Activities of the Total Energy and Materials Control System Investigation Committee in the Japan Research and Development Center for Metals

Takashi NAKAMURA, Hidesato MABUCHI,1) Eiji OKADA1) and Hiroshi UESUGI2)

Institute for Advanced Materials, Tohoku University, Katahira, Aoba, Sendai, 980-8577 Japan.
1) The Japan Research and Development Center for Metals, Toranomon, , Minato-ku, 105-0001 Japan.
2) Technology Administration & Planning Dept., Kawasaki Steel Corp., Uchisaiwai-cho, Chiyoda-ku, 100-0011 Japan.

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Suppression of the explosion of the world population and the surprising increase of waste and emissions are major targets confronting mankind in the next century. Metal industries have consumed a tremendous amount of energy and discharged a large quantity of CO₂ and solid waste, although the metals they have produced have supported a high quality of life. Recycling and waste minimization are key words for sustainable development in a highly industrialized society.

The Total Energy and Materials Control System (TEMCOS) investigation committee began in 1997 in the Japan Research and Development Center for Metals (JRCM) to address these problems. The goal of TEMCOS is the achievement of zero waste and energy minimization to make a strong inter-process linkage between different industries. Activities of the committee are described here.

KEY WORDS: recycling; minimization of energy consumption; zero waste; inter-linkage of process.

1. Introduction

It has been well recognized since publication of “The Limits of Growth”¹ by the Roman Club that mass production systems for a large quantity of consumption will be changed due to the diffusion of the harmful waste and the drying up of resources (especially energy resources). Nevertheless, the present period can be called the most active in terms of material production and consumption in the history of human beings, although there is a great difference in the various parts of the world. The essence of the environmental problem now being faced is the result of the growth and diversification of production activity to maintain a comfortable human lifestyle and the discharge of too much untreated waste. However, it is very difficult to evaluate the ability of the earth to “clean itself up” scientifically, and is also difficult to rapidly change our present lifestyle. In the distant future we must have a new social system to reduce energy consumption and production activity based on a new philosophy. Therefore, cutting down the quantity of waste discharged without curtailing production activity is desired. This is the concept of “sustainable development”.

A change from ordinary production systems and processes which use the best virgin raw materials to novel high efficiency systems and processes using secondary raw materials is requisite in the metal production industry.

This report summarizes the activity of the TEMCOS investigation committee to learn which direction the future metallic material industry should aim.
Cooperation of the two industries can be an answer for "sustainable development" to suppress the quantity of waste discharged without curtailing production activity. There is a possibility that all by-products and waste can be used by each industry. There have been several national projects on the recycling of metals and prevention of the diffusion of harmful waste; their effects have so far been limited but remarkable results can be expected with the collaboration of the two industries above.

Cooperative progress is being made between these industries and is contributing to cutting down the amount of waste discharged by the industrial society as a whole. Relationship and flow of materials and energy between the metal production industry and other industries is shown in Fig. 1. The metal production industry which utilizes huge quantities of energy and materials can treat by-products and waste discharged from all other manufacturing industries and become the center of those which use by-product and waste effectively.

The cement industry is also effectively handling waste. Each industry shows different characteristics for waste treatment, and through cooperation realization of a good overall system should be possible. The metal production industry in particular can handle metallic resources and a great contribution is expected from them.

Table 1. Quantities of the waste from the steel and non-ferrous metals industries.

|                        | Steel Industry          | Non-Ferrous Metal Industry |
|------------------------|-------------------------|---------------------------|
|                        | Quantity (1,000 t)      | Percentage (%)           |
|                        |                        |                          |
| Waste Oil              | 190                     | 0.7                       |
| Sludge                 | 4,808                   | 17.8                      |
| Bottom Ash             | 37                      | 0.14                      |
| Fly Ash                | 2,595                   | 9.6                       |
| Waste Acid             | 548                     | 2.0                       |
| Waste Alkali           | 16                      | 0.06                      |
| Waste Plastic          | 437                     | 1.6                       |
| Waste Rubber           | 9                       | 0.03                      |
| Waste Metal            | 581                     | 2.1                       |
| Waste Glass, Ceramic   | 568                     | 1.4                       |
| Slag                   | 16,653                  | 61.8                      |
| Construction Waste     | 809                     | 2.4                       |
| Total                  | 27,051                  | 100                       |
|                        | Quantity (1,000 t)      | Percentage (%)           |
|                        |                        |                          |
|                        | 115                     | 3.2                       |
|                        | 2,163                   | 60.5                      |
|                        | 9                       | 0.25                      |
|                        | 14                      | 0.39                      |
|                        | 85                      | 2.4                       |
|                        | 608                     | 17.0                      |
|                        | 120                     | 3.4                       |
|                        | 2                       | 0.05                      |
|                        | 64                      | 1.8                       |
|                        | 43                      | 0.36                      |
|                        | 355                     | 9.9                       |
|                        | 26                      | 0.7                       |

Fig. 1. Relationship with other industries about secondary metal resources and recycling.
3. TEMCOS Activity

The TEMCOS investigation committee seeks to contribute to the configuration of a circulation type society by totally controlling energy and materials. In other words, it is aimed at creating a recycling system in both the industrial and civil societies in which very high energy efficiency and waste minimization are achieved by forming inter-process linkages between various industries. Establishment of such linkages will accelerate use of by-products and waste from other industries thus achieving optional energy utilization.

