# REDUCTION OF BLAST FURNACE COKE-RATE
# A VISION OF USINOR

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Summary

To improve their economic performances and their competitiveness, one of the objectives of Usinor ironmaking plants has been since a long time to decrease the coke consumption in the blast furnaces. For more than ten years, we have been working on two complementary ways to reach this target : reduction in the overall consumption of reducing agents and increase in the quantity of coal injected into the blast furnaces. The different improvements concern grinding and injection facilities and blast furnace operation control.
This text use mainly the historical data of french blast furnaces of Usinor.

Keywords : coal injection – coke rate - reducing agents ratio.

1st INTERNATIONAL MEETING ON IRONMAKING – September 24th to 26th, 2001– Belo Horizonte
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## 1 INDUSTRIAL SITUATION AND EVOLUTION OF THE OPERATING POINTS

The production of flat carbon steel products is ensured in France by the 3 integrated plants of Usinor group: Dunkirk plant (Sollac Atlantic), Florange plant (Sollac Lorraine) and Fos-sur-Mer plant (Sollac Méditerranée).
During the last fifteen years, the industrial outline was improved and rationalised. Today seven blast furnaces produce approximately 13MT of hot metal per year.

Figures 1 and 2 give the main characteristics of these blast furnaces and the date of their last relining.

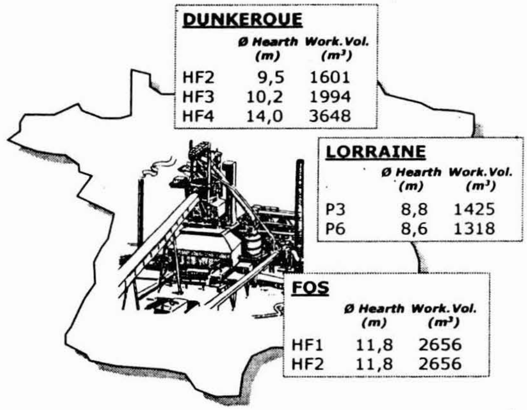


Figure 1 : Characteristics of French Blast furnaces of Usinor

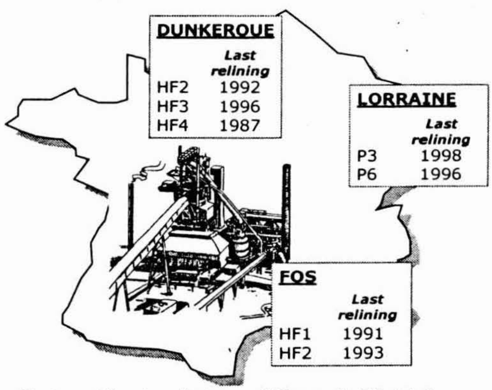


Figure 2 : Date of last relining of French Blast furnaces of Usinor

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Each one of the three ironmaking plants is equipped with a coking plant whose characteristics are given in figure 3.

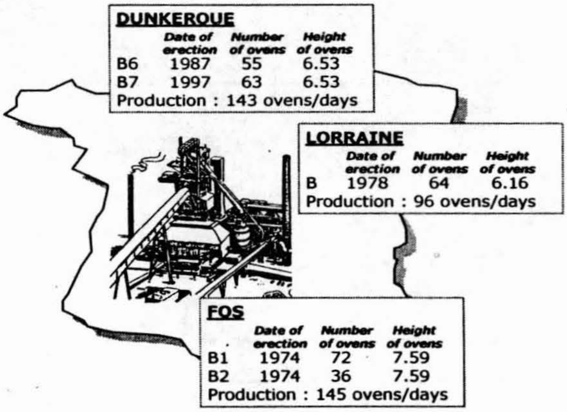


Figure 3 : Characteristics of French Coke plants of Usinor

The production of hot metal of the three plants has changed during the last decade as it is shown on figure 4.

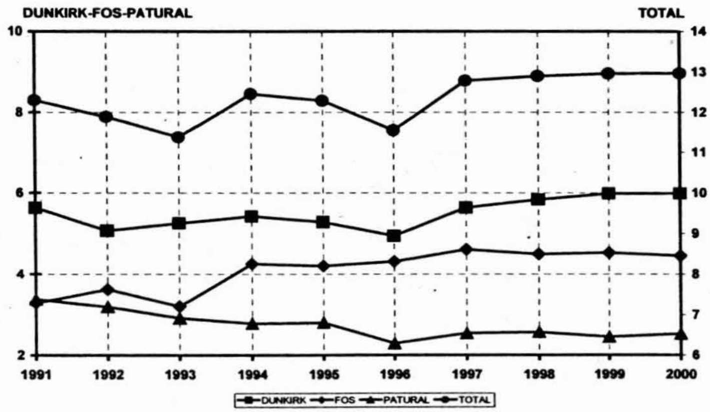


Figure 4 : Evolution of hot metal production

In the same time, the production of blast furnace coke has also changed (see *figure* 5). This evolution is the result of rationalisations, modernisation (start-up of a new battery of coke ovens in Dunkirk in 1997 and stoppage of the oldest one) or diminution of production rate to increase the lifetime of batteries (Fos-sur-Mer).

