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ELECTRIC PIG IRON SMELTING

by

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1. The reports and calculations of the United Nation's Economic Commission show that the production of crude steel is continuously increasing. A further increase is to be counted on. We suppose that already in 1970 a production of 600 million tons of crude steel will be achieved or even surpassed. Now as before the pig iron produced in liquid state from iron ores with reductants will be the principal raw material for the steel production. The annual quantity of pig iron to be produced is almost equal to the quantity of finished products. But only a small part of the pig iron is used directly in the foundries for castings. The bigger part however is converted to steel. Waste and scrap are continuously circulating. Their quantity is bigger in industrially developed- and considerably smaller in the undeveloped countries. The quantities of sponge- and ball-iron as raw materials for the steel production beside the pig iron are not important.

2. Pig iron is produced today mostly in blast furnaces, in electric pig iron furnaces - representing a further development of the by Thysland and Hole created construction-, and in blast low-shaft furnaces. The main quantity of pig-iron is produced in the blast furnace which has during the last 10-20 years developed to a production unity, that can not be compared with any other regarding its dimensions, capacity and thermal efficiency. The blast furnace requires as reducing agent and fuel a strong, not too reactive coke, having a lump size of 40 to 80, respectively 120 mm with a very high static and abrasion resistance. The production of coal convenient for the production of blast furnace coke is getting more and more difficult, so that the increasing requirements are harder and harder to satisfy. In the industrially higher developed countries it is getting difficult to find miners for this production. This results in a continuous increase of coal- and coke prices. Not

long ago the expenses for coke represented almost 1/3 of the price obtained for the pig iron. The necessity to lower the coke consumption became the first demand for each blast furnace plant. The blast furnace experts have been successful and the coke consumption in the blast furnaces was reduced till to 550-600 kg per ton of pig-iron, when applying to well known measures. A further reduction of the coke consumption is limited and can not be expected owing to the general requirements of an integrated steel plant on gas, fuel and thermal economy.

3. Before the last World War the electric pig iron furnace was limited to units of small efficiency and to countries disposing over vast quantities of hydroelectric power. The experiments of that time have been bound to the fact that the electric furnace can use normal coke and also that of smaller granulometric composition.

Because carbon is reducing iron ore in the electric pig iron furnace only directly the carbon consumption varies from 310-320 kg per ton of pig iron. That corresponds to 1/3 to 2/5 of the coke needed at that time in blast furnace. For the production of one ton of electric furnace pig iron, beside the coke still about 2400 KWh were necessary. Therefore, roughly taken, the electric pig iron operation was in comparison with the blast furnace operation economical when the price for these 2400 KWh was nearly equal to the costs of about 450 kg of blast furnace coke. In spite of this even then the electric energy prices have been too high for the electric pig iron furnace to obtain a more universal signification for a regular and important steel production. The capacity of the electric pig iron furnace has been in the last years increased to 24, 35 and 50,000 KVA and may have as a covered three-phase pig iron furnace its limits at about 65-75000 KVA. With help of metallurgical practice and measures used with blast furnaces the specific power consumption per ton of pig iron has been reduced.

4. After the war in Yugoslavia 4 electric pig iron furnaces with a classical low transformer capacity of about 12,000 KVA have been constructed. These furnaces are now being enlarged. One furnace of 24,000 KVA, five furnaces each of 35,000 KVA and others are under construction. The reason that the Yugoslave iron and steel industry, which has till now erected some big blast furnaces, continues to build them, has provided so many electric furnaces to increase the pig iron production, is due to the fact that this country has no coking coal but disposes with considerable water powers and significant deposits of hard brown coal and lignite. The deposits of

brown coal are estimated to about 3, and those of lignite to 25 millions of tons. These mines are situated over the whole country.

Extensive tests and studies, by the Metallurgical Institute in Ljubljana have proved that it is possible to obtain by carbonization a product of the original shape of the used nut or lump coal which has a sufficient static and abrasion resistance to be used in pig iron low-shaft furnaces. It is only necessary to observe very strictly the drying and reheating conditions which are characteristic for each sort of such coals, which differ from mine to mine but can be experimentally fixed in advance.

In the electric pig iron furnace at Štore some thousand tons of pig iron have been produced to test the above brown coal and lignite coke and it has been proved that they can fully replace the metallurgical coke and that they even promote and increase the silicon and manganese reduction. With regard to their reducing ability the brown coal and lignite coke is approaching the nearer to charcoal the younger its origin. In Fig.1 the reducibility of a normal blast furnace coke is shown in comparison with a typical lignite coke. With this diagram elsewhere obtained results and experiences are confirmed and even enlarged as shown in diagrams Fig.2. The lignite coke is intensifying the carburation and the desulphuration of the reduced iron in the solid phase. Since the electric conductivity of such coke is lower as that of the metallurgical coke a smooth furnace operation and a lowering of the power consumption is the consequence. Fig.1 shows the reducibility of a normal blast furnace coke and a lignite coke at different temperatures.

The brown coal and lignite coke can be under Yugoslav conditions generally produced and carbonized cheaper than a normal coking coal. Using such coke in sintering plants, prereduction kilns, low-shaft and electric pig iron furnaces, only about $^2/_3$ of the production costs otherwise paid for the imported coking coal will be necessary. Such coke naturally cannot be used in a normal blast furnace.

Summarized: The brown coal and lignite coke produced as above can equivalently replace the metallurgical coke at least for the production of pig iron in the electric furnace.

