PROCEEDINGS OF THE FIRST AUSTRALIA-CHINA-JAPAN SYMPOSIUM ON IRON AND STEELMAKING

第一届澳中日钢铁冶金学术研讨会论文集

主　编　赫冀成
副主编　邹宗树

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Economical Steel Manufacturing Process

Ruiyu YIN, Chunxia ZHANG

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ABSTRACT

Chinese steel industry has successively implemented six key technologies since 1990s, which settled stable foundation for further development.

In the 21st century, Chinese steel industry should fully exert the three functions-function of steel product manufacture, function of energy conversion and function of waste reusing. The integration and re-construction of new generation steel manufacturing process should be based on the existing advanced technologies and equipment, combined with the newly developed technologies and equipment and advanced interface technologies. Supported by the clean steel production technologies with high efficiency and low cost, "interface" technologies of dynamic-orderly operation, integrated technologies of process engineering, technologies of energy conversion systematically and efficiently, re-resource utilization technology for wastes, eco-industrial linking technology and technology of precise process designing and operation management with IT, steel industry will achieve resource saving and environment friendly, the eco-industrial conditions will be created for steel enterprises to get along into circulative economy society.

The Study of Metal Cycles in China

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1 INTRODUCTION

At the end of 1999, we began to think over the problem: "Why has China's steel industry been severely deficient in scrap resources for a long time, while in other countries the situation has been better or much better?" We felt that it is a problem of substance flow analysis (SFA). The key for solving the problem was the exploration of a model and the formulation of some indicators, which are suitable for the analysis. Thus, we conceived a model of Fe-flow in the life cycle of steel product, and formulated resource and environmental indicators for the flow analysis. Based on the model and indicators, theoretical study and practical verification were carried out. We found that the main reason of severe deficiency in scrap resources for steel industry in China is its continued rapid growth of steel output.

After that, we began to study lead, iron and copper cycles in China by using both the model we conceived and the model widely used in existing literature. These studies have been carried out in the period of 2002-2005.

In this period of time, we were interested in studying the methodological problem of SFA, and the study is still continuing now.

2 Exploration of the model and indicators for Fe-flow analysis

It was the first stage in the course of our study on metal cycles in China.

2.1 The model of Fe-flow in the life cycle of steel product

Fig. 1 shows the model of Fe-flow in the life cycle of steel product in a nation, which we explored for studying the scrap resource problem of steel industry.

The year of interest is designated as the year τ, during which the annual output of steel of the nation is P_τ t/a. The span of a product life cycle is assumed to be $\Delta\tau$ years. In the year (τ-$\tau\Delta$), the annual output of steel of the nation is $P_{\tau-\Delta\tau}$ t/a. The import and export of steel scraps, products and goods are not taken into consideration in the model.

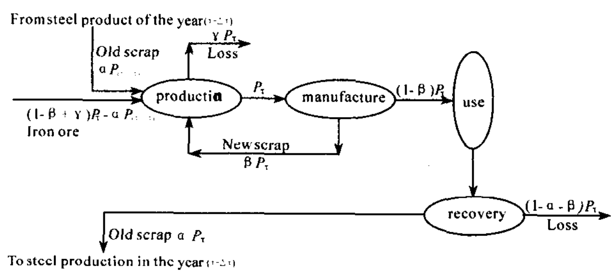

Figure 1 Typical graph of reaction rate vs. temperature during sample cooling.

Each product life cycle consists of four stages, i. e. production, manufacture, use and recovery. All the flow rates indicated in Fig. 1 are not that of materials in kind, instead they are the flow rates of Fe contained in flowing materials. As just mentioned, the output of steel in the year τ is P_τ t/a. When it flows through manufacture stage, it split into two parts: βP_τ t/a of new scraps and From steel product of the year (τ-$\Delta\tau$) $(1-\beta)p_\tau$ t/a of steel goods. The new scraps are recycled to production stage, while the steel goods flow to use stage. In recovery stage, αP_τ t/a of old scraps are recovered from retired steel goods. Old scraps will go to the production stage in the year$(\tau+\Delta\tau)$. The unrecovered$(1-\alpha-\beta)P_\tau$ t/a of steel wastes and γP_τ t/a of iron losses in production stage are dissipated into environment.

