DEVELOPMENT OF SILICOMANGANESE SMELTING AT NIIGATA WORKS

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SYNOPSIS

When commercial furnaces were dissected and examined during their downtime, the existence of coke bed was confirmed in all furnaces with the shape of the bed varying from furnace to furnace. Studies of the relationship between the bed shapes and the furnace operating conditions and performances before their shutdown showed that the thickness and location of coke bed are important factors affecting furnace operation and performance. In other words, they decide the top positions of electrodes -- that is, their immersion length -- and also determine the stableness of furnace operation. Afterwards, researches were conducted both in laboratory and through operation tests about the causes of varying coke bed thickness and location, resulting in a number of findings. To apply these findings to actual furnace operation, it is necessary to develop the means of knowing and then controlling coke bed thickness and location while the furnace is in operation. Such development has been under way with the help of computer. This report describes the progress of the above research and development and also touches upon the effects of some of the traditional techniques already in wide use, such as the sizing of raw materials. At the same time, the report indicates some ideas for increasing the effects of these traditional techniques.

INTRODUCTION

Ferro-alloy production at NKK (Nippon Kokan K.K.) continued to expand until 1973 in keeping with the growth in steel output, with its production facilities being constantly modernized and enlarged. The worldwide recession after 1973, however, necessitated a reduction in steel production which in turn resulted in a drop in ferro-alloy output. Since this turnaround, NKK has been conducting systematic efforts to develop technologies aimed at cost reduction. Following the analysis 1) of the structure inside an experimental furnace which was publicized in 1974, four commercial furnaces were dissected and examined. This resulted in confirming the existence of coke bed and in finding out that the coke bed is an important factor affecting furnace performance as it determines the top positions of electrodes. After these findings, efforts were made to identify the factors governing coke bed thickness and location

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and to develop systems for measuring or estimating and then controlling the thickness and location. The efforts have led to some technical achievements recently. They have also given a number of suggestions as to the direction of future research and development.

This report briefly describes the current state of production at NKK and major technologies developed during the past decade. It then states the progress of recent research and development with some of its achievements and also the intended direction of future development.

I. Production of Manganese Ferro-alloys at NKK

1. Productions of crude steel and manganese ferro-alloys in Japan:

Figure 1 shows Japan's productions of crude steel and manganese ferro-alloys in the last 12 years. Manganese ferro-alloy production peaked in 1974 but then the curve turned downwards as did the curve for crude steel production. The output of ferro-alloys was reduced at larger rates than that of crude steel. This resulted chiefly from a rise in ferro-alloy imports and a fall in specific consumption of ferro-alloy by steelmakers as a result of their technological innovations.

2. Current state of NKK:

Established in 1912, NKK is a manufacturer of steel and heavy machinery (including ships).

Ferro-alloys are produced as part of the activities of the steelmaking division. Table 1 shows the variety of ferro-alloys being produced by NKK with the production capacity for each product.

Three manganese ferro-alloys -- high-carbon ferro-manganese, medium-carbon ferro-manganese and silico-manganese -- are produced chiefly at Niigata Works and all the other items at Toyama Works.

3. History and current state of Niigata Works:

Both Toyama and Niigata are located on the Japan Sea side of the Japanese archipelago where there is a large rainfall -- and snow in the winter -- providing abundant hydro-electric power. Toyama Works was established in 1917 and Niigata Works in 1935 with an eye to utilizing this ample electric energy, the supply of which peaks in the snow-melting season, and to benefit from the advantages of transporting both raw materials and products by the Japan Sea.

Niigata Works purchases electricity from Tohoku Electric Power Co. which, as will be seen from Figure 2, recently depends on the thermal means to generate the majority of its electricity. This enables Niigata Works to operate regularly throughout the year without being affected by the turn of the high and low water seasons.

Figure 3 shows a history of production of the three manganese ferro-alloys at Niigata Works. As previously stated, the production peaked in 1974.

Table 2 shows historical changes in the capacity, production and manpower of Niigata Works. It indicates the present level of production at as low as 60% of capacity.

II. Progress of Silico-manganese Production Technologies

Looking back at the latest decade, the first five years was a period of intensified production in large quantity through the expansion of ferroalloy production facilities or electric furnaces in order to meet rapidly increasing steel production. By contrast, the last five years were dedicated to curtailment of production as well as rationalization and technical development aimed at cost reduction in the face of dwindling steel production caused by the recession, increased ferroalloy outputs by resources-producing countries and their export offensives, and soaring raw materials and power costs. Expanding electric furnace capacity requires general enhancements in equipment and control techniques, including those for preparatory processing of raw materials, electric furnace control, product processing, and environmental control. And to challenge the goal of cost reduction that comes in the next stage following a successful furnace expansion, it is necessary to develop higher-level and more rational technologies than those needed for just operating a large furnace in a stable way.

This report will first describe the technologies developed during the expansion period of Niigata Works and then those developed in the last few years.

1. Technologies developed during the expansion period:

Operational technologies to be presented here are those developed and practised by NKK.

(1) Increase of electric furnace capacity and improvement of peripheral equipment;

(a) Increase of electric furnace capacity:

Niigata Works developed and installed Japan's first totally-closed furnace (4,000 KVA) in 1954. With this the works accumulated technical experiences in the control of a closed furnace, particularly the operation of gas cleaning equipment to make effective use of gas. These experiences led to the construction of a 9,000 KVA rotating furnace in 1962, the development of which is shown in Table 3;

(b) Improvement of peripheral equipment:

Table 4 outlines the computer system, sintering and casting machines with their chief purposes of installation. Some of the peripheral equipment and arrangements that are not shown in Table 4 are, briefly:

(i) Insulation monitor: This constantly monitors the state of insulation between electrodes and peripheral equipment and sounds an alarm when necessary to protect equipment;

(ii) Electrode baking monitor: This monitors the state of electrode baking to prevent electrode accident;

(iii) Evaluation of furnace-bed rotation: Through alternate use of tapholes, this brings the merit of a prolonged hole life and also is effective in melting the charge evenly;

(iv) Gas cleaner: Venturi scrubber permits compact design and extends the period when the machine can be operated without repairs. Incidentally, Niigata Works sells the gas after dehumidizing it by reboiler and secondary dust collection by EP;

(v) Improvement of work environments: This includes prevention of heat and dust around the tapholes, runners and metal pouring outlet, and ventilation of the air around the furnace-top work area and gas treating equipment to provide against possible gas leakage.

(2) Some alterations in raw materials:

Formerly, silico-manganese was produced from raw materials comprising high-grade manganese ore and high-carbon or medium to low-carbon ferro-manganese slag with an addition of low-grade manganese ore and a small amount of quartz as a silica source. CaO source such as limestone, MgO source such as dolomite, and woodchip for the purpose of improving permeability were added depending on requirements. Silica-bearing low-grade manganese ore -- an important silica source -- was imported from countries such as Indonesia, India, Rumania and Mexico, but the import became increasingly difficult as a result of either exhaustion of resources or soaring prices (including ocean freight). A limited volume of domestically-produced ore is still used today. The declining availability of imported low-grade manganese ore was coped with by the use of a larger amount of quartz. Tests were carried out over a certain period with respect to the selection of quartz sizes and supply sources.

The tests statistically show that different silica sources result in different silica yields -- a rate at which silica is reduced into silicon and taken into the product -- given in Table 5. It was also found out that there is a limit to the amount of quartz that could be used, and that an excessive use of it would destabilize operation and deteriorate performance.

Today, stable operation is achieved by introducing a concept of Free Silica (F. SiO_2) as shown in the equation below and by maintaining this value at a constant level.

$$\text{F. } SiO_2 = \text{Total } SiO_2 - \text{Total } CaO \cdot 60/56$$

To maintain a proper electrode immersion length, the ratio in weight of coke to the entire raw materials -- or coke density -- is limited to a certain level in silico-manganese production. This coke density, however, tends to rise with the use of an increased amount of quartz and high-grade manganese ore.

The use of limestone is accompanied by the following endothermic reaction which increases the specific power consumption and coke. It also sometimes generates unwelcome CaC_2 in the furnace. MgO should be considered in relation with (Al_2O_3), and if (Al_2O_3) can be held below 15%, there is no need for concern.

$$\left\{\begin{array}{l} CaCO_3 \rightarrow CaO + CO_2 \\ CO_2 + C \rightarrow 2CO \end{array}\right.$$

(3) Sizing of raw materials and use of sinter:

This section will state on the results of sizing tests for all raw materials except coke, the impact of whose particle size will be discussed later on. The results of the tests are shown in Figure 4, in which d represents the average equivalent particle diameter 2) and d' the converted average equivalent particle diameter of MnO_2 shown in the following equations:

$1/d = \Sigma Xi/di$, where Xi is the weight of material in size di.

$1/d' = \Sigma Xi \cdot (MnO_2)i/di$, where $(MnO_2)i$ is the weight of MnO_2 included in Xi.

The reason why d' was considered was because the surface area ratio of MnO_2 particle is believed to be the factor most contributive to the indirect reduction rate of MnO_2, although the simple average equivalent particle diameter contributes only to the distribution of gas flow speed within the furnace.

As is seen from Figure 4, it is not d but d' that follows generated gas CO_2 closely. In other words, CO_2 is seen to rise higher as d' becomes smaller. It is well known that a rise in CO_2 helps largely in improving specific consumption of power and coke.

It is also well known that a small d will block gas flow in the raw material layer, becoming the potential cause of bridging or eruption and adversely affecting stable furnace operation.

Another major cause of bridging and eruption is moisture in raw materials (including coke). In case this moisture can be held low, the d size can be reduced correspondingly.

The above discussion leads to the conclusion that d, which is related to raw material moisture, should be made as large as possible and d' should be made as small as possible.

In other words, in order to increase the effect of sizing, the particle diameter of ferromanganese slag with a low Mn^{4+}/T.Mn should be made large, while the particle diameter of manganese ore with a high Mn^{4+}/T.Mn should be made small. Niigata Works is producing sinter to utilize the fine ore that arises as a result of sizing and to recycle the fine materials that are generated in the works.

However, the amount of production is small because of the said circumstances. Since such sinter accounts for only 10-20% of the Mn-bearing raw materials, its use does not have an impact to be spoken of.