5. The experiences of experts, engaged in pig iron production with covered three-phase furnaces with immersed electrodes, agree that a certain content of Al_2O_3, at least 8-12%, is necessary not only on purpose to lower the melting point but also the

conductivity of the slag. The physical and chemical composition of the ore and burden with its electrical characteristics should be taken into consideration particularly when fixing the diameter of the electrode circle. The experiences agree also regarding a rather high quantity of slag, of about 500 kg per ton of pig iron and the silicon content in the pig iron of 0.7-1 to have a most regular and economic furnace operation. As in every shaft furnace, also in the electric furnace the dust is an enemy of the regular production. The granulometric composition of the reductant can be varied from 10-40 mm and can be generally the finer the higher the silicon percentage in the pig iron may be. The experiences obtained with the best operating Yugoslav electric furnace at Štore and those in other countries show a dependence of the energy consumption to the iron percentage of the ore - as it is shown in Fig.3a. This diagram is worked out for the production of low silicon pig-iron with a slag having already the necessary Al_2O_3 content, and when the necessary lime is added burnt or in self-fluxing sinter. For each 100 kg of slag over the slag optimum of about 500 kg an additional quantity of electric energy of about 50 KWh can be put into calculation and of about 100 KWh when charging limestone. The differences between the lowest and highest energy consumption of about 200 KWh per ton of pig iron depends on local burden conditions, furnace constructions, and individual efforts and experiences of the engineers. Generally we can state that the pre-war consumption of about 2400 KWh has been today decreased to about 2000 KWh when operating with a medium rich burden. The electric furnace operation in the iron and steel plant at Štore has during its long period of practice proved this.

The following table indicates the power consumption in KWh per ton of pig iron and its dependency of the burden yield at the Štore - 12000 KVA - pig iron furnace during the last four years:

	Burden yield in %	KWh/Ton	Production in tons
1959	43.5	2,360	27,241
1960	41.8	2,342	24,787
1961	43.1	2,234	35,624
1962	42.7	2,203	36,536

The burden contained 48 to 51.5 % of self-fluxing sinter and 52 to 48.5 % of crude ore. The basicity of the sinter was 0.7 and the rest of the lime was charged as limestone. Sixty per cent of the furnace production was basic pig iron and forty per cent foundry pig iron.

Figure 3B illustrates with its curve the relation: KWh consumption to the burden yield based on the experiences of the Store plant for an average pig iron composition of 1.5-2.5% of Si.

6. Because the carbon consumption of an electric furnace can not be essentially lowered below 380-400 kg of coke per ton of pig iron while the same has been in blast furnaces lowered to 550-600 kg, a comparison between the economy of an electric pig iron furnace and a blast furnace depends even more than before the war on the prices for electric power. If at that time the costs for 2400 kWh had to be equivalent to those for 450 kg of blast furnace coke, this relation has today decreased at a normal electric pig iron furnace operation of 2000 kWh per ton of pig iron to only 200 kg of coke. The costs for 10 KWh should approximately correspond to the costs of 1 kg of coke. There are very few countries where electric energy could be obtained at such a low price. Thus the thermal equivalent for 1 kWh has consequently become more than before the most expensive heat energy. At a more or less permanent price of ore the higher costs for the electric energy can be opposed only by means of lowering the fuel costs and the specific energy consumption.

As already mentioned above the production of lignite- or brown coal coke will frequently bring a lowering of fuel costs. The lowering of energy consumption is possible - suppose a rich and easily reducible burden is used - only when the shaft work deficient to the electric pig iron furnace - is done outside of it and the cheapest fuel and its own furnace gas is used. That means that the reduction of ore in an electric pig iron furnace should be carried outside of it as much as possible.

7. The latest methods to combine the so-called direct reduction processes with the pig iron production in an electric furnace have the scope to use for the reduction the cheapest fuel as also simultaneously to discharge as much as possible the pig iron furnace from the reduction work. In this way big savings of energy will be obtained still using the expensive electric energy only for the reduction of silicon and manganese for the remaining quantity of iron oxygen and for the melting and overheating of iron and slag. Only the combination of such reduction processes with the electric furnace when operating with immersed electrodes will be discussed. The processes depending upon contact reactions and open bath, as for instance STRATEGIC UDY should not be taken into consideration in this report.

Most of the mentioned prereduction processes are using for prereduction the rotary kiln. But also the DWIGHT-LLOYD sintering grate is promising good results. Lump ore, sinter or pellets are to be reduced with a solid carbon carrying fuel, as lignite, brown coal, anthracite, semi-coke or coke breeze; also the own furnace gas and furnace oil can be used. Some processes use the charging of hot prereduced burden, the others prefer a cool burden after screening it from the fuel ash, excess coal or coke, reduced fines etc. A first full scale industrial plant started to operate only this month and we are not yet entitled to give any judgement or opinion about the value and convenience about any of them.

However as the existing methods for calculating the material and heat balances are well proved and generally used, it is justified to work out energy balances and estimations of production costs also for such combined processes.

In Fig. the energy consumption curves in electric furnaces, if the cold charged burden has been prereduced to 50% (curve II), and to 75% (curve III) are shown. These two curves are calculated for the same conditions as the curve I. of diagram in Fig.3

Such processes are lowering not only costs for the reduction carbon and those for the electric energy, but also what may be more important is the fact, that with the same transformer and the same furnace a far larger quantity of pig iron can be produced. Because of this the amortization rate and the fixed production costs will be lowered. Also regarding the total energy consumption per ton of pig iron the electric furnace operation can be well compared with that of a modern big blast furnace. The blast furnace is up to day needing for the thermic burden preparation, the overheating of the wind and its production considerable quantities of heat; increasing the extent of indirect reduction and lowering the specific coke consumption the quantity of gas and its calorific value is more and more diminished.

For the production of one ton of pig iron in a big blast furnace about 5.5 million calories are needed (after the deduction of the calorific value of the furnace gas being at disposal for other consumers). For an electric pig iron furnace using up to 75% of prereduced rich pellets a similar total heat consumption of 5.5 million calories is reckoned. Using the cheapest reductants also the production costs of both units became similar.