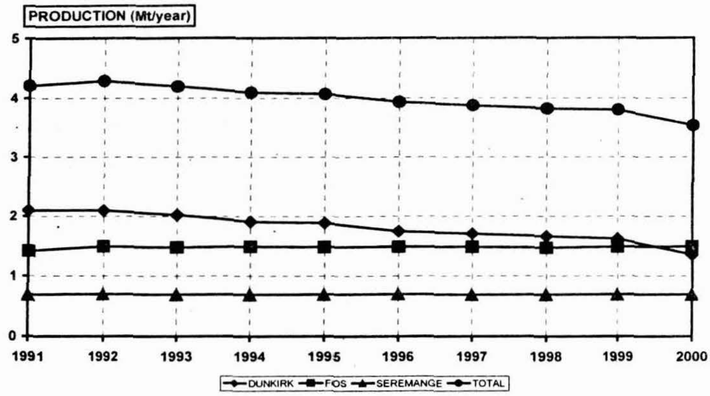


Figure 5 : Evolution of coke production

*It appears clearly that the production of coke is not sufficient to ensure the* requirements in reducing agents of the blast furnaces (cf figure 6 in which the evolutions of coke and hot metal production are compared).

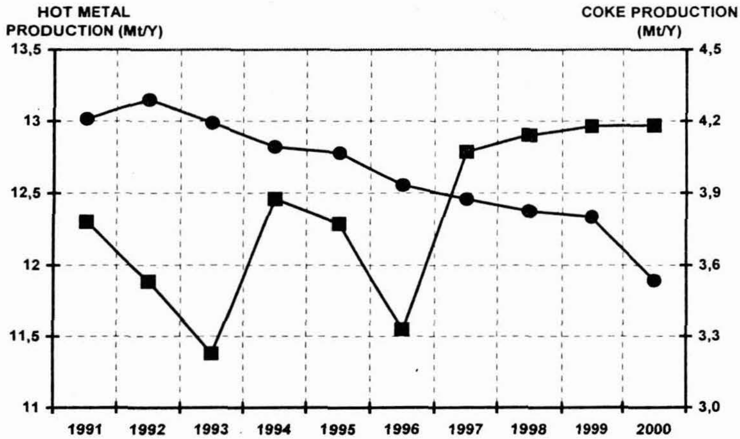


Figure 6 : Evolution of hot metal and coke production

To improve the economic performances of the ironmaking plants, and to limit the need for imported coke, one of the major objectives of Usinor in this field has been since a long time to decrease the coke consumption in the blast furnaces. For more than ten years, we have been working on two complementary ways to reach this target : reduction in the overall consumption of reducing agents and increase in the quantity of coal injected into the blast furnaces. These two objectives are not independent, because the realisation of high levels of coal injection requires a good control of blast furnaces operation, which also results in optimising the consumption of reducing agents.

We will see in the continuation of this paper how these goals are pursued, and which are the forecasts for the future.

## 2 ACTIONS TO DECREASE THE CONSUMPTION OF COKE IN THE BLAST FURNACES

### 2.1- Development of Pulverised Coal Injection

The coal injection is obviously an effective way to decrease the consumption of coke in the blast furnaces.

The pulverised coal injection started industrially at Usinor in 1983 at Dunkirk's plant. This technique then was gradually extended to all the blast furnaces in activity ; the two blast furnaces of Patural (Lorraine) were equipped with a coal injection in 1998 and 1999.

Figures 7 and 8 show the evolution of the annual quantity and annual rate of coal injected on French blast furnaces of Usinor.