The concept of TEMCOS was originally rooted in the Committee for Effective Utilization of Secondary Resources in the Metal Industry, the chairman of which was Professor M. Tokuda, Tohoku University. Its main activities were studying the kind and quantity of waste discharged by the metal production industry and the creation of technical projects to find ways to reduce this amount. The following two projects were begun by the committee.

1. Utilization of sludge produced in the metal production industry
2. Utilization of aluminum dross

Recovery of non-ferrous metals from the sludge produced in iron and steel work is being carried out in project (1), and treatment of Al dross in electric arc furnaces is being attempted as a reductant and flux to recover the energy and resources in the project (2). Both projects are ongoing and producing fruitful results.

The TEMCOS investigation committee was formed in 1997, and its organization is shown in Fig. 2. It is divided into two working groups: one is a planning group and another a technical group overseeing the research and development. Investigation of the actual status of by-products and waste, proposal feasibility and determination of future areas for development are discussed in the planning group. Subjects in the TEMCOS investigation committee is involved in the following:

1. Concept of the actual manner of linking various industries which we call “inter-process linkage”
2. Utilization of an energy-resources cascade
3. Concept of higher resource productivity
4. Recycling systems and processes
5. Minimization of emission to protect the earth’s environment
6. System of assessing TEMCOS activity

There are currently two R & D projects focused on to configure a circulation type society and the support to realize it. One is development of a novel process for recovery of Zn from EAF dust. Metallic Zn is directly recovered from this dust in an EAF dust treatment furnace using a carbon filter which works at high temperature and a system to rapidly cool gas containing Zn vapor. The other is development of a technique for the recovery of valuable metals from sludges or precipitates in iron and steel making, especially in making stainless steel. The targets of this project are the recovery of valuable metals and the removal of F ions from sludges.

Since waste and energy consumption have been successfully reduced in the metal production industry, we would like to promote the spread of the TEMCOS concept to other industries. An image of a future industrial circulation system based on this concept is shown in Fig. 3 by Hayashi.

The sustainable development of an industrial society can be achieved in harmony with nature after a circulation type industrial structure has been developed in which an eco-design is accepted for all products; the metal production industry will continue to perform its essential role of recycling materials and treatment of waste. The subjects requiring study and development and their part in the committee’s future program are shown in Fig. 4. Although there are many subjects requiring attention, the inter-process linkage is the primary and most important concept to realize such a system. Many unit operations are involved in producing goods and various by-products and waste are discharged at each stage of these operations. These materials sometimes become raw materials for another product, for example, blast furnace slag is used for cement and used tires are good for as fuel in cement and the non-ferrous metal industry. Such cases are few, however, and are usually found between certain industries. This inter-process linkage between different industries is strongly desired to achieve a so-called zero emission society. It is very important to grasp what kind and the quantity of by-products and waste discharged by each industry and also how this is treated quantitatively. Investigations have normally been done only in limited field and the data summarized in individual industries, so that there is very little data available to set up inter-process linkage. We, therefore, surveyed the amount and characteristics of raw materials, by-products and waste in the industries which are providing basic materials, for instance, the metal production industry, chemical industry and petroleum industry, because of the large quantity of materials and energy they treat.

Since by-products and waste from the chemical and petroleum industries are not large in amount but of so many different kinds, it is expected to be difficult to research them precisely. Chemical companies in particular produce many diverse materials and discharge various wastes so that we have to decide investigate the data of one specific company, not the whole chemical industry. This investigation must particularly grasp the chemical composition and state of waste, for example, solid, liquid, or slurry. Classification of the waste defined by law is thus not sufficient to achieve a true inter-process linkage to use in reduction of the amount. One of the key points in the TEMCOS activity is how precise data on waste is collected and how accurate it is.

Three actions must be taken to realize the purposes of the committee.

