

Application of Optimal Sinter Burden Design

Yanling Zhang¹⁾, Junshan Gao²⁾, Shiqi Li¹⁾, Liming Kang³⁾, Lina Fu³⁾

1) Metallurgy School, University of Science and Technology Beijing, Beijing 100083, China

2) Management School, University of Science and Technology Beijing, Beijing 100083, China

3) Tangshan Iron & Steel Corp., Tangshan 063000, China

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Abstract: The application of the optimal sinter burden design in the sinter shop of No.1 Iron-making Plant in Tangshan Iron & Steel Corp was reported. By using burden calculation and simulating production under different situations, it is demonstrated that the technology can provide the relevant information in product quality and cost etc. for decision-makers. The technology has been used to guide production of the Sinter Shop since 2000, and a remarkable achievement has been obtained.

Key words: computer aided decision-making; optimal burden design; sinter

1 Optimal Sinter Burden Design (OSBD)

1.1 Mathematical Model

(1) Decision variable. Burden feed X_j ($j = 1, 2, \dots, m$), where m is the total number of feeds used. In practice m can be up to 50.

(2) Constraints. (a) Sinter quality requirement: including sinter composition such as R_2 , w_{TFe} , w_{SiO_2} , w_{MgO} (mass fraction, so as the follows.) etc. and its metallurgical property constraints. Both lower and upper limits are specified. (b) Feed material availability constraint. (c) Nonnegative constraint: $X_j \geq 0$.

(3) Objective function. The burden cost $f(X)$ is taken as the objective function:

$$\min f(X) = \sum_{j=1}^m C_j X_j \quad (1)$$

where C_j is the price of raw material j ($j = 1, 2, \dots, m$).

Clearly, this is a non-linear programming problem, because constraints on R_2 , w_{TFe} , w_{SiO_2} , w_{MgO} etc. are non-linear functions of decision variables. Since it will be an extremely difficult task to solve such a large scale non-linear programming model, even to prove the existence and uniqueness of its solution, the model has been tried to turn into a linear one, details of that have been reported in references [1,2].

1.2 Software development

The framework of this software is shown in figure 1.

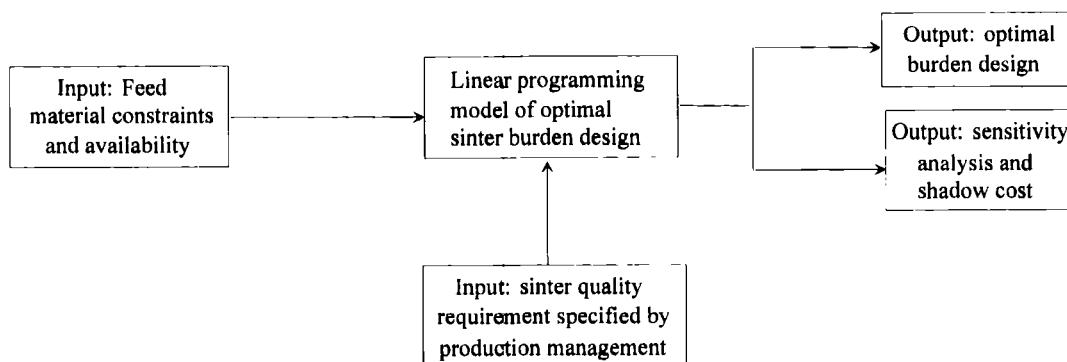


Figure 1 The software framework of OSBD.

This software is developed with Microsoft Visual Basic 6.0 and Microsoft ACCESS Data Base.

2 Engineering Background

No. 1 Iron-making Plant in Tangshan Iron & Steel

Corresponding author: Yanling Zhang
E-mail: ZYL268@263.net

Corp (No.1 Iron-making Plant of TISC) has two sintering machines each with 24 m^2 grate area, which provide an annual capacity of $9 \times 10^5\text{ t}$ sinter. There are 10 feed channels in burdening section. Feed is charged by a rotary table feeder which keeps the feeding accuracy within $\pm 2\%$ error. Samples are taken and examined every 2 h, and the results will return in 2 h.

