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ID/WG.14/38
2 July 1968

ORIGINAL: ENGLISH

Second Interregional Symposium
on the Iron and Steel Industry

Moscow, USSR, 19 September – 9 October 1968

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MODERN TECHNO-ECONOMIC INDICES AND WAYS OF THEIR ATTAINMENT IN BLAST FURNACES, STEEL MAKING AND ROLLING MILLS[1]

by

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* This is a summary of a paper issued under the same title as ID/WG.14/38.

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Every operational activity is subject to the law of expenditure and returns, for only the profits as the value of the obtained result itself make it possible to secure a mill and, in the future, to provide the product of the company, which has been made available at the costs of work and funds. The control over the operations, especially the control over the production, is based on chosen data like productivity, efficiency and rentability, that is to say on ratios of characteristic operational figures, in which expenditure and returns of the production are adjoined.

In my report, I will consider the modern techno-economic indices of the iron and steel production and the possibilities of attaining them. Doing this, it is in my opinion absolutely necessary also to consider first the conditions under which steel mills in the Federal Republic of Germany - which is representtative for the Common Market - have and will have to work, and second regard separately the techno-economic indices on one side and the purely economical or purely technical data on the other one. From that the targets follow automatically under which I have to see and judge the obtained techno-economic indices in order to find them to be a true standard for the furnished results.

The situation of the iron and steel industry in the world since World War II is characterized by a disproportionately quick increase of the world's consumption of steel, which has its reasons at first in the backlog after the war and its second phase in the quickly proceeding industrialization (graph 1: Development of the Rolled-Steel Finished Production). To cover this extraordinary increase of the demand for steel new big steel producing units were built up. Remarkable is the fact, that not only the traditional steel producing countries expanded their capacity, but that the number of suppliers grew steadily, too. Today, 15 countries put out 90 % of the world's total steel production, while 50 years ago there were only five of them.

Behind the planning of every industrial nation lies of course the wish to sell on every market in order to gain a high share in covering the world's demand for steel. In 1967 this competition made the world's crude steel capacity rise up to 580 million tons per year, while the world's crude steel consumption only amounted to 498 million tons per year. Thereby the up to that time well-balanced advantage of the capacity ahead of the demand was very much interfered with. This change of structure of the marketing situation , which was a change from a market of producers to a market of buyers, intensified the competition among the suppliers on every market in the world bringing a considerable loss of profits to every producer by the way of concurring prices.

To balance these losses the iron and steel industry - especially within the Common Market - had to take measures to rationalize in order to make up for the shrinking returns by decreasing the costs of the production process, thus lowering the operational expenses. On the field of quantity steel production this development was essentially influenced by the introduction of the oxygen refining steel process, since this new process increased the productivity of steel production considerably by the use of large producing units.

Graph 2 shows you how the oxygen refining steel process has replaced the so far known classical processes of steel production within the Common Market. At the same time, we tried to show the expected development of the oxygen steel process within the Common Market up to 1975. The same conditions also apply to the Federal Republic of Germany. While in 1956 the quantity steel production was based on the open hearth process (55 %) and the Thomas process (45 %), in 1967 this relation changed to 40 % SM-crude steel, 25 % Thomas crude steel and 35 % oxygen refined steel.

Another important figure for judging the structural changes on the field of iron and steel production is the output-structure of rolling mills' finished products. Regarding the quantity development of the last ten years in the greatest steel producing countries of the world, you will notice a disproportionate increase of the production of flats in comparison to steel shapes (graph 3). This trend, which is very important for the equipment of iron-works is mainly due to two influences:

1) a relative decrease of expansion in the capital goods industry, which is a customer of hot rolled bars and steel shapes, and an over-proportionate increase of the consumers' goods industry (automotive industry, packing industry, etc.) which is a customer of flats, especially fine and very fine sheets. This definite trend to flats has its parallel in the long-range development of political economics to economical systems which are orientated after the consumption, and it should reach in the long run a share of about 60 % in the total rolled steel finished production;

2) This trend is furthermore supported by the technical changes in the subsequent treatment of steel. Here especially the advance of the welded constructions and the cold rolled sections are to be mentioned.