(4) Mn^{4+}/T.Mn and carbon balance:

Generally speaking, generated gas CO_2/CO increases in proportion to the level of Mn^{4+}/T.Mn in charged raw materials, and specific power consumption decreases with the increase in CO_2/CO 3). The relationship that the rate of reduction by CO rises with the increase of Mn^{4+} in raw materials can be expressed as:

$$X = a\ Mn^{4+}/T.Mn + b$$

where a and b can be obtained for each furnace from data accumulated over a long period. If X is obtained for a given Mn^{4+}/T.Mn and that heat efficiency η in the furnace is provided, the heat balance in a furnace can be known through calculation.

In Figure 5 the dotted line indicates specific power consumption corresponding to Mn^{4+}/T.Mn at a time $\eta = 0.725$.

It means that specific power consumption falls with the increase in Mn^{4+}/Mn. As Figure 5 indicates, however, actual specific consumption seems to show a curve of second degree having its minimum value against a certain Mn^{4+}/T.Mn value. Consequently, η can be expressed in a curve of second degree with its maximum value against a certain Mn^{4+}/T.Mn value.

The reason why η can be expressed in such a curve in relation to Mn^{4+}/T.Mn may be explained as follows:

When Mn^{4+}/T.Mn exceeds a certain level, excessive heat generated in the raw material layer is carried away as sensible heat of the gas. In addition, raw materials with a high Mn^{4+} generally have a high level of combined water, are fragile and show high rates of heat cracking and reduction disintegration. This permits only a shallow immersion of electrodes, causing instable furnace operation and increasing the loss of heat out of the furnace. In case the level of Mn^{4+}/T.Mn is too low, an adequate amount of heat necessary for heating the raw material layer cannot be secured.

These facts seem to suggest that one method for ensuring prolonged and stable furnace operation is by selecting a proper Mn^{4+}/T.Mn and blending manganese ores with low thermal-cracking and reduction-disintegration rates.

(5) Recent performance trend:

Figure 6 shows a history of specific power consumption in the past 10 years. For F14 (25MVA) that started up in 1969, the performance peaked in 1973, dropped in 1975-76, but recovered in 1979 to approach the 1973 level. F17 (40MVA) has followed a similar trend since its start-up in 1973.

The good performance in 1973 resulted from a change to quartz and a drop in the use of limestone, while the poor performance in 1975-76 was due to either excess or shortage of Mn^{4+}/T.Mn accompanied by an inadequate coke adjustment. It is believed that the improvement in the subsequent years can be attributed to a combination of the various technical enhancements that have been stated, sizing of raw materials, and the more recent innovations that will be discussed in the following pages.

2. More recent technical developments:

First of all, four furnaces -- F14, F17 (both of which have been mentioned), F19 (9MVA) and Toyama Works' F1 (40MVA) -- were dissected for examination during their downtime. The examination revealed the existence of coke bed (dry coke layer) of a varying shape in each furnace and that the thickness and location of coke bed plays an important role in deciding furnace operation.

The need was realized to study such items as the role of coke bed, factors contributing to coke bed formation, the means of knowing coke bed thickness and location in actual operation, and the method of controlling them. Although the research and development on these matters is still under way, some of the findings and results achieved so far will be stated below.

(1) Dissection of furnaces:

The mentioned four commercial furnaces were shut down in the middle of normal operation and were dissected for examination after they were allowed to cool down naturally. Table 6 shows the details of F19 and F1. These specifications differ from those of F14 and F17 because F19 and F1 were converted from high-carbon ferro-chrome furnaces. Efforts were made to correct the difference by feeding through the furnace-top bin proper amounts of raw materials corresponding to the decline of the raw material layer during the cooling.

In dissecting the furnace, the raw materials were dug in a way to expose the vertical sections of two of the three electrodes, followed by the measuring and photographing of their sectional structure and shapes.

At the same time, samples were taken according to previously planned methods, including core samples by boring means. As for F19, a full range of structural surveys was conducted covering the raw material layer to the furnace bottom by burying resin.

These surveys and the following analyses resulted in a large number of findings, of which those suiting the purpose of this report will be stated.

Figure 7 shows chiefly the coke bed thicknesses and locations and the electrode top positions in the four furnaces. Table 7 shows the relative positions of the electrode tops and the coke amounts that existed in the furnaces, together with the coke bed thicknesses and features.

In Table 7, a refers to the coke amounts existing in the dry and wet coke layers, and b to the normal coke amounts for the four furnaces calculated on the basis of a furnace volume ratio that results from assuming the a for F19 as normal.

Table 8 puts together the raw material and operational performances before the furnace shutdowns, in which kWh/t taken from Figure 5 are figures excluding the influence of MnO_2 explained in Figure 5. Figure 8 shows the relationship between a/b in Table 7 and kWh/t for last month, and that between a/b and c/d in Table 8.

After studying these data and considering various indicators of furnace operating conditions such as changes in the furnace pressure, temperatures of outlet gas and gas compositions, particularly CO_2, H_2 and heat balance, the following observations seem to result.

That is, it is the coke bed location that decides the position of the electrode top, and it is its thickness that determines the degree of stableness of furnace operation. And the decisive factors in coke bed thickness and location in a certain furnace are manganese ore properties and coke particle size, although the thickness and location are also partially related to the furnace capacity and other specifications.

G.S. Andryukin 4) confirmed the existence of coke bed by using a small furnace and pointed out cyclical changes of its thickness and location between tap and tap, the occurrence of a disturbance to the cyclical changes when the thickness and location are not proper, and the importance of controlling the coke bed for satisfactory furnace operation. R.C. Urquhart 5), meanwhile, stated the importance of coke bed as electric conductor and the influence of coke particle size on the coke bed.

These are all important indications, and they coincide well with the outcomes of our surveys and tests and with our operational experiences.

(2) Our views of coke bed:

a) It is our basic thinking that the thickness and location of coke bed determine the electrode top position and the stableness of furnace operation, that these largely affect the results of operation, and that there exist the optimum coke bed thickness and location for each furnace.

Referring first to coke bed thickness, this affects the balance and speed of the direct reduction reaction of Mn and Si that takes place in the layer below the coke bed and the temperature in that part of the furnace. The bed also lies between the raw material layer, which is a solid layer, and the refining layer, a liquid layer, separating them and thus preventing various troubles that could arise if unmolten raw materials fall into the high-temperature molten layer. This way the thickness of coke bed contributes to stable furnace operation.

In addition, the coke bed is believed to function as a distributor of the CO gas generated in the direct reduction layer into the indirect reduction layer above.

The function of coke bed location is to decide electrode top position. Since the depth of furnace is fixed, the thickness of the raw material layer is determined by the location of coke bed. As a result, this location has a major effect on the indirect reduction reaction of MnO_2, the main reaction in the raw material layer. It is a most important thing to facilitate the indirect reduction reaction of MnO_2, let the heat arising from the reaction absorbed fully into the raw material layer and thus to lower the temperature of the gas discharged out of the furnace to a minimum. To realize these, it is necessary to locate the coke bed at a deep position to enable the electrode top to come down so much deeper.

(b) In view of the importance of coke bed that has been stated, the primary direction of study should be in identifying the governing factors that affect its thickness and location. As already mentioned, these factors include raw material properties and coke particle size. Because of the fact that the coke bed separates the solid and liquid layers, the particularly important raw material properties are the temperature at which the materials melt and drip, and heat-cracking and reduction-disintegration properties that affect the temperature. Some results of our study on these will be stated in a separate section.

(c) Then in actual furnace operation, it becomes necessary to find out the thickness and location of coke bed at any given time. For this, both computing and direct method are conceivable, of which the former will be discussed in relation to the tests regarding the impact of coke particle size. The use of computer will also be touched upon briefly.

(3) Impact of coke particle size on coke bed:

Figure 9 shows varying coke particle sizes and the change in the coke amount remaining in the furnace as a substitute for coke bed thickness. Figure 9 also gives coke efficiency as well as the changes in discharged gas temperature and CO_2 which are considered apparent properties of coke bed location. The coke efficiency and remaining coke amount in Figure 9 were calculated by the following equations:

$$\text{Coke efficiency} = \text{Theoretical coke amount}/\text{Actual coke amount}$$

$$\text{Remaining coke amount} = (\text{Actual coke amount} - \text{Theoretical coke amount}) \times \text{Accumulated output}$$

Figure 9 indicates that as coke particle diameter grows smaller, the amount of remaining coke decreases -- that is, the thickness decreases. As regards the location, CO_2 increases following closely the amount of remaining coke.

These may be considered in association with the reacting surface area of coke particle. They may be interpreted to mean that a reduction in particle diameter increases the surface area for each unit weight and this results in cutting coke amount and raising coke efficiency. However, as already mentioned with reference to raw material particle diameter, further reduction in coke particle diameter would block good gas flow of the raw material layer, leading to unstable operating conditions.

(4) Melting and dripping temperature of raw materials:

Figure 10 shows the results of melting and dripping tests for the materials given in Table 8. Figure 11 shows the relationship between MnO/SiO_2 and the meltdown temperature for these and other raw materials. These demonstrate the existence of a low-melting-point compound in the neighbourhood of $MnO/SiO_2 = 2$.

In considering desirable silico-manganese operation on the basis of these data, it is noted that blending low-melting-point ore with low-melting-point high/mid-carbon ferromanganese slag would raise the location of coke bed.

It is impossible, however, to use only high-melting-point raw materials as long as slag is used as material. The right solution to this problem, therefore, should be to realize the right blending rate between low-melting-point slag and high-melting-point manganese ore.

(5) Disintegration during reduction:

Figure 12 shows the disintegrating rates during reduction of the raw materials given in Table 8, and Figure 13 the relationship between $Mn^{4+}/T.Mn$ and disintegrating rates for these and other raw materials.

As previously said, ores should be evaluated from the two viewpoints of whether they can maintain an adequate $Mn^{4+}/T.Mn$ while continuing to keep a proper melting point, and whether they will not crack or disintegrate when heated and indirectly reduced to block the gas flow of the raw material layer.