Raw materials for sinter include iron-bearing materials, flux and fuel. In this shop, iron-bearing materials come from over thirty local mines that are varied in contents and prices. In addition, steel making or iron making by-product such as steel-slag, mill scale, flue-dust, steel-making slurry, returned sinter and returned pellet etc. must be consumed, which are characterized by a wide fluctuation of chemical compositions and prices: w_{TF} 27.6%–69.0%, price 14–280 ￥/t. The traditional way of burden design is by trying method: fix certain feed materials first and then adjust other feed materials until the final chemical composition is satisfied, i.e. w_{TF} in sinter is around its target value $\pm 1.0\%$, and R_2 around its target value ± 0.1 . Obviously, it is hard to get stable product quality by this way due to the amount of work within limited time. Furthermore, cost hasn't been considered in burden calculation.

Compared with the traditional burden design method, the optimal sinter burden design has advantages both in product quality and burden cost, because the latter searches the optimal solution in feasible zone [3,4]. "Optimal" means the lowest cost and "feasible" means all of constraints are met, where w_{TF} will be kept around its target value $\pm 0.25\%$ and R_2 will be kept around its target value ± 0.03 .

3 Three Level Applications of OSBD in No.1 Iron-making Plant of TSIC

In the sinter shop of No. 1 Iron-making Plant of TSIC, OSBD has been applied on the following three levels: shop floor level, short-term planning level, medium and long-term planning level. The framework of application is shown in figure 2.

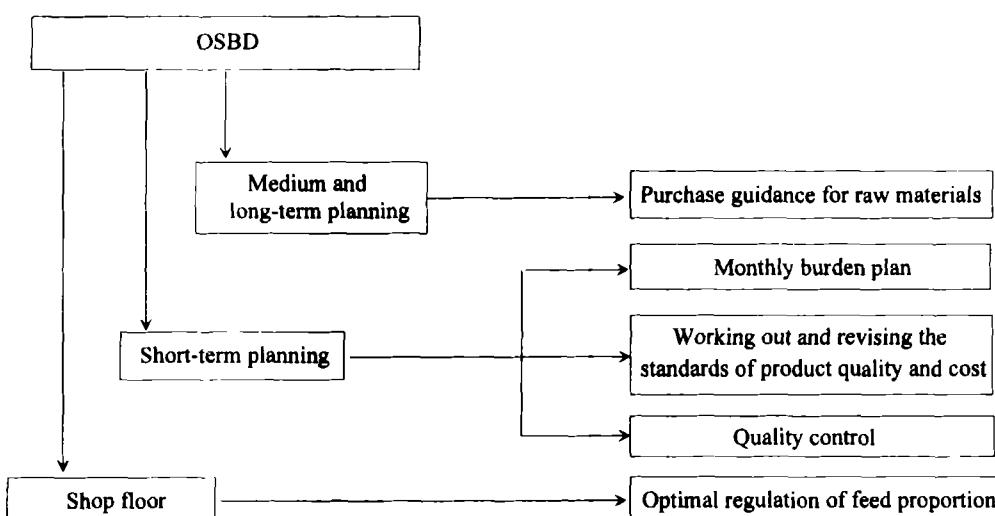


Figure 2 OSBD framework of application in No. 1 Iron-making Plant of TSIC.