Similarly, the old scraps $\alpha P_{\tau-\Delta\tau}$ t/a fed to the production stage in the year τ comes from the steel produced in the year$(\tau-\Delta\tau)$.

According to mass balance calculation, $(1-\beta+\gamma)P_\tau-\alpha P_{\tau-\Delta\tau}$ t/a of Fe is needed from iron ore input for steel production in the year τ.

Please note that there are some additional assumptions for Fig. 1, i. e. (1) new scraps go back to production stage in the same year of their generation; (2) all recovered old scraps go to production stage in the same year of their generation, i. e. the year$(\tau+\Delta\tau)$.

Now, the definition of variables α, β and γ will be given below.

Let the annual input of recovered old scraps to the production stage in the year τ is equal to $A=\alpha P_{\tau-\Delta\tau}$;

the quantity of new scraps generated in the manufacture stage in the year τ is equal to $B=\beta P_\tau$;

the quantity of iron losses in the production stage in the year τ is equal to $C=\gamma P_\tau$.

Therefore

$$\alpha=\frac{A}{P_{\tau-\Delta\tau}} \qquad (1a)$$

$$\beta=\frac{B}{P_\tau} \qquad (1b)$$

and $$\gamma=\frac{C}{P_\tau} \qquad (1c)$$

Eq. (1a, 1b, 1c) are the definition equations of variables α, β and γ.

2.2 Resource and environmental indicators for Fe-flow analysis

In Fig. 1, each flow rate in the product life cycle is expressed as a formula, which consists of, in maximum, five variables, i. e. : P_τ, $P_{\tau-\Delta\tau}$, α, β and γ. Thus, it is able to derive formulas of resource and environmental indicators for Fe-flow analysis.

(1) Steel scrap index

Steel scrap index in the year τ, S_τ, is equal to the sum of the input of old scraps and new scraps to the production stage in the year τ, $\alpha P_{\tau-\Delta\tau}+\beta P_\tau$, divided by the output of steel in the same year, P_τ. That is

$$S_\tau=\frac{\alpha P_{\tau-\Delta\tau}+\beta P_\tau}{P_\tau} \qquad (2)$$

or $$S_\tau=\alpha\frac{P_{\tau-\Delta\tau}}{P_\tau}+\beta \qquad (2')$$

Steel scrap index defined by eq. (2), (2′) is the criterion of the richness of steel industry in scrap resources in the year τ. The higher the value of S_τ, the richer is the steel industry in scrap resources, and vice versa.

It is essential to point out that the variation of annual output of steel of a nation has significant influence on the value of S_τ of that nation. Eq. (2) or (2′) tells us that

—if the output of steel keeps constant, i. e. $P_\tau=P_{\tau-\Delta\tau}$, the value of S_τ will be equal to $\alpha+\beta$;

—if the output of steel increases, i. e. $P_\tau>P_{\tau-\Delta\tau}$, the value of S_τ will be smaller than $\alpha+\beta$;

—if the output of steel decreases, i. e. $P_\tau<P_{\tau-\Delta\tau}$, the value of S_τ will be higher than $\alpha+\beta$.

In addition, eq. (2) and (2′) tells us that if $\alpha=0$, the value of $\frac{P_{\tau-\Delta\tau}}{P_\tau}$ will have no influence on the value of S_τ. In any case, it is equal to β. On the contrary, if $\alpha=1$, $\frac{P_{\tau-\Delta\tau}}{P_\tau}$ will have the greatest influence on the value of S_τ, which is equal to $\frac{P_{\tau-\Delta\tau}}{P_\tau}+\beta$.

These are important and useful concepts in studying resource issues.

(2) Iron ore index

Iron ore index in the year τ, R_τ, is equal to the quantity of iron ore used by steel industry in the year τ, $(1-\beta+\gamma)P_\tau-\alpha P_{\tau-\Delta\tau}$, divided by the output of steel in the same year, P_τ. That is

$$R_\tau=\frac{(1-\beta+\gamma)P_\tau-\alpha P_{\tau-\Delta\tau}}{P_\tau} \qquad (3)$$

or $$R_\tau=1-\alpha\frac{P_{\tau-\Delta\tau}}{P_\tau}-\beta+\gamma \qquad (3')$$

Iron ore index defined by eq. (3) and (3′) is the criterion of the dependence of steel industry on iron ore. The higher the value of R_τ, the higher is the dependence of steel industry on iron ore.