The electric pig iron furnace has the disadvantage to be in comparison with the modern super blast furnace still a small pig iron producer though it should be expected that a big furnace of 60,000 kw will be able to produce about 40-50 tons of pig iron per hour with prereduced material. This is of course a quantity which has been estimated 30 years ago as a big production.

On the other side the electric pig iron furnace has in comparison with the big blast furnace the advantage to be a producer of quality pig iron especially for the best and special foundry qualities. The production costs for such pig iron are more favourable as those of a blast furnace and this even by somewhat higher prices for the electric energy.

8. Many nations have become independent and have founded their own States. Most of those countries are disposing over iron ore, but not with coking coal for blast furnaces. Many of those States otherwise dispose of coal, which can be transformed to lump coke, to be used in low-shaft furnaces. If enough electric energy at a reasonable price is available the electric pig iron furnace will become for such territories an important pig iron producing unit. It will be the basis for the foundation of a foundry, iron and steel machine and tool industry and for the general industrial development of such countries.

RESUME:

The presented paper describes the development of the electric pig iron furnace and during the last years obtained results in carbonizing non-coking coals to be used in such furnaces. The so-called direct processes used for prereduction of iron ores outside the electric furnace and combined with this for pig iron production are discussed.

The energy consumption and production costs for electric pig iron are confronted with those obtained with the blast furnaces. The possibilities offered by electric pig-iron production for the industrial development of countries in development are pointed out.

Table 1

Chemical Composition and analysis

	Metallurgical coke	Lignite coke		
	[illegible]	[illegible]	[illegible]	V
Moisture	-	-	-	-
Ash	10.26	12.1	10.90	16.94
Vol.matter	1.02	6.2	7.78	7.42
$C_{fix.}$	87.00	80.2	80.70	73.45
$S_{tot.}$	1.72	1.5	0.62	2.19

Ash analysis

	M	Z	K	V
SiO_2	39.08	31.20	20.25	15.98
Fe_2O_3	9.94	15.54	15.59	7.91
Al_2O_3	30.82	23.07	13.00	11.50
MnO	0.20	-	0.67	0.19
CaO	10.23	16.60	22.83	27.19
MgO	3.63	4.67	12.51	7.14
SO_3	4.94	-	13.93	29.07
P_2O_5	0.43	0.39	0.45	0.36
Mn_2O_3		0.18		
S	1.57	2.28	5.59	11.67
Fe	6.96	10.78	10.92	5.54
Mn	0.15	0.13	0.52	0.14
P	0.09	0.17	0.09	0.08

FIGURES

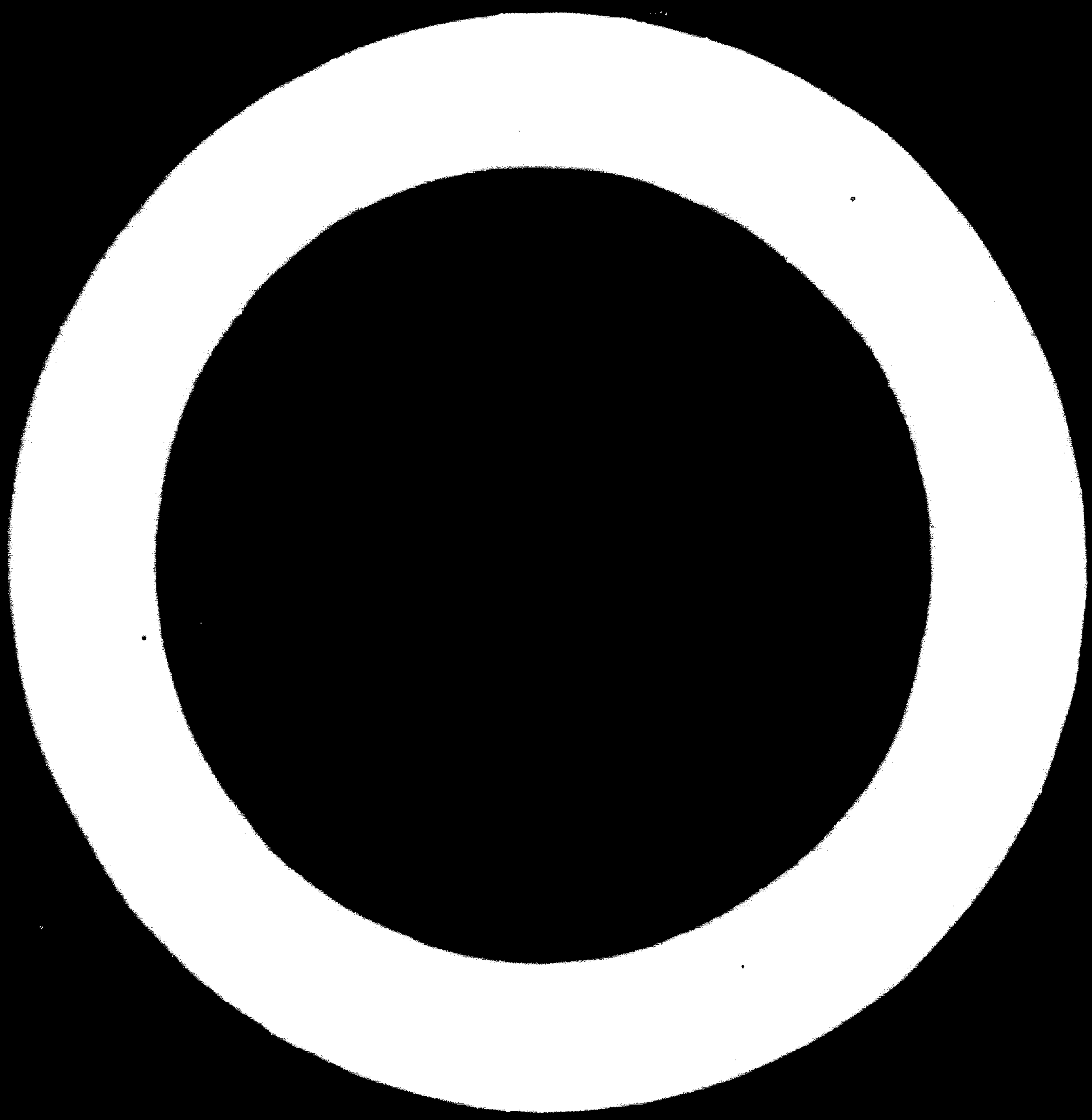
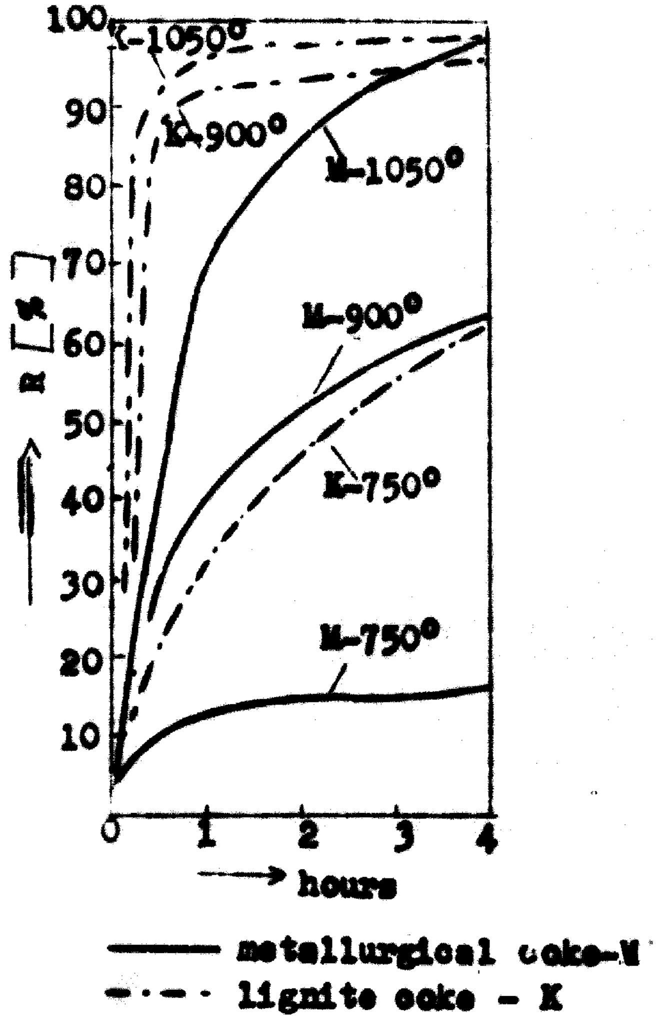