Beside the high steel capacities and the structural changes in the output of rolling mill finished products, the new conditions of marketing for the iron and steel industry within the Common Market must be emphasized. Under the aspects of rationalizing the use of material, an increasing rate of overseas ores with a high content of iron was brought into use in the metallurgical process. In 1966, no more than 40 % of the total iron ore consumption were allotted to inland ores, compared to 58 % in 1960. The determining factors for this development were the change of the relative costs per ton of pig iron by iron containing overseas ores, the decrease of freight to the Fe-unit, and the decreasing use of coke in the metallurgical process.

Gentlemen, these fundamental structural changes in the iron and steel industry of the Common Market within the last decade have led to extensive changes and adjustments of production conditions and methods, and have called for a considerable rise of the specifical output of machines and plants. Parallel to that the growth of the production units was speeded up in order to be able to compare in international competition. These changes have found their reflection in all techno-economical indices of our branch of industry.

Here I am already speaking of techno-economical indices in which the purely technical figure - as it is known to you e.g. as ton per hour or horse power per machine - is connected with its effect on the economical result of the manufacturing process, in other words a purely economical figure like the rentability of capital or turnover. This techno-economical index serves directly the wanted purpose and therefore gives direct evidence. Techno-economical indices always refer to operational facts and serve the operational analysis, especially measuring the efficiency as the relation of input and result.

Indices are always ratios, that is to say figures which can give evidence on the relation of facts to each other, and that in terms of

1) classification numbers, e.g. fixed cost and total cost
2) indices, e.g. fixed costs of several months
3) proportional numbers, e.g. consumption of coke per ton of pig iron.

All these ratios have their own value of evidence, the highest though possess the proportional numbers. They are the only true indices by showing the connection between related figures e.g. a caused or a proportionate relation.

The special techno-economical figure or proportional number can therefore be defined as a standard which by connecting technical facts with economical data contributes to an optimal techno-economical control over an operation. Beside the specific consumption figures of the put in material corresponding to the results obtained, we also have to consider the specific amounts of consumption as they appear in the subsequent treatment. Those techno-economical indices of consumption are completed by the cost indices. This means the specific expenditure of plants and its annual capacity as well as e.g. the repairs of plants compared to their dimension and capacity. Finally the specific output of plants and its relation to their consumption figures belong to the term of techno-economical indices.

In the following, I will point out to you the development of techno-economical indices in the iron and steel industry. It seems logical to me to proceed according to the flow of material.

Starting with the blast furnaces in the Federal Republic of Germany we observe an increase of capacity in the last 15 years which can very much be explained by the steady improvement of the burdening. At the present time, the blast furnace burden consists of about 60 % of sinter, 3 % of pellets, 27 % of classified ores and 10 % of additions and auxiliaries. We are counting on a rise of the pellet share, but that won't affect the outstanding importance of sinter for German blast furnaces. For this reason we first have to go into the development and the present day state of the sintering technique in the Federal Republic of Germany.

The sintering capacity of German steel mills amounts to about 30 million tons per year using mainly self-fluxing sinter with an iron content of 55 - 60 %. During the past years, more efficient sintering plants were put into operation. Until 1958 conveyor belts with a maximum draft area of 75 m^2 were built. With two exeptions, which can be explained by the special internal situation of the mill, the draft area of the belts built since 1960 lies between 120 - 210 m^2. The nominal capacity of these down-draft installations varies from 600.000 to 1.000.000 Nm^3/h. Thus the annual production of finished sinter of a 150 m^3 belt could be increased up to 1,8 million tons. The average sinter production capacity related to the operated draft area was increased from 0,8 to 1,3 $t/m^2 + h$, with a peak output of 1,8 t/m^2+h.

Judging these specific results we have to consider the increasing demand for quality sinter, which among other things is the result of the demand for a smaller confraction (5 - 30 mm). To meet this demand, which causes a multiple crushing and sieving of the cooled sinter, the share of return material is increased. Modern plants have a share differing between 40 and 60 %.

A high specific output with a correspondingly high quality of sinter requires an optimum of fuel in order to get a completely sintered mixture as well as to avoid a melting and a too wide reduction. Because of the high share of fine ores and concentrates the average composition of the charge is about 70 kg breeze/t of produced sinter corresponding to a consumption of heat of $410 \cdot 10^3$ kcal/t produced sinter.

The high share of fine ore requires to pay special attention to the crumbling of the sinter mixture which is done in a second mixing drum in a modern plant. An addition of 7 % of water and 2 % of quicklime has proved to be the best with fine ores. In order to reach the self-fluxing at a basicity rate of about 1,1 limestone or dolomite are added to the sinter mixture at a rate of 5 - 6 %.