1. The properties and the quantity of discharge in a complex must be investigated precisely and the manner of use of the discharge in that complex must be identified.
2. Concrete techniques for inter-process linkage must be developed.
Fig. 3. Concept of Total Energy & Materials Control System.\textsuperscript{5)}

Fig. 4. Scheme and R & D subjects of the TEMCOS investigation committee.\textsuperscript{6)}
A simulation model must be established to evaluate the environmental impact and economic effect after the inter-process linkage is applied. For example, iron and steel work accepts the discharges from other industries as raw materials as shown in Table 2.\(^2\)

### 4. Technical Targets to Be Developed

To configure a circulation type society of while continuing development after entering the next century, it is necessary that not only energy-resources recycling but also a cascade be utilized, where various types of energy are used hierarchically based on their individual qualities. We performed wide-ranging examinations focused on energy recovery by the heat to heat method, and then established a research program to enable utilization of medium and very-low-temperature exhaust gas in iron particles, etc. This means that chemical heat utilization technology was chosen to utilize the potential of medium- and low-temperature waste heat, which is difficult to use, in the form of a cascade.

We are now considering two basic techniques for development for the inter-process linkage. One is recovery of heat energy which exhaust gas has at medium and low temperatures (below 700°C). Figure 5 shows recovery ratios of heat energy exhausted from each process and its temperature in the steel making process.\(^7\) The highest recovery ratio of heat energy is achieved from cokes which have a temperature around 1 000°C, and recovery of this energy becomes difficult below 700°C. This is thermodynamically understandable. Then following results can be seen from Fig. 5.

1. A large amount of non-recoverable heat is found at middle and low temperature processes.
2. There is a certain amount of heat which can be used at high temperature processes for exergy.
3. No utilization of heat has been attempted with a high temperature slag.

Although recovery of high temperature slag heat has long been attempted and several processes have been developed, those processes are not used commercially because of their high cost. A new idea for the chemical regeneration of exhaust gas using a high temperature gas like LD converter gas (LDG) has been discussed, and a key point in this would be the kind of waste gas chosen. NH\(_3\) gas generated from Al dross treatment was selected as the regeneration gas in this project. Al dross discharged from remelting Al scrap process is a very difficult waste to treat. It normally consists of metallic Al, Al\(_2\)O\(_3\), AlN and some halide compounds such as Na\(_3\)AlF\(_6\) making it forbidden in a landfill. NH\(_3\) gas is generated by the following reactions.

\[
2\text{AIN} + 3\text{H}_2\text{O} = 2\text{NH}_3 + \text{Al}_2\text{O}_3
\]

\[
2\text{NH}_3 + \text{CO}_2 = \text{CO} + 2\text{H}_2 + \text{N}_2 + \text{H}_2\text{O} \text{and }2\text{NH}_3 = 3\text{H}_2 + \text{N}_2
\]

Through these decomposition reactions, ammonia turns to hydrogen which is easy to use and has higher exergy than ammonia. Since hydrogen and CO gases are not only as fuel but also as raw materials in the chemical industry, a separation technique should be developed. Such technique would be easy to use in other processes.

Another technical subject is heat recovery of very low temperature heat energy exhausted from each process and its temperature in a steel work.\(^7\)

| Secondary Product | Use |
|-------------------|-----|
| Sulfuric acid     | Neutralization |
| Hydrochloric Acid | Washing |
| Caustic soda      | Acid washing |
| Calcium hydroxide | Acid washing |
| Carbide slurry    | Energy |

| Metallurgical Industry | Use |
|------------------------|-----|
| Metallic catalyst      | Alloy material |

| Electric Industry | Use |
|-------------------|-----|
| Sulfuric acid     | Neutralization |
| Nitric acid       | Acid washing |
| Hydrochloric acid | Acid washing |
| Hydrofluoric acid |

| Other Industries | Use |
|------------------|-----|
| Slag              | Oxidizer |
| Sintering material | Oxidizer |

Fig. 5. Recovery ratios of heat energy exhausted from each process and its temperature in a steel work.\(^7\) (right: enthalpy standard, left: exergy standard)
temperature waste gas (around 200°C) using fine iron particles obtained from the melting processes of fly and bottom ash in an incinerator. These iron particles are now only used as counter weights. Iron particles are firstly heated by low temperature waste gas and are used to drying of sludge. Normally a major problem in treating sludge is the drying, which requires a large amount of energy to evaporate water. This process has the following characteristics:

1. The entire process is simple and no great facilities investment is necessary.
2. Only evaporation of moisture occurs due to low temperature drying.
3. Sludge and iron particles after drying can be separated by a magnetic separator and the iron particles reused.

5. Conclusion

The activities of the TEMCOS Investigation Committee in JRCM were briefly reported and we are able to confirm that the reduction of energy use and minimization of waste has become very popular and important in the metal production industry. However problems remain in implementing the inter-process linkage between different industries. There is a great barrier to break down before trust is realized. If the amount and properties of by-products and waste are known, the details of processing are also revealed, and most companies will normally not make this known. However, no more waste will be allowed in landfill in the future and the Bassel convection has already been ratified in Japan. This means that the cost of waste treatment has become more expensive, so that it is weakening Japan's ability to be competitive on the international scene. We therefore need a new system and processes to proposed here to confront this situation.

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