fig 1.



Reduction of hematite with metallurgical
and lignite coke

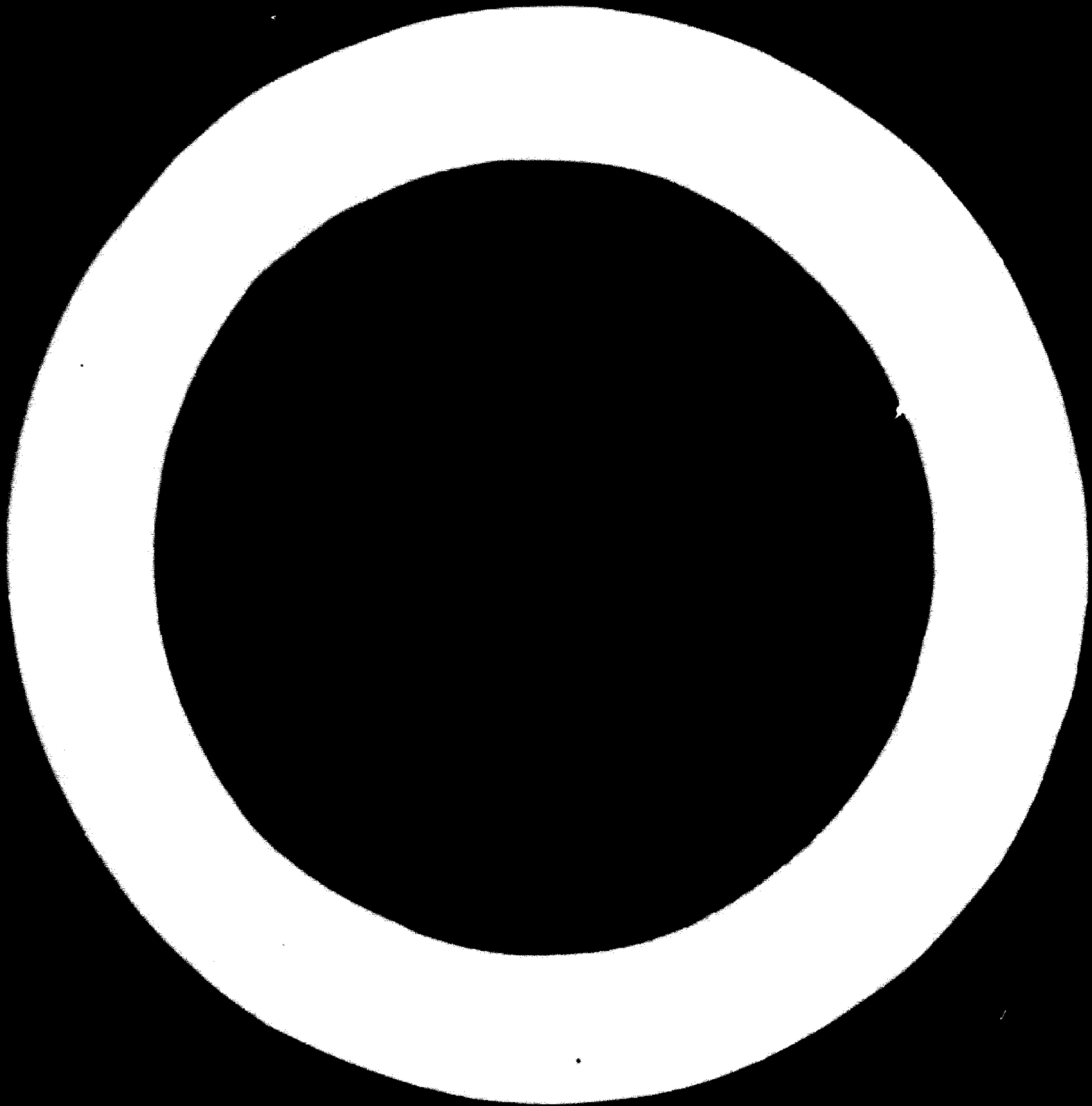
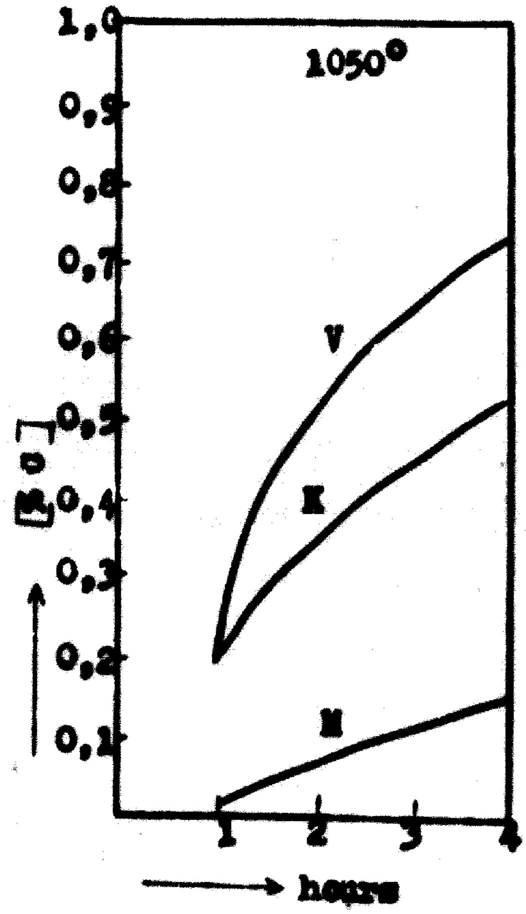