A steady increase of capacity of every single plant can be noticed on the field of sintering plants like on the field of other producing plants. The larger capacities of single plants lead beside a lowering of the specific consumption figures to a degression of the capital requirements. The effects of this essential figure may be seen in graph 4. This picture shows the investment - expressed in units of money per ton of sinter and year - in relation to the capacity. It becomes obvious that with a change to larger capacities a fundamental degression of the specific capital requirement goes hand in hand. Besides you may observe that a plant with a large belt requires less capital than a plant with two smaller belts, although both plants do have the same capacity. This advantage of degression, however, decreases steadily with the increase of capacity.

The following graph shows how the operating costs i.e. staff costs, energy costs, repairs, and capital costs depend upon the capacity respectively the draft area in m^2. It is very essential that a degression of the operating costs is primarily due to the lowering of the capital costs. E.g. the direct labor hour rate shrinks with a change from 50 m^2 - to 200 m^2 - sintering belts from 0,12 to 0,04 direct labor hours per ton of produced sinter. The staff costs, cost of repairs and capital costs have a share of 70 % in the total manufacturing costs, however they decrease to about 50 % if a 200 m^2-belt is used.

Since the input is proportional to the production and thus independent from the capacity of the plant, a lowering of the costs of finished sinter can only be attained by lowering the manufacturing costs. So just by looking at these few techno-economical data we come to the conclusion that an essential reduction of the costs of finished sinter can only be attained by expanding the capacity, i.e. degressing the capital requirement.

Beside the improvement of the burdening, the rise of the hot blast temperature and the inforced replacement of coke by oil or natural gas, the increase of capacity is explained by the use of larger furnaces. To characterize the capacity of a blast furnace you usually mark the pig iron output per day or respectively the coke rate because of the dependence of the pig iron output from the specific consumption of coke.

The dependence of the furnace output from the kind of burdening and the size of the furnace is rather well described by the relation $K = \gamma \cdot D^2$.

K = through-put of coke (t/24 h)
D = hearth diameter (m)
γ = factor of efficiency

The factor of efficiency of blast furnaces which are run with a well classified burden varies between $\gamma = 15$ and $\gamma = 20$. In graph 6 the connexion between the through-put of coke and the hearth diameter is shown at different factors. That shows plainly how with an increasing diameter the increase of the factor of efficiency becomes very effective . That leads to the conclusion that in order to obtain high results on the field of blast furnaces an excellent burdening is necessary.

The pig iron production E, the through-put of coke K, and the specific consumption of coke k are related to each other like this: $E = \frac{K}{k}$ (t pig iron/24 h).

E = pig iron production (t/24 h)
K = through-put of coke (t/24 h)
k = specific consumption of coke (t coke/t pig iron)

This relation combines all operational conditions by connecting the attainable through-put of coke with the specific consumption of coke at a given weight of burden. The influence of lowering the specific consumption of coke and launching blast furnaces with larger hearth diameters on the development of the pig iron production in the Federal Republic of Germany is shown in graph 7.

Till 1957, an increase of the pig iron output went hand in hand with an increase of the number of furnaces in operation despite an increase of the average capacity of furnaces. In the following, the number of furnaces decreased while the pig iron production grew on steadily. This tendency, which becomes obvious through the development of the annual average pig iron production per furnace, grew stronger especially during the last three years.

The medium pig iron production per furnace - which in 1967 amounted to about 352.000 t/year - meaning an increase of 130 % since 1950-will grow on in the years to come.

The largest blast furnaces in the Federal Republic of Germany being operated at the present time have a hearth diameter of 9,5 m with a useful content between 1.600 and 1.850 m^3. The capacity of those furnaces varies between 800.000 and 900.000 t/year.

These data have to be considered under the fact that the German steel mills have at first put their efforts toward lowering the specific consumption of coke because of the high cost of purchased coke. It is known that from a certain production rate on a further increase of capacity has the disadvantage of a higher specific consumption of coke. Furthermore you have to consider the fact that in the Federal Republic of Germany blast furnaces are operated damped on Sundays and holidays.

During the next years several already planned blast furnaces with hearth diameters of 11 - 12 m and á useful content of 2.500 - 3.000 m^3 will be put into operation. In order to get a constant gas passage over the total crosscut a minimum pressure of 1,5 atm is put on the throat. Large blast furnaces are expected to yield an annual pig iron production up to 2.000.000 t.