Substituting eq. (2) into eq. (3), the relationship between R_τ and S_τ can be obtained:

$$R_\tau=1+\gamma-S_\tau \qquad (4)$$

It is evident from eq. (4) that the higher the value of S_τ, the lower is the value of R_τ under the condition of constant γ.

It is also essential to point out that the variation of annual output of steel of a nation has significant influence on the value of R_τ of that nation. Eq. (3) or (3') tells us that

—if the output of steel keeps constant, i. e. $P_\tau = P_{\tau-\Delta\tau}$, the value of R_τ will be equal to $1-\alpha-\beta+\gamma$;

—if the output of steel increases, i. e. $P_\tau > P_{\tau-\Delta\tau}$, the value of R_τ will be higher than $1-\alpha-\beta+\gamma$;

—if the output of steel decreases, i. e. $P_\tau < P_{\tau-\Delta\tau}$, the value of R_τ will be lower than $1-\alpha-\beta+\gamma$.

In addition, eq. (3) and (3') tells us that if $\alpha=0$, the value of $\frac{P_{\tau-\Delta\tau}}{P_\tau}$ will have no influence on the value of R_τ. In any case, it is equal to $1-\beta+\gamma$. On the contrary, if $\alpha=1$, $\frac{P_{\tau-\Delta\tau}}{P_\tau}$ will have the greatest influence on the value of R_τ which is equal to $1-\frac{P_{\tau-\Delta\tau}}{P_\tau}-\beta+\gamma$.

These are important and useful concepts in studying resource issues.

(3) Iron loss index

Iron loss index, Q, is equal to the quantity of iron losses in a life cycle of steel product, $(1-\alpha-\beta)P_\tau+\gamma P_\tau$, divided by the output of steel in the year τ, P_τ. That is

$$Q=\frac{(1-\alpha-\beta)P_\tau+\gamma P_\tau}{P_\tau} \qquad (5)$$

or $$Q=1-\alpha-\beta+\gamma \qquad (5')$$

It is evident from eq. (5') that Q is a function of α, β and γ. The higher the value of γ and the lower the values of α and β, the higher is the value of Q.

From eq. (3') and (5'), it is easy to find the relationship between Q and R_τ*:

$$Q=R_\tau+\alpha\left(\frac{P_{\tau-\Delta\tau}}{P_\tau}-1\right) \qquad (6)$$

Eq. (6) tells us that if $P_{\tau-\Delta\tau}=P_\tau$ or $\alpha=0$, Q will be equal to R_τ. That is to say that if the output of steel keeps constant or there is no recycling of old scraps, the Fe in iron ore input will totally transfer into losses or pollutants in the period of a life cycle of steel product.

These are also important and useful concepts in studying environmental issues.

3 Study of scrap resources for steel industry

It was the second stage in the course of our study on metal cycles in China.

3.1 Theoretical study

For the sake of simplicity, only illustrative examples will be given in this paper.

Referring to the model shown in Fig. 1, three illustrative examples will be given below with the following identical assumptions:

$\Delta\tau=20$ years, $\alpha=0.40$, $\beta=0.05$ and $\gamma=0.10$.

These examples differ from each other only in the variation of annual output of steel.

Illustrative example No. 1

The annual steel output of a nation has been keeping constant at 100×10^6 t/a for more than 20 years till the end of the year 2000. Draw its Fe-flow diagram in the life cycle of steel product of the year 2000 and calculate its steel scrap index and iron ore index of the same year.

Solution. The year 2000 is designated as the year τ. The year $(\tau-\Delta\tau)$ should be the year 1980, as $\Delta\tau=20$ years. Both the annual outputs of steel in 2000 and 1980 are equal to 100×10^6 t/a, as it has been keeping constant more than 20 years till the end of the year 2000. That is, $P_{2000}=P_{1980}=100\times10^6$ t/a.

Substituting all known variables, includingandinto the formulas of flow rates in Fig. 1, we get Fig. 2.

