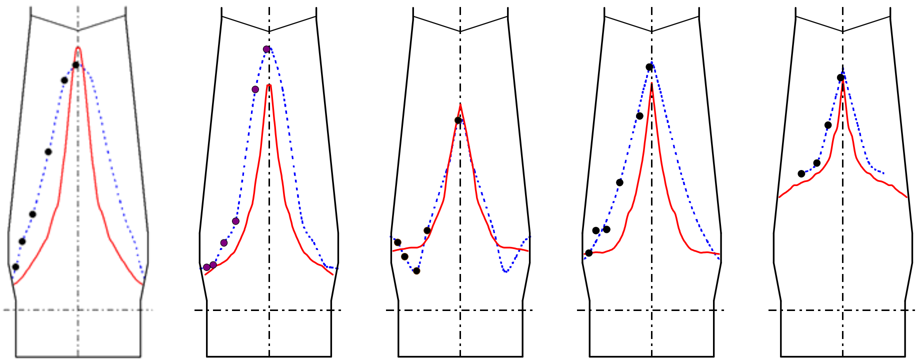

Figure 3. Measured and calculated upper face of the cohesive zone (Oct. 96, May 98, Oct. 00, June 01, July 01)

Industrial use of the model

MOGADOR started running on line at ArcelorMittal Gent (former Sidmar) in July 2001. Several examples of the extensive use of the model have been presented earlier (2).

The model is also used on line in AcelorMittal Dunkerque (BF 3 & 4), Bremen (BF 2) and Florange (BF 3).

MOGADOR is under investigation in Corus, mainly at BF 6 & 7 of Ijmuiden and at Queen Anne BF of Scunthorpe.

Study of the recycled gas penetration into the lower shaft

The mathematical simulation shows that the gas injected into the stack does not penetrate very deeply inside the furnace (Figure 4).

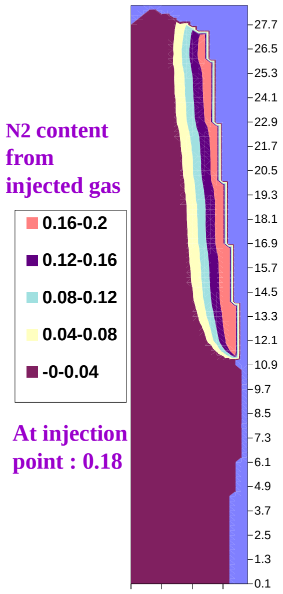

Figure 4. Illustration of gas penetration into the BF

However, it should not be a severe problem because

- the injected gas and the gas ascending from the bosh have rather similar compositions in terms of reducing power;
- the horizontal gas flow rate profiles remain almost unchanged above the injection point (Figure 5).

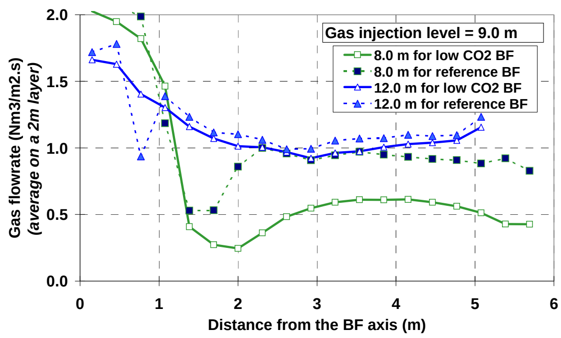

Figure 5. Horizontal profiles of gas flow rates for the conventional BF and the ULCOS BF process

Study of the reduction behaviour

The progress of reduction is calculated by MOGADOR along the solid trajectories.

Calculated temperature (Figure 6) and gas composition profiles are provided to SP10.2 to test the reduction behaviour in laboratory.

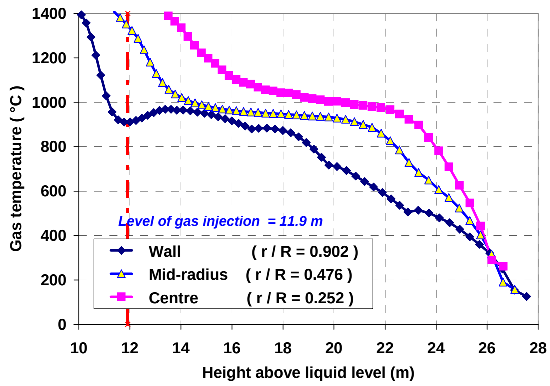

Figure 6 – Example of reduction progress calculated for the ULCOS BF process

The kinetics involved in the model is then tuned to fit the calculated reduction profile with the experimental results. A good agreement is recorded (Figure 7).