Beside the increase of the blast furnace capacity by building larger furnaces we put an effort on raising the specific capacity. One of the most important measures was the use of foreign ores or concentrates with a high iron content in order to decrease the burden net weight. We succeeded in lowering the burden net weight from 2.340 kg/t pig iron in 1953 to appr. 1.770 kg/t pig iron today. Besides the physical-chemical preparation of the burden was pushed forward. In this connexion especially the sintering plants are to produce the sinter with a hardly varying composition, which is superior by high compactness and an oxidation rate of more than 93 %.

At the same time, we tried to get a very small grain fraction. The percentage of grains below 5 mm should not be more than 5 %, the coarse grain should not exceed 50 mm. For 80 % of our total burden a grain structure of 5 - 30 mm is regarded as the optimum.

Parallel to that the coke is adjusted to the grain structure of the burden; a fine share of about 2 % is sieved and grains over 80 mm are crushed. All these steps of improving the burden were substantial for the development of the structure of the fuel and the specific amount of slag as shown by graph 8. In this connexion we have to speak of a specific consumption of fuel since in the meantime almost every German blast furnace is run with an addition of heavy oil.

As shown in graph 8, the average specific consumption of fuel was lowered from 920 kg coke/t pig iron to 580 kg coke and 30 kg oil / t pig iron. During the same period, the medium amount of slag decreased from 670 to 410 kg/t pig iron.

Modern blast furnaces with a good burden preparation had in 1967 an annual average fuel rate of 480 kg coke and 60 kg oil/t pig iron.

Responsible for the decrease of the specific fuel consumption is beside the intensive burden preparation the steady raise of the air blast temperature. The average air blast temperature of all furnaces was 980° C in 1967. Some furnaces came even up to an air blast temperature between 1.250 and 1.300° C in continous operation. These high temperatures are basic requirements for an intensified replacement of coke be heavy oil or valuable coal. They are attained by using hot-blast stoves with an adjacent combustion chamber, the use of special refractory material and enriching the blast furnace gases with fuel of a high calory content.

Another possibility of raising the output of blast furnaces is the use of oxygen. The enriching of the air blast with 1 % oxygen results in an output increase of about 4 %. German blast furnaces usually work with an enrichment of 1 - 2 % oxygen.

In Germany, the specific capacity of blast furnaces is usually expressed by the output of pig iron related to the size of hearth and an operation time of 24 hours. The specific capacity of a furnace currently amounts to an average of 33 $t/m^2 \cdot 24$ h. Some furnaces with a good burden preparation and high air blast temperatures reach a rate of 45 - 50 $t/m^2 \cdot 24$ h corresponding to the KIPO-figures of 0,55 - 0,60 $m^3/t/24$ h.

On the field of blast furnaces, the change to larger plants is accompanied by a degression of the capital requirement. Graph 9 shows the investment for modern blast furnaces in relation to the pig iron capacity. The parameters are the hearth diameter and the number of furnaces. Remarkable is the fact that with large scale blast furnaces (hearth diameter greater than 10 m) the by further enlarging of the diameter or increase of the number of blast furnaces increasing pig iron capacity is only followed by a rather slight decrease of the capital requirement.

From the degression of capital requirement follows a corresponding decrease of the capital service (amortization and interest/t pig iron). Also degressive are the following kinds of costs: maintenence cost, costs of gas cleaning, cost of blast furnace charge, cost of energy, and especially staff costs. 7-m-furnaces require a rate of 0,70 direct labor hours/t, 9,5-m-furnaces require only 0,20 h/t, and 12-m-furnaces require 0,10 h/t. Another impression give the air blast costs which have a minimum with 11 m furnaces and then progress steadily.

On graph 10, the operating costs of modern blast furnaces are plotted in relation to the pig iron capacity. The slight increase of the operating costs of blast furnaces with large hearth diameters can be explained by the progressive development of the air blast costs which amount to almost 1/3 of the total operating costs of large scale blast furnaces. Graph 10 reveals that at the latest state of engineering blast furnaces with a hearth diameter of 11 and 12 m work most efficiently.

Parallel to the development on the field of blast furnaces the successes on the field of crude steel production went along. Here, too, a raise of capacity by enlarging the plants took place beside an increase of the specific capacity.