Fig. 2 is the Fe-flow diagram in the life cycle of steel product of the year 2000. In 2000, the steel industry consumed 65×10^6 t/a iron ore, 40×10^6 t/a old scraps, which are evolved from the steel produced in 1980, and 5×10^6 t/a new scraps generated in manufacture stage.

Similarly, from the steel produced in 2000, 40×10^6 t/a old scraps will evolve and go to steel industry in 2020.

According to eq. (2), the steel scrap index in 2000 is equal to

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* The reciprocal of R_τ and Q are "iron-resource efficience" respectively.

$$S_{2000}=\frac{(40+5)\times 10^6}{100\times 10^6}=0.46$$

And according to eq. (3), the iron ore index in 2000 is equal to

$$R_{2000}=\frac{65\times 10^6}{100\times 10^6}=0.65$$

<u>Illustrative example No. 2</u>

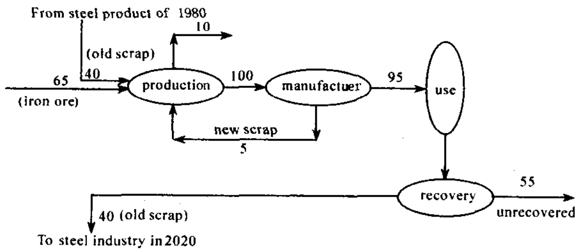

Figure 2 For illustrative example No. 1 ($\times 10^6$ t/a)

The annual steel output of a nation has been increasing rapidly. It was 40×10^6 t/a in 1980 and 120×10^6 t/a in 2000. Draw its Fe-flow diagram in the life cycle of steel product of the year 2000 and calculate its steel scrap index and iron ore index of the same year.

Solution. In addition to the known values of α,β,γ as given above, we know that

$P_{2000}=120\times 10^6$ t/a and $P_{1980}=40\times 10^6$ t/a.

Thus, the Fe-flow diagram in the life cycle of steel product of the year 2000 can be drawn, see Fig. 3.

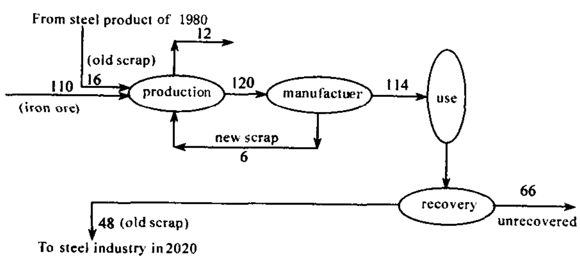

Figure 3 For illustrative example No. 2 ($\times 10^6$ t/a)

According to eq. (2), the steel scrap index in 2000 is equal to

$$S_{2000}=\frac{(16+6)\times 10^6}{120\times 10^6}=0.18$$

And according to eq. (3), the iron ore index in 2000 is equal to

$$R_{2000}=\frac{110\times 10^6}{120\times 10^6}=0.92$$

<u>Illustrative example No. 3</u>

The annual steel output of a nation had dropped a lot. It was 130×10^6 t/a in 1975 and 90×10^6 t/a in 1995. Draw its Fe-flow diagram in the life cycle of steel product of the year 1995 and calculate its steel scrap index and iron ore index of the same year.

Solution. In addition to the known values of α,β,γ as given above, we know that

$P_{1995}=90\times 10^6$ t/a and $P_{1975}=130\times 10^6$ t/a.

Thus, the Fe-flow diagram in the life cycle of steel product of the year 1995 can be drawn, see Fig. 4.

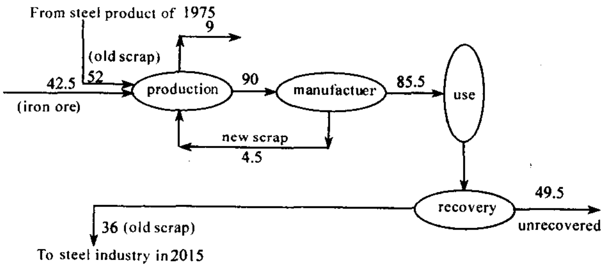

Figure 4 For illustrative example No. 3 ($\times 10^6$ t/a)

According to eq. (2), the steel scrap index in 1995 is equal to

$$S_{1995}=\frac{(52+4.5)\times 10^6}{90\times 10^6}=0.63$$

And according to eq. (3), the iron ore index in 1995 is equal to

$$R_{1995}=\frac{42.5\times 10^6}{90\times 10^6}=0.47$$

The calculated results in above three illustrative examples are listed in Tab. 1.