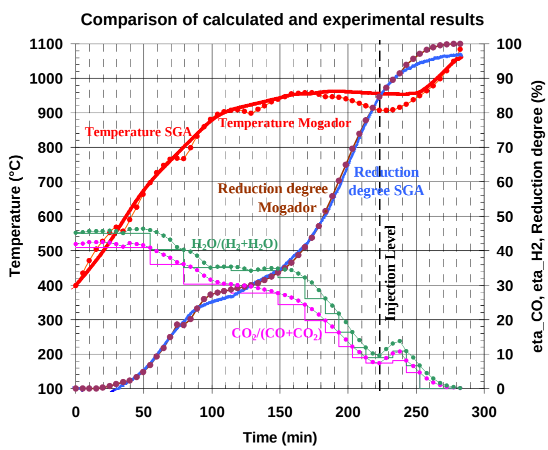

Figure 7. Comparison of calculated and experimental progress of reduction degree for the ULCOS BF process

Based on these results, no problem of reduction kinetics is expected in the ULCOS BF process.

Study of the cohesive zone

Position and shape of the cohesive zone are calculated after adapting the burden distribution to the new process (Figure 8).

The model shows that the cohesive zone is slightly thicker than in conventional operation. This seems to be in contradiction with the first results from the dissected Experimental BF of Luleå. Hence, the model parameters have to be adapted further.

The total pressure drop inside the BF is also reduced (respectively 1.13 , 0.79 and 0.99 bar for the conventional BF, version 1 and version 4), which confirms the possibility of a significant productivity increase.

Conclusion

Using MOGADOR, a 2-D mathematical model of the blast furnace at steady state, the internal behaviour of the ULCOS BF has been simulated. Based on the results, initial anxiety has been eased concerning the gas penetration into the stack, the progress of ore reduction and the position and shape of the cohesive zone.

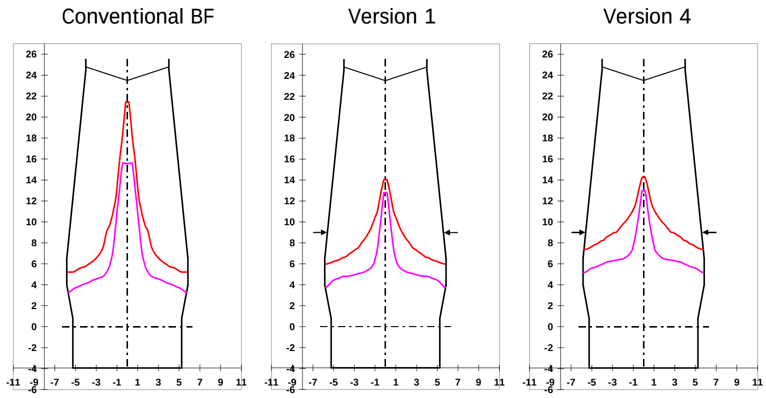

Figure 8. Calculated cohesive zone for versions 1 and 4 of the ULCOS BF compared to conventional BF

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References

[1] G. Danloy, J. Mignon, R. Munnix, G. Dauwels, L. Bonte. "A blast furnace model to optimize the burden distribution". 60th Ironmaking Conference Proceedings, Baltimore, 2001, Vol. 60, pp. 37-48.

[2] G. Danloy, J. Mignon, R. Munnix, G. Dauwels, L. Bonte – Industrial application of the CRM blast furnace model at Sidmar – Proceedings of METEC Congress 03 and 3rd International Conference on Science and Technology of Ironmaking, Düsseldorf, 16-20 June, 2003, pp. 83-88.

[3] A. Hamilius, M. Deroo, G. Monteyne, R. Bekaert, R. D'hondt. "Blast furnace practice with stave-coolers and with a rotating chute for burden distribution". Ironmaking Proceedings, Chicago, 1978, Vol. 37, pp. 160-168.

[4] M. Bracke, G. Dauwels, L. Bonte. "The use of a microwave device for the burden profile measurement and verification of the off-line burden distribution model results". European Commission. ECSC Workshop. Düsseldorf, 27-28 Jan. 1998, pp. 73-83.

[5] M. Sasaki K. Ono, A. Suzuki, Y. Okuno, K. Yoshizawa. "Formation and Melt-down of Softening-Melting Zone in Blast Furnace". Transactions ISIJ, Vol. 17, 1977, pp. 391-399.

[6] L. Bonte, R. Vervenne, F. Stas, R. Bekaert, G. Danloy. "Process control techniques for the realization of high hot metal quality, high productivity and high pulverized coal injection at the Sidmar blast furnaces". 1998 ICSTI/Ironmaking Conference Proceedings, Toronto, 1998, Vol. 57, pp. 257-278.

[1] Priority 3 of the 6th Framework Programme in the area of "Very low CO_2 Steel Processes", in co-ordination with the 2003 and 2004 calls of the Research Fund for Coal and Steel