OPTIMIZING SOME FACTORS CONTROLLING HIGH MANGANESE BAHARIA IRON ORE SINTER QUALITY.

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ABSTRACT

There are many factors controlling the sinter quality. One of the most important parameters that affect the sinter quality is the amount of water added to the raw materials before sintering process. Besides, the amount of coke breeze used during sintering process is of second importance. This investigation deals with optimizing both moisture content of the raw mix and amount of coke breeze added to the sinter mix for obtaining high quality iron ore sinter. It was found that 15% water added and 9% coke breeze give the highest sinter quality. The effect of both moisture content and amount of coke breeze on the different sintering parameters (vertical velocity, sinter strength, productivity at Blast furnace yard, amount of ready made sinter, reducibility and total porosity of the produced sinter) were investigated. Besides, a petrography study of the produced sinter at different moisture and coke rates was conducted.

1. INTRODUCTION

Iron and Steel company in Egypt depends mainly on Baharia iron ore as the main ore used in the production of pig iron. The main process used for preparation of such ore to the blast furnace is the sintering process. It is well known that the productivity of the blast furnace increases to a large extent with increasing the properties of the iron ore sinter fed into it (i.e. increase of sinter strength leads to an increase in the blast furnace productivity and decrease coke consumption in blast furnace [1]).

There are different parameters controlling the quality of the produced sinter such as amount of water and coke breeze added to the raw mix, basicity of the charge, bed height, ...etc.

Many investigators have studied the effect of both moisture content and amount of coke breeze added on the sintering process:

Korotich et al [2], and Seshardi [3], reported that the optimum water content in the sinter mix required for maximum productivity of good sinter quality does not necessarily coincide with the optimum water content in the sinter mix required for maximum pre-ignition permeability.

Voice et al [4] and Pozyuk et al [5], indicated that increasing return fines content in the sinter mixture reduced the moisture required to give a permeable mix.

Hay [6], illustrated that the moisture requirement decreased with increasing particle size of the sintering charge mixture.

Abd El-All et al [7], found that the vertical speed of the sintering process increased gradually with the increase of water content until reaching a maximum at 13% and then decreased.

Shalabi et al [8], indicated that the sintering time for particular sintering charge depends on the amount of water added to the charge. Also they indicated that any variation in the amount of water added from the optimum, even in very small amount, leads to a sensible drop in the productivity.

Bogan et al [9] concluded that insufficient amount of coke breeze prevent reaching the required sintering temperature, while an excessive amount of it, increases the sintering temperature beyond its limit, hence causing melting of the sintering charge components, not semi-melting.

Some investigators [9-12], found that the yield of ready made sinter and consequently the specific productivity increase linearly with increase in coke content.

Some investigators found that the optimum fuel content for sintering of hematite, proceeding with high efficiency is acquired only together with 4 – 5% coke [13-18]. Higher values lead to an increase in FeO and Fe metal. It was observed that decreasing the coke from 5 to 4% is accompanied by a 10% increase of fine produced from shatter test, decreased of amount of ready-made sinter by 18% and decreased metallic iron and FeO by 9% [7].

Shalabi et al [19], found that increasing the amount of coke breeze from 1% to 9% in the raw mix of low manganese iron ore, the amount of ready made sinter, the productivity and the mechanical strength were increased.

El-Hussiny [20], indicated that the increase of coke breeze content in the raw mix of low manganese iron ore, improves the amount of ready made sinter and its strength. The productivity of the sintering machine and the productivity at blast furnace yard reaches maximum values at 7% coke breeze while the percentage of sulfur in the produced sinter decreased to a minimum value at 5% coke breeze. Also, the degree of reduction was decreased as the amount of coke breeze increased.

The aim of this study is to optimize the most important parameters that affect to a large extent, the sinter quality i.e., amount of water added during preparation of the raw mix and amount of coke breeze used during sintering and their effect on sinter quality.

2. MATERIAL AND EXPERIMENTAL WORK.

2.1 Materials.

The raw materials used in this work were El-Baharia Oasis high manganese iron ore (El-Gedida iron ore deposits), limestone, recycled sinter (sinter return), and coke breeze. The chemical compositions of the raw materials used are given in Table 1.

2.2 Apparatus and Technique

Sintering experiment were conducted in a laboratory down draft sinter pot., (3 kg). Airflow was provided by two fans in series, which were capable of producing suction pressure in excess of 11.76 Kpa. Pt-Pt. Rh. Thermocouple measured the temperature of the waste gas, which gives an indication of the end of the sintering process. The raw materials whose basicity (CaO/SiO_2) was 1.2 were blended together. A sinter bed of 0.5 kg sinter (+10 mm) was placed over the grate of the pot to protect it against the high temperature during the sintering operation. The green mix was loaded over the sinter bed layer in the sinter pot.

The green mix was ignited with a gas flame over a period of 3 minutes. The ignition was done under suction pressure of 5.88 KPa., while the sintering process was done under suction pressure of 11.76 KPa. The sintering time was determined by time elapsed from start of ignition until the exhaust gas temperature reached a maximum value [1,10,12]. At the end of the sintering experiment the sinter cake was dropped from the sinter pot on to a steel plate laid on concrete.

The productivity of the sintering machine was calculated according to the following relation [1].

$$P = 14.4 * V * K * p \qquad (1$$

Where:

P is the productivity of sintering machine (+7 mm.), ton/(m^2 day).

V is the vertical velocity of sintering machine, (V = H/T) m/min.

H is the height of the charge, m.

T is the time of sintering, min.

K is the percentage of ready-made sinter from the charge, (+7 mm.).

P is the bulk density of the charge, ton/m^3.

The sinter cake was screened over a sieve of +10 mm.[1,21], then the sinter of +10 mm was taken and dropped four times from a height of 2 m. Then the out sinter after shatter test was screened over a sieve of +7 mm. The sinter strength (W) was calculated as the percentage of (-7 mm) sinter relative to +10 mm sinter [20,22].

$$\text{Sinter strength (W)\%} = M_1 * 100/M_2 \qquad (2$$

Where:

M_1 is the weight of sinter –7mm after shatter test, kg.

M_2 is the weight of +10 mm sinter before shatter test, kg.

When W is high this mean that the strength of sinter is low and vice versa.

The productivity at blast furnace yard was calculated according to the following relation [13,14].

$$P_{B.F.} = P * (100 - W)/100. \qquad (3$$

Where:

$P_{B.F.}$ is the productivity at blast furnace yard, ton/(m^2 day).

P is the productivity of sintering machine, ton/(m^2 day).

W is the sinter strength, %.

The reducibility was done using H_2 atmosphere as a reducing gas, under the following conditions (temperature of reduction = 800 °C, H_2 flow rate = 1.5 l/min., and time of reduction = 30 min.).

The total porosity of sinter was measured using the Pycnometer method [1].

The softening temperature of the produced sinter was carried out in the softening apparatus according to the standard methods [24].

3. RESULTS AND DISCUSSION.

3.A. Effect of amount of water.

3.A.1 Effect of moisture addition on the technical parameters of the sintering process.

The effect of water added to the raw mix on the technical parameters of the sintering process was studied at 8% coke breeze of the dry charge.

Figs. 1&2, illustrate the relation between the amount of water added and the technical parameters of the sintering process.

As shown from Fig. 1, the vertical velocity increases with increasing moisture content from 12% to 15% reaching a maximum at 15% and then decreases thereafter. This could be explained in view of the fact that the increase of water content up to the optimum value increases the average diameter of micro pellets in the raw mix and thus the permeability of the sinter charge is improved [3,4]. Increasing moisture content beyond the optimum value, i.e., 16%, the condensed water in the lower part of sintering machine creates muddy slurry, which decreases the permeability of the charge during sintering leading to the increase of the time of sintering [3]. Also, it may be attributed to the fact that increasing the quantity of water leads to the formation of soft pellets, which collapse together causing a decrease in the permeability [23].

It is also noticed that the ready made sinter, sinter strength, productivity of sintering machine and productivity at blast furnace yard increase with the increase of moisture content attaining maximum values at 15% water and then sharply decreased thereafter as shown in Figs. 1 & 2. The increase of ready-made sinter and sinter strength with increasing the amount of water added up to 15% is due to the improvement of heat utilization during the sintering process. While the increase in productivity is due to the improvement of the ready made sinter and vertical velocity. The productivity at the blast furnace yard is greatly related to the productivity and the strength of the produced sinter as concluded from equation 3. Thus the productivity at blast furnace yard is increased by increasing water content up to the optimum (15%).

3.A.2 Effect of Moisture Content on the Chemical Composition. Reducibility, Porosity and Softening Temperature of the produced sinter.

From Table 2, It is clear that the FeO content increases with the increase of water content up to 15%. This could be explained in terms of the improvement of the permeability which leads to the improvement of heat transfer causing the dissociation of higher iron oxides to lower oxides [8,24]. Any increase of water content above the optimum value leads to a decrease in FeO content due to low permeability of the sinter charge, which leads to a low heat transfer and subsequently the dissociation of higher iron oxides to lower ones is substantially decreased.

It can be also noticed that the MnO increases with the increase of water content up to 15% and then decreases, this may be explained by the twinning between the manganese oxide and iron oxide contents in the produced sinter.

The decrease in sulfur content with increasing the water up to 15% is related to the improvement of the permeability and the heat transfer which in turn lead to a decrease in sulfur content, while the increase of sulfur content in the produced sinter at 16% water content is due to the fact that the heat is not sufficient for the desulfurization [8].

It can be easily noticed that the minimum amount of Na^+ & K^+ is 0.300% and 0.1240% respectively, at 15% water added. This can be attributed to the high heat transfer and high heat utilization leading to high removal of Na^+ and K^+ at the optimum value.