fig 2.



Carbonisation of reduced
iron ore
with metallurgical coke - M
lignite coke - K,
lignite coke - V

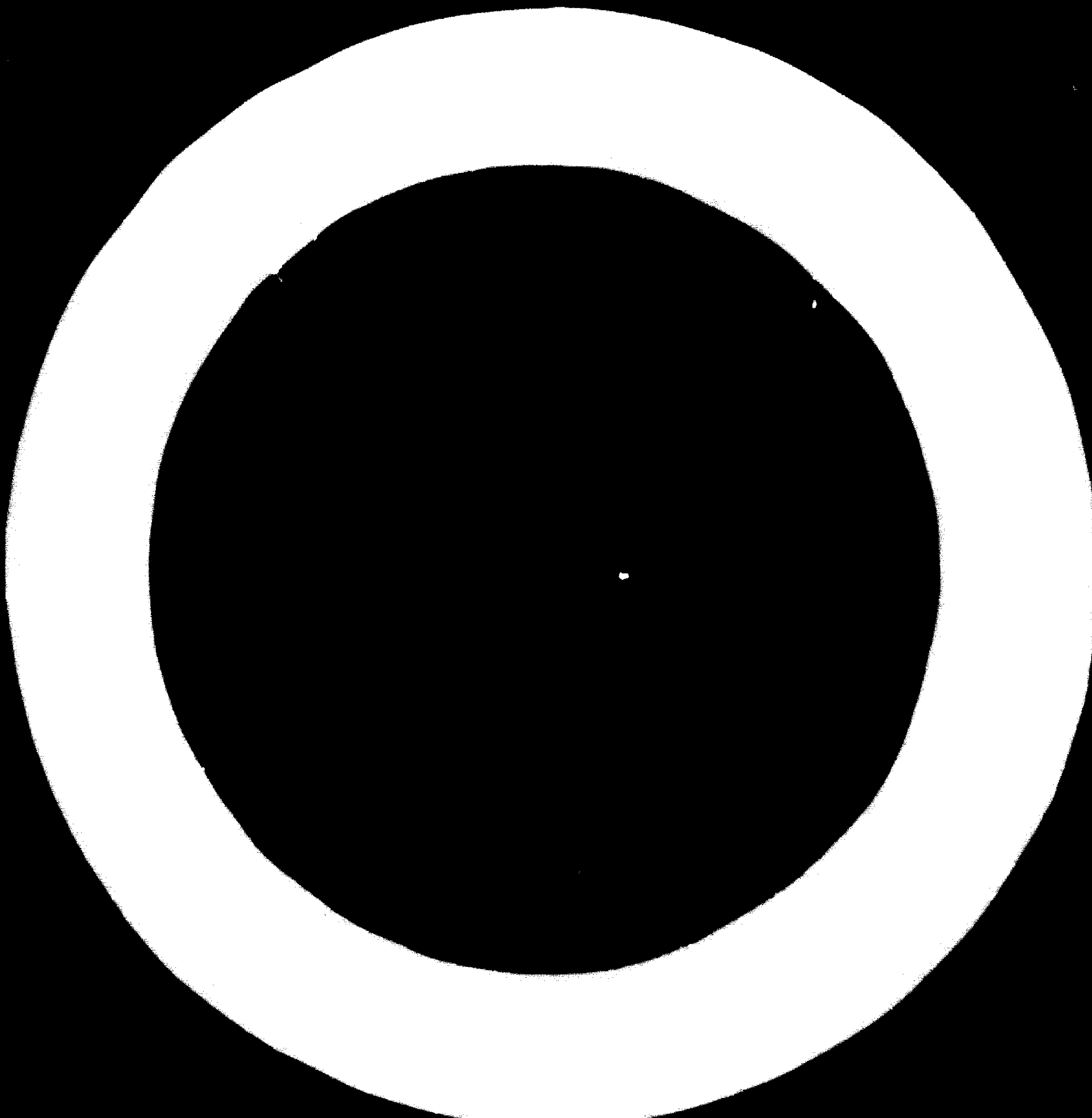
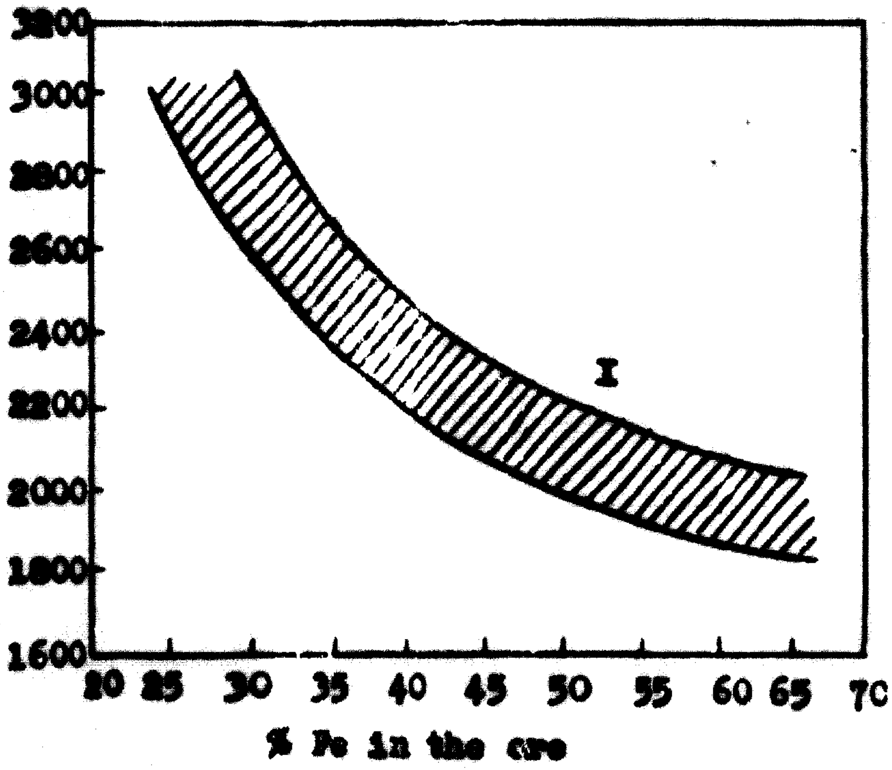


