THE SEVERAL UTILIZATIONS OF SLAG FROM FERRO- ALLOY MANUFACTURE

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## 1. Introduction

The Hachinohe works of Pacific Metals Co.,Ltd. utilizes rotary kilns and electric furnaces for monthly puroduction of Ferro-alloys that includes 3,000 $^{T-Ni}$ of ferro-nickel 4,600 $^{T}$ of ferro-shrome and 1,500 $^{T}$ of ferro-manganese, and directly uses hem in the melted state to produce 12,000 $^{T}$ of stainless steel. At the same time, we generate 90,000 $^{T}$ of high temperature slag in the Ni system, 5,000 $^{T}$ in the Cr system, 1,500 $^{T}$ in the Mn system and 2,000 $^{T}$ in the SUS system.

It is therefore necessary for us, as it is for other Ferro-alloy manufacturers, to develop applications that make use of thses large of slag as a useful resource or methods to process them into useful materials that make active use of their characteristics to add value to our operations. In an effort to do this, Hachinohe Works has been developing various ways of processing slag, and improving those methods found to have merit. The following introduces representative examples of our efforts.

## 2. Characteristics of each type of slag

Table I lists typical compositions of ferro-nickel, ferro-chrome, ferro-manganese and stainless steel slag.

### 2-1 Nikel slag

The primary characteristic of Ni salg is that it is has high Mgo content, but not very much CaO. It also has a high melting point, so the smelting temperature must be high, which makes processing difficult. On the other hand, that also means that products with good heat resistace can be expected. Since it also includes FeO in amounts that can't be ignored, it is promising as a heavy material.

Another characteristic of Ni slag is that, since the percentage of nickel contained in the nickel oxide ore is as little as 2.4 ~ 2.5%, production of 20% Fe-Ni requires about 40 $^{T}$ of ore to produce one ton of nickel. Of that 40 $^{T}$, about 5 $^{T}$ escapes in vapor in loss of ignition, etc., leaving about 30 $^{T}$ of slag. During processing, heat producing about $74\times10^{6}$ Kcal is used. Thus, in the molten state it is at a temperature of approximately 1,600 ℃ .

### 2-2 Chrome slag

Compared to Ni slag, Cr slag contains a higher percentage of $Al_2O_3$ contents, and the heat resistance of products made from it is higher. At the same time, abrasion resistance can also be expected from them, but the processing technology becomes more difficult.

### 2-3 Manganese slag

Mn slag has a high CaO content, but the smelting temperature is as low as approximately 200℃. Therefore, it handles well in processing and should allow advanced processing.

### 2-4 SUS slag

There is less of this salg generated than there is of slag, so it is not suirable for processing at high temperature. We are now considering how to make efficient of its CaO content.

Table I Typical composition of slag (%)

| | $SiO_2$ | MgO | CaO | $Al_2O_3$ |
|---|---|---|---|---|
| Ni slag | 53.0 | 34.0 | 0.5 | 2.5 |
| Cr slag | 28.0 | 26.5 | 4.0 | 21.0 |
| Mn slag | 25.5 | 3.0 | 24.0 | 6.5 |
| SUS slag | 30.0 | 9.0 | 57.0 | 1.0 |

## 3. Heat recovery by air blasting process

### 3-1 Heat recovery

The ferro-nickel smelting process requires the use of $71\times10^{6}$ Kcal of energy to prooduce one ton of nickel. Of this, about $13\times10^{6}$ Kcal is maintained as heat in the molten slag, which is 18% of the total, but the temperature of the molten slag is as high as 1,550 to 1,600℃, which makes it difficult to handle, so that energy usually abandoned rather than recovered. Our company, however its eye on this amount of heat energy. In 1972, Pacific Metals started developing the technology to recover and apply this wasted energy and after several basic tests, developed an "Air Blasting Process" to recover and apply the held heat. In 1980, this process was set up at the Hachinohe Works, and it has been operating very well since then.

### 3-2 Air blasting process

This process consists of three main steps, air blasting granulation, heat exchange and heat usage, as shown in Figure I.