The reducibility of the produced sinter is illustrated in Fig. 3. It is clear that the reducibility of the produced sinter is minimum at 15% water added. This is due to the low porosity of the produced sinter (Fig. 3) and also to the high amount of FeO [2,5,25-27], (Table 2.)

Fig. 3, shows that the porosity of the produced sinter decreases gradually with the increase of water content reaching a minimum value at 15% moisture then it jumps back to the original value at 16% water content. The decrease in total porosity with the increase of moisture content in the raw mix could be explained by the following: 1- At low moisture content (12%), low granulation extent and low permeability take place which aggravate the heat transfer through the sinter charge and lead to a decrease in melt formation and hence the porosity of the produced sinter increases. 2- The increase of moisture content from 12% to 15% improves the granulation extent and the permeability of sinter charge, which leads to the increase of the rate of heat transfer which match the rate of coke consumption achieving maximum bed temperature. This extent of matching leads to higher melt formation and low porosity. 3- At higher moisture than the optimum (15%) the permeability decreases due to the formation of muddy slurry, which leads to higher porosity after evaporation.

Softening temperature of the produced sinter in oxidizing atmosphere is illustrated in Fig. 4. It can be noticed that the initial (Ti) and final softening (Tf) temperatures increase with increasing water content giving a softening interval from (~835.0 °C and ~847.5 °C) to (~851.0 °C and ~861.0 °C) when the water added changed from 12% to 16% respectively. The increase of softening temperature is due to the increase of FeO content. The porosity also plays an important role since the low total porosity values helps in increasing the initial and final softening temperature [28].

3.3 <u>Effect of moisture content on the petrography of the produced sinter.</u>

Inspection of the diffractograms of X-ray analysis of the studied samples are shown in Fig. 5, from the different lines of diffractograms, the following phases can be identified. Magnetite, γ-hematite, α-hematite, calcium diferrite, calcium ferrite, wustite, dicalcium ferrite in addition to manganese ferrite $MnO.Fe_2O_3$.

It was observed that γ-hematite in case of 15% water addition is less than in case of 12% and 16% (Fig. 5) which could be explained by the improvement of the permeability of the raw mix at optimum moisture content (15%) which leads to the improvement of heat transfer in the hot zone thus the decomposition of Fe_2O_3 to Fe_3O_4 takes place [8,24].

It is clear from the photomicrograph of the produced sinter, (Figs 6 - 8) that at 12 % moisture the microstructure of the produced sinter was magnetite in globular and dendrite, crystals embedded in silicate matrix. At the optimum value of moisture content (15%) the structure is crystalline magnetite in the form of fine and large crystals and dicalcium silicate crystals embedded in silicate matrix. In case of 16 % water added the structure of the produced sinter was magnetite of different shapes embedded in silicate matrix .

B- Effect of amount of coke breeze

3.A.1 <u>Effect of coke breeze content on the technological parameters of the produced sinter.</u>

The effects of variation of the amount of coke breeze in the raw mix on the technological parameters of the produced sinter are shown in Figs. 9 & 10.

It was observed that the rate of sintering (vertical velocity) decreases with increasing coke breeze rate (Fig. 9) this fact may be due to the longer time required for coke combustion and also due to the increase of the amount of melt which decreases the permeability of the raw mix during the sintering process [28].

From, Fig. 9 it is evident that the amount of ready made sister increases from 65% to 74% with increasing the coke content from 8% to 11% respectively. This can be explained in view of the increase of amount of melt as a result of the increase of heat.

It is clear that the strength is greatly affected by coke breeze content Fig. 10. The remarkable improvement in sinter strength when the coke breeze content increases from 8% to 11% may be attributed to the heat input and mineralogical composition of the produced sister. At lower coke breeze content, the heat input is not sufficient for complete melting and coarse porous structure of sinter is formed causing low sinter strength. It is supposed that increasing coke breeze content 8% to 11% leads to an increase in the heat input and hence increases the melting and subsequently the strength of sinter is improved [1,21,24].

The productivity of the sintering machine and the productivity at the blast furnace yard increase and reach maximum value at 9% coke breeze (Fig.10). The increase of the productivity with the increase of coke breeze content from 8 to 9% is correlated to the increase of the amount of ready made sinter at these coke contents. Any increase in the coke breeze content more than 9% leads to an increase in melt formation, a decrease in the permeability leading to a decrease in the vertical velocity and productivity.

3.A.2. Effect of Coke Breeze Content on the Chemical Composition, Reducibility, Porosity and Softening temperature of the produced sinter.

Table 3 shows the chemical composition of the produced sinter when different amount of coke breeze in the raw mix was used. It can be noticed that the FeO and Fe_{met} contents increase with the increase of coke breeze content from 8 to 11%. This could be due to the increase of the heat input caused by the gasification of coke producing carbon monoxide, which leads to the reduction of higher iron oxides to lower oxides [8,24,27,29].

The decrease of the content of sodium and potassium ions in the produced sinter with increasing coke breeze content, could be explained in view of sublimation of these ions by increasing heat input

Also it is clear that the amount of MnO slightly increased from 5.04% to 5.20 % when the coke breeze increased

The increase of sulfur content from 0.21 to 0.35% in the produced sinter with increasing coke breeze content from 8 to 11% is due to the fact that the oxygen gas is consumed by coke breeze in the gasification process to produce carbon monoxide and dioxide, thus the remainder oxygen is not enough to combine with sulfur producing SO_3.

Fig. 11, shows that the reducibility of the produced sinter decreased with the increase of coke breeze rate, this is attributed to the increase of the FeO content (Table 3) and the decrease in the porosity of the produced sinter Fig. 11.

From Fig. 11, it can be noticed that the total porosity decreases with increasing coke breeze content, this may be due to the increase in heat input which leads to increase melt formation subsequently the porosity of the sinter decreased.

It is clear that the softening temperatures (Ti, Tf) increase with increasing coke breeze content (Fig. 12). The increase in the initial and final softening temperature (Ti, Tf) is attributed to the increase of FeO content and also is due to the decrease in porosity caused by the increase in melt formation [28].

3.6. <u>Effect of Coke Breeze on The Petrography of The Produced Sinter.</u>

Inspection of the X-ray diffractograms Fig. 13, of the produced sinter, the following phases can be easily identified γ-hematite, α-hematite, magnetite, manganes-ferrite, wustite, monocalcium ferrite, dicalcium ferrite, A remarkable increase in magnetite and wustite can be observed as the coke breeze content increases, in addition the Mn_2O_3 is reduced to Mn_3O_4.

The photomicrographs Figs. 14 & 15, show the presence of crystalline globular magnetite and monocalcium ferrite in different textures embedded in a silicate matrix.

CONCLUSIONS

According to the present study on the effect of water amount and coke breeze on the properties of the sinter produced from sintering of Baharia high manganese iron ore, the following conclusions considered:

1- The addition of water to the raw mix has a great effect on the technological parameters of sintering process and the optimum value of water added depends on the type of iron ore used in sintering process.

2- The optimum amount of water added to El-Baharia iron ore that has high manganese content (5.2%) is equal to 15%. At the optimum value, the amount of ready made sinter, sinter strength, vertical velocity of sintering process. productivity of sintering machine and productivity at blast furnace yard attain maximum values.

3- The maximum amount of wustite FeO (13.25%) and Manganese oxide MnO are obtained when 15% water additin was used. Also, the minimum sulfur, sodium and potassium ions contents in the produced sinter are obtained when 15% water was used.

4- The minimum degree of reduction is reached when 15% water was used. This is due to the minimum porosity and high FeO content in the produced sinter.

5- As the amount of coke breeze increases, the vertical velocity decreases while the amount of ready made sinter and sinter strength increased.

6- The productivity of sintering machine and productivity at blast furnace yard reaches their maximum values at 9% coke breeze.

7- The amount of FeO and Fe_{metal} increases with the increase of the amount of coke breeze, while the amount of Na^+ and K^+ decreases. Also, slight increases in MnO content were noticed.

8- The minimum sulfur content in the produced sinter is obtained at 8% coke breeze; this is due to the favorable condition sufficient to remove sulfur during the sintering process at this rate of coke breeze.

9- The degree of reduction decreases when the amount of coke breeze increased, this is due to the increase of FeO content and the decrease in the total porosity.

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Table. 1. Chemical composition of raw materials.

Component, %.	Iron ore	Limestone	Coke breeze	Sinter return
Fe_{total}	48.99	—	2.24	51.5
FeO	—	—	—	18.93
Fe_{metal}	—	—	—	0.49
Fe_2O_3	69.86	—	3.203	—
SiO_2	9.09	1.4	4.55	10.39
CaO	0.275	53.21	0.73	11.12
MnO	5.2	—	—	2.18
Al_2O_3	2.92	0.76	2.2	1.57
MgO	0.74	0.24	0.082	0.27
Na_2O	0.31	0.074	0.04	0.193
K_2O	0.365	0.027	0.106	0.04
Cl^-	0.42	0.1	--	0.07
CO_2^-	---	42.2	--	---
P_2O_5	0.58	0.07	0.022	—
S	0.39	0.04	1.08	0.12
C	—	---	88.39	---
TiO	0.11	---	—	—
L.O.I.	8.85	—	1.23	---
BaO	0.605	—	---	---
ZnO	0.245	—	—	—

Table 2. Effect of moisture content on the chemical composition of produced sinter.