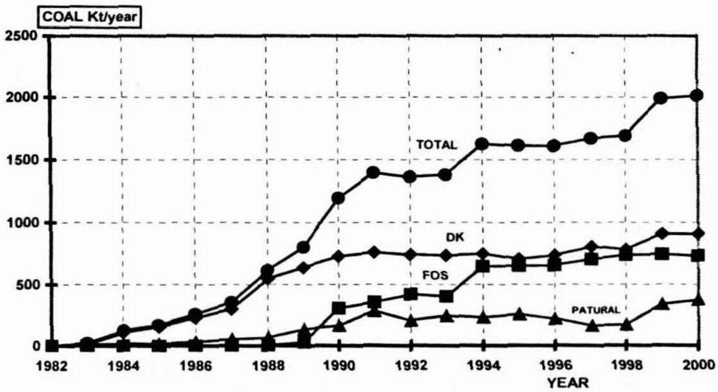


Figure 7 : Evolution of annual quantity of coal injected

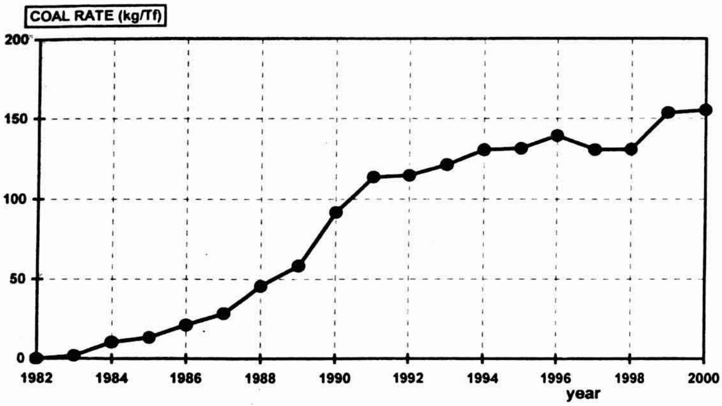


Figure 8 : Evolution of coal injection rate

The mean level carried out in 2000 is 155kg/t. HM for the whole of blast furnaces.

The development of the coal injection has to be done only in coherence with the main objectives of ironmaking plant : economic performance (complete cost price including depreciation of the investments) – lifetime - production of pig iron in accordance with the need. With this intention, the philosophy of Usinor is to increase the coal injection step by step. Two types of actions are carried out :

- To control and optimise the technology of coal grinding and injection
- To control blast furnace operation with a high level of injection. The actions concerning this last point will be developed in the following paragraph.

From the point of view of grinding and injection technology, the targets are :

- Optimal use of the grinding capacities installed with a strict control of the size distribution of pulverised coal.
- Reliability of grinding and injections facilities.
- Control and regularity of the total coal flow rate injected.
- Regular coal distribution on each tuyeres.

Many improvements were carried out to achieve these goals, such as for example :

- **Performance of grinding facilities** : modifications of grinding installations were carried out for example in Fos (increase in the capacity of drying, improvement of the size separators...) to use to the maximum the installed grinding capacities. To increase the flow rate of grinding, the initial target of size distribution was softened : the target for minus 75µm has been changed from 90% to 80%.
However, the proportion of over 200µm remained very low (approximately 5% for an objective of 10% max). This objective is coherent with the observation made in Dunkirk, which shows that the increase in sludge amount with the speed of top gas depends on the proportion of minus 200µ in pulverised coal. [1]

- **Use of coal mix** : to diversify the supplying sources, several types of coals are used. To avoid the variability of grinding operations or the variations of blast furnaces operating point, a mix of two coals is used : the target is to maintain constant the volatile matter content and the grindability of the mix.

- **Regulation of coal flow rate :** a second injection tower has been installed in Dunkirk and pneumatic regulators to regularise the flow of injection (cf figure 9) replaced the rotary feeders

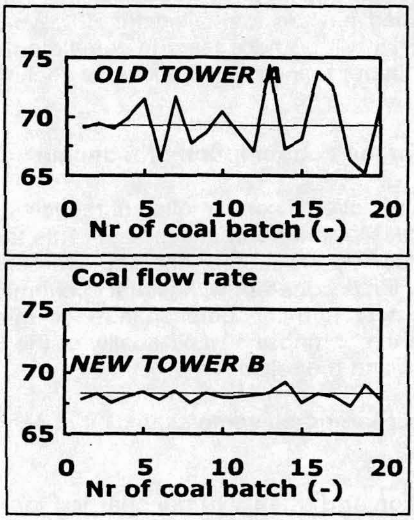


Figure 9 : Evolution of coal flow rate regulation in Dunkirk

- **Equal distribution of the injection on each tuyere** : a particular attention was given to the equal distribution of injection on all the tuyeres (see table 1) :

| | |
|---|---|
| DUNKERQUE 4<br>PATURAL 3-6 | 2 % |
| FOS 1 - 2 | 4 % |

Table 1 : Variability of coal flow rate by tuyere

+ In Fos, the system of distribution (static distributor and Laval tuyere) makes it possible to obtain a good équi-distribution of coal on the different tuyeres. The controls carried out on several occasions have shown that the differences of flow rate between the tuyeres were low (standard deviation of 4%).