(6) Use of computer:

The need to detect and control coke bed thickness and location for furnace operation has been stated. With this need in mind, our computer system was expanded in December 1979 to conduct the following functions with respect to coke bed:

(a) Estimation of furnace conditions:

Indication of tap-to-tap cyclical changes
Coke amount that remains in furnace
Calculation of coke efficiency
Calculation and indication of electrode top positions

(b) Increased raw material information:

Calculation and indication of average equivalent particle diameter
Calculation and indication of compounded average moisture

(c) Indication of change in long-term furnace condition index .

(d) Incorporation of statistical methods:

Various values representing a) - c) can be processed statistically.

(7) Operational performance trend:

Figure 14 shows operational performances between November 1978 and December 1979.

The performance fell in March and April, but picked up rapidly in May and June, and after leveling out recovered further in November and December. Relating these movements with the raw material processings that were actually conducted, May saw the blending of high-melting-point ore and a drop in $Mn^{4+}/T.Mn$; in June was introduced the control of coke particle size to adjust coke volume and stabilize its size; and since November higher-melting-point ore was mixed, which probably contributed to the high performance.

Conclusions

During the period of equipment expansion, the emphasis of technical development was placed on the enlargement of furnace, necessary improvements of peripheral equipment, and stabilization of furnace operation from the aspects of raw material particle size, moisture and blending. With the period of slowdown setting in after 1975, it became necessary to emphasize cost reduction more than ever. To achieve this objective, furnaces were dissected and examined utilizing their downtime. This resulted in reconfirming the importance of coke bed and then developed into various intensive studies regarding the thickness and location of coke bed. Main subjects of study are:

(1) Coke particle size
(2) Melting and meltdown temperature of raw materials
(3) Disintegration during reduction of raw materials
(4) Use of computer.

These studies are still in their initial stages. However, some of the findings acquired through the studies are already being used in operating our large furnaces.

We would be happy if this report could be of any help to parties concerned with ferro-alloys.

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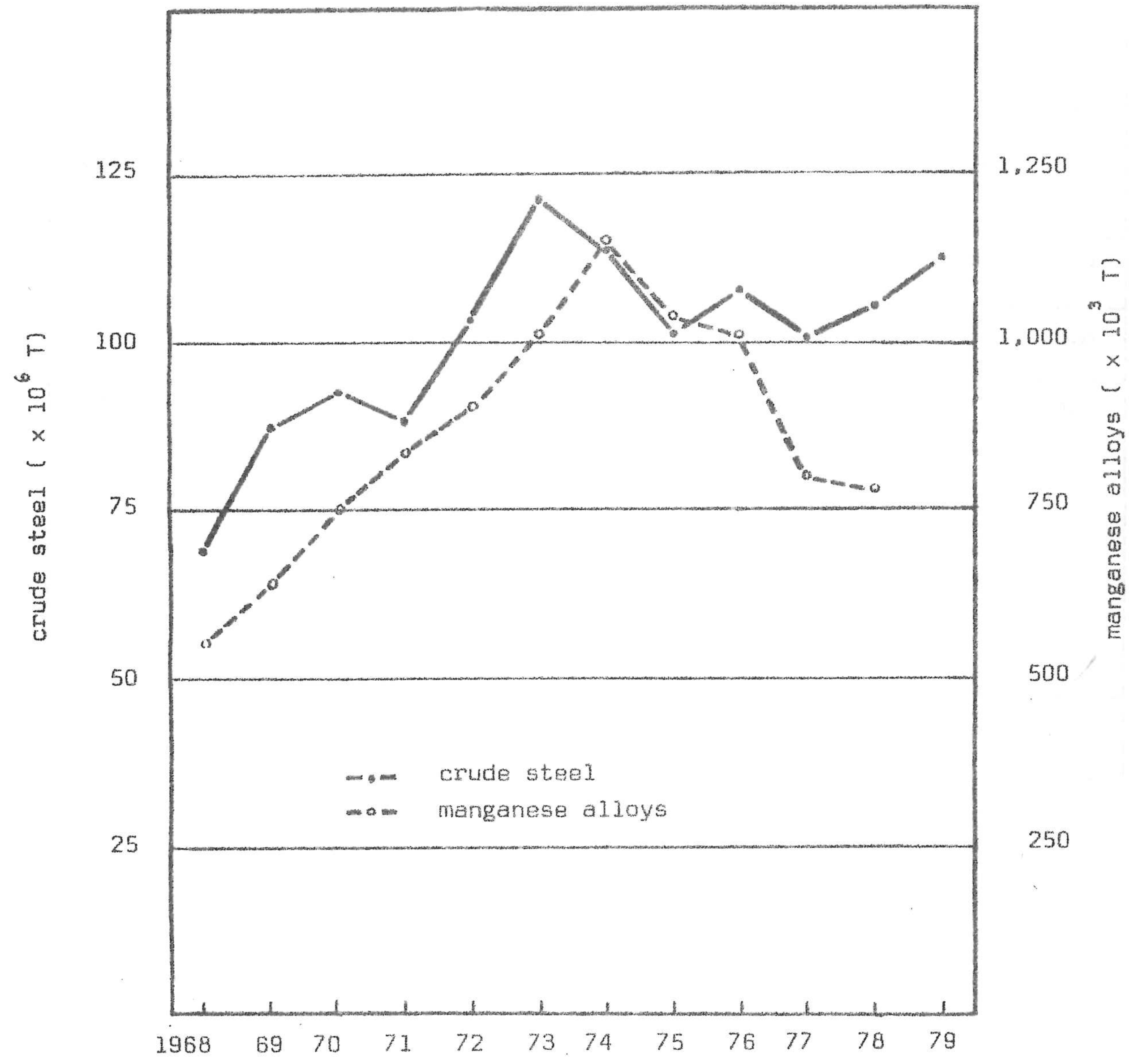


Fig. 1. Production of crude steel and manganese alloys in Japan.

Table 1. Production capacity of ferroalloys in NKK

Niigata Works		Toyama Works	
Products	Annual capacity (T)	Products	Annual capacity (T)
H.C. FeMn	97,000	H.C.FeCr	106,800
M.C. FeMn	27,500	L.C.FeCr	33,000
SiMn	127,500	SiCr	30,000
		L.C.FeMo	360
		Others	580
		FeMn, FeCr including N2	670
Total	252,000	Total	171,410

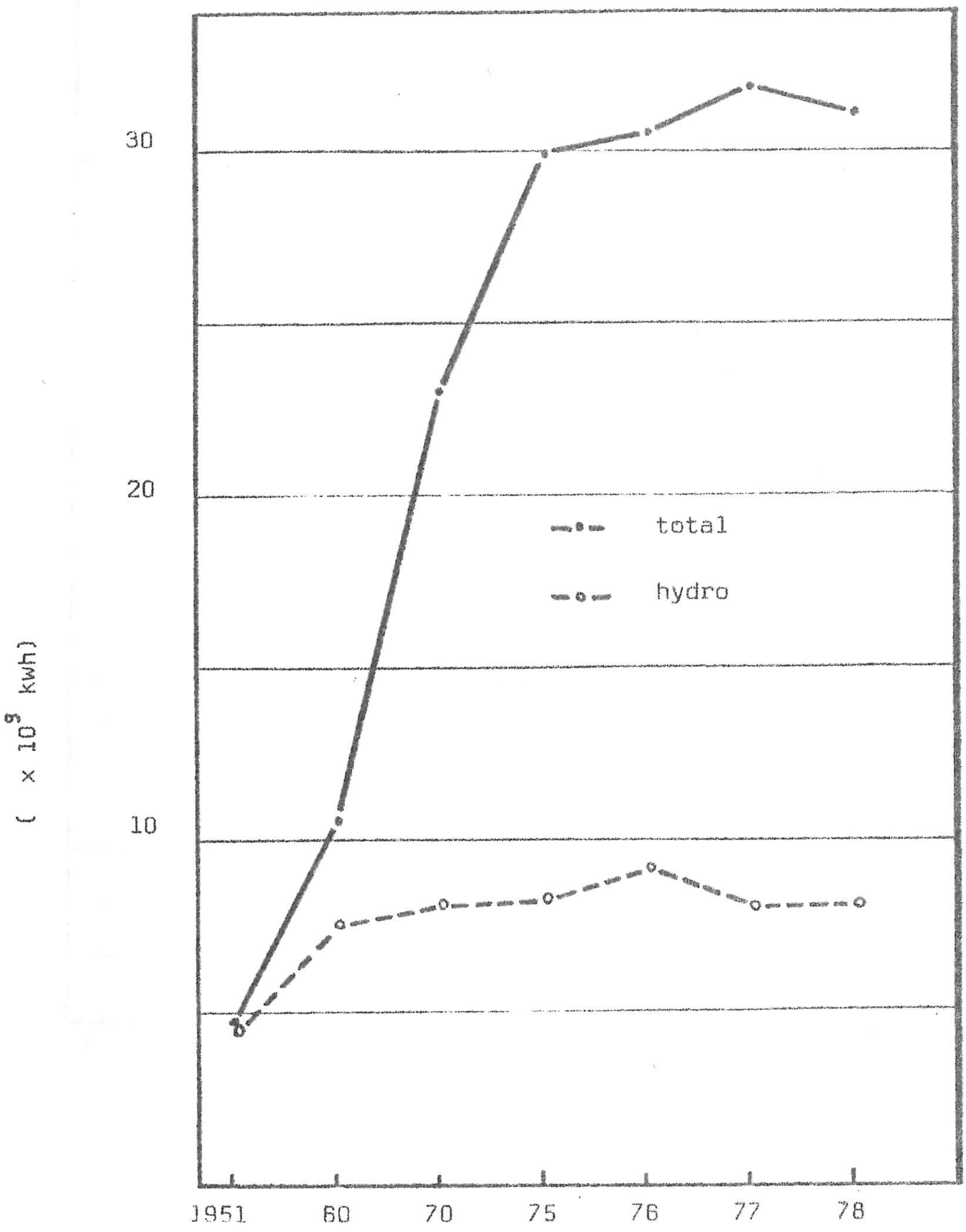


Fig. 2. Electricity output generated by The Tohoku Electric Power Co., Inc.