#### 3-2-1 Air blasting

The molten slag is moved from the electric furnace to the blasting machine, where air gushes up from the bottom at the entrance to granulate the slag. The granulated hot slag is then carried by skip container to the upper part of the storage tank, where lumps are removed by a screen, then stored under controlled heat conditions.

After any generated slag wool is removed, the air used for air blasting, is used with the hot air recovered in the next step of the process. The slag is tapped every three hours to drain off 100 $^{T}$ at a time, at a tapping speed of 120 $^{T/h}$, which takes 50 minutes.

#### 3-2-2 Heat exchange

A variable speed vibration feeder continuously

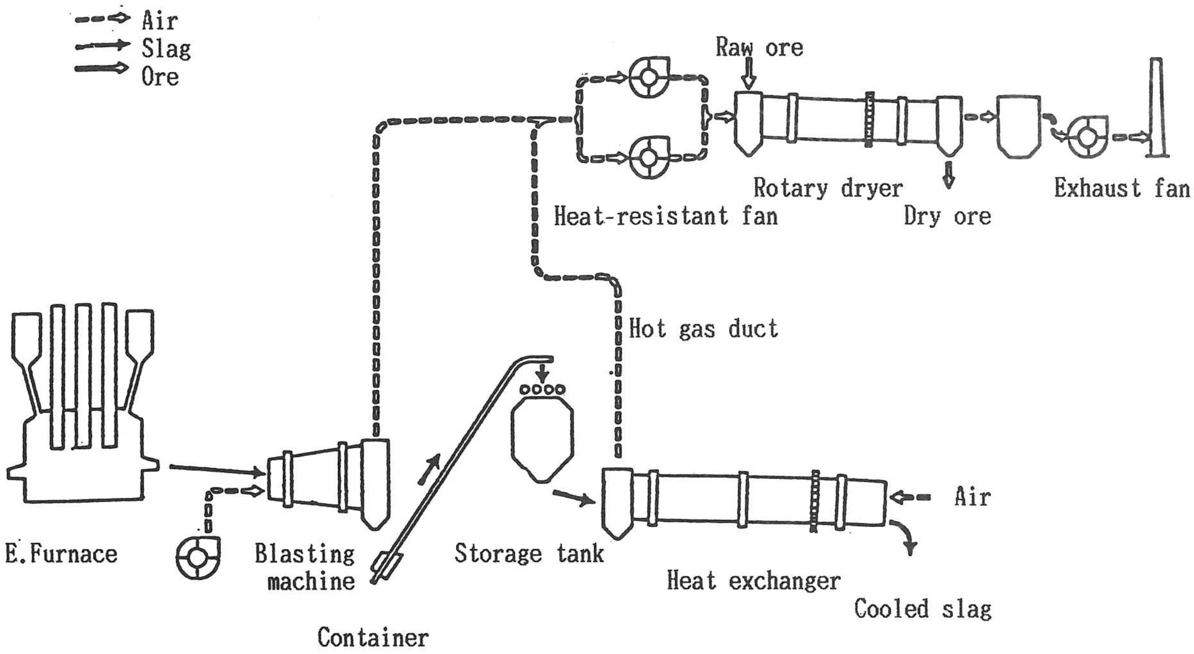


Figure I Flow sheet of air blasting process

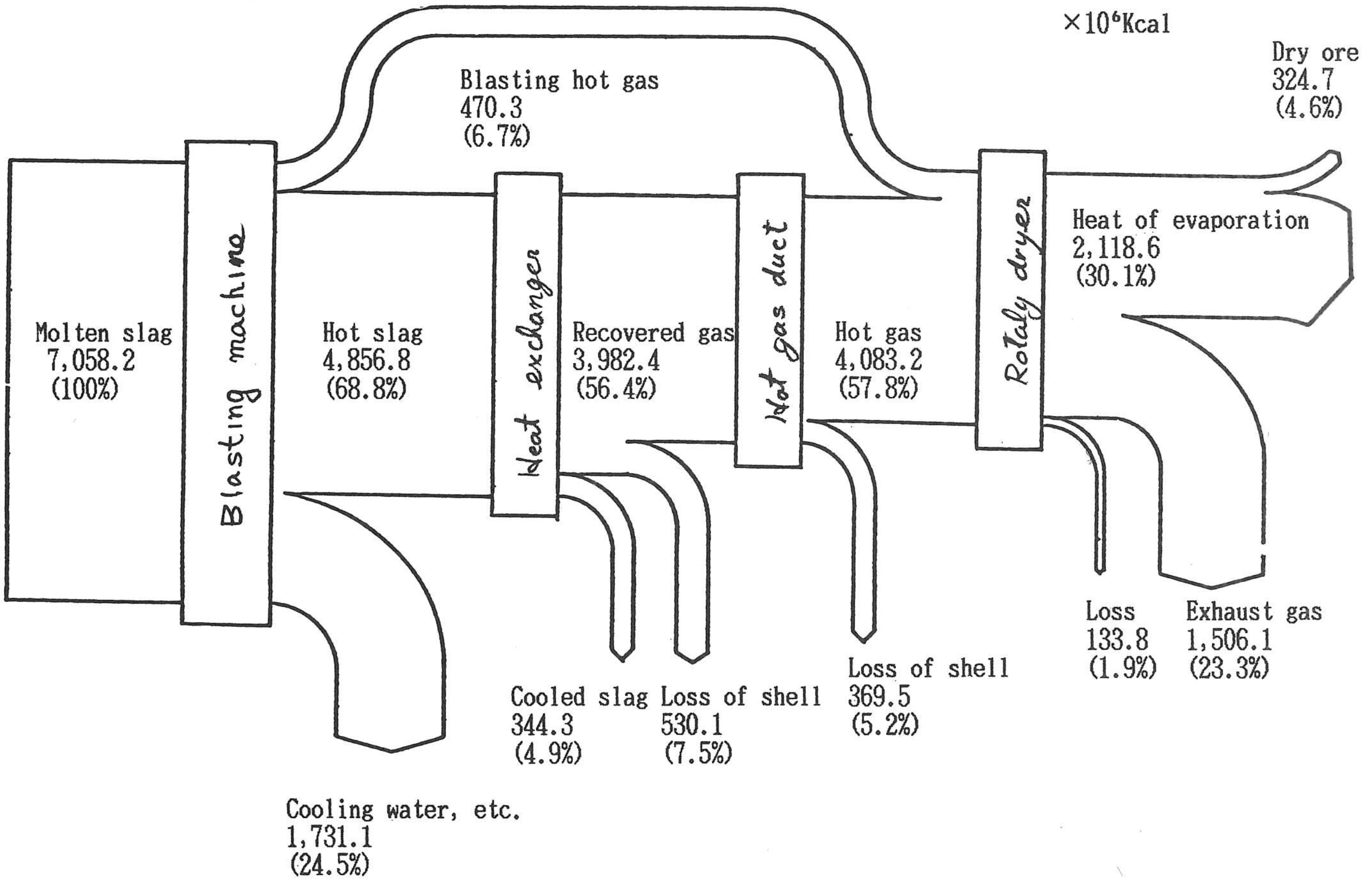


Figure II Heat flow balance of air blasting process

removes a fixed amount of hot slag grains from the storage tank and input them to the rotray heat exchanger. The vibration feeder is installed an abrasion resistant casting and this is covered by a heat resistant case.
The amount of slag fed ranges from 30 to 35 $^{T/h}$ and is adjusted to maintain a certain lever in the storage tank and at a specific temperature. Here, the stored hot slag grains are fed continuously to provide constant heat from the intermittent slag tap.
In the heat exchager, the high-temperature slag flows at a speed of approximately 1.3 m/min, as scoop up by a lifters. The actual heat exchange is performed by counter flows of air that cool the slag down gradually, so that it is at a temperature of 100 ℃ when it leaves the heat exchanger 30 minutes later.
Inside the heat excanger, the lining of the high-temperature zone the bricks in the low-temperature zone are abrasion resistant castings made in-company, to increase insulation within the heat exchanger, the lining is back with 1 to 2 mm of heat resistant wool. The lifter is made of material that changes shape with temperature, thus increasing the heat exchange rate. The temperature of air rises to 370 ℃ for approximately 50,000 $Nm^3$ and is recovered.