+ In Dunkirk and Patural, regulations of coal flow rate per line (with individual measurement of flow rate) have been installed. With these system it is possible to reach very good levels of equal distribution (standard deviation of 2%).

- **Reliability of injection** : a control of luminosity was installed on all the tuyeres of the blast furnaces in Fos : if the luminosity decreases below a limit value on a tuyere, the coal injection is stopped and nitrogen is injected. It is thus possible to prevent major incidents of injection with big effect on the blast furnace.

All these improvements made it possible to increase the profitability of the investments carried out for coal injection. However, in a context of increase in hot metal production, it will be necessary to complete the facilities in the three plants to continue, in the future, to increase the level of coal injection.

### 2.2- Reduction in the consumption of reducing agents

The reduction in the overall consumption of reducing agents is one of the elements of the competitiveness of the ironmaking plant. This target is not independent of other targets like productivity or lifetime, and improvements in total reducing agents ratio make sense only if it is coherent with global economic optimum.
We know that to decrease consumption in reducing agents in the blast furnaces, the main factors are the composition and quality of the burden, the control of the blast-furnace operation and the reliability.

We will see in this paragraph some examples of actions carried out in these fields at Usinor:

#### 2.2.1- Composition and quality of the charged matters

- **Composition of the burden.**

The proportion of prepared burden (sinter and pellets) in the blast furnaces of Usinor depends on the industrial layout of the plant (sinter capacity) and on the targets of productivity. We have gradually increased this proportion of prepared burden on the Blast furnaces : according to local situations, prepared burden rate varies from 85% (case of the HF4 of Dunkirk) to 100% (case of Patural blast furnaces) (cf table 2).

| WORKS | DUNKIRK | FOS | PATURAL |
|---|---|---|---|
| PREPARED BURDEN RATIO (%) | | | |
| YEAR 2000 | 85 | 93 | 100 |
| YEAR 1990 | 81 | 88 | 85 |

Table 2 : Evolution of prepared burden ratio

The level of prepared burden ratio is even more important when the productivity is high and the coke consumption is low as it is shown on figure n°10. The practice of Usinor in this field is not different from the practice of others blast furnaces in Europe.

The limitation of the proportion of lump ores in the burden is favourable to reach smooth blast furnaces operation, and thus low consumption of reducing agents.

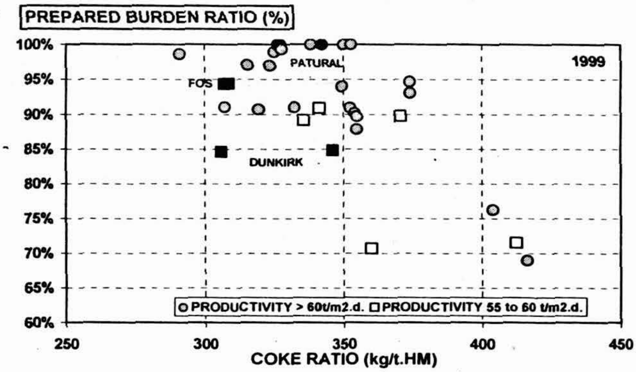


Figure 10 : Prepared burden and coke rate in Europe

**- Quality of the burden.**

The most important point is the regularity of the burden quality. We have developed a quality control, which uses Total Quality tools : the definition of the targets (average value and standard deviation / variability), the follow-up of the obtained results and the preventive and corrective actions are led in collaboration between the different entities of the ironmaking plant.

The significant parameters for burden quality are :

+ The chemical analysis (blast furnace balance, alkaline and zinc input, ...).

+ The size distribution (fines in the higher part of the shaft).

+ Cold strength or mechanical resistance during transformation (fine formation in the shaft and in the hearth).

We will illustrate this point through actions done on coke quality : in a context of high level of coal injection, it is necessary to increase the quality of charged coke. The analysis of coke samples, which were taken with tuyere probe, showed us that the degradation of coke in the blast furnace is clearly related to its initial quality (cf fig 11 and 12).