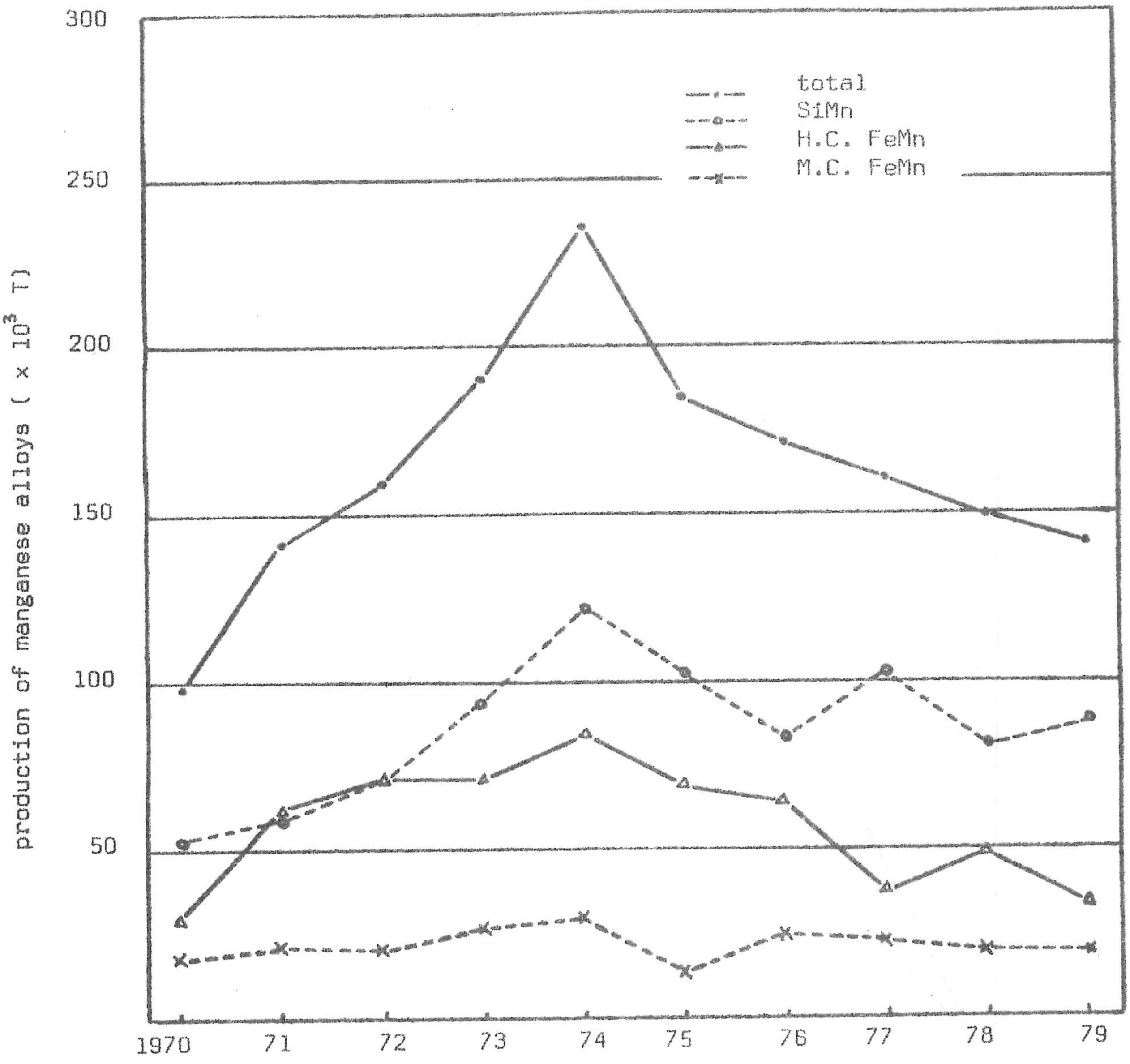


Fig. 3. Production of manganese alloys at NKK, Niigata Works.

Table 2. Production capacity and output at Niigata Works

Year	1970		1974		1979	
Item (T)	capacity	output	capacity	output	capacity	output
H. C. FeMn	30,000	29,000	97,000	84,000	97,000	34,000
M. C. FeMn	27,500	17,000	27,500	29,000	27,500	19,000
SiMn	53,500	52,000	127,500	121,000	127,500	88,000
Total	111,000	98,000	252,000	234,000	252,000	141,000
Output / capacity (%)	88.3		93.3		56.0	
Workers	367		422		290	
Output / worker (T/man)	267		557		486	

Table 3. Details of furnaces F12, F14 and F17

Constructed in	1962	1969	1973
Furnace number	F12	F14	F17
KVA	9,000	25,000	40,000
Type	Rotating, closed	Rotating, closed	Stationary, closed
Shell diameter mm	8,740	11,260	14,000
Shell depth mm	3,750	5,565	7,925
Hearth diameter mm	6,250	9,558	11,364
Top of shell to hearth mm	2,300	3,500	5,600
Electrode diameter mm	1,000	1,470	1,750
Electrode spacing c/c mm	2,500	3,675	4,200
Secondary voltage V	Δ - Δ 92 ~ 154	Δ - Δ 60 ~ 220	Δ - Δ 132 ~ 260
Secondary ampere KA	52	90	125
Tap holes	3	6	Metal : 2 Slag : 2

Table 4. Main peripheral equipments

Equipment	Computer	Sintering machine	Casting machine	Metal treatment
Constructed in	1976	1973	F14 : 1969 F17 : 1973	F17 : 1973
Outline of specification	memory : core : 64 KB disk : 1MB x 2 type : FACOM U-300	capacity : 200 T/D type : DL length x width : 12.6 m x 1.2 m	capacity : F14 : 60 T/H F17 : 200 T/H length x width : F14 : 26 m x 1.4 F17 : 70 m x 1.4 type : F14 : casting by ladle F17 : direct casting	capacity : revolving hopper : 20 T x 14 crusher : 30 T/H stockyard : 300 T x 16 bag filter : 420 m/min.
Main purposes	1. To control batching system of raw materials 2. Collecting, calculating and logging of operation variables 3. Furnace operation reporting 4. Calculation and printout of carbon balance, material balance and heat balance	1. To use the screened fine ores and cokes 2. Utilizing dust from gas cleaning equipments, bag-filters and electric precipitators	1. To reduce under size products 2. Decreasing labour power for crushing and sizing of products	1. Automatic treatment of products 2. Decreasing labour power for crushing and sizing of products 3. Improvement of environment

Table 5. Silicon recovery differentia by it's sources.

silica source	silicon recovery
High grade ores	40 %
Low grade ores	50
Iron ores	50
H.,M.C.FeMn Slag	30
Quartz	77
Coke	50

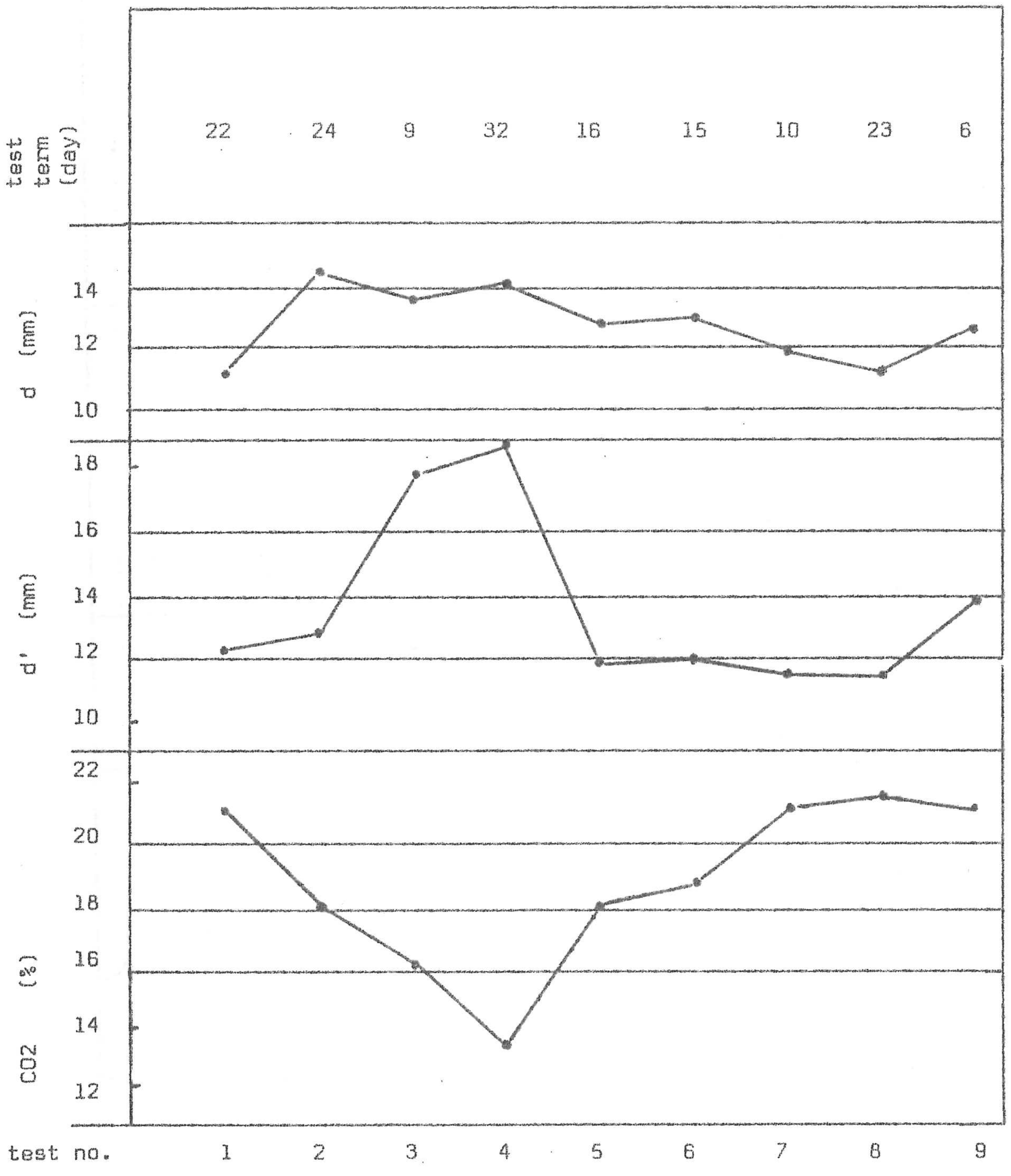


Fig. 4. Relations between CO2 and d, and d' in the operation test using screened ores and not screened ores.