Graph 11 shows the development of the various steel making processes and the course of the total crude steel production in the period of 1960 - 1967. Herewith the extreme increase of the share of the oxygen refining steel process from 2 to 31 % within the last seven years attracts immediate attention. This structural change in steel making took place mainly at the expense of the classical Bessemer process; in the future, however, equally essential shares of the open hearth steel will be replaced.

In the following, the present day state of both processes (oxygen refining steel process and open hearth process) shall be shown by some characteristic indices. Finally I will compare the costs of both processes.

Judging the capacity of German open hearth steel mills you have to consider the fact that in 1961 the last new open hearth furnace was put in operation. The largest open hearth furnaces in Germany are dimensioned for a weight of charge of 320t at a hearth area of 100 m^2, so their corresponding capacity amounts to about 320.000 t per year. The normal pig iron output of German open hearth furnaces varies between 300 and 600 kg/t crude steel. The specific heat consumption of these furnaces lies between 0,7 and 1,0 $\cdot$ 10^6 kcal/t; furnaces that are operated without using fluent pig iron have a rate of 1,5 $\cdot$ 10^6 kcal/t.

The heating of open hearth furnaces is done by the means of fuel oil respectively by fuel oil and gas. The condition for a high specific capacity is a short smelting period. That, however, requires a high supply of heat. Modern furnaces need 0,5 $\cdot$ 10^6 kcal/m^2 hearth area and hour.

To increase the supply of heat experiments are run aiming at an intensification of the oil and gas oxidation. A very wide spread method is to blow oxygen into the flame. At the present time the optimum amount is about 20 $Nm^3/t \cdot h$. Beside that we also work with compressed air which causes an atomization of the fuel and results in the desired sharp and short flame. A standard is the use of 1,2 Nm^3 compressed air per kg of oil.

All efforts to shorten the smelting period will succeed only if the charging period is squivalently decreased. The use of 80 to 100 t of scrap iron per hour is at this time regarded as a good charge capacity. However, planning the charge, you have to consider that the scrap iron has to offer a surface as large as possible in order to be smelted quickly. Blocks and packages of scrap iron are quickly fed but lengthen the smelting period.

The specific index of capacity of open hearth furnaces is the capacity related to the hearth area. It amounts to 10 - 15 $t/m^2 \cdot 24$ h according to the quantity of pig iron put in. Beside from this hearth area capacity also the hourly output is given, with modern furnaces in the order of 35 t/h.

Graph 12 shows the connexion between the hourly output and the tap weight of open hearth furnaces in the Federal Republic of Germany. The peak capacity is undoubtedly attained by furnaces with a high weight of charge and varies between 45 - 35 t/h. At the same time we plotted the total tap-to-tap-time. You will notice that it is rather independent of the tap weight and that it varies between 6 and 10 hours according to the program. Besides by marking the various points differently, it is shown at which rate of oxygen the open hearth furnaces are run. A definite relation between the hourly capacity and the rate of oxygen cannot be seen. This can be explained by the fact that furnaces run without or just with little additional oxygen are influenced by other measures e.g. use of compressed air which increases the smelting capacity.

The second steel making process treated is the oxygen refining steel process which is constantly gaining significance. It was introduced to the Federal Republic of Germany in 1957 by the construction of an LD-steel mill with two converters of 40 t tap weight each and an annual crude steel output of 600.000 t.

Within the last ten years the number of oxygen converter steel plants rose to 9, the medium weight of charge rose to 130 t. The most modern LD-steel mill produces about 2,5 million t crude steel per year with two converters of 250 t each. Compared to an open hearth steel mill the equivalent capacity would only be reached by 8 furnaces an a weight of charge of 300 t.

Beside the increase of capacity by raising the tap weight the capacity of the LD-steel mills was raised by the more and more secure control over the smelting process. So the introduction of the multihole nozzle brought an increase of capacity with a simultaneous improvement of quality.

Another increase of capacity of steel mills was attained by lengthening the durability of converters. By using improved stone qualities the durability was raised from 200 up to 300 charges per converter. The specific index of durability of a LDAC-converter is about 300 , the one of an LD-converter is about 550 charges.

All the measures mentioned were followed by a decrease of the tap-to-tap-time to 40 - 50 minutes. Remarkable is furthermore the fact that planning the converter the relation of belly in m^3 and weight of charge in t was assumed as being 1,0, however in operation it was lowered to 0,8 - 0,7.