3.1 Application on shop floor level

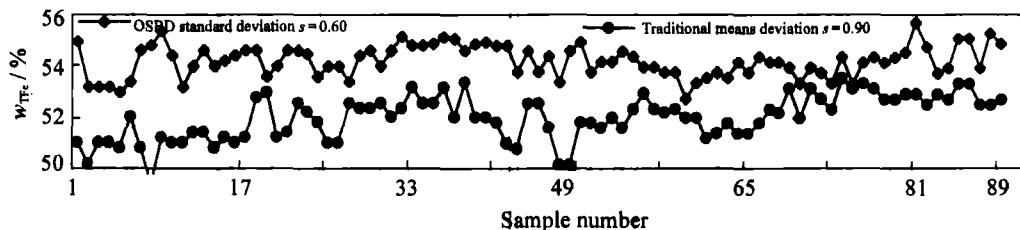
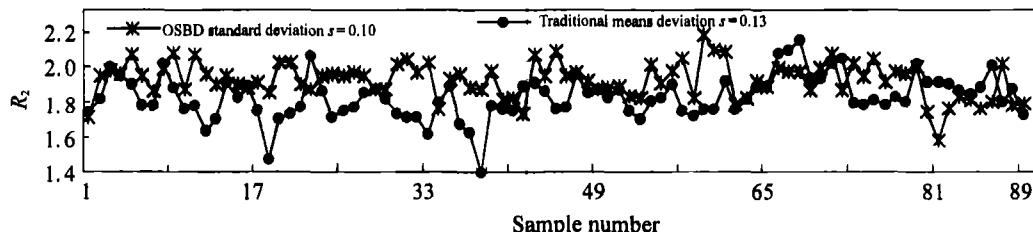
Once sinter chemical composition was found out of target range, it is necessary to adjust the feed proportion for the sake of quality steadiness. Traditional way is: adjust two or three feed materials of the burden design according to experience, and then test if the result can meet the requirement. For example, if R_2 is lower than its target value by 0.1, increasing limestone proportion by 1% and decreasing iron fines by 1% will be tried, if R_2 is still not qualified after a period of time (usually as 8 or 16 h), another adjustment will be made. Obviously, serious disadvantages exist in this way, such as keeping one composition correct and often resulting in others' fluctuation. OSBD can avoid this since in the feasible zone, it will always meet all the constraints. When one or more constraints changed, OSBD will give a new solution based on new feasible zone, which will meet all constraints.

Comparisons of R_2 and w_{TF} between sinter produce using traditional method of burden design in Nov. 1999 and industrial test period using OSBD in Dec. 1999 in No.1 Iron-making Plant of TSIC are shown in figures 3 and 4, and the related average value and standard deviation are shown in table 1. As can be seen clearly, OSBD increases w_{TF} and R_2 and keeps product contents surge in a narrower range, thus good and more stable product quality can be obtained.

3.2 Application on short-term planning level

(1) Working out a monthly burden plan.

On the short-term plan level OSBD can be used to help to work out the monthly burden plan. Table 2 shows the comparison of raw material quality between the plans in Sept.1999 made by the conventional methods and an recalculation with the assistance by OSBD under the same raw material condition. It can be seen that

Figure 3 Comparison of w_{TFe} fluctuation.Figure 4 Comparison of R_2 fluctuation.Table 1 Comparisons of w_{TFe} and R_2

Time	$w_{TFe} / \%$		R_2	
	Average value	Standard deviation	Average value	Standard deviation
Nov. (traditional way)	52.04	0.90	1.83	0.13
Dec.(OSBD)	54.25	0.60	1.93	0.10
Improvement	+ 2.21	-0.30	+ 0.10	-0.03

Table 2 Comparison of two kinds of monthly burden plan

Raw material	Traditional plan / %	Optimal plan / %	Cost/YUAN·t ⁻¹	$w_{TFe} / \%$	$w_{SiO_2} / \%$	$w_{CaO} / \%$	$w_{MgO} / \%$	R_2
Concentrate	52.09	50.93	190	63.78	8.56	1.00	0.80	—
Returned pellet	2.53	2.68	170	60.39	9.54	1.70	1.08	—
Returned sinter	10.14	10.72	160	50.02	7.73	15.60	3.96	—
Steel-slag	4.36	4.47	18	27.52	9.96	26.70	10.22	—
Steel-making slurry	5.63	5.36	120	60.59	6.09	4.40	1.66	—
Lime	4.40	4.64	160	0.00	5.43	80.80	7.92	—
Iron pieces	3.48	3.57	140	70.00	6.00	1.00	0.00	—
Limestone	6.97	7.14	36	0.00	2.01	49.20	4.50	—
Dolomite	5.86	6.07	36	0.00	1.78	31.00	20.45	—
Coke fine	4.55	4.63	220	0.00	5.86	1.32	0.03	—
Sinter by conventional method		184.92		54.60	7.19	12.83	3.93	1.78
Sinter with the assistance of OSBD		181.75		55.03	7.23	12.53	3.68	1.73

with OSBD assistance, w_{TFe} was increased by 0.43% and sinter cost was decreased by 3.17 YUAN (RMB)/t, the benefit increased obviously.

(2) Working out or revising product quality and cost standard.

The main changing factors to affect product quality and cost in sinter production are raw material condition, while the equipment performance and staff operation remain almost the same level. Therefore standards of quality and cost must be kept with the current material conditions.