3-2-3 Heat application

The hot air recovered by, the heat exchanger are pushed 200 meters through a air duct to a rotary dryer two fans designed to resist of up to 550 ℃ installed in paraller. Fine slag and wool contained in the hot gas are removed by a cyclone dust collector set midway through the duct.
The duct has a two-layer structure of heat resistant castings and an iron-panel lining, while the cyclone is surrounded by insulating material to keep its temperature. The temperature drop during transportation through the duct is 50℃.
The rotary dryer utilizes heat of 320 ℃.
For primary drying, nickel ore is fed in at a speed of 60 $^{T/h}$ . Its 30% water content is reduced to around 21%, the heat of the gas thus generated is reduced to about 110℃ by exchange, and the gas is then exhausted.
There are chains and various lifters inside the dryer to promote heat exchange.
This system allows the C-type heavy oil normally used to in heat furnace to be replaced by recovered heat, without any degradation of dryer performance. Hachinohe Works currently saves about 500 kℓ of C-type heavy oil per month using this system.
Table Ⅱ shows typical monthly operating conditions.

Table Ⅱ typical monthly operating conditions

| | Amount | Temperature (℃) |
|---|---|---|
| Blast slag | 16,600 T | 1,550 |
| Hot slag | 16,200 T | 1,200 |
| Cooled slag | | 100 |
| Blasting hot gas | $4,880\times10^6 Nm^3$ | 320 |
| Heat recovered gas | $35,500\times10^6 Nm^3$ | 370 |
| Drying gas | $40,380\times10^6 Nm^3$ | 335 |
| Exhaust gas | | 120 |
| Row ore | 35,000 T<br>mois 29.5 % | 15 |
| Dryed ore | mois 21.7 % | 40 |
| Ave temperature | | 15 |

3-3 Heat balance

The heat balance in each can found from the monthly operating conditions described above, and from analysis of those operating conditions.
Our heat flow are as shown in Figure Ⅱ.

3-3-1 Efficiency

Heat recovery efficiency for each process is:

| | | |
|---|---|---|
| Air blasted granulation | 68.8 % | + 6.7 % |
| Heat exchange | 82.0 % | ↓ |
| Heat application | 58.9 % | |

This provides an absorption heat recovery efficiency of 34.7%.

3-3-2 Energy conservation

At the entrance to the dryer, heat of 4,083.2 $\times10^6$ Kcal/month is generated and using for primary drying of ore. Since the efficiency of the standard heat furnace is 90%, the amount of C-type heavy oil saved can be calculated as

$$4,083.2 \times10^6 Kcal/0.9 \div 9,200 Kcal/\ell = 493 \times10^3 \ \ell$$

That is, our system saves 493 kℓ of C-type heavy oil every month.

3-4 Air-blasted slag

3-4-1 Properties

The air-blasted slag passes through three stages of cooling : quick cooling from the 1,600 ℃ range down to the 1,200℃ range, maintenance at a temperature in the 1,200℃ renge for about 2 hours, and medium-speed cooling from 1,200℃. This process produces Enstatite particles, which are hard and most of which are spherical. Which particle size distribution is listed in Table Ⅲ.

Table Ⅲ Particle size distribution (%)

| -0.3mm | 0.3~0.6 | 0.6~1.2 | 1.2~2.5 | 2.5~5.0 | +5.0 |
|---|---|---|---|---|---|
| 0.1 | 3.7 | 23.1 | 35.7 | 29.0 | 8.4 |

3-4-2 Fine aggregate

Due to near exhaustion of such resources as river, inland and mountain sand, which are used as the fine aggergate for concrete, and to deterioration of the quality of such sand, crushed sand is starting to be used in its place. Table Ⅳ compares the quality characteristics of air-blasted slag and river sand as fine aggergate.The absolute values rate is high, so less water and cement is required,and the water absorption rate is low, so the brake water rate can be held down. During tests, the the amount of cement was reduced to 6%, without any loss of strength. In prticular, the specific gravity of the dry surface is high, which means that it has characteristics well suited for use as heavy concerte, thus it is expected, to find use as marine concerte.