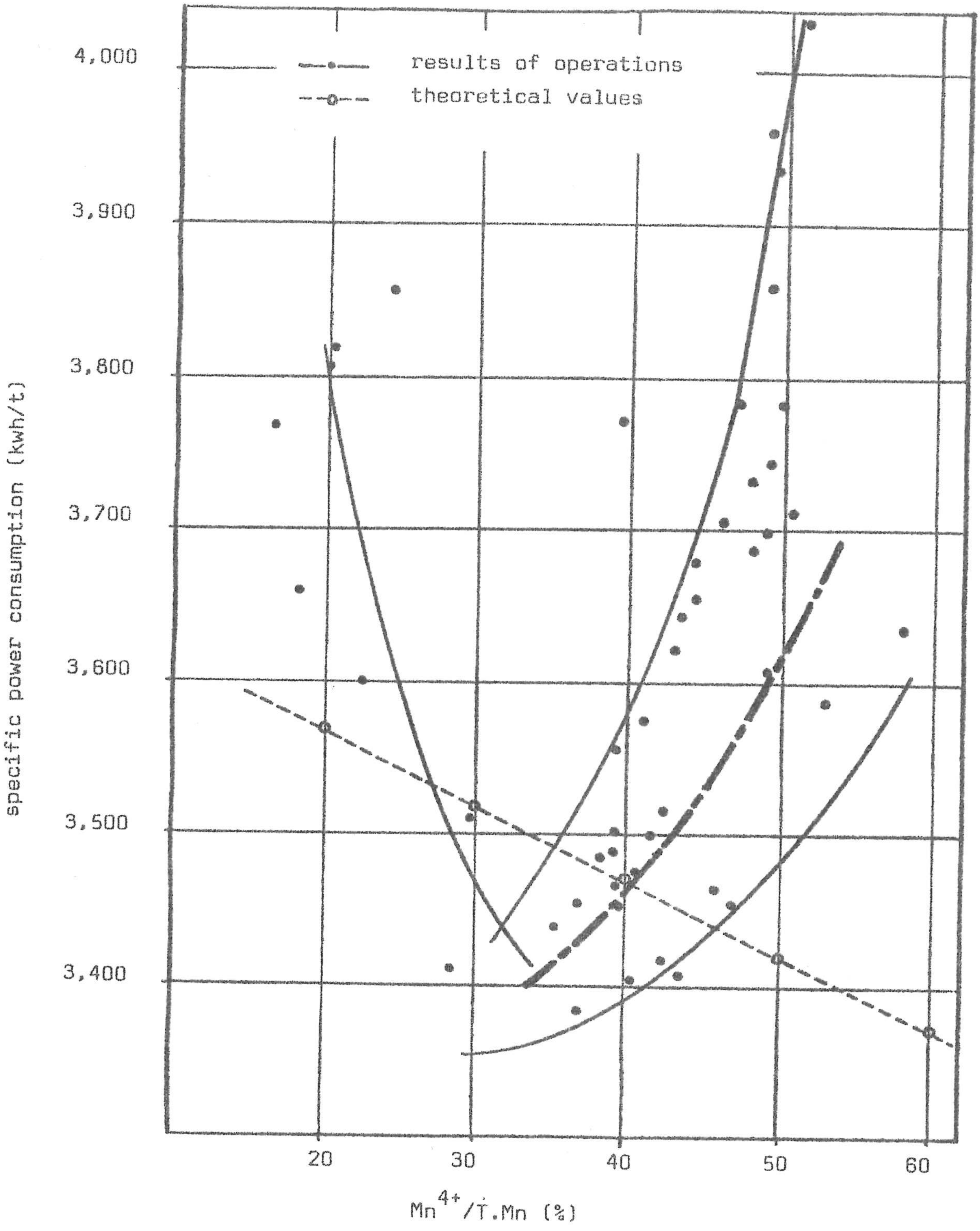


Fig. 5. Variation of kwh/t with $Mn^{4+}/T.Mn$ in the raw materials : results of operations in the long term, and calculated values on the conditions of $x = aMn^{4+}/T.Mn + b$, and $\eta = 0.725$. Here, x is indirect reduction ratio of MnO_2, and η is heat efficiency in the furnace.

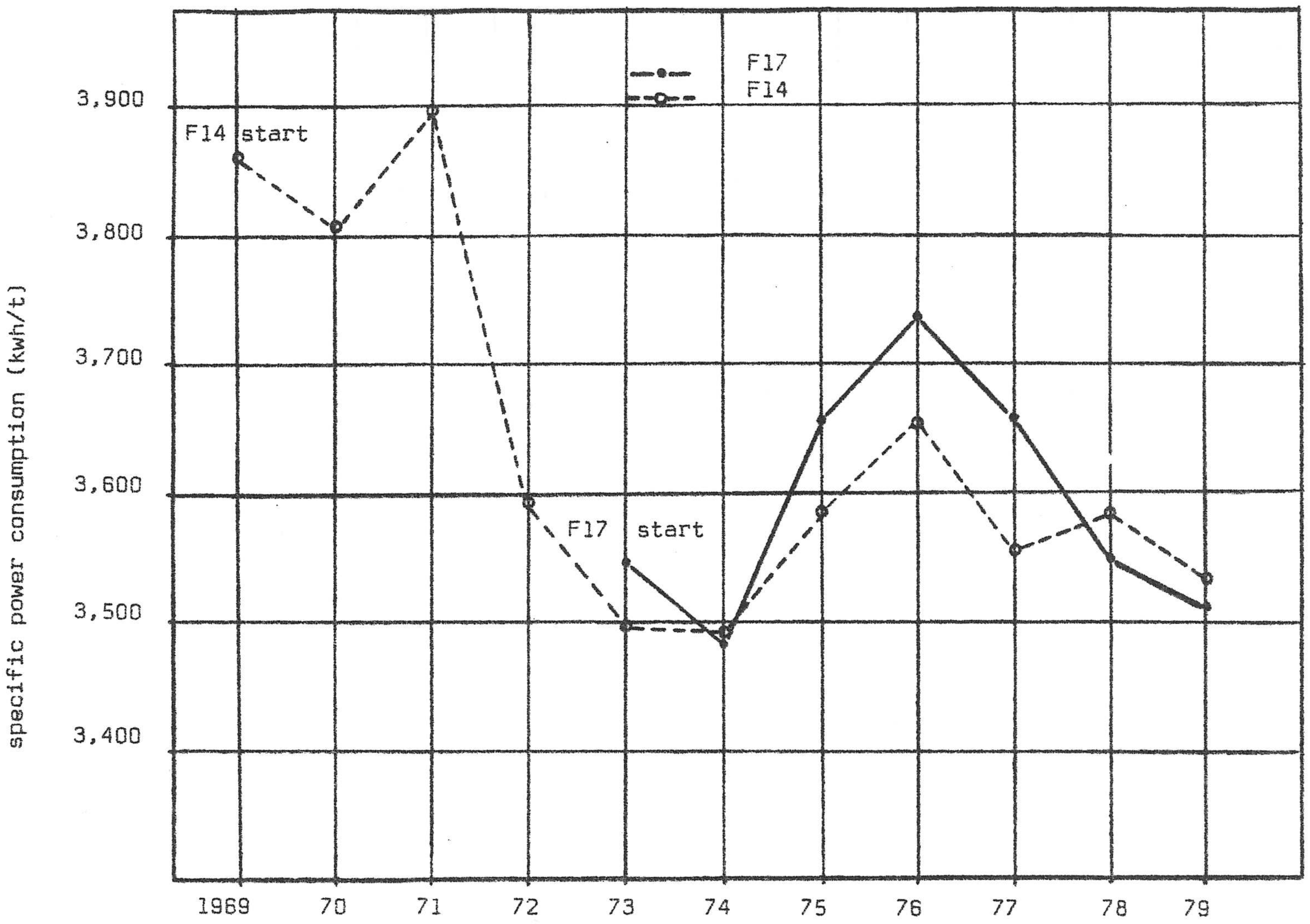


Fig. 6. Specific power consumption in recent decade.

Table 6. Details of furnaces F19 and F1

Constructed in	1970	1969
Furnace number	F19	F1
KVA	9,000	40,000
Type	Stationary, closed	Rotating, closed
Shell diameter mm	7,640	11,500
Shell depth mm	4,550	6,160
Hearth diameter mm	5,750	8,900
Top of shell to hearth mm	2,700	3,900
Electrode diameter mm	900	1,500
Electrode spacing c/c mm	2,160	3,538
Secondary voltage V	Δ-Δ 75 ~ 150	Δ-Δ 155 ~ 325
Secondary ampere KA	42	115
Tap holes	1	8