The highest and the optimum product grade with dif-

ferent kinds of concentrate (sinter $R_2=1.95\text{--}2.05$) are shown in table 3, where the optimal grade refers the sinters produced when lowest cost is achieved (Note: comparable cost is the cost at the same product grade, which is 53.5% in table 3).

Technicians of No.1 Iron-making Plant of TSIC have timely revised standard based on this to guarantee product quality. First, raw material quality requirement were put forward according to fixed sinter quality standard, for example, when sinter composition target was $R_2 2.0$, $w_{TFe} 54.5\%$, Qianxi concentrate of $w_{TFe}\geq 65.5\%$ was required, while Qianan and Zunhua concentrate of

Table 3 Effect of different kinds of iron concentrated powders on sinter

Raw material			The highest grade			The optimum grade		
Name	w_{TFe} / %	w_{SiO_2} / %	Grade / %	Cost / YUAN·t ⁻¹	Comparable Cost/ YUAN·t ⁻¹	Grade / %	Cost / YUAN·t ⁻¹	Comparable Cost/ YUAN·t ⁻¹
Qianan concentrate	66.5	6.3	55.2	188.93	181.44	53.5	179.96	179.96
	66.0	6.8	54.6	186.85	182.14	53.0	178.00	180.21
	65.5	7.3	53.8	183.22	181.90	52.5	176.04	180.45
	65.0	7.8	53.2	181.11	182.43	52.0	174.07	180.69
	64.5	8.3	52.5	179.33	183.74	52.0	175.36	181.98
Qianxi concentrate	67.0	5.0	56.6	193.57	179.90	54.5	183.15	178.74
	66.5	5.5	55.8	190.23	180.09	54.0	181.19	178.98
	66.0	6.0	55.2	187.61	180.17	53.2	177.95	179.27
	65.5	6.5	54.5	185.36	180.95	53.0	177.30	179.51
	65.0	7.0	53.8	182.55	181.22	52.5	175.35	179.76
Zunhua concentrate	66.5	6.0	55.5	189.92	181.10	54.0	181.94	179.73
	66.0	6.5	54.8	187.16	181.42	53.5	180.01	180.01
	65.5	7.0	54.2	184.39	181.30	52.5	175.41	179.82
	65.0	7.5	53.4	181.45	181.89	52.0	173.91	180.52
	64.5	8.0	52.6	178.04	182.89	52.0	174.31	180.92

$w_{TFe} \geq 66.0\%$ were required. Product quality standard will be revised when material situation varies. For example, in Sept. 2000, only Qianan concentrate with $w_{TFe} \leq 66.0\%$ was sufficient, the optimum grade of sinter thus should be 52.5%–53.0%, therefore sinter grade was temporarily revised to 52%–54% from Sept 4th to Sept 16th in 2000.

Comparison of burden ($w_{TFe} 54.0\% \pm 0.5\%$, $R_2 2.0 \pm 0.05$) cost between different kinds of concentrate at different quality level is shown in **Figure 5**. Based on these data one can see the burden cost should be 181.10–182.0 YUAN(RMB)/t if high quality concentrate with $w_{TFe} \geq 66.0\%$ is sufficient, otherwise it should be 182.17–182.84 YUAN (RMB)/t under the worsened concentrate with $w_{TFe} < 66.0\%$.

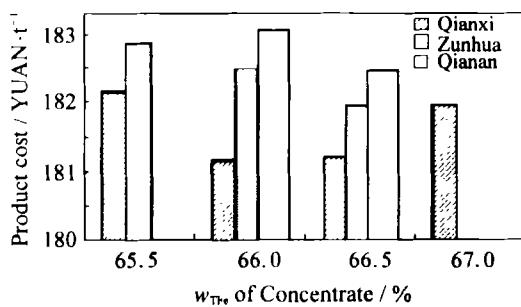
(3) Quality control.

Quality control is an important task to the enterprise. The total quality management puts prevention as the first and requires as few as possible or no defective products formed during the production of process. In the

sinter shop of No.1 Iron-making Plant of TSIC, feed performance variation is the main cause lead to unqualified products. For example, w_{TFe} of returned sinter is always lower than the ordinary sinter even if the material structure and other feed quality don't vary. But these returned sinters with lower w_{TFe} have to be consumed, which will make the final products grade tend to drop, and even result in out-of-grade product. With the help of OSBD it can predict when product grade will reach prescribed minimum after a burden plan is worked out, and then select one or two types of high-class concentrate with proper price, which will move sinter grade. By the same principle, time of reaching upper limit can be predicted, thus correspondingly concentrate with inferior quality and low price can be selected to bring product grade into required level. Product quality can be guaranteed by repeating the course with a low burden cost. **Figure 6** shows the sinter' grade fluctuation from 11th to 30th in Nov. 2000 when OSBD was used to guide quality control.