Tab. 1 Calculated results of illustrative examples No. 1, No. 2 and No. 3

ordinal No. of example	No. 1	No. 2	No. 3
steel scrap index	0.45	0.18	0.63
iron ore index	0.65	0.92	0.47

What is the reason of great disparities among the calculated results in illustrative examples? The unique reason is the variation of annual output of steel.

In example No. 2, the annual output of steel increased rapidly, so that the value of is low, and the value ofis high. In example No. 3, on the contrary, the annual output of steel had dropped down, so that the value ofis high, and the value ofis low. The situation of example No. 1 is between example No. 2 and No. 3.

3.2 Estimation of steel scrap index for Japan, China and USA

The history of steel output variation in the above illustrative examples No. 1, 2 and 3 are similar to that of Japan, China and USA, respectively. In order to check the calculation results in illustrative examples, the steel scrap indexes for Japan, China and USA were estimated on the basis of statistical data. The results of estimation are listed in Tab. 2.

Tab. 2 Estimated values of steel scrap indexes for Japan, PR China and USA

year	Japan	PR China	USA
1988	0.3400	0.1820	0.7514
1989	0.3638	0.1996	0.7580
1990	0.3793	0.2039	0.7346
1991	0.3766	0.1976	0.7823
1992	0.3980	0.1924	0.7390
1993	0.3838	0.1895	0.7472
1994	0.3852	0.1922	0.7298
1995	0.3763	0.1080	0.6321
1996	0.3967	0.0970	0.5627
1997	0.4133	0.0830	0.5767

Tab. 2 shows that the steel scrap indexes for Japan are in the range of 0.34 ~ 0.41, for China—0.10 ~ 0.18 and for USA—0.57 ~ 0.75. They coincide with the calculation results in illustrative examples pretty well.

3.3 Brief summary

(1) In case of increasing steel production, the scrap resources for steel industry is relatively deficient, and the more rapid the increase, the more is the deficiency.

In case of decreasing steel production, the scrap resources for steel industry is relatively rich, and the more rapid the decrease, the more is the richness.

The case of constant steel production is situated between the above two cases.

(2) The continued rapid growth of China's steel output is the main reason of severe deficiency in scrap resources for its steel industry. It is inadvisable and unfeasible for China to lay stress on scrap-based steelmaking process, so long as its steel production is increasing rapidly.

4 Study of iron, copper and lead cycles in China

It was the third stage in the course of our study on metal cycles in China.

The successful study of scrap resource problem by using the model described in this paper gave us the confidence of its application to metal flow analysis. Thus, my Ph. D. students, Ms. Mao Jiansu, Mr. Bu Qingcai and Mr. Yue Qiang began to study the lead, iron and copper cycles in China, respectively. They used not only the model described in this paper, but also the model widely used in existing literature.

The result of their study based on the model described in this paper will be given below.

Iron cycle in China

Fig. 5 shows the iron cycle in China in 2001.

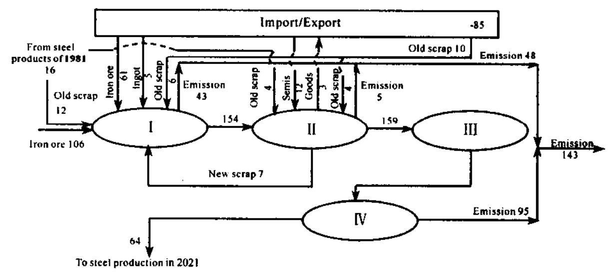

Figure 5 The iron cycle in China in 2001 (unit: 10^6 t)
I —Production; II —Fabrication&Manufacture; III—Use; IV—Waste Recovery

The average life span of steel products was determined to be 20 years.

The outputs of steel and steel goods in China in 2001 were 154×10^6 and 159×10^6t, respectively. The new scraps (7×10^6t) were recycled to production stage, while the steel goods (159×10^6t) flowed to use stage. In recovery stage, 64×10^6t (40% of steel goods produced in 2001) of old scraps were recovered from retired steel goods. These old scraps will go to the production stage in 2021. The unrecovered steel wastes (95×10^6t) and iron losses in stage I and stage II (48×10^6t) were dissipated into environment.