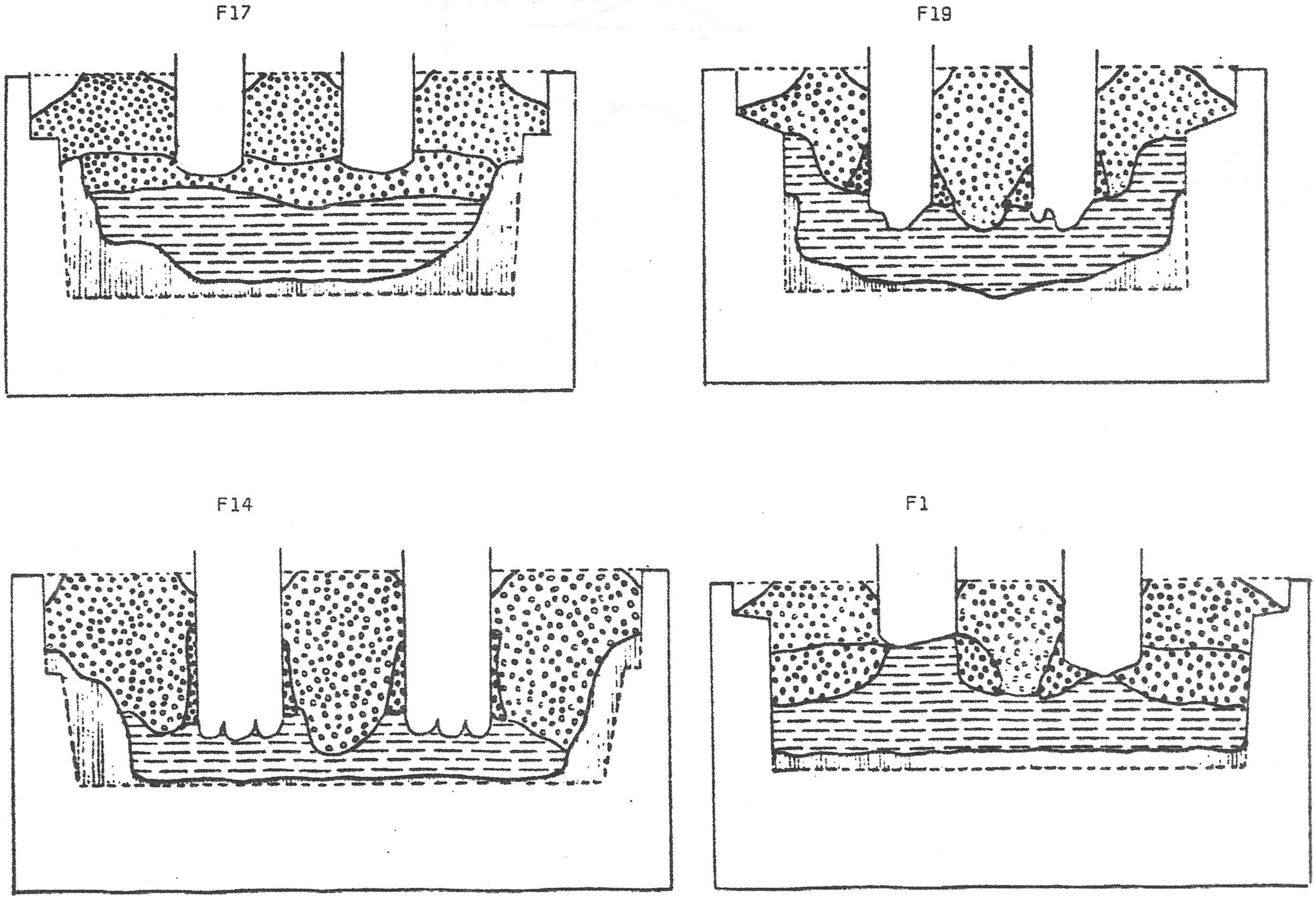


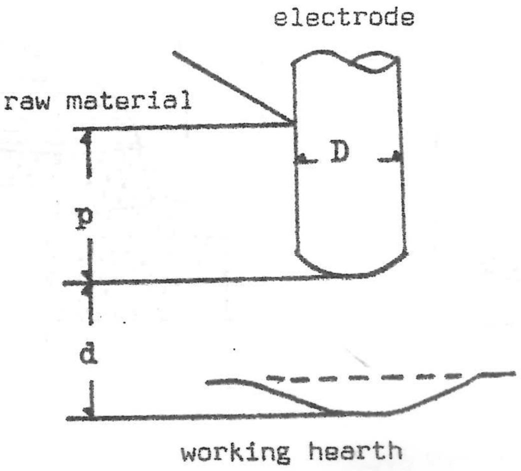
Fig. 7. Structure of working volume during the melting of silicomanganese after natural cooling.

▩ coke bed, ⁘ raw materials in solid state, ☰ melted raw materials, slag and metal
▥ self lining

Table 7. Electrode penetration and coke bed

Furnace number	F17	F19	F14	F1
Operated term from to for	15 Aug., 1973 1 Jul., 1977 3 years 10 months	2 May, 1977 30 Jan., 1978 9 months	7 Feb., 1975 30 Jun., 1978 3 years 6 months	4 Jan., 1978 7 Jul., 1978 6 months
Operated time after last tap	1 hrs 10 min.	2 hrs	2 hrs	2 hrs
Electrode penetration (= p)	1.14 D	2.61 D	2.00 D	1.30 D
Distance between the tip of the electrode and the working hearth (= d)	1.77 D	0.44 D	0.37 D	1.30 D
p/(p + d)	0.392	0.856	0.844	0.500
Coke remained in the coke bed (a)	210 t	16.3 t	14.0 t	77.0 t
Calculated coke to be remained (b*)	135 t	16.3 t	60.4 t	48.5 t
a/b	1.56	1.00	0.23	1.59
Coke bed	plain	conical	cylindrical	plain
It's feature and thickness	very thick (about 1,000 mm)	thin (about 600 mm)	very thin (about 300 mm)	thick (about 800 mm)

p, d and D are as following :



* b is calculated by the ratio of the volume inside the furnace on the condition the coke in F19 is normal.

Table 8. Raw materials used in the dissected furnaces and results of operations.

Furnace number	F17	F19	F14	F1
Raw materials %				
Ore : A	43	19	16	6
B	10	-	17	-
C	9	-	8	-
D	-	44	-	-
E	10	-	14	-
F	-	-	-	48
G	-	-	-	46
Sinter	-	-	8	-
H.C.FeMn Slag	20	15	15	-
M.C.FeMn Slag	8	22	22	-
Mn^{4+}/T.Mn %	47	26	52	20
Operational performance kwh/t for last month* (=c)	3,600	3,545	3,654	3,755
kwh/t taken from Fig. 5 (=d)	3,571	3,560	3,660	3,673
c/d	1,008	0,996	0,998	1,022

* corrected to Si = 15.0 %

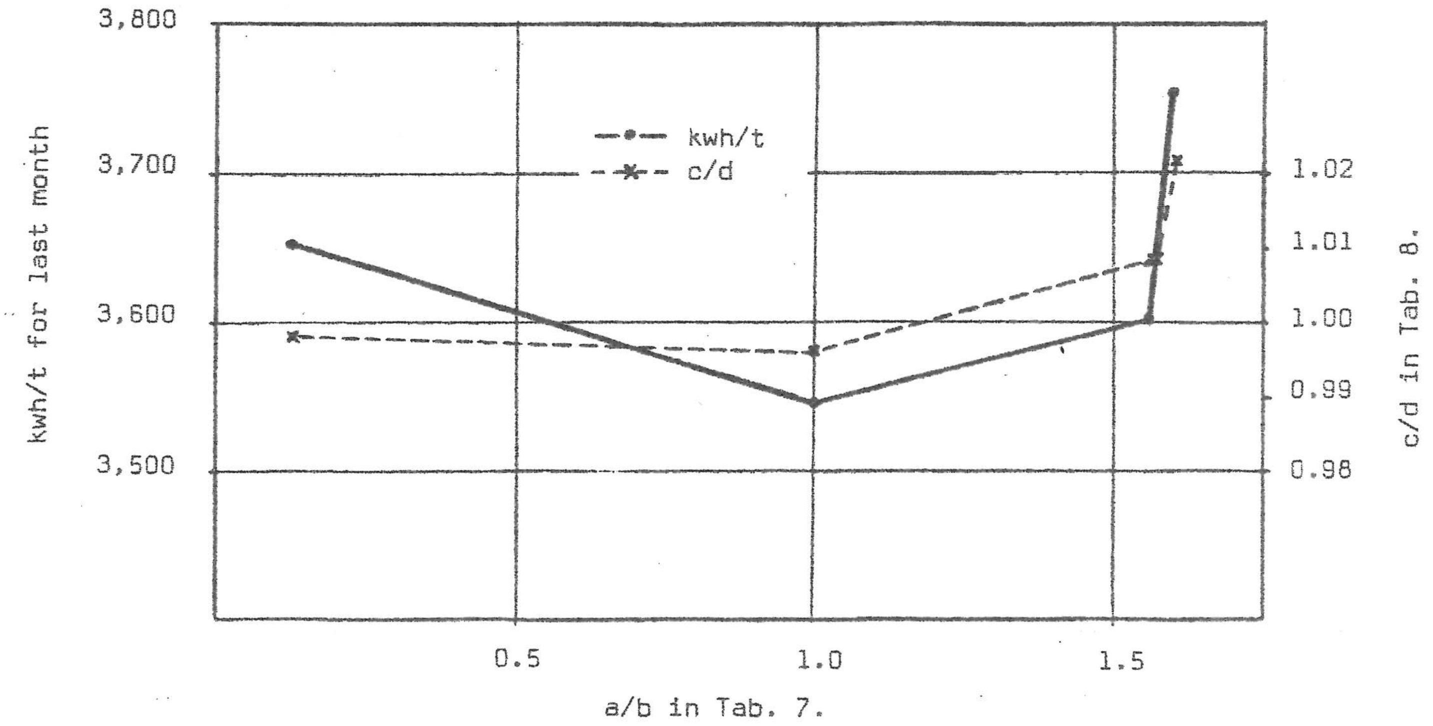


Fig. 8. Relation between kwh/t for last month, c/d in Tab. 8, and a/b in Tab. 7.