The oxygen requirement of German LD-steel mills amounts to appr. 55 Nm^3 per t of crude steel. The consumption of cool scrap iron related to the fluent pig iron lies between 20 and 30 %. This share could be increased but it would result in a longer smelting period. Besides using a lot of scrap iron would call for preheating.

A rough comparison of costs of open hearth mills and oxygen converter steel plants leads to the conclusion that in the Federal Republic of Germany the operating costs of oxygen converter steel plants only amount to 55 % of those of the open hearth mills. This comparison, however, is not correct regarding the fact that most of the open hearth steel mills have a lower capacity than the smallest German oxygen converter steel plant.

Comparing the investment costs of open hearth and oxygen steel mills of the same capacity you will find that oxygen mills require 30 % less investment. Graph 13 shows the investment of LD-mills with 2 and 3 converters in relation to the capacity. Remarkable in this comparison is the fact that at a constant crude steel capacity the number of converters has no influence worth mentioning on the capital requirement.

In graph 14 the operating costs of LD-mills with two converters are compared to efficient open hearth mills working with four furnaces. Since the comparison itself is related to LD-mills with a rather low capacity and SM-mills with a rather high capacity the degression of the operating costs in the overlapping range of capacity is more obvious with LD-steel mills than with SM-mills. Beside the capital costs, the maintenance costs, the staff costs and the lining costs share in the degression of costs. The following graph reveals these facts:

process	SM		LD	
units	4 furnaces à 100 t	4 furnaces à 320 t	2 converter à 40 t	2 converter à 220 t
capacity	(400.000 t/y)	(1.300.000 t/y)	(600.000 t/y)	(2.300.000 t/y)
direct labor hours/t	1,6	0,4	1,0	0,20
maintenance costs (money/t in %)	100	80	70	40
lining costs (money/t in %)	100	75	30	10

A comparison of costs between both processes must not only be based on the operating costs. On the contrary the total costs have to be taken into consideration. The investment costs amount to 68 % (open hearth process) and to 80 % (LD-process) of the total costs. For this reason it is substantial to regard beside the operating costs the corresponding relation of the pig iron costs to the price of scrap iron in order to be able to judge which one of the processes is the more economical.

Graph 15 shows you a comparison of the manufacturing costs of the SM-and LD-steel in relation to the price of scrap iron, based on the following representative costs of modern plants in the Federal Republic of Germany:

operating costs LD-steel	(220 t-converter)	= 30,-- DM/t
operating costs SM-steel	(300 t-SM furnace)	= 60,-- DM/t
pig iron costs	(9 m-blast furnace)	= 155,-- DM/t

Regarding the LD-steel a constant consumption of scrap iron was assumed at 250 kg/t, while the consumption of scrap iron in the SM-process varies between 500 - 800 kg/t. From graph 15 you can gather that the efficiency of the SM-process compared to the LD-process is essentially depending upon the price of scrap iron. For an amount of 800 kg of scrap iron per t of SM-steel a price of only 100,-- DM/t of scrap iron could be estimated before the SM-process would work as profitable as the LD-process. But it must also be taken into account that such an amount of scrap iron would considerably increase the operating costs of an SM-steel mill because of the higher consumption of energy. At the present time, the inland scrap iron costs about 130,-- DM/t the imported scrap iron about 170,-- DM/t. These figures reveal the great significance of the oxygen refining steel process for the Federal Republic of Germany.

Besides it has to be considered that a change to larger blast furnaces is followed by another decrease of the pig iron costs, strongly influencing the widening of the oxygen refining steel process. What is more, the variation of the amount of scrap iron being used in the LD-process makes it possible to adapt oneself to the economical optimum at an extremely low price of scrap iron.

Now that we have characterized the development on the field of blast furnaces and steel mills by discussing the changes of the techno-economical indices we will go into the techno-economical figures on the field of rolling mills. In the beginning I described the significance of the flat bar steel for the future development of the metallurgical industry. To avoid a too wide extent of my report I will confine myself to the field of flat bar steel production.

The connexions between steel mill and plants treating the semi-finished steel are cogging or slabbing mills and concurring with those the continous casting plants, which in 1967 already worked up 4,8 % of the world's total crude steel production, and the capacity of which is estimated at 10 % in 1970.