Table Ⅳ compares the quality characteristics

| | Water R. | Values R. | Gravity |
|---|---|---|---|
| Air-blasted slag | 3.32 % | 69.5 % | 3.02 |
| River sand | 1.76 % | 62.9 % | 2.58 |

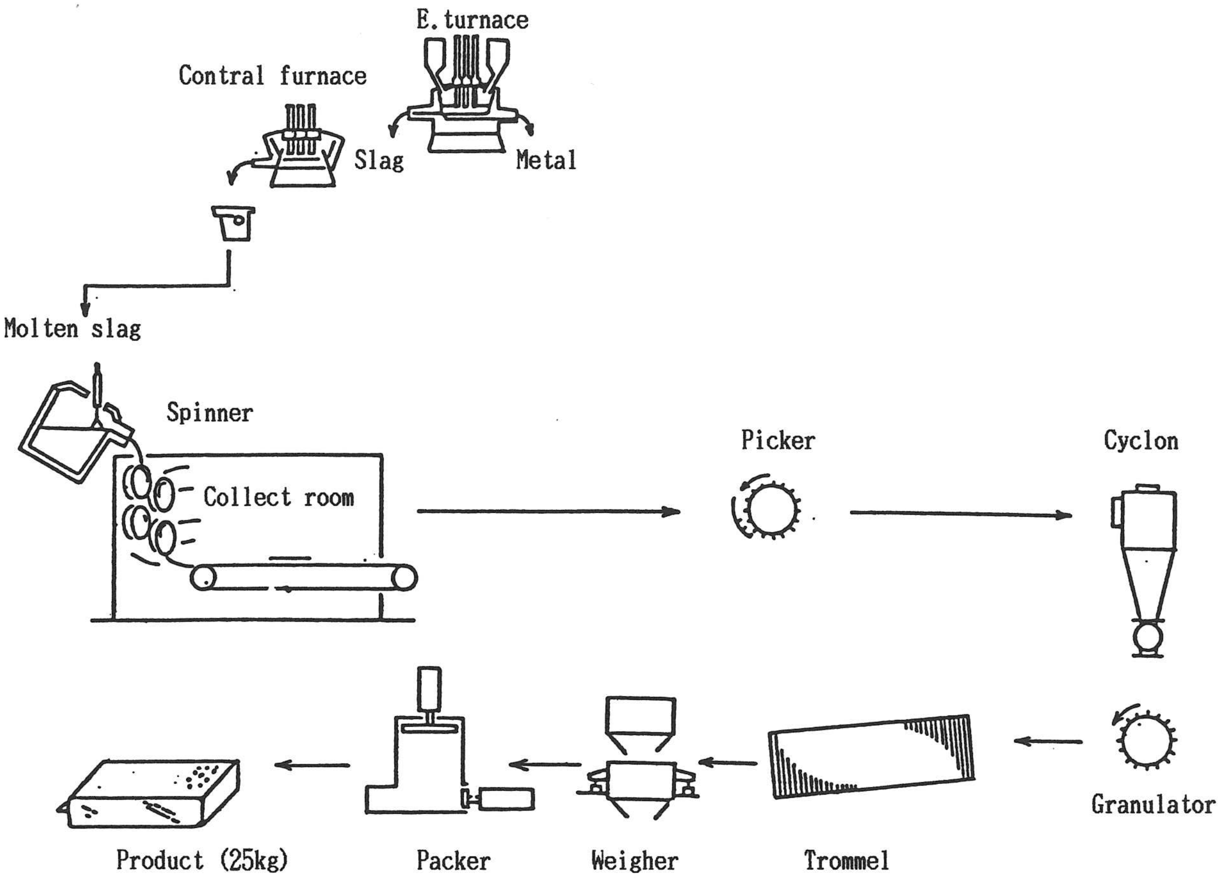


Figure Ⅲ flow sheet of wool production process

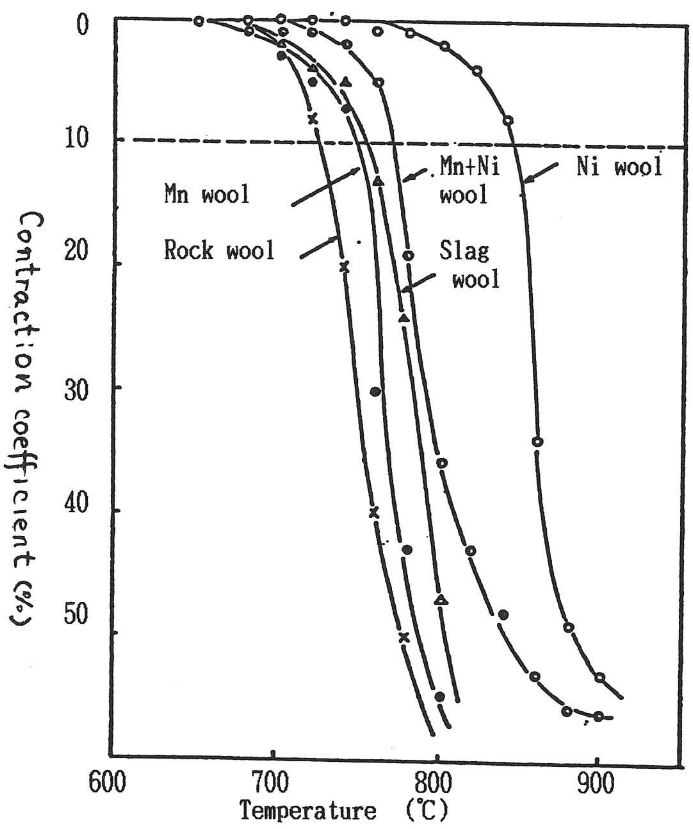


Figure Ⅳ Relation temperature-contraction

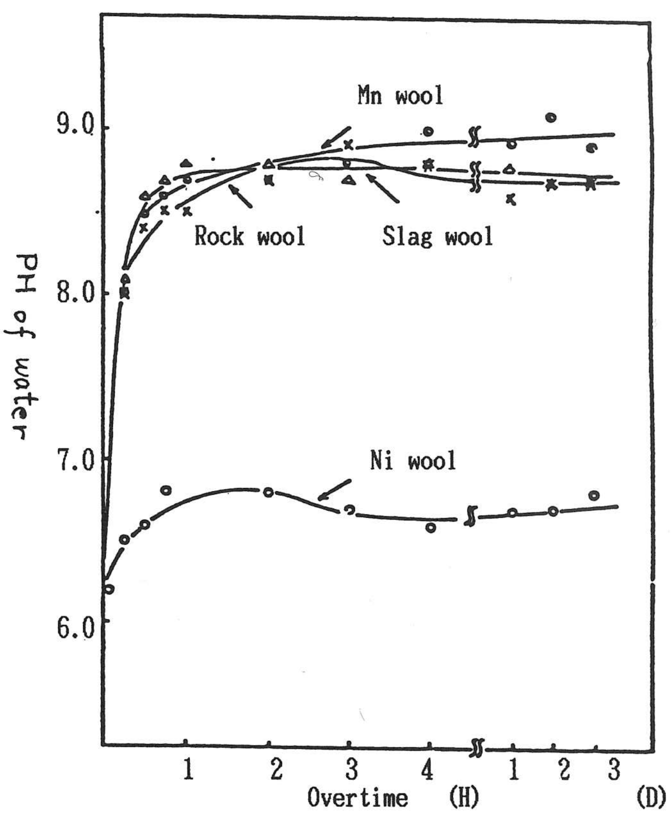


Figure Ⅴ pH value-overtime

## 4. Methods of producing wool

### 4-1 Ferro-manganese slag & Ferro-nickel slag wool

The demand for inorganic fiber, such as, rock, glass and ceramic wools is increasing in various industrial fields for use as building materials, heat insulting materials, etc., because of its excellent characteristics, including fire resistance, adiabatic stability and noise absorption. Recently, the use of inorganic fiber has extended to agriculture, as well, due to its permeability and water retentivity.

The slag wool that is used utilizes blast furnace or ferro-manganese slag as its raw material, while the rock wool uses basalt, peridotite, etc., which are natural rock, the glass wool uses quartz sand, etc., and the ceramic wool uses synthesized alumina, silica, etc..