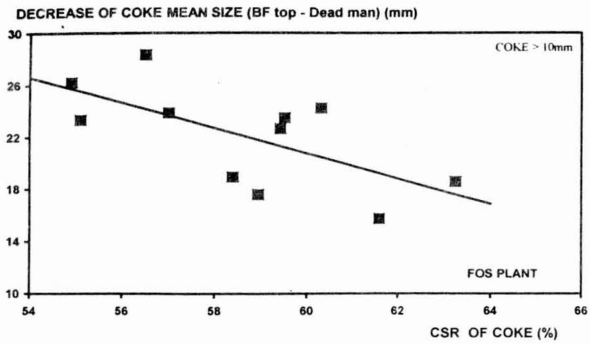


Figure 11 : Evolution of coke size in the blast furnace (use of tuyere probe)

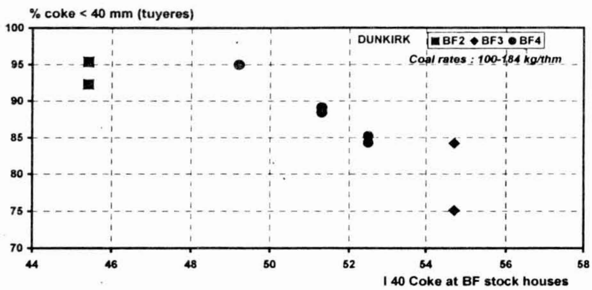


Figure 12 : Evolution of coke size in the blast furnace (use of tuyere probe)

The actions, that have been done to increase coke quality, are : modification of coke size distribution by increasing the screening size (cf table 3) and improvement of coke strength (see examples on figures 13 and 14).

| | SOLLAC Dunkerque | | SOLLAC Fos | SOLLAC Orne & Fensch |
|---|---|---|---|---|
| BF | 2 - 3 | 4 | 1 - 2 | P3 - P6 |
| Screening size (mm) | under stock houses 25 | 25→30 | coke oven plant 25 → 40 | under stock houses 25 → 35 |
| Small coke size (mm) | 6 - 30 | | 10 - 40 | 6 - 35 |
| Small coke charging pattern | Mixed with sinter under stock houses | | Mixed with sinter under stock houses | Mixed with sinter at sinter plant outlet |

Table 3 : Evolution of coke screening size

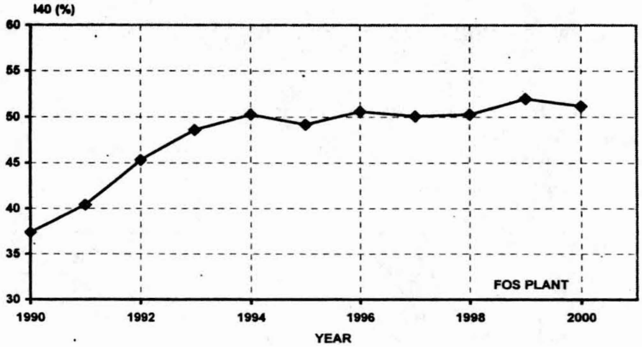


Figure 13 : Evolution of coke quality (I40)

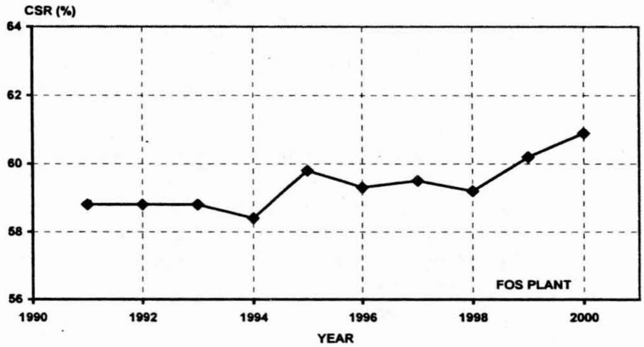


Figure 14 : Evolution of coke quality (CSR)

### 2.2.2- Improvement of Gas distribution

The philosophy of burden and gas distribution can be illustrated by 3 main orientations.