The largest continous casting plants of today have a capacity of about 2.000.000 t per year and put out slab cross-cuts with a width up to 2.100 mm. During its relatively short period of evolution the continous casting has gone through a considerable rise of capacity. At the beginning of the 60's the plants had a ladle weight of 30 - 50 t while today ladle weights up to 270 t have been realized. Correspondingly the hourly output of the continous casting plants has gone up to more than 100 t per hour.

The reason for this quick development has undoubtedly to be seen in the efficiency of the continous casting process in comparison to the conventional crude steel treatment. Assuming the same investment expenditure for continous casting plants and slabbing resp. cogging mills with the same capacity and the same operating costs, the efficiency can be explained by the drop of the costs of the casting pit and by the better relation of input and output of fluent pig iron compared to semi-finished steel. The profit of recovery of continous casting plants in comparison to slabbing or cogging mills is 8 - 15 %. These advantages yield a profit of 40 - 50 DM per t of semi-finished steel from the fluent crude steel to the semi-finished steel, and thus indicate the efficiency of the continous casting process. Still many conventional blooming and slabbing trains are built which does not mean a miss estimation of the continous casting process but indicates that the process is not yet under perfect metallurgical control.

In analogy to the raise of plants on the field of blast furnaces and steel mills, the same development occurs necessarily on the field of slabbing trains because the cost advantage of the preceding stage can only be realized if the following plants can take off the capacity produced by the preceding plants. Beside a considerable lowering of the costs in rolling mills can only be caused by an enlargement of the single plants and thus by a degression of the fixed costs. The decrease of costs, though, appears only, if the premise of full employment is fulfilled.

The enlarging of plants is made clear best considering the fact that in 1967 in the Federal Republic of Germany a cogging train of 1888 was shut down which had at the beginning of the operation put through slabs weighing 1 t and hit a peak capacity of 12,5 t per hour. Comparing these figures to the momentarily largest slabbing mills, which put through crude slabs weighing up to 45 t and have an hourly output of about 1.500 t, you can realize the development on this field to its total extent.

These modern slabbing trains have a final capacity of 5.000.000 t per year and a propulsive output of 920 mt. This development has its effects on the operating costs seen in the increase of capital costs and decrease of staff costs. Graph 16 shows these groups of costs of old and new trains in the Federal Republic of Germany. New trains mean trains launched after 1955. That shows that trains with an hourly output up to 150 t require more staff costs than capital costs while subsequently the opposite tendency can be noted. This tendency can be explained by the high hourly output which is caused by an intensive investment, resulting in a high degree of mechanization which on the other side is compensated by the savings on the field of staff costs. The diagrams only refer to the rolling process (pit furnace to shears) and are only to show the tendency of the development of costs. On the other side they indicate how much the fixed costs will influence the costs structure of very efficient trains. So our target has to be to attain the costal minimum of these trains by the highest continous balance possible in order to make full use of the possibilities that these large plants offer.

As another important factor of costs, the consumption of electric energy of slabbing or cogging trains should be regarded. Old slabbing and cogging trains still had a specific current consumption per ton of finished product in the order of 8 - 12 kWh while today because of the steadily increasing propulsive output the modern quickly running universal slabbing trains have to count on a current consumption of about 25 - 35 kWh per t. Assuming a price of current of about 5 Pfg. for the driving motor, these costs amount to 8 - 10 % of the total operating costs of a universal slabbing train. That should make clear what a great significance comes to an influence on the consumption of the electric energy. Within this analysis, the dependence of the installed propulsive output from the weight of the most heavy crude slab will not be treated because those explanations would lead too far off.

The high capacity of slabbing mills, however, can only be realized if a correspondingly powerful pit furnace is installed before the trains. Using these modern pit furnaces, you have to aim at a high capacity and at the same time at a low consumption of heat in relation to the through-put. There the tendency must be stressed that constructing pit furnaces a change is being made to larger chambers with a relining weight between 200 and 250 t per chamber. The annual through-put of such a chamber, using warm ingots only, amounts to about 200.000 t per year. This capacity corresponds to a hearth area capacity of about 1000 kg/m^2 and hour.

The main cost factor in using pit furnaces are the fuel costs. Examining the consumption of heat a little closer, you will notice a definite dependence of the hearth area capacity (graph 17). Pit furnaces with an increase of capacity require less heat. The consumption of heat approximates asymptotically a limit of 210 kcal per kg under which one cannot remain even with heating without losses. The varying hearth area load has been plotted as the parameter.

