Heat and mass balances in the ULCOS Blast Furnace

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The ULCOS blast furnace process aims at reducing the CO_2 emission of the blast furnace by 50% in two steps:

- decrease of the carbon consumption by recycling most of the top gas after CO_2 removal, which requires operating the blast furnace with pure oxygen ;
- underground storage of CO_2.

Heat and mass balance calculations allow choosing the configurations with high carbon savings taking into account the experience gained with the conventional BF practice. Examples of different flow sheets are presented with their main advantages and drawbacks. The model validity is also demonstrated.

Introduction

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- decrease of the carbon consumption by recycling most of the top gas after CO_2 removal, which requires operating the blast furnace with pure oxygen ;
- underground storage of CO_2.

Different configurations of the flow sheet are possible, which can be compared based on heat and mass balance calculations.

Heat and mass balance models

Heat and mass balance calculations of the blast furnace process at steady state aim at two objectives. Firstly, they aim at characterising the operational efficiency of a given BF based on measured results. Secondly, they intend to predict future results of the same BF under different operating conditions.

The first calculations are based on « all » measured data. Briefly, this includes mainly the quantity, temperature and chemical analysis of all the materials entering (ores, coke, blast, oxygen, coal, fuel oil…) or exiting (hot metal, slag, top gas) the blast furnace. Balances of C, N2, H2 and O2 allow verifying the consistency of these data and calculating the chemical efficiency of the operation in terms of approach of the thermodynamic equilibrium (also called gas utilisation at wüstite level). The material balances are applied not only to the whole BF, but also to its upper and lower parts, which are separated by the line where all the iron oxides are reduced into wüstite. Take note that modern BF are very efficient chemical reactors as their gas utilisation is generally higher than 95%. The heat balances provide the heat losses of both the upper and lower parts of the BF. A heat balance of the raceway area provides the RAFT (Raceway adiabatic flame temperature).

The second type of calculations makes use of the same input data, except the coke rate and the slag and top gas characteristics, which have to be predicted using the results of the first calculations (mainly the chemical efficiency and the heat losses). As the equations and hypotheses are the same, both types of calculations provide exactly the same results if they are applied to the same data. The interest of the second type of calculations is its ability to predict the answer of the BF when one or more input data are modified, for example when a different coal is injected or when more oxygen is added to the blast.

Applied to the conventional blast furnace process for more than 40 years, heat and mass balance models of the BF at steady state proved to be a powerful tool to analyse operational results and to predict future results under modified conditions. As a consequence, they are particularly helpful for research and development engineers.

For their application to the top gas recycling blast furnace, these models have been completed to simulate the CO_2 removal unit (including its yields in CO_2, CO, H_2 and N_2) and to allow the recycling of the product gas into the BF both at tuyeres and lower shaft levels.

Version 1

In version 1, the decarbonated top gas is recycled cold at main tuyeres and hot at the stack tuyeres. An example is described at figure 1.

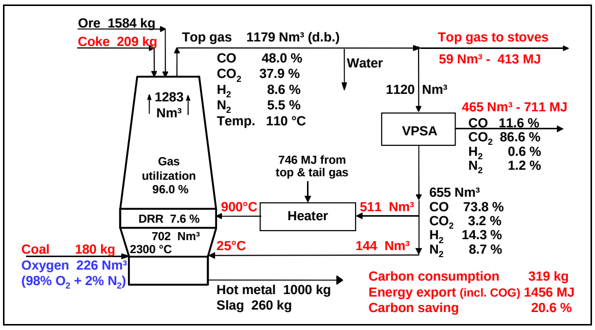

Figure 1. Example of flow sheet in version 1

This version is challenging in reaching the required high ore indirect reduction degree (problem of reduction kinetics) and in creating a good raceway for gas distribution in the lower BF. To obtain good carbon savings it is required to work with a high flame temperature.

The advantages include the heating of one gas stream only, at low temperature and the possibility to operate at higher coal rates. Moreover, this version presents a high potential in productivity increase.