1. Decrease of the coke base to limit thickness of ore layer and improve smelting conditions (fig. 15).

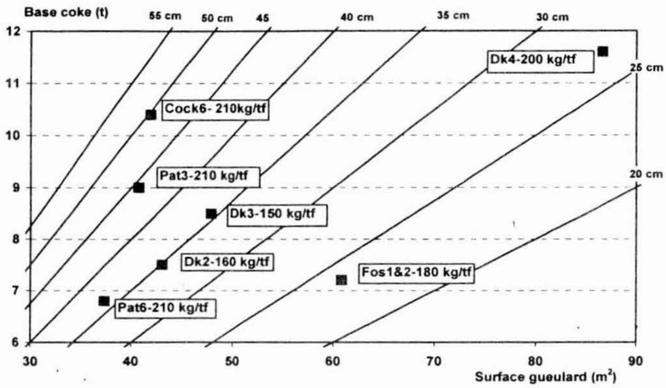


Figure 15 : Evolution of burden practice

2. Increase the distance between wall and maximum coke / (coke + ore) ratio along the radius. The target is to limit thermal loads and maintain a good lifetime of the shaft. (fig. 16) (See also fig 20 about gas distribution DK4: Oct99).

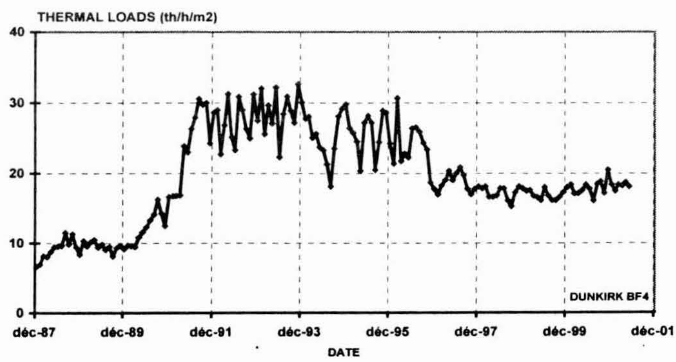


Figure 16 : Evolution of thermal losses on BF4 (Dunkirk)

3. Develop the central flow using central coke charging or improving the burden segregation along the radius (fig 17).

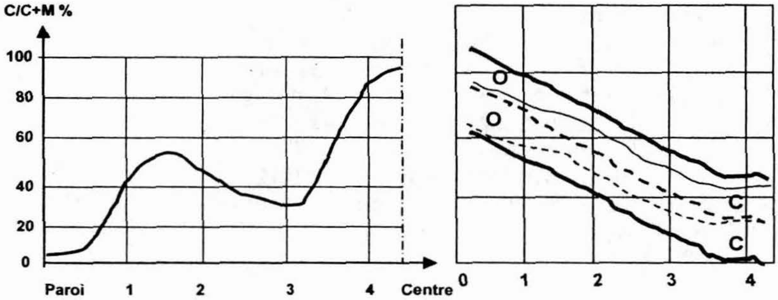


Figure 17 : Burden profiles and coke distribution (Fos)

Since some years, we have installed, on all our blast furnaces, radar profilemeters to improve the control of burden distribution in the shaft. This equipment is used for a good and quick adjustment of the gas distribution with the coal injection rate.
To understand the major evolutions of the thermodynamical phenomena in the shaft, we practice a multi-point probing using a tool developed by IRSID (Fig 18 shows an example of measurement results)

Figure 18 : Example of temperature distribution (mullet points probing)

By this way, we have a good image of the gas and temperature distribution in the shaft. It's also possible to estimate the smelting zone and to adopt the better countermeasure to optimise Blast-Furnace operation.

### 2.2.3- Blast conditioning

Blast conditioning (O2, flame temperature, top gas temperature, kinetic power...) is very important for BF operation control, especially with high injection level. Actions depend on local context of each blast furnace.
For example at SOLLAC DUNKERQUE BF 4, after the starting of a 2nd injection tower (1996), new rules were defined to adjust blast conditioning, taking in account increasing of the coal injection level. Main targets are:

- Constant top gas temperature: 100~120°c
- Constant production
- Higher blast temperature: 1230~1240°c

Calculations, with Blast Furnace mathematical model (MMHF) developed by I.R.S.I.D, have permitted to quantify these rules and to adapt them to operational conditions.

### 2.2.4- Control thermal state of the blast furnace

To optimise the consumption of reducing agents, it is necessary to reach a good level of control of blast furnace thermal state. USINOR has developed during the last ten years on line operator guide, and in particular the expert system called SACHEM. Main goal of these tools is to propose actions to maintain the thermal state of the blast furnaces at the optimum level. Sachem is operational in Fos/Mer, Patural, on the blast furnace n°4 of Dunkirk, and in adaptation on the HF2 of Dunkirk.

### 2-3 Intermediate Conclusion

The achievement of high levels of coal injection requires a good control of the blast furnaces operations. Many actions are carried out to progress in process control. The results obtained until today show that it is possible to reach reductions in coke consumption higher than those expected by the simple effect of replacement ratio of coal injected (see on figure 19 shows it in the case of BF1 of Fos/Mer).