Moisture, %.	Chemical composition, %.									
	Fe_{tot}	FeO	Fe_{met}	Na^+	K^+	MnO	S	C	CaO	SiO_2
12	46.4	10.29	0.3	0.324	0.110	4.33	0.26	0.18	13.53	10.7
14	46.8	11.24	0.35	0.354	0.124	4.44	0.24	0.16	13.76	10.72
15	47.6	13.25	0.4	0.30	0.124	5.04	0.21	0.15	13.86	10.8
16	46	9.0	0.2	0.324	0.130	4.8	0.27	0.25	13.69	10.67

Table 3. Effect of coke breeze amount on the chemical composition of the produced sinter.

Coke breeze,%.	Chemical composition, %.									
	Fe_{tot}	FeO	Fe_{met}	Na^+	K^+	MnO	S	C	CaO	SiO_2
8	47.6	13.25	0.4	0.30	0.124	5.04	0.21	0.15	13.86	10.8
9	47.95	16.0	0.5	0.29	0.110	5.12	0.27	0.17	13.86	10.82
10	48.7	17.89	0.6	0.27	0.104	5.14	0.29	0.22	13.69	10.7
11	49.3	18.66	1.0	0.236	0.087	5.2	0.35	0.35	13.74	10.86

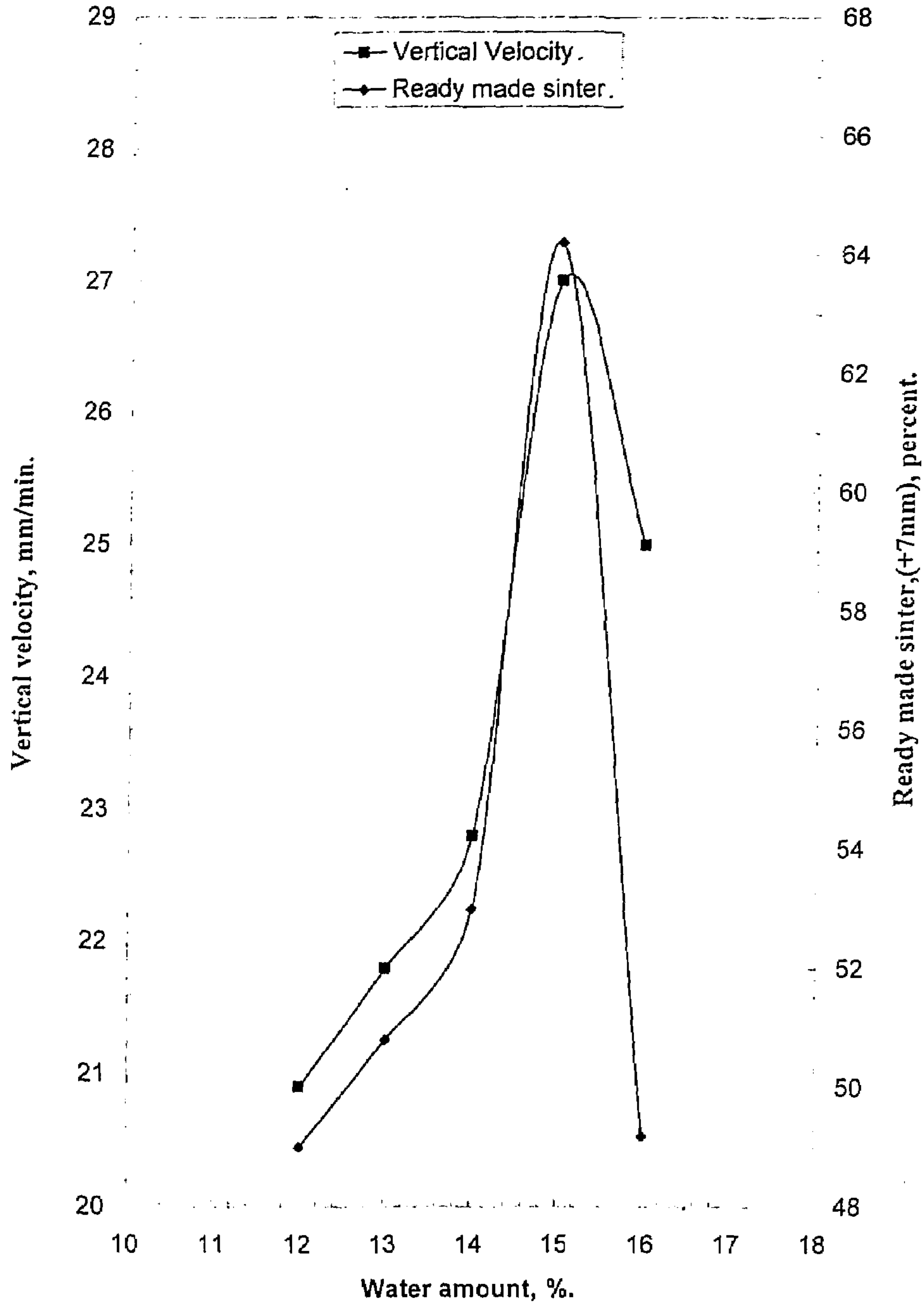


Fig. 1. Effect of different water addition on the vertical velocity of the sintering process and the amount of ready made sinter.

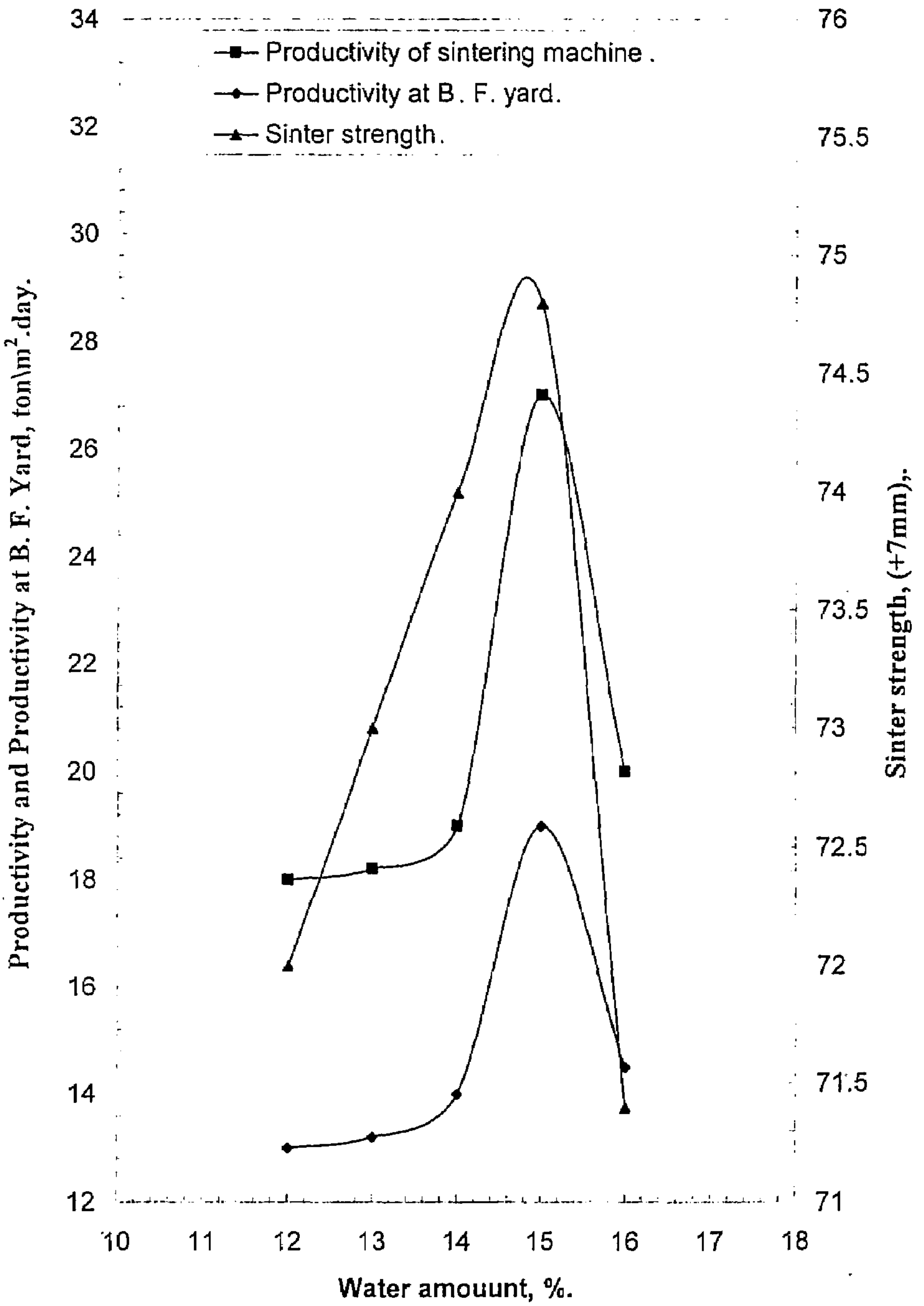


Fig. 2. Effect of different amount addition on the productivity of sintering machine, productivity at blast furnace yard and sinter strength of the produced sinter.