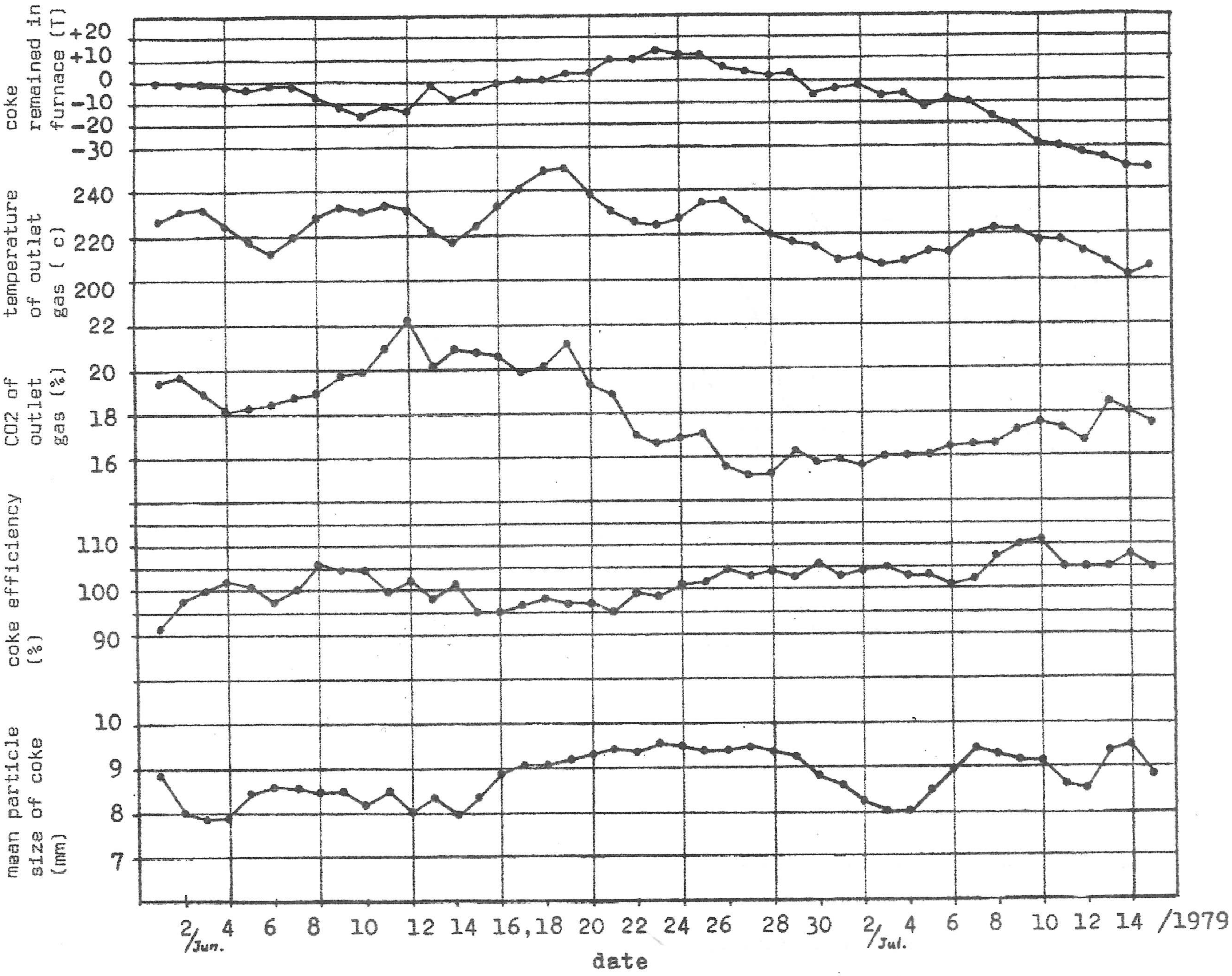


Fig. 9. Operation result of F17.

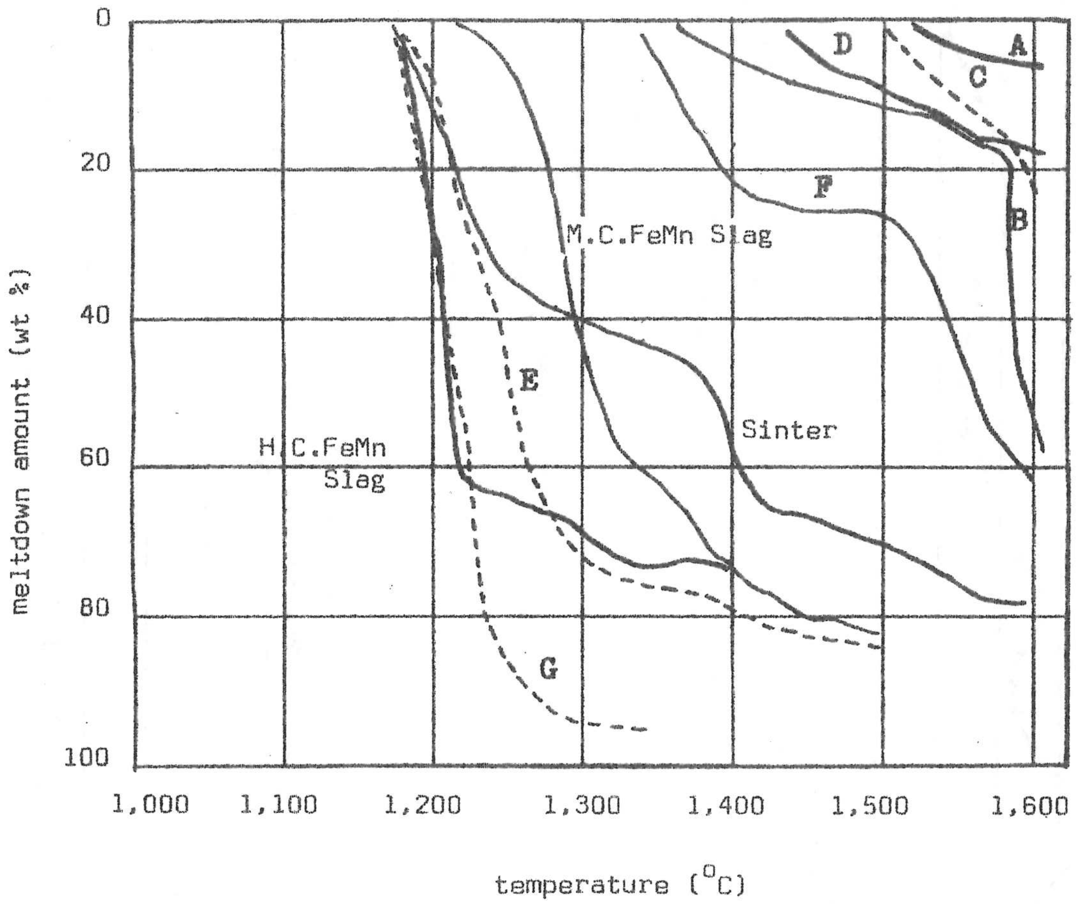


Fig. 10. Meltdown temperature of raw materials : raw materials are the same given in Tab. 8., and test conditions are :

Material : 5-8 mm, 200 grs
Crucible : Graphite
Gas : N2, 3 ℓ/min.
Heating rate : 7^{o} C/min.
Applied load : 0.5 kg/cm^{2}.

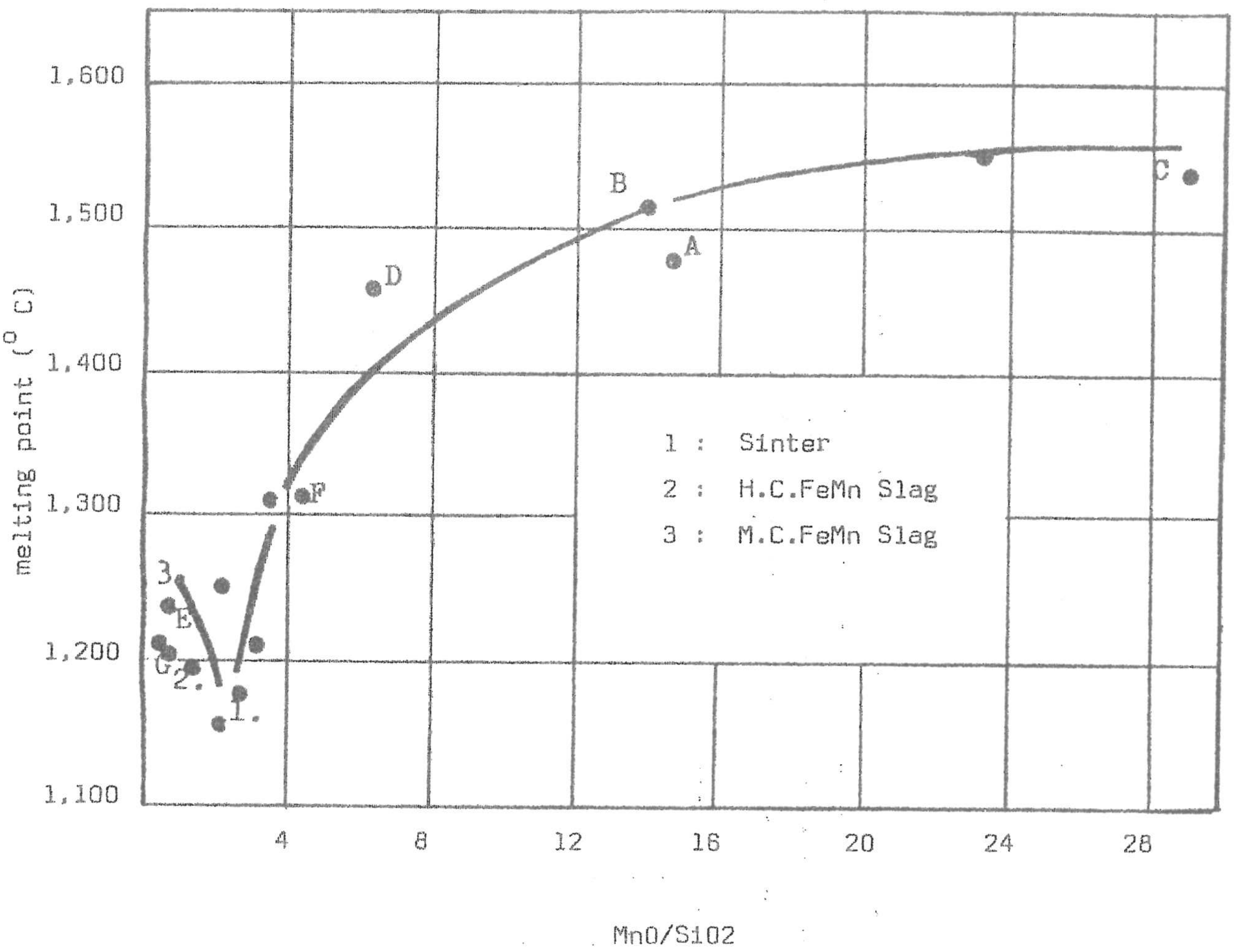


Fig. 11. Relation between MnO/SiO2 and melting point : raw materials are the same given in Tab. 8.