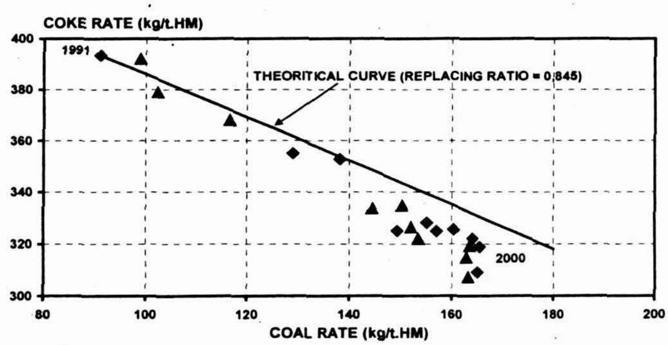


Figure 19 : Evolution of coke and coal rate (Fos blast furnaces)

## 3- AN EXAMPLE OF OPERATION WITH LOW COKE RATE

The operational results of Dunkirk blast furnace n°4 in October 1999 are a good illustration of a blast furnace operating point with low coke rate. These results are presented in table n°4.

This furnace is the biggest blast furnace in France (14 m of hearth diameter). The last campaign began in 1987 and ended in summer this year (2001). The relining is in progress and the blowing in is forecast for October.

| DK 4 October 1999 | | |
|---|---|---|
| Production | (t) | 277 392 |
| Productivity | (t/d) | 9 024 |
| | (t/m³/d) | 59 |
| CONSUMPTION | (kg/thm) | |
| | . large coke | 265 |
| | . small coke | 31 |
| | . coal | 178 |
| | total equiv. | 442 |
| BLAST | | |
| Blast volume | (kNm3/h) | 335.3 |
| Oxygen | (kNm3/h) | 15.4 |
| | (%) | 24.2 |
| Temperature | (°C) | 1235 |
| Moisture | (g/Nm3) | 10.0 |
| Flame T° | (°c) | 2101 |
| Blast speed (Tuyere) | (m/s) | 225 |
| BURDEN | | |
| Sinter | (kg/t) | 1178 |
| Lump ore | (kg/t) | 250 |
| Pellets | (kg/t) | 197 |
| Total | | 1625 |

| DK 4 October 1999 | | |
|---|---|---|
| PERMEABILITY | | |
| Pressure loss | (bar) | 1.27 |
| TOP CONDITIONS | | |
| Top temperature | (°C) | 105 |
| Top pressure | (bar relative) | 2.05 |
| Dust | (kg/thm) | 5 |
| COKE QUALITY | | |
| H2O | (%) | 5.5 |
| I 20 | (%) | 78.9 |
| I 40 | (%) | 50.3 |
| SINTER QUALITY | | |
| < 5 mm | (%) | 5.4 |
| 5 - 15 mm | (%) | 47.1 |
| ISO | (% > 6.3 mm) | 80.1 |
| Fe2+ | (%) | 6.3 |
| COAL QUALITY | | |
| < 200 µ | (%) | 90.4 |
| HOT METAL QUALITY | | |
| Température | (°C) | 1496 |
| Si | (%) | 0.367 |
| St dev. Si | (%) | 0.137 |
| S | (%) | 0.024 |
| Slag volume | (kg/t) | 288 |

Table 4 : Results of BF4 (Dunkirk) in October 1999

As it can be seen, the coke consumption is low (less than 300kg/t.HM) with only 265kg/t.HM of large coke.

During the same periods the other parameters or results are satisfactory :
- Top conditions have been maintained : the top gas temperature is good (105°c) and the dust rate is limited (6kg/t.HM).
- The quality of burden and injected coal are steady and in accordance with the targets.
- The hot metal quality is good with a Si standard deviation of 0.137 %.

Burden and gas distributions in the shaft are indicated on figure 20. The height layer is low and the maximum coke ratio is close to 2,5m from the wall. With an average top gas temperature of 105°C, the central temperature is higher 500°c and the gas efficiency (CO2/(CO+CO2)) is higher than 40%. The upper and lower curves indicate the minimum and maximum values of these parameters during the month. The stability of the gas distribution is an indicator of the stability of blast-furnace operation.