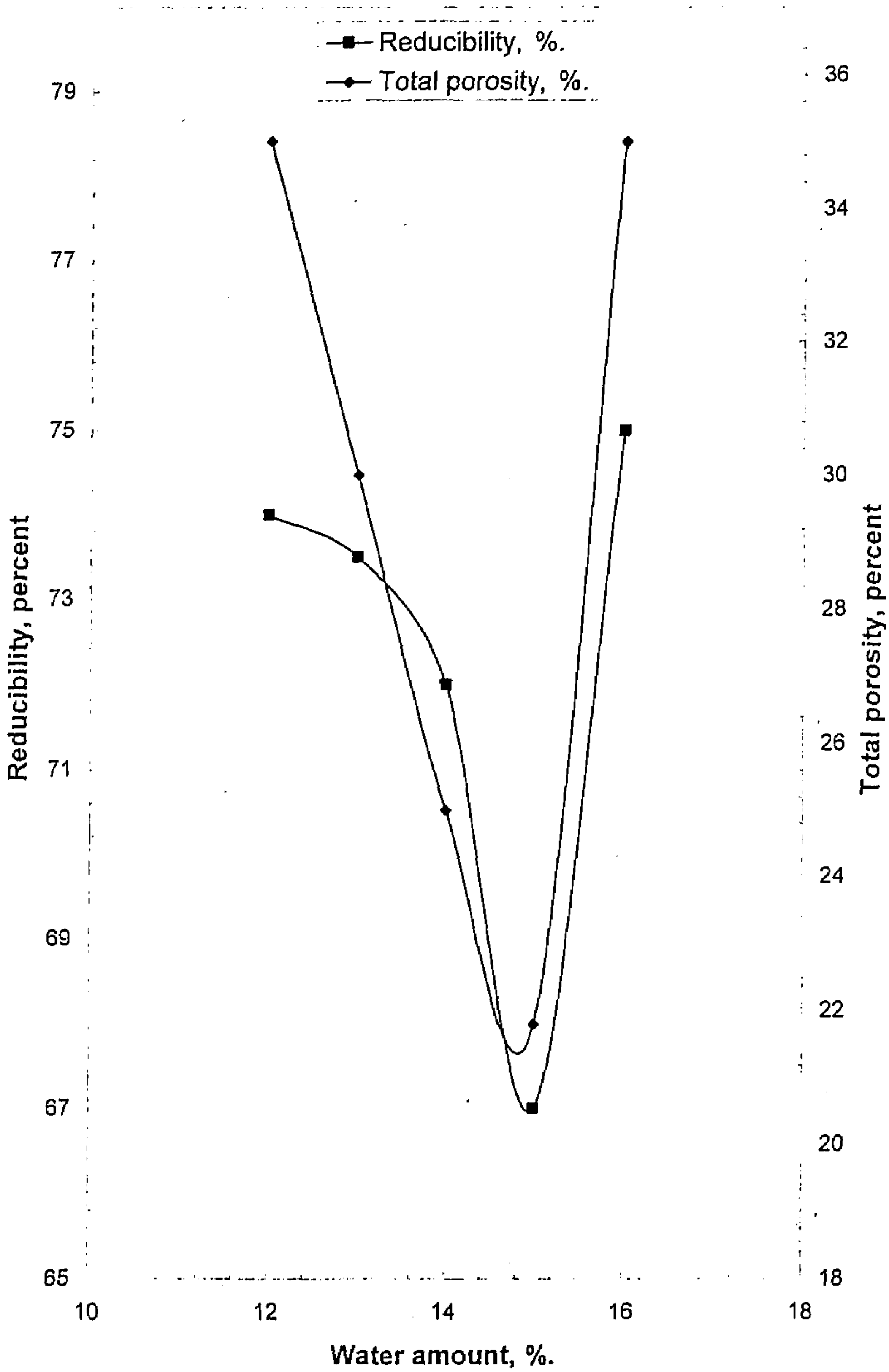


Fig. 3. Effect of different water amount on the reducibility and total porosity of the produced sinter.

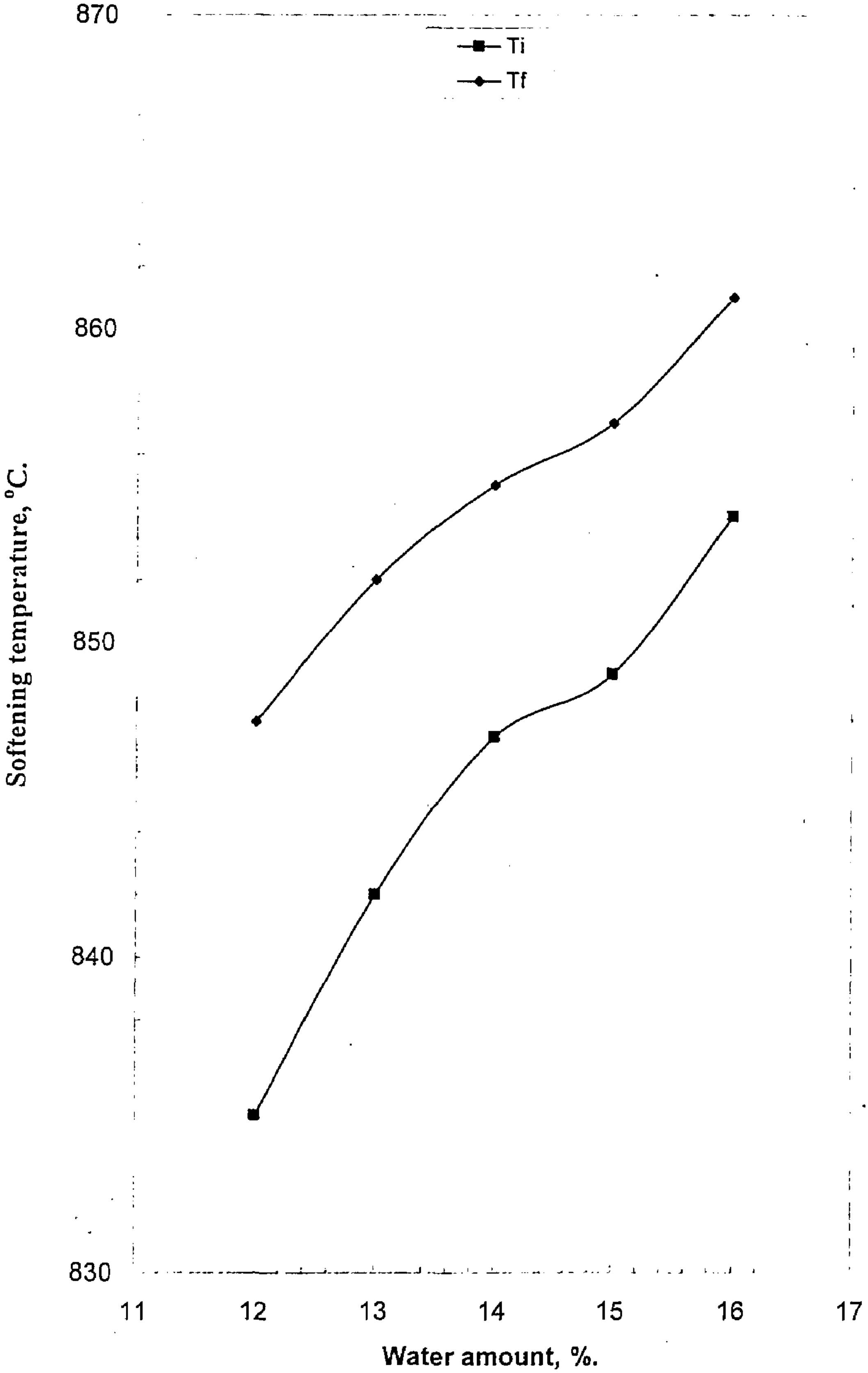


Fig. 4. Effect of water amount on the initial and final softening temperatures.