Version 3

In version 3, the decarbonated top gas is recycled hot at the main tuyeres only. An example is described at figure 2.

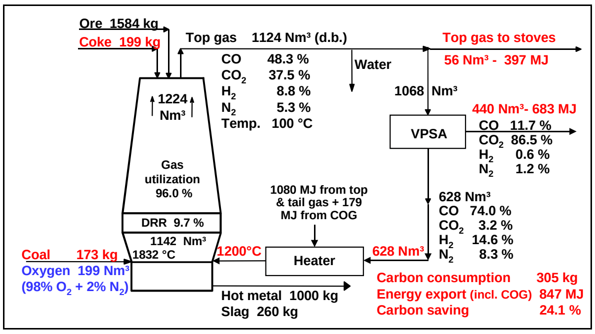

Figure 2. Example of flow sheet in version 3

This version has the advantage of avoiding shaft injection (lower investment cost, good raceway, easier operation).

However, it requires operating the BF either at very low flame temperatures either at very low PCI rates to reach competitive carbon savings. It presents a low potential in productivity increase.

Version 4

In version 4, the decarbonated top gas is recycled hot at main tuyeres and hot at the stack tuyeres. An example is described at figure 3.

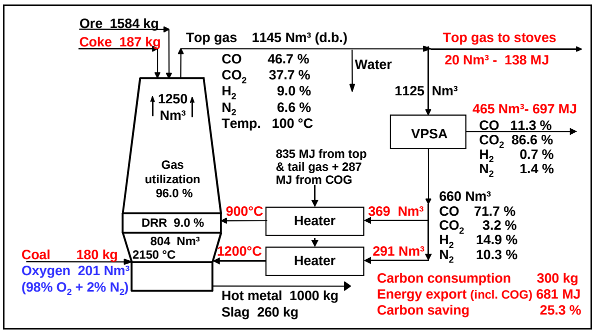

Figure 3. Example of flow sheet in version 4

This version has the big advantage of recording the highest carbon savings. This is obtained in a comfortable range of coal rates (100-170 kg/thm) with a lower sensitivity to the flame temperature and attractive productivity increase,

Compared to version 1, it shows a lower strain on indirect reduction requirement and on raceway size.

However, it is slightly less economical than version 1 due to a lower energy export and slightly lower coal rates.

Validation of the model predictions

Heat and mass balance models have been validated since many years under conventional BF operation.

With this new process, the first ULCOS campaign at the Experimental BF of LKAB in Luleå (Autumn 2007) demonstrated also the interest and the validity of the models for the prevision of both carbon savings (figure 4) and reduction of CO_2 emissions.

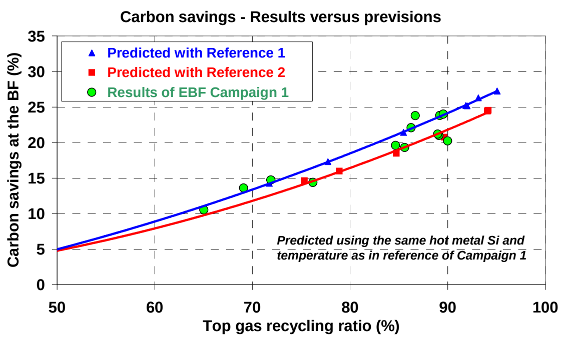

Figure 4. Comparison of experimental results with model previsions

Conclusion

Heat and mass balance models proved to be very usefull tools to predict the results of the ULCOS blast furnace process with top gas recycling, to compare the advantages and drawbacks of the different possible configurations, and to assess their feasibility.

This study demonstrates that the ULCOS blast furnace process should allow reaching the aims of reducing the CO_2 emission at the BF by around 25% provided challenging issues are solved. Taking into account underground storage of CO_2, this should result in a reduction of emission by more than 60% at the level of the hot rolled coil.

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[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