3.3 Application on medium and long-term planning level

With OSBD, the effect of feed with different ingredients on product cost can be obtained by using sensitivity analysis, so is the corresponding reasonable price for material with different quality level. **Figure 7** shows the comparison of simulated burden cost among the following three kinds of concentrates whose price was fixed on the principle above, where price of A is thought as standard. In this simulation, the fuel and flux were kept same and product $w_{TFe} 53.5\% \pm 0.5\%$, $R_2 1.95\text{--}2.05$. Therefore, three types of burden cost are al-

**Figure 5 Comparison of production cost by using different concentrate.**

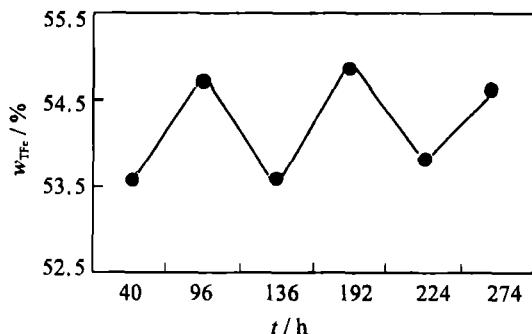


Figure 6 Circulation for w_{TFe} of product.

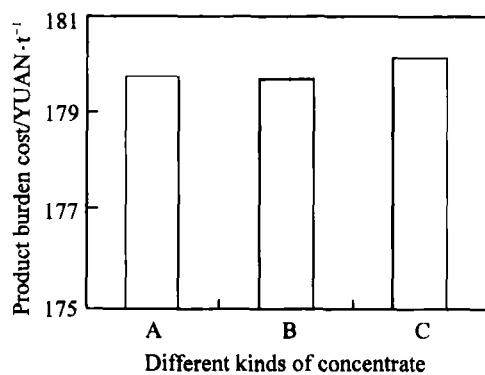


Figure 7 Comparison of burden cost, A: w_{TFe} 66.0%, w_{SiO_2} 6.6%, 215 YUAN/t; B: w_{TFe} 66.0%, w_{SiO_2} 6.0%, 216.8 YUAN/t; C: w_{TFe} 65.5%, w_{SiO_2} 7.3%, 210.65 YUAN/t.

most at the same level, which means that the price is reasonable.

4 Conclusions

(1) Using OSBD to guide sinter production of No.1

Iron-making Plant in TSIC in 2000, sinter quality has been improved: steadiness ratio of w_{TFe} was increased by 0.58%, that of R_2 by 13.65%, and the overall ratio of product up to standard was increased by 8.98%; sinter w_{TFe} increased by 2.62%; comparable sinter cost reduced: by an average 1.74 YUAN(RMB)/t, and the total economic benefit was up to 1.66 million YUAN(RMB) per year (benefit brought by other factors was deducted already).

(2) The introduction of computer-aided operation in the sinter shop reduced the working intensity greatly. Furthermore, it demonstrated that computer-aided decision-making in planning and production management at various levels was feasible.

(3) If this technology can be spread to other sinter shops, to burden design procedures of metallurgical production processes, more remarkable achievement will be obtained.

References

- [1] L. H. Zhou. *Model Structure and Means for Optimal Sinter Burden Design* (in Chinese) [D]. Beijing: University of Science and Technology Beijing, 2000, p. 30.
- [2] Y. L. Zhang, S. Q. Li, J. Wu. *Journal of University of Science and Technology Beijing* (in Chinese) [J]. 22 (2000), Special Issue, p. 94.
- [3] Y. Z. Jia, S. R. Wang, S. Q. Li. *Iron and Steel* (in Chinese) [J]. 30 (1995), p. 1.
- [4] Y. C. Cai, S. Q. Li. *Iron and Steel* (in Chinese) [J]. 25 (1990), p. 24.