Similarly, 16×10^6t of domestic old scraps fed to the production and manufacture stage in 2001 came from the steel produced in 1981 (Besides, 10×10^6t of old scraps were imported for steel production and manufacture in 2001). In addition, 106 × 10^6t of Fe from domestic iron ore input and 61 × 10^6t of Fe from imported iron ore input was needed for the production.

It can be seen from Fig. 5 that large amount of iron-bearing resources (85 × 10^6t) was imported from overseas market.

The calculated values of iron ore index R and steel scrap index S were 1.117t/t and 0.162t/t (including 6 × 10^6t of imported steel scraps) in China in 2001, respectively. It means that the dependence of steel industry on iron ore was very high. It is the consequence of continued rapid growth of steel output. China's steel industry was obliged to operate mainly on iron ore. In addition, the value of iron loss index Q was high (0.929t/t), which was closely related to the high dependence of steel industry on iron ore.

Copper cycle in China

Fig. 6 shows the copper cycle in China in 2002.

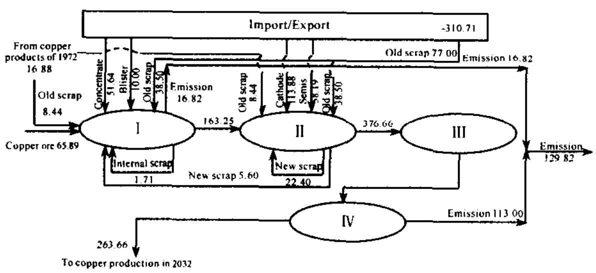

Figure 6 The copper cycle in China in 2002 (unit: 10^4 t)

Ⅰ—Production; Ⅱ—Fabrication&Manufacture;

Ⅲ—Use; Ⅳ—Waste Recovery

The average life span of copper products is 30 years.

The output of copper in China in 2002 was 163.25 × 10^4t. The output of copper goods (376.66104t) was much more than the output of copper, because large amounts of Cu-bearing resources were imported. From manufacture stage, new scraps (5.6 × 10^4t) were recycled to production stage. In recovery stage, 263.66 × 10^4t (70% of copper goods produced in 2002) of old scraps were recovered. These old scraps will go to the production stage in 2032. The unrecovered copper wastes (113.00 × 10^4t) and copper losses in production stage (16.82 × 10^4t) were dissipated into environment.

Similarly, 16.88 × 10^4t of domestic old scraps fed to the production and manufacture stage in 2002 came from the copper production in 1972 (Besides, 77 × 10^4t of old scraps were imported for copper production and manufacture in 2002). In addition, 65.89 × 10^4t of Cu from domestic copper ore input and 51.64 × 10^4t of Cu from imported concentrated copper ore input was needed for the production.

It also can be seen from Fig. 6 that large amounts of copper-bearing resources (310.71 × 10^4t) were imported from overseas market.

The calculated values of copper ore index R and copper scrap index S wereand (including 38.50 × 10^4t of imported copper scraps) in China in 2002, respectively. The copper loss index Q was 0.795t/t. The problems and challenges in copper cycle were similar to that in iron cycle as just mentioned.

Lead cycle in lead-acid battery system in China

Fig. 7 shows the lead cycle in lead-acid battery system in China in 1999.

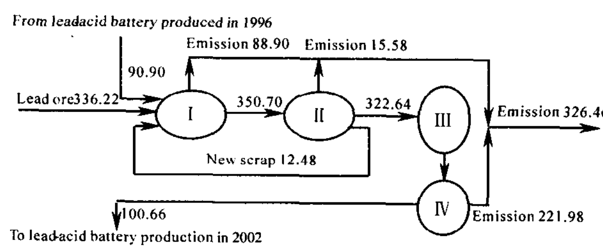

Figure 7 The lead cycle in lead-acid battery system in China in 1999 (unit: 10^3 t)

Ⅰ—Production; Ⅱ—Fabrication&Manufacture;

Ⅲ—Use; Ⅳ—Waste Recovery

The average life span of lead-acid battery is 3 years.