fig 3 a



Consumption of KWh - per ton of pig iron
in relation to the Fe % of iron ore

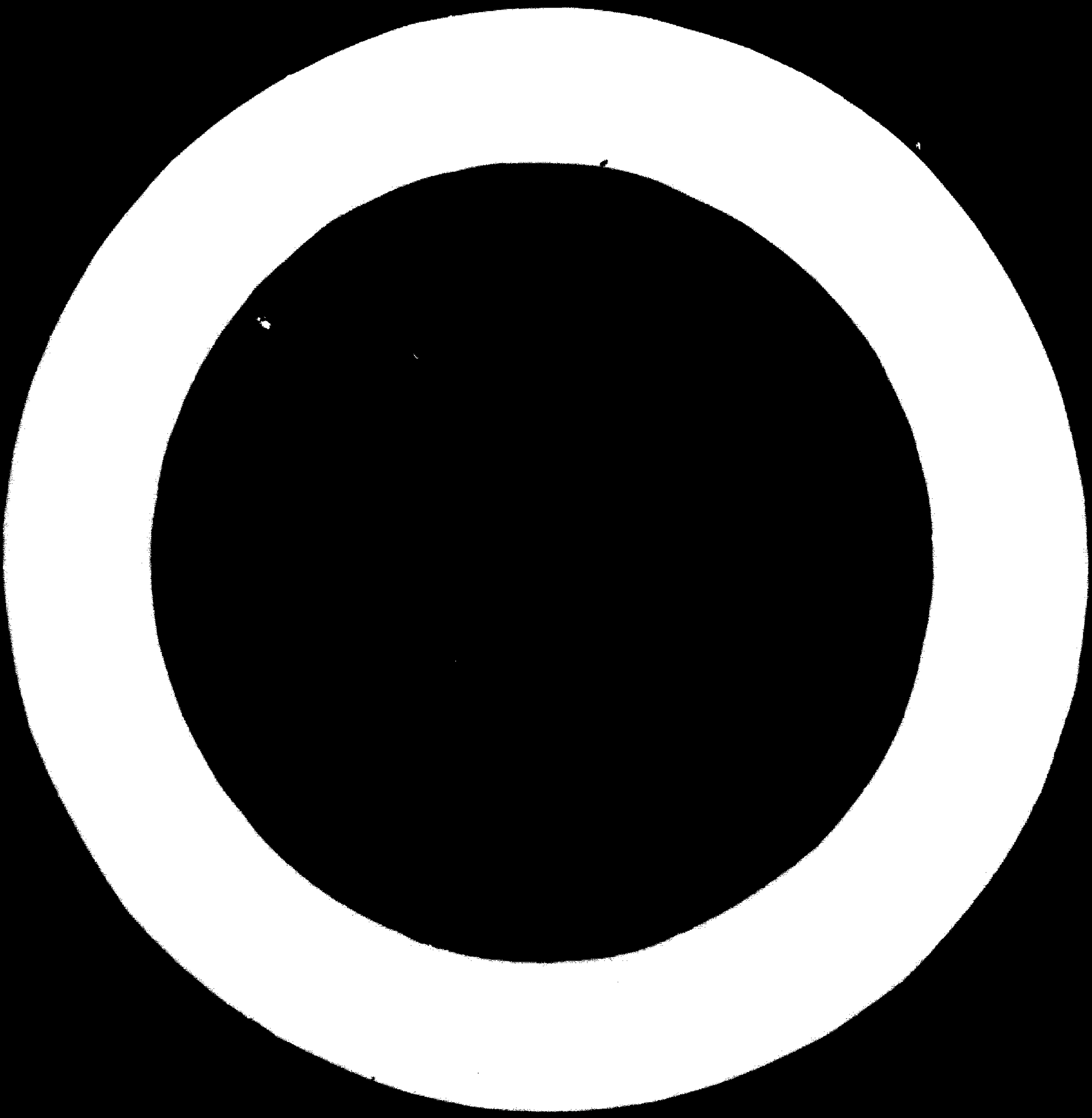
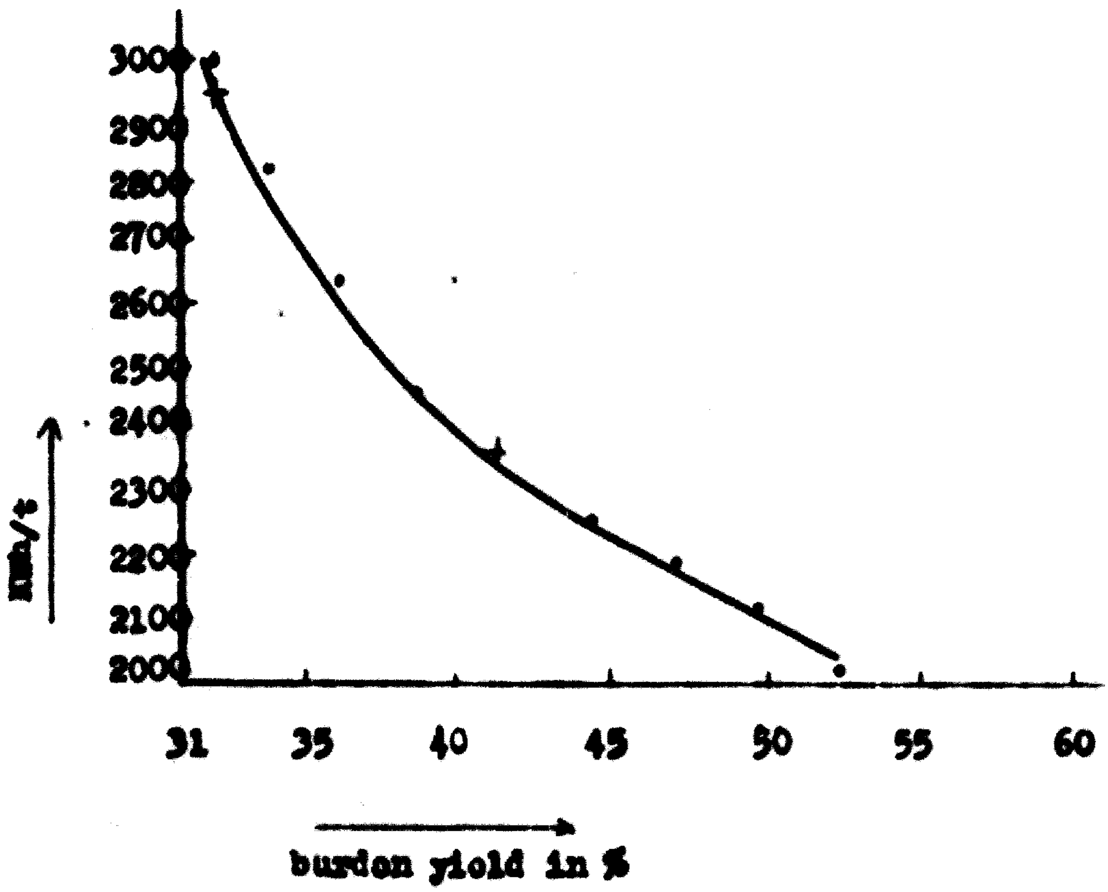