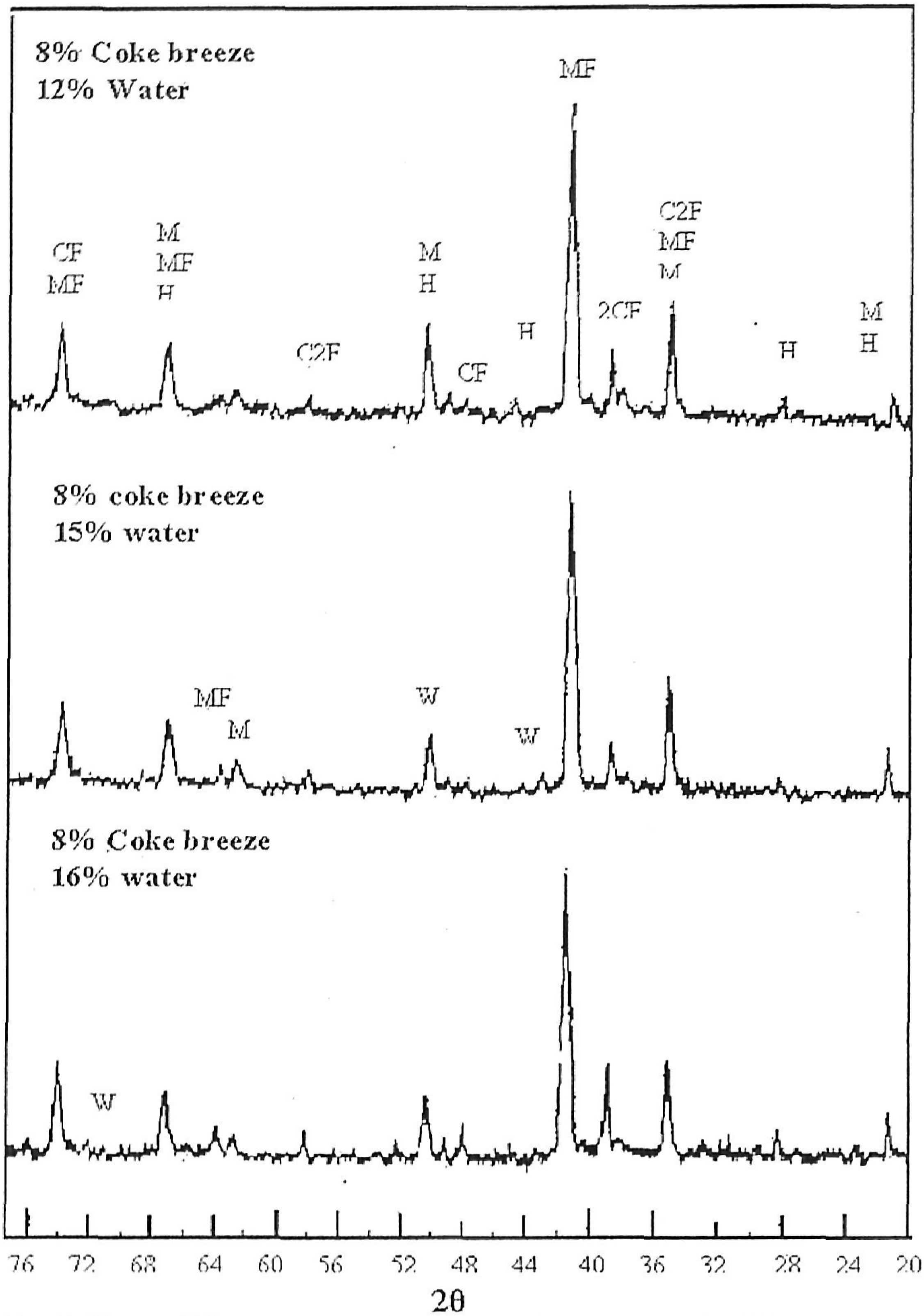
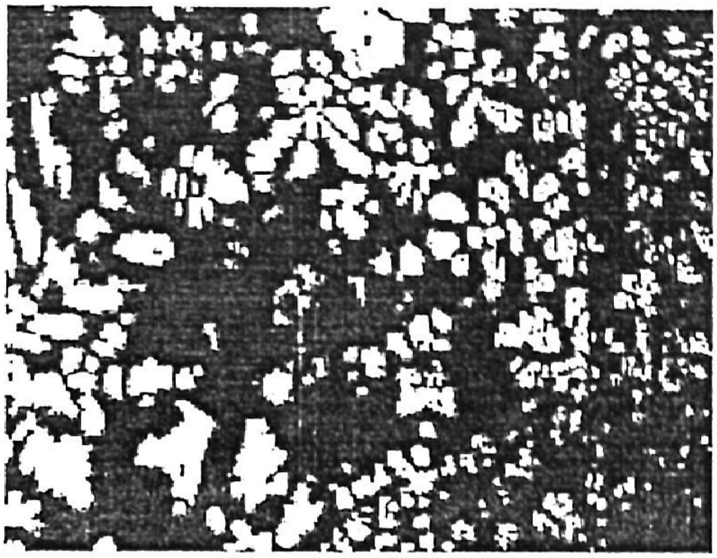


Fig. 5. X-ray diffractogram of sinter agglomerate with different amount of water added to the raw mix.

M = Magnetite, H = Hematite, C2F = $CaO.2Fe_2O_3$, MF = $MnO.Fe_2O_3$, 2CF = $2CaO.Fe_2O_3$, CF = $CaO.Fe_2O_3$, W = Wustite.



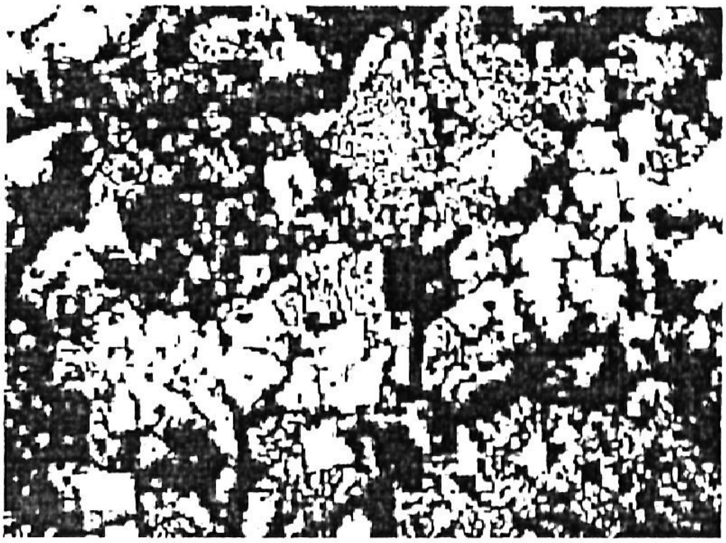


Fig. 6. Microstructure of produced sinter, (12% moisture).
Magnetite in golobular form and denderitic crystals (white), pores and cracks (black), silicate matrix (grey), (X = 200).

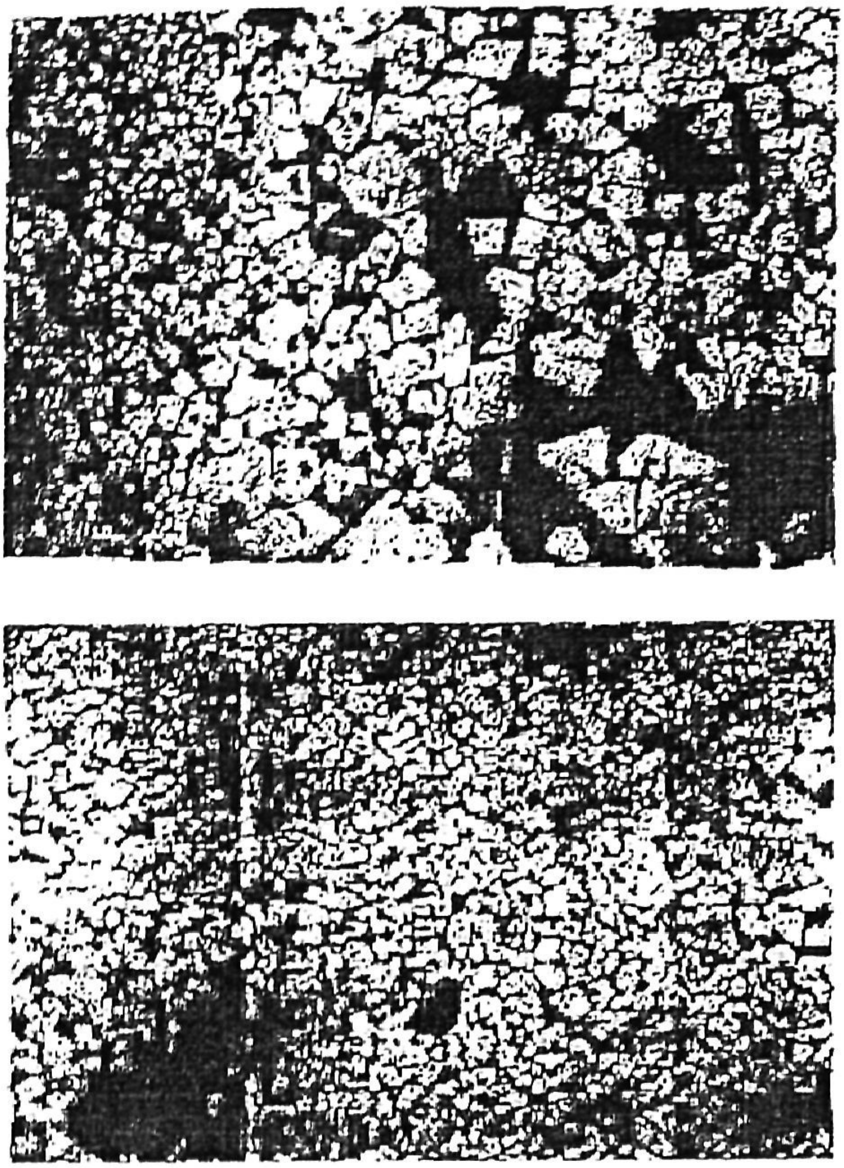


Fig. 7. Microstructure of produced sinter, (15% moisture).
Magnetite in the form of fine and large crystals (white), elongated dicalcium silicate crystals (black), silcate matrix (grey)., (X = 200).