The output of lead-acid battery in China in 1999 was 322.64 × 10^3t. The domestic old scrap recycled in lead-acid battery system in 1999 was 90.90 × 10^3t, which came from the lead-acid battery of 1996. The quantity of lead losses in the life cycle of lead-acid battery was 326.46 × 10^3t.

The calculated values of lead ore index R and lead scrap index S wereandin China's lead-acid battery system in 1999, respectively. The lead loss index Q was 1.012t/t. The problems and challenges in lead cycle of lead-acid battery system were also similar to that in iron cycle.

5 Concluding remarks

(1) Continued rapid growth of metal production has been one of the most important characteristics of China's metal industry, to which attention should be paid in studying the resource and environmental issues of China's metal industry and metal system.

(2) The model of Fe-flow in the life cycle of steel product (Fig. 1) clearly shows the variation of steel output with time. Therefore, the scrap resource issues for steel industry were studied successfully by using the model.

(3) The study of iron, copper and lead cycles in China was carried out according to the model shown in Fig. 1. Thus, an alternative method of SFA was put forward and formulated.

(4) No discussion on the methodology of SFA was given in this paper, though it is an interesting topic. In this regard, we wrote a paper entitled "Two approaches of substance flow analysis-an inspiration from fluid mechanics", and it was submitted to the JIE last year.

(The reciprocal ofand Q are "iron-resource efficiency" and "iron-environment efficiency" respectively.

DEVELOPMENT OF RECENT IRON-MAKING TECHNOLOGY IN NIPPON STEEL

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ABSTRACT

Since the mid 1970s, Nippon Steel has promoted concentration of its facilities for greater efficiency. Against this background, this paper describes leading technology, which copes with high production while overcoming pressing issues, such as the obsolescence of equipment, degradation of resources, and environmental problems.

1 INTRODUCTION

NIPPON STEEL has grown by continuously adopting the latest technology while coping with changes in the environment.

Recently, we have been actively engaged in the following issues:

1) Raising production efficiency and coping with equipment obsolescence

2) Coping with the degradation of resources

3) Coping with the increasing scale of global environmental problems

Here, concrete examples and details of these activities are introduced, and we take a look at the direction of future technology.

2 Recent situation concerning iron & steel production in Japan

The Japanese production of crude steel and pig iron peaked at 120 million and 91 million tons, respectively, in 1973, and has been gradually declining ever since. Recently, however, aided by a favorable turn in the external environment, including the recovery of the domestic manufacturing industry, and the increased demand for iron & steel, alongside the development of the Chinese economy, a high level of production is being maintained for the first time in 30 years, with crude steel production in excess of 110 million tons, and pig iron production in excess of 82 million tons. (Fig. 1)

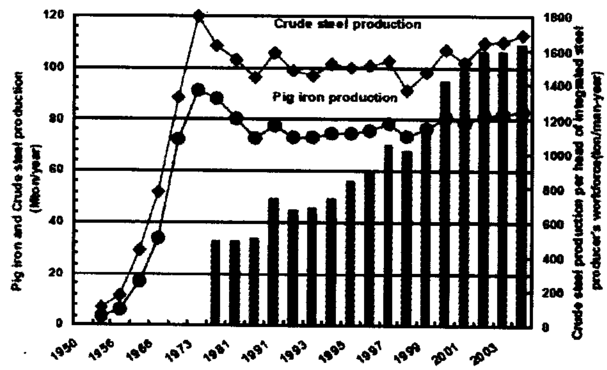

Figure 1 Trend of Japanese pig iron and crude steel production, and labor productivity

During this period, the number of blast furnaces was reduced from 68 in 1973 to the present 26, along with the increasing concentration of steel production at large-scale steelworks. (Fig. 2) Because high production was achieved at these concentrated facilities, production has reached 1,600 t/man-year, which is twice the labor productivity compared to that 10 years ago.

3 Raising production efficiency and coping with equipment obsolescence

3.1 Measures to Prolong the Service Life of Equipment

Some 40 years have passed since large scale steelworks were constructed in Japan, and their equipment is becoming increasingly obsolete. (Fig. 3) In particular, in the iron-making department, maintaining and re-