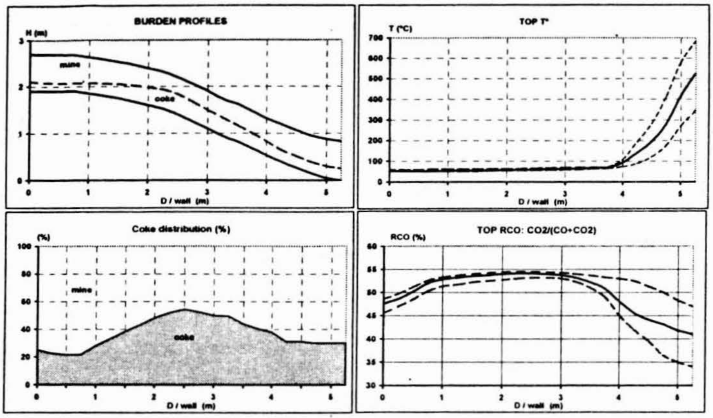


Figure 20 : Burden and gas distribution (DK4 Oct 1999)

## 4 CONCLUSIONS

The achievement of low levels of coke consumption is an objective, which takes part in the improvement of the competitiveness of USINOR ironmaking plants. This target is, in addition, coherent with the evolution of the industrial outline. The results obtained are encouraging : in 1999 among the five blast furnaces in Europe whose coke consumption was lower than 310kg of coke per tons of hot metal, three are blast furnaces of Usinor (cf fig.21).

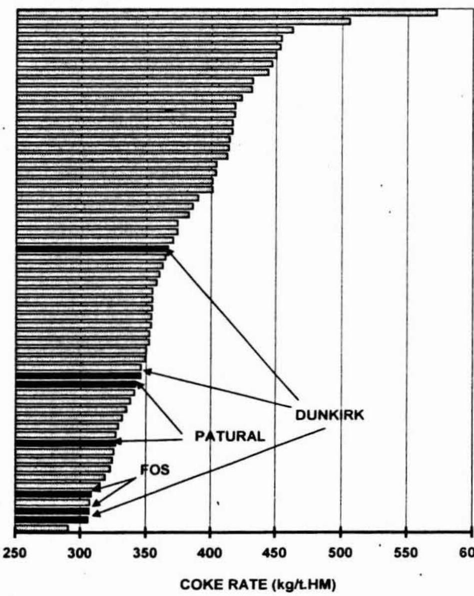


Figure 21 : coke rate for European blast furnaces (1999)

In the future we will continue to progress in the two directions:

- Increase of coal injection : our philosophy is to increase the ratio of coal step by step to preserve a good control of blast furnaces operation even with high levels of injection, and thus to ensure the profitability of the investments which will be necessary for that. The figure 22 shows the levels of injection that would have to be reached to ensure a self-sufficiency coke supply for the different ironmaking plants in various scenarios of production.

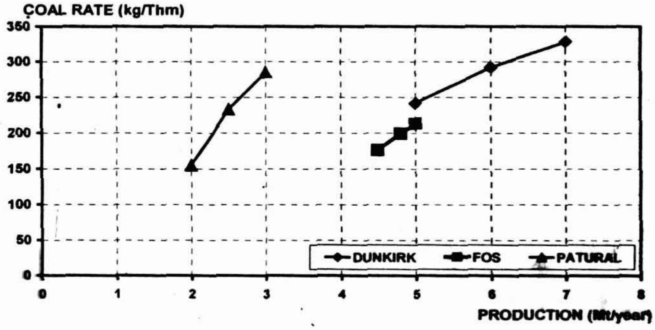


Figure 22 : coal injection rate needed for self-sufficiency coke supply

- Reduction in the consumption of reducing agents : that means an always better control of blast furnaces operations. The actions carried out at Usinor aiming to a better understanding of the internal phenomena, to an improvement of burden regularity and quality and to the stabilisation and optimisation of the operation participate to the achievement of this target.

| | DUNKIRK BF 4 | FOS BF1 | PATURAL BF 6 |
|---|---|---|---|
| COAL RATE (kg/t.HM) | 195 | 183 | 200 |
| COKE RATE (kg/t.HM)* | 296 | 302 | 289 |
| TOTAL COKE EQ. (kg/t.HM) | 455 | 461 | 460 |

* (Including nut coke)

Table 5 : Results of 3 French blast furnaces in June 2001

The results obtained recently on 3 blast furnaces (on a month basis : see table 5) show that the improvements in terms of coke consumption continue in the three ironmaking French plants of Usinor.


[1] : Conditions for achieving very low coke rate in the blast furnaces
(F. Didelon / Ph. Lacroix / JM. Libralesso / D. Sert) – ICSTI 98 - Toronto