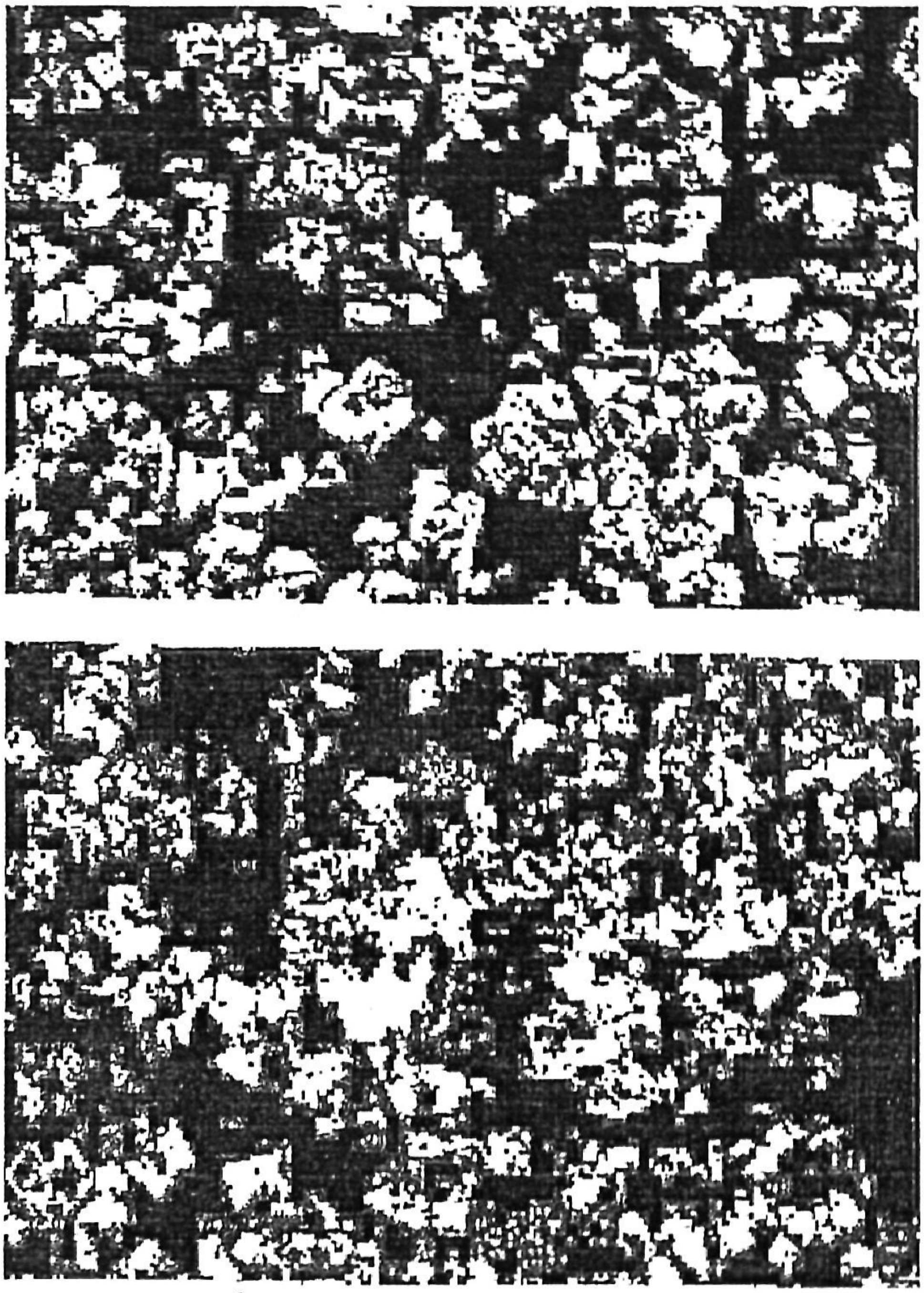


Fig. 8. Microstructure of produced sinter (16% moisture).
Magnetite of different shapes (white), pores (black), silicate matrix (grey). (X = 200).

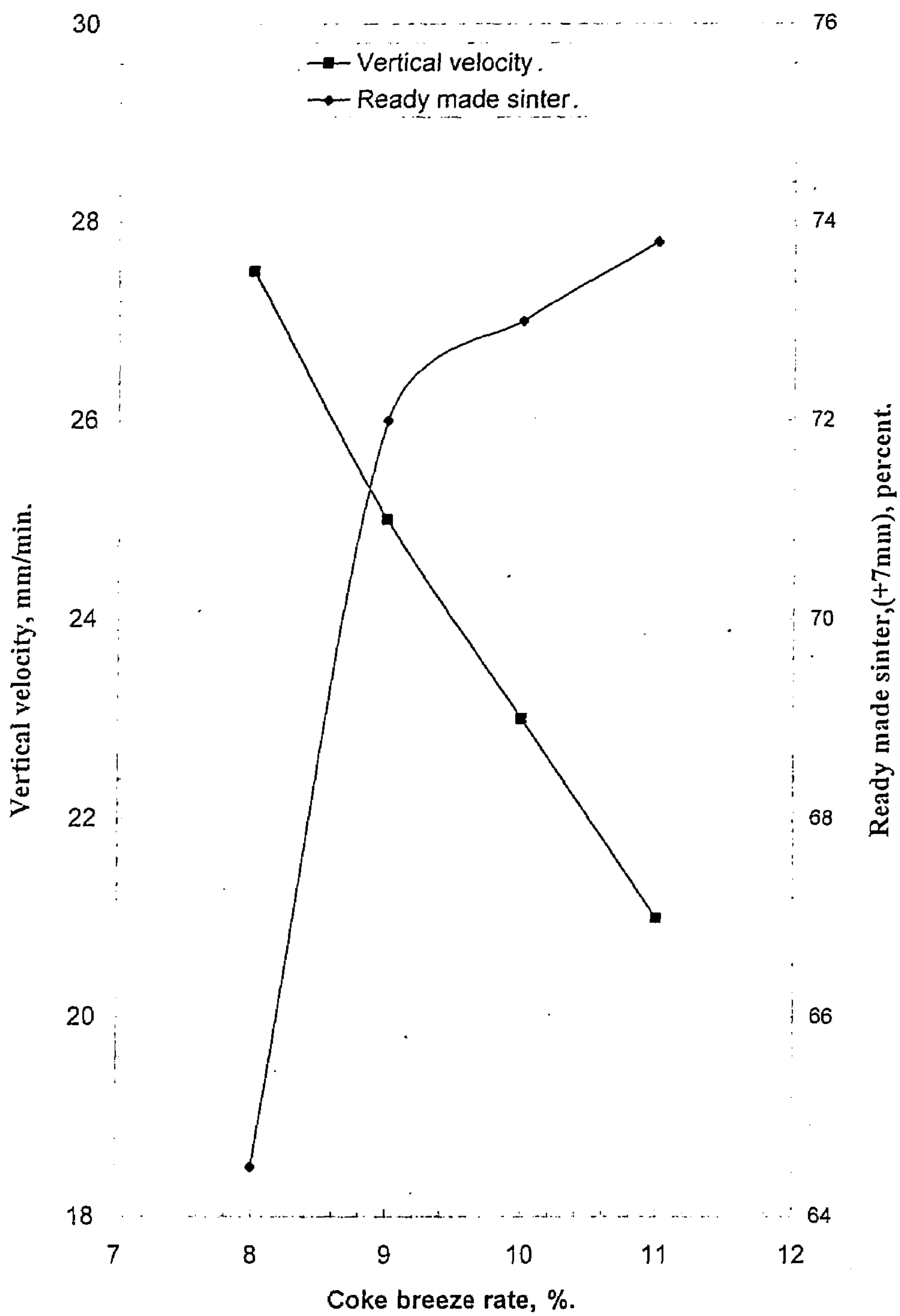


Fig. 9. Effect of coke breeze rate on the amount of ready made sinter and vertical velocity of sintering process.

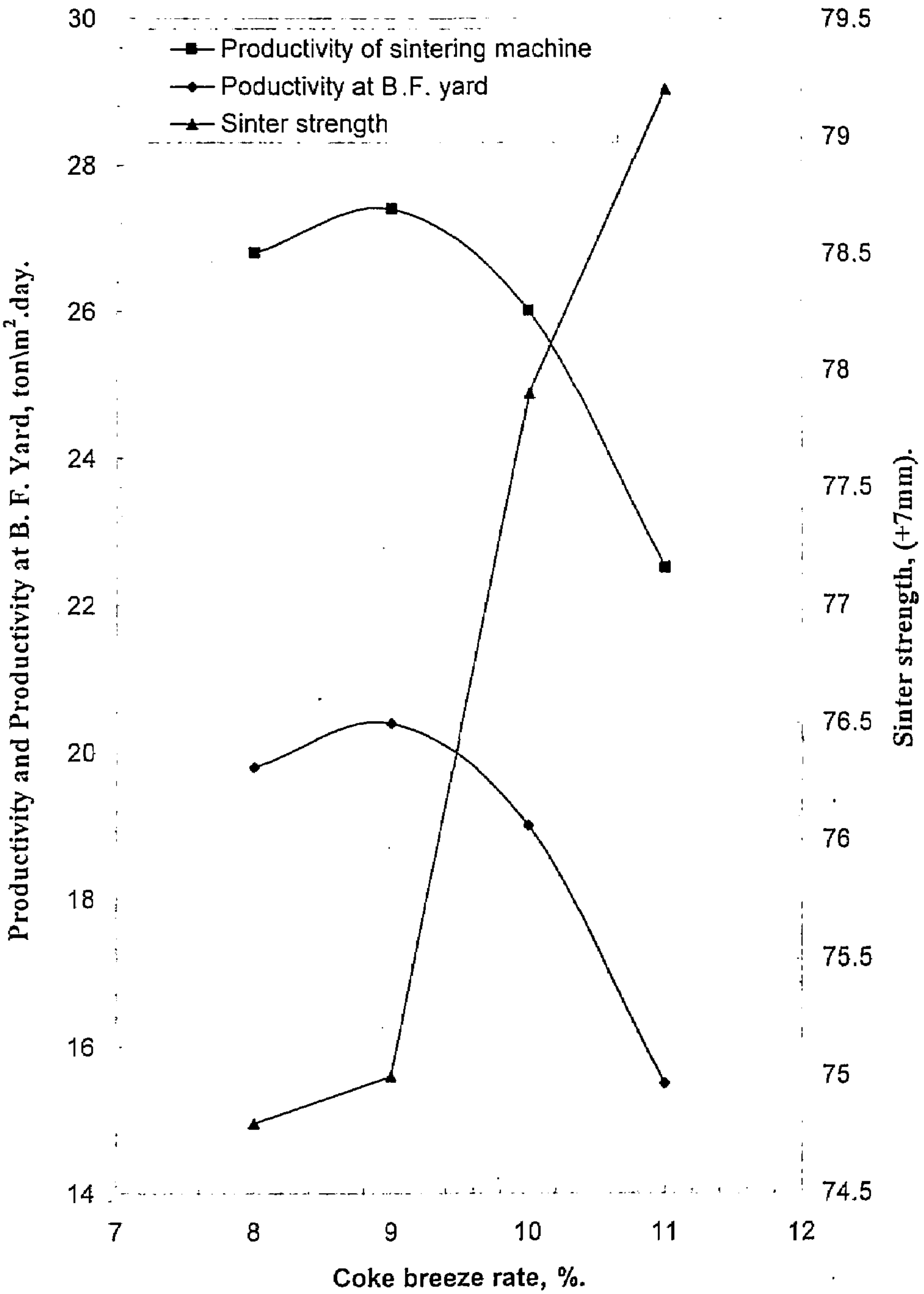


Fig. 10. Effect of coke breeze rate on the productivity of sintering machine, productivity at B.F. yard and strength of the produced sinter.