fig 3 b

Štore electric pig-iron furnace



Relation KWh - consumption and burden yield
for foundry pig iron production

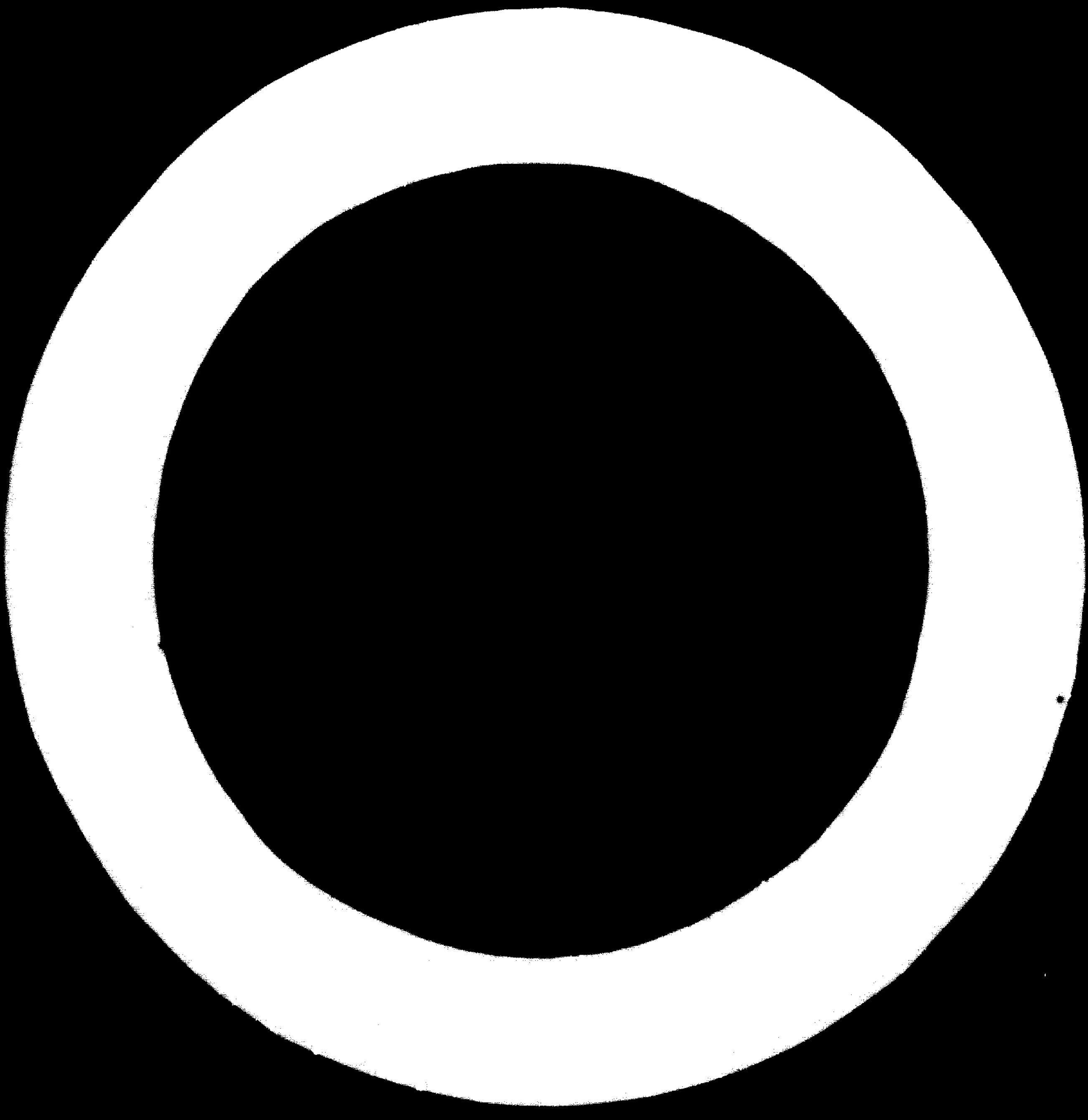
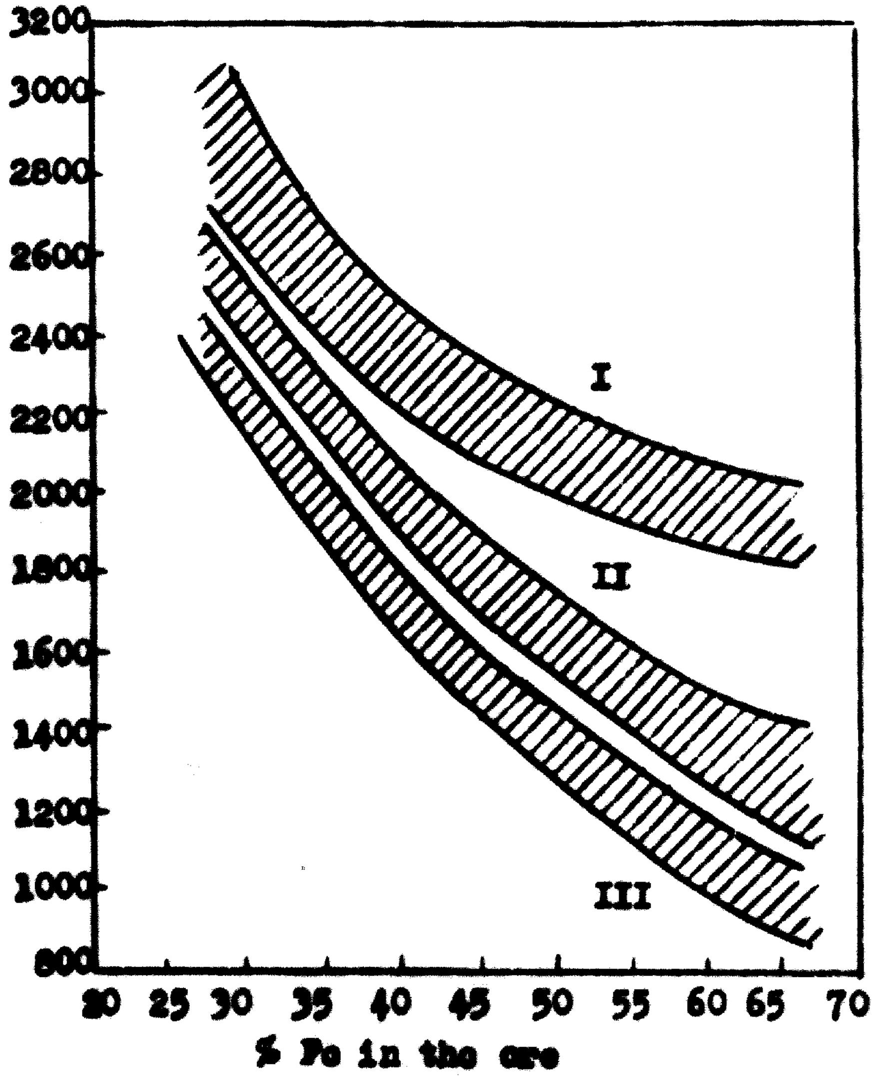


fig 4.



Consumption of KWh - per ton of pig iron
in relation to the Fe % of iron ore
the prereduction degree

[redacted]

8. 8. 74