The wool is produced by the so-called spinning method, which uses centrifugal force, or the blowing method, which makes use of high-speed currents of air or steam. Standard inorganic fiber contains alkali, usually an especially high concentration of CaO. For example, blast furnace slag contains about 35～40% CaO, Ferro-manganese slag about 25～30% and rock wool about 20～30%, in general. If CaO is present as a component of the raw material, it brings down the melting point for raw material down when that raw material is melted in an electric or cupola furnace and makes fiber production easier. CaO may also be added in the form of lime stone, etc..

However, as indicated in the above description, fiber that contains CaO has poor heat resistance, and the CaO can be dissloved by reaction with alkali or water. This causes a problem when the fiber is used for in-solution cultivation, hydroponic cultivation, etc., in agriculture, since the pH of water that comes in contact with the fiber will rise and this will influence plant growth.

On the other hand, when inorganic fiber is produced using raw material that does not contain CaO, the melting point is quite high, which makes fiber production more difficult and increases production cost. Ceramic wool is one such case.

We therefore eyed the use of ferro-nickel slag, which has lower CaO content and is easy and cheep to obtain, for the making of inorganic fiber, and performed various kinds of tests concerning fiber production. We found out that adjusting the temperature for compontents other than CaO, made it easier to produce fiber even for slags like those described above, which usually have a high melting point and is difficult to make into fiber. This allowed us to establish a stable production method.

### 4-2 Nickel wool production process

Figure Ⅲ shows the nickel wool production process. The molten slag generated intermittently in the electric furnace is fed into a 5,000 KVA control furnace. Where other control materials are added to regulate the temperature. The slag is then poured into $10^{T}$ /group slag pans. These pans are the immediately placed on tilting equipment to which an oil burner is attached, and the melted slag is tipped into a continuously heated 4-wheel spinner to make fiber.

The nickel wool produced by the 4-wheel spinner drops down a net conveyer located at the bottom of the collection room and is carried out to the next process. Nickel wool 15 to 20 cm thick is spread (rough cutting process) by a picker, then spread to thumb size by an impeller-breaker type granulator. At the same time, any shot (solid slag) contained in the wool is removed.

Thumb-sized nickel wool is placed on the conveyer, fine-grain shot is removed as the conveyer moves through a cyclone, and the wool is loaded into a trommel.

The trommel is where the finishing process occurs. It includes a revolving screen 1.8 m in diameter and 4.8 m long. The screen promotes granulation of the nickel wool and removes any remaining shot.

The gtanulated nickel wool is placed in the hopper of a scale and weighed. It is then compressed by a compressed-air bailer into a 0.5m ×1.0m×0.2m cube and packed in vinyl bags. Each packed bag weighs 25 kg.

### 4-3 Comparison of nickel and various other wools

#### 4-3-1 Components of nickel wool

Nickel wool has the follwing characteristcs compared to standard slag wool and rock wool:

1. High $SiO_2$ : $SiO_2$ increases alkali resistance and greatly strengthens the fiber.
2. Very low CaO : CaO decreases alkali resistance.
3. High MgO : Provides higher alkali resistance than CaO, and increases heat resistance.
4. Includes FeO : Increases heat resistance, makes the fiber more flexible.
5. Contanins suitable amount of $Al_2O_3$ : Combines with $SiO_2$ for increased fiber strength.

#### 4-3-2 Characteristics of nickel wool

Since nickel wool is made from nickel slag and a highspeed centrifuge is used, it has the following characteristics :

1. It has the same fiber diameter and bulk density as standard products.
2. Heat resistance is at least 100 ℃ higher than for standard products.
3. It has excellent alkali resistance.
4. Its pH value when containing water is less than 7.0, which is lower than the pH of standard products.

Figure Ⅳ shows the relation between temperature and contraction coefficient, which Figure Ⅴ shows the change in pH value over time.

## 5. Conclusions

It os important to decrease our use of limited natural resources. Even gravel and sand, supplies of which we used to think were inexhaustible, will be in short supply in the future. We now know that slag can be substituted for those resources, and can save energy.

For healthy development of the Ferro-alloy industry and to conserve resources and energy, it is necessary that slag be used effectively. The Hachinohe Works of Pacific Metals Co.,Ltd. would be pleased if this report can be of some value in industry's efforts in this area.