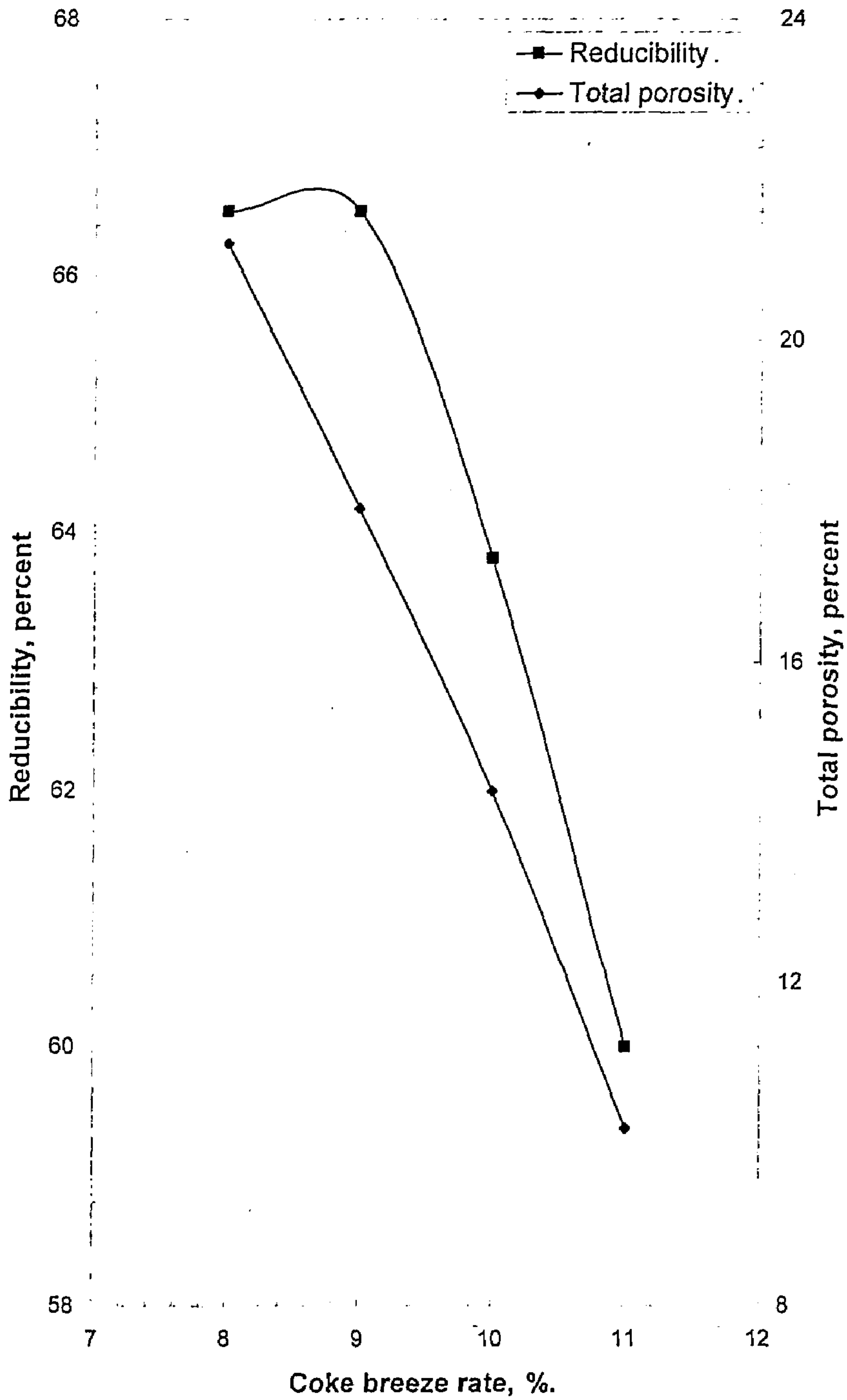


Fig. 11. Effect of coke breeze rate on the reducibility and total porosity of the produced sinter.

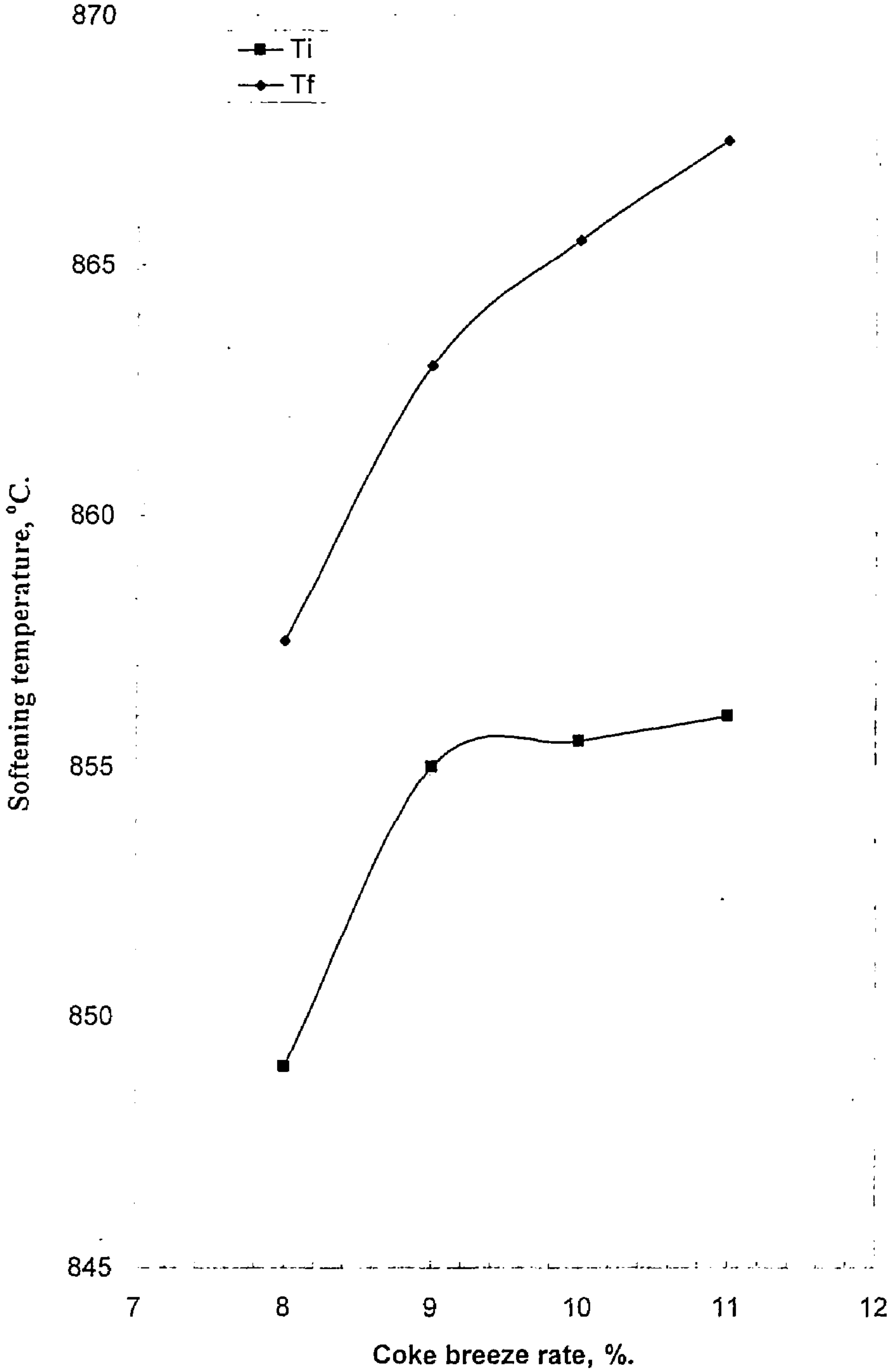


Fig. 12. Effect of coke breeze rate on the initial and final softening temperature on the produced sinter.