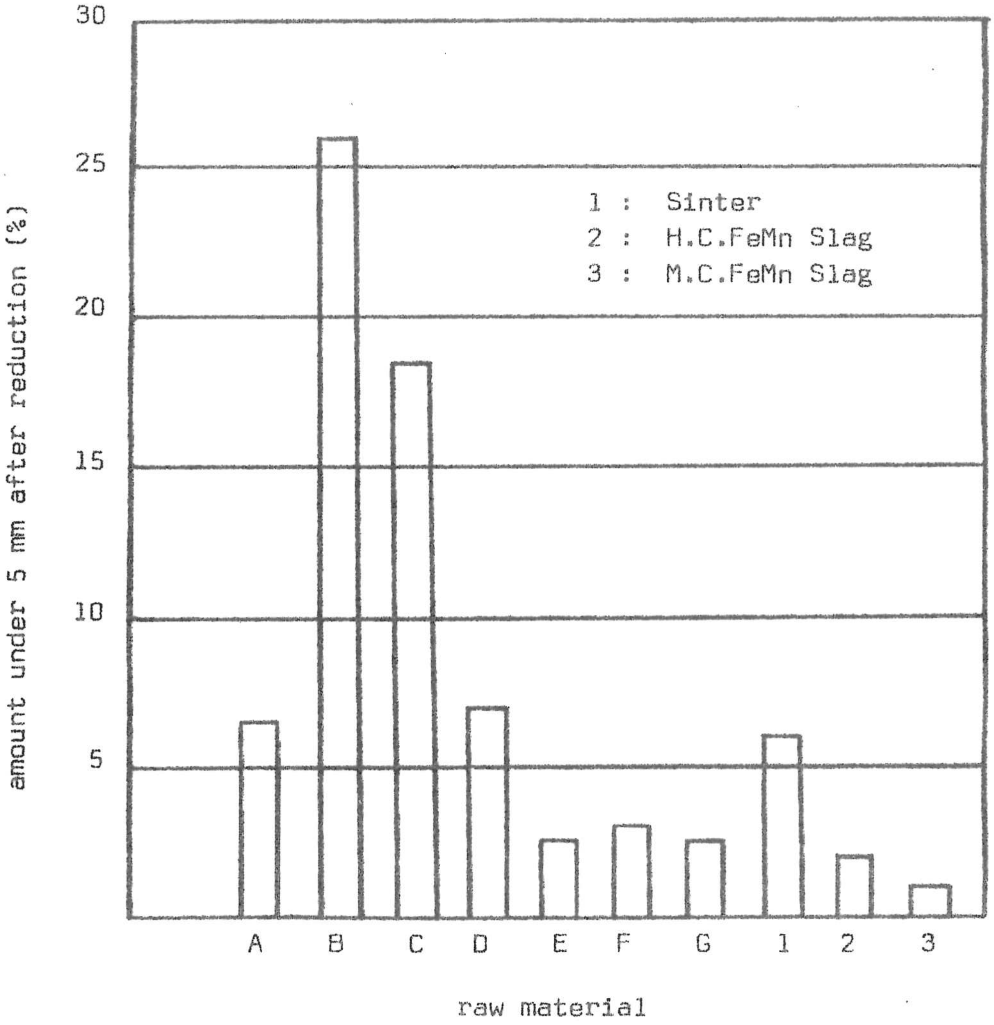


Fig. 12. Disintegration of raw materials : raw materials are the same given in Tab. 8, and test conditions are :

Material : 5-50 mm, 500 grs

Gas : CO 70%, CO2 30%, 15 ℓ/min.

Heating rate : 25 → 500°C/25 min, 500 → 1,000°C/65 min.

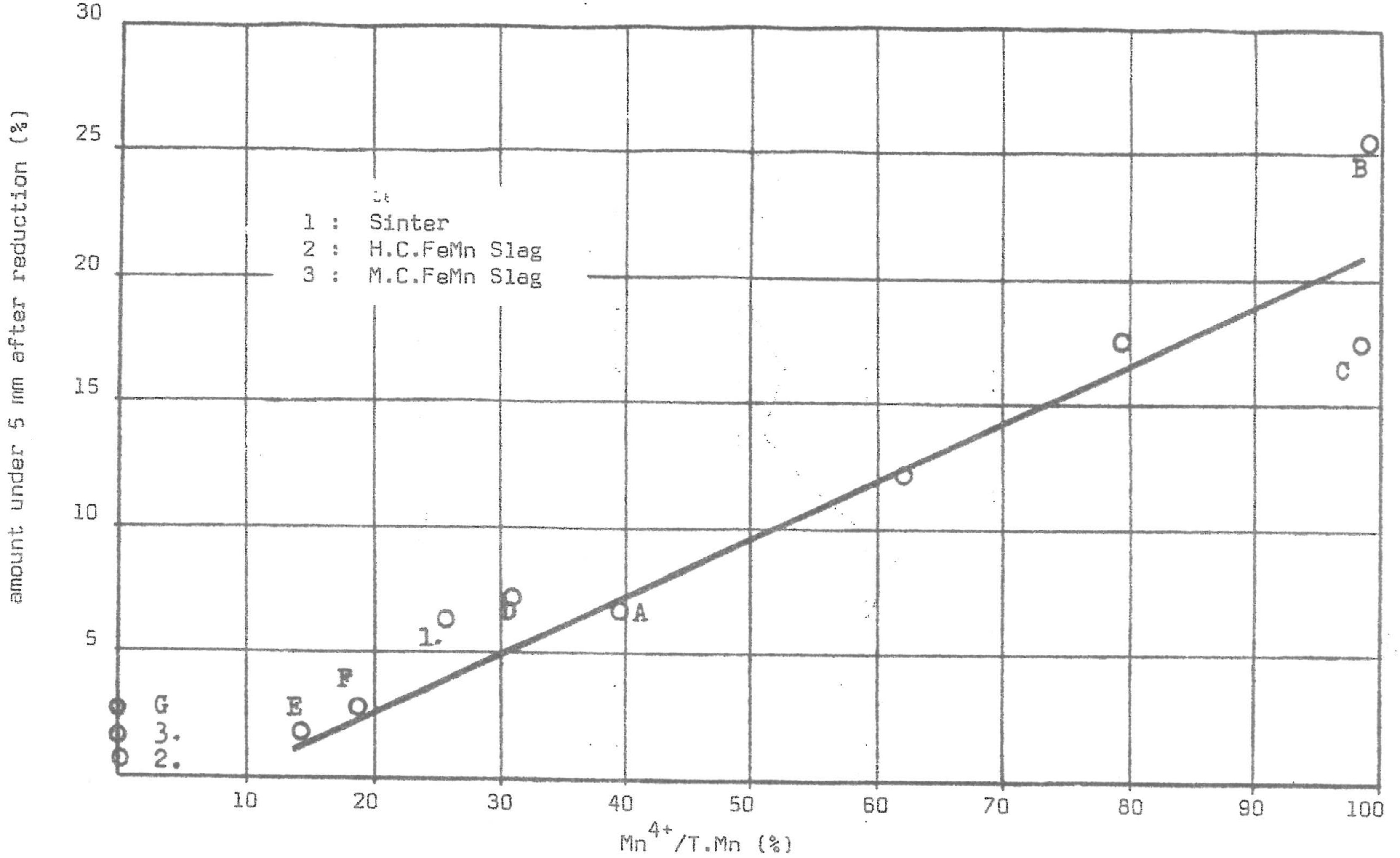


Fig. 13. Relation between Mn^{4+}/T.Mn in raw materials and disintegration during reduction : raw materials are the same given in Fig. 12.

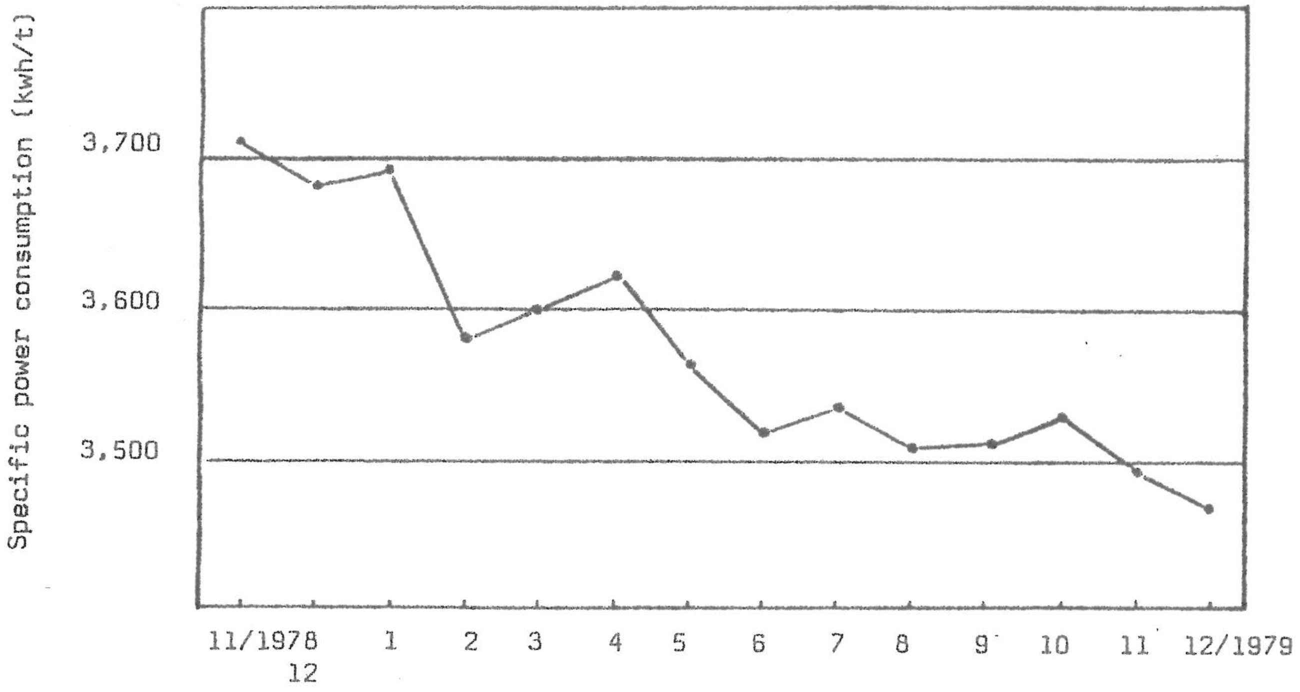


Fig. 14. Specific power consumption of F.14.