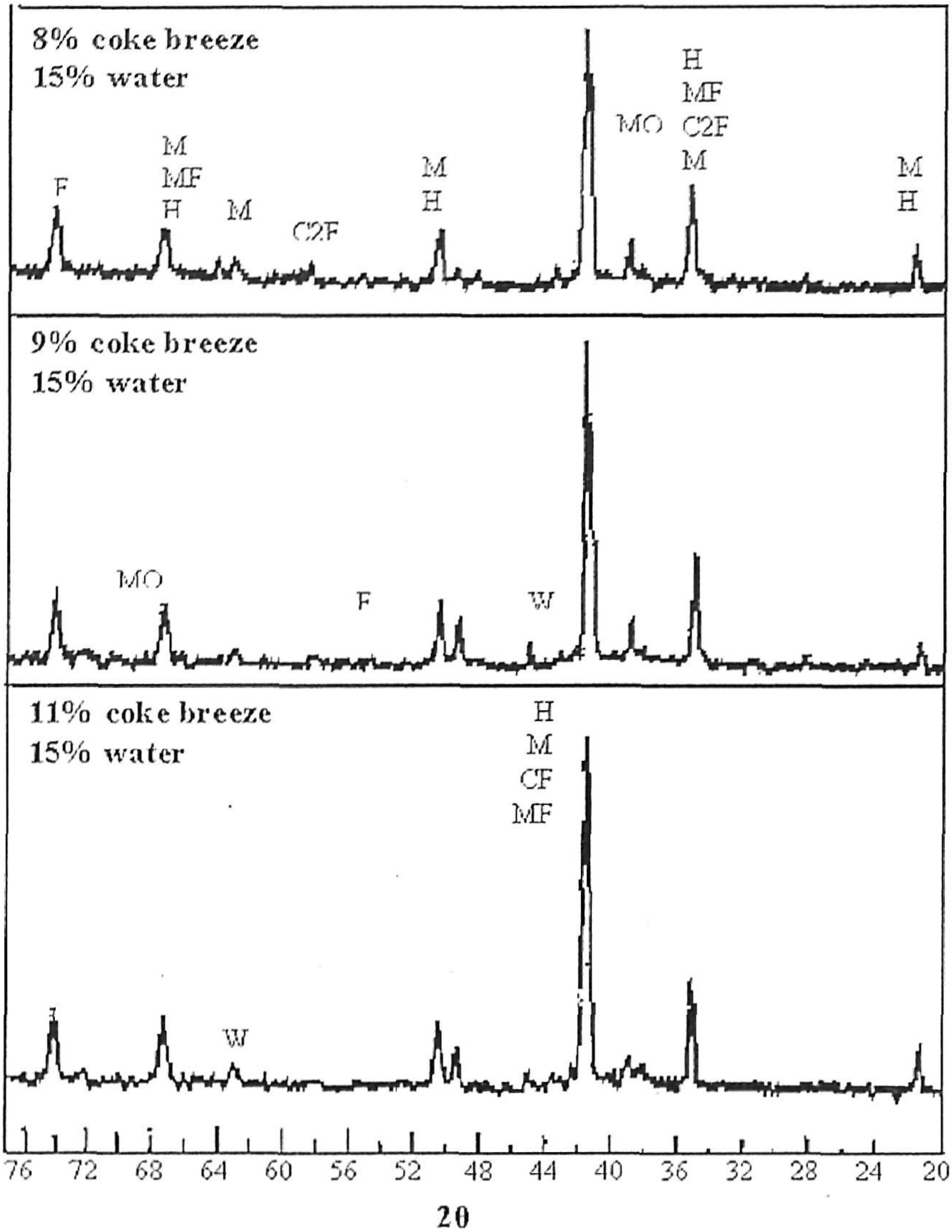


Fig. 13. X-Ray diffractogram of sinter agglomerate with different amount of coke breeze.

M = Magnetite, H = Hematite, C2F = $CaO.2Fe_2O_3$, MF = $MnO.Fe_2O_3$, 2CF = $2CaO.Fe_2O_3$, CF = $CaO.Fe_2O_3$, W = Wustite.

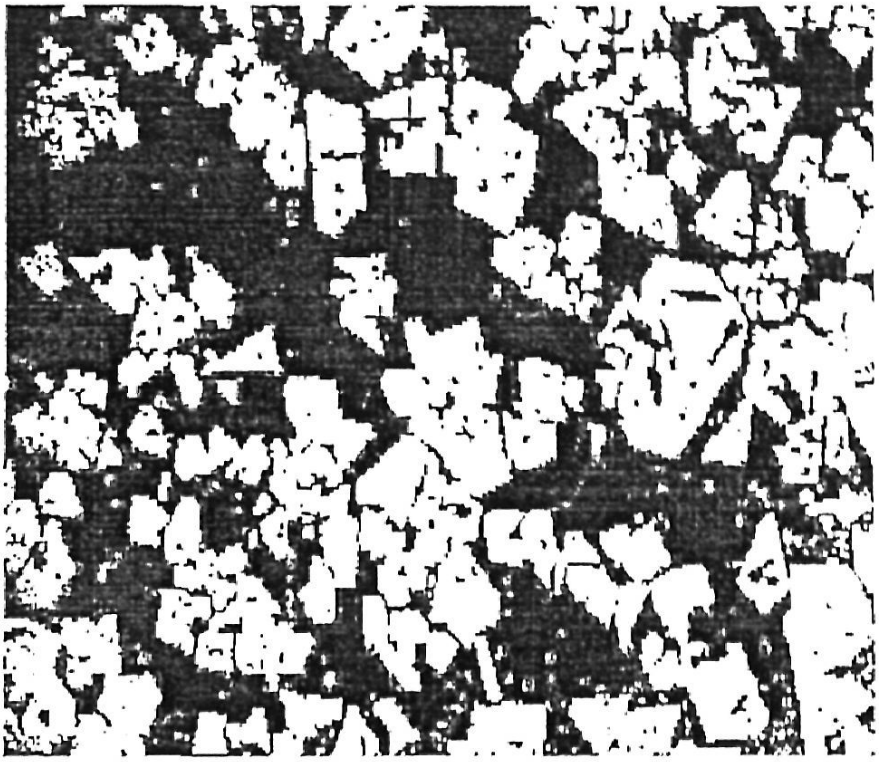


Fig. 14. Microstructure of sinter produced by addition of 9% coke breeze (15% moisture).
Magnetite in the form of large crystals (white) embedded in silicate matrix (grey), pores (black). (X = 200).

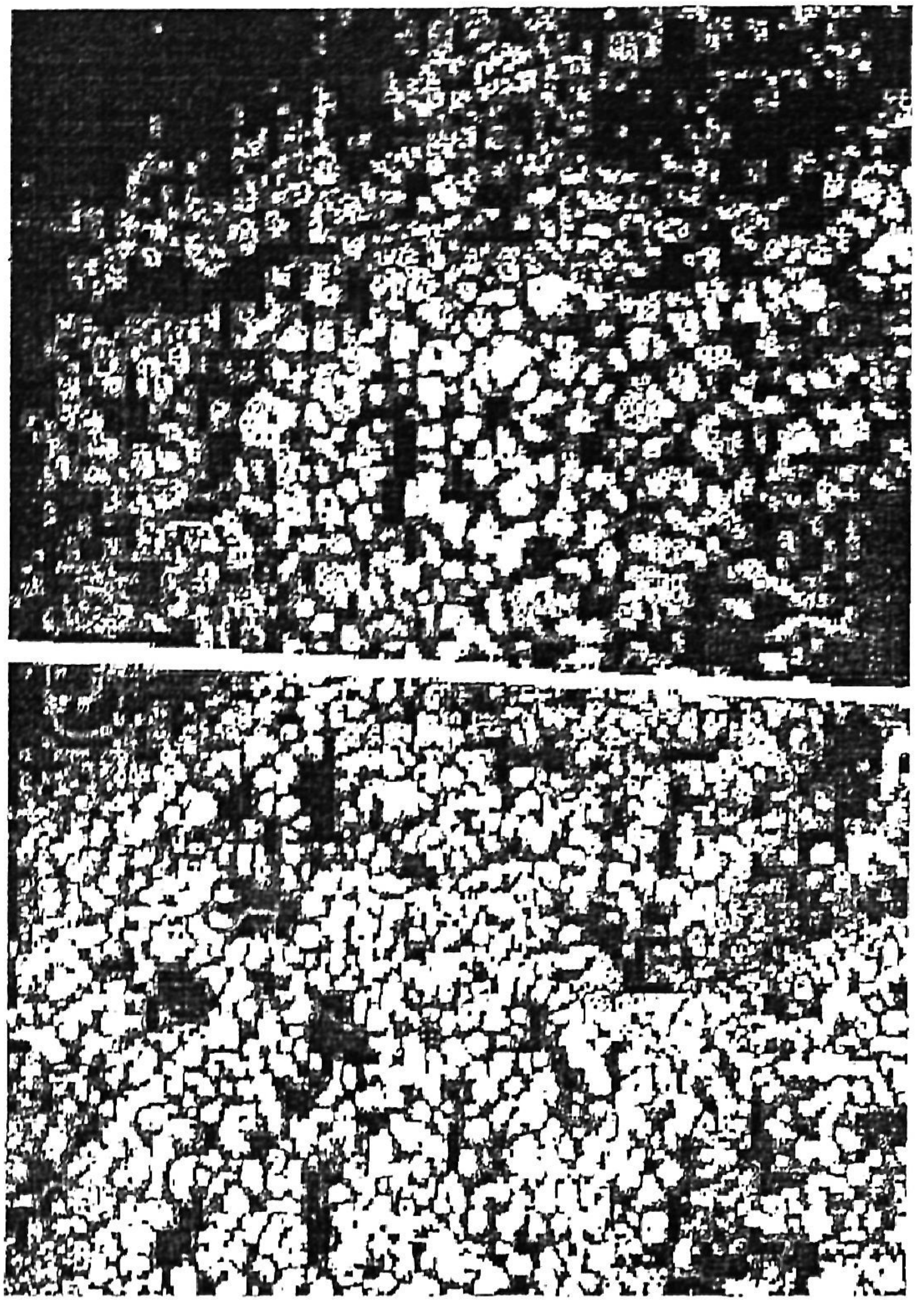


Fig. 15. Microstructure of sinter produced with addition of 11% coke breeze (15% moisture).
Magnetite in globular form (white) and mono calcium silicate (black) embedded in silicate matrix (grey). (X = 200).