On the following graph 18 the relation between the available hearth area of pit furnaces and the possible annual weight rate of charge is shown. This picture reveals that an increasing hearth area of the chambers results in an increasing specific through-put. This increase is due to the growing call fill and a simultaneously growing hearth area load.

In graph 19, the heating period of cold ingots is plotted to the output of a hearth area, the thermal stress, and the kind of burner used. Obviously a growing output of the hearth area increases the weight rate of charge of pit furnace plants. At the same time,however, it shows the dependence of the hearth area output from the heat supplied per unit time, which itself is influenced by the burner used.

Another characteristic of large plants on the field of rolling mills is the absolute increase of the maintenance costs and the cost of repairs. While on one side the progressing mechanization and automatization results in a decrease of the manufacturing staff working at the trains, an expansion of the repairing crews is noticed. This expansion is primarily explained by keeping the repairing crew ready at all times in order to repair breakdowns immediately, thus keeping up the capacity of a train. At the same time, larger dimensions and more complicated ways of driving and controlling made the costs of repairs rise quickly. Usually a reduction of the manufacturing staff costs is made up to 70 % by the additional repairing crews. We try, however, by organizational and constructive measures to stop the increase of the cost of repairs.

As organizational steps are to be mentioned the preventive servicing, the production of spare sparts in groups of related parts, and a premium bonus system.

Finally I want to attract your attention to the output of slabbing and cogging mills. Because of extensive controlling measures,by a precision planning of production programs through the use of computers, and through the work of the quality departments, the output of the slab ingot resp. raw ingot to the billet resp. slab has been increased up to 82 - 88 %. The yield, of course, depends upon the size resp. the weight, the quality, and the final dimension of the slab ingot. From the above reasons the wide range of various yields results. Our target is to get a constant yield between 87 - 90 %.

The tendencies noticed on the field of slabbing mills can also be observed on the field of broad strip mills. Here, too, the trend goes to more efficient trains. The higher capacity is primarily expressed by the higher bundle weight, the higher weight per cm of strip width, and an increased strip width. Ten years ago the weight per mm of strip width was around 10 kg. Today modern trains carry a weight of 20 - 25 kg per mm strip width. That means an increase of the bundle weight from 8 - 12 t to 35 t. So trains put into operation ten years ago had a monthly capacity of 120 - 150.000 t while today trains with a width of 2.200 mm reach a monthly maximum capacity of about 350.000 t. This rapid increase of capacity illustrates best the progress on the field of broad strip mills. Correspondingly to the constant expansion of the size of plants, however, the costs of investment have gone up, too.

Today in the Federal Republic of Germany hot rolling trains like those are estimated at an investment expenditure of 160 DM per t produced per year. Such a high investment requires very high capital costs within the operating costs. A normally balanced train requires a capital service of 20 - 30 % of the operating costs, while the staff costs of these trains amount to only 5 (max. 10) %. So hot rolling trains have the same tendency as every metallurgical plant treated before: the increasing size of plants ties up a multiple of capital which leads to a considerably higher capital stress on one side and to a decrease of the staff costs on the other one.

Another essential cost factor of those trains are the costs of energy. The current consumption of a modern hot rolling train varies between 70 and 85 kWh per t. These relatively high costs of energy have their reasons in the installed capacity of the stands which amounts to more than 120.000 kWh. Besides you have to take into account a cooling water consumption of 35 m^3 per t of finished product and a compressed air consumption of 15 - 20 Nm^3 per t of production.

A very important problem of modern hot rolling trains is the durability of the rolls since the cost of rolls make up 15 % of the total operating costs. There you have to consider that rolls of intermediate stands have a durability of about 400.000 t of production and the finishing stands have one of 75 - 100.000 t. These figures, of course, refer only to the working rolls of a broad strip train.

Because of the high stress of fixed costs on efficient trains we try to balance them as good as possible in order to decrease the costs by an increased production, To reach this target there are several different auxiliaries. The most important to be mentioned is the planning of the production program. A good planning makes it possible to have the train always work at its optimum. The planning requires detailed knowledge of the orders, kind and number of orders, and of the capacity in relation to the different qualities, strip width, and bundle weights. These data are absorbed by a computer which controls the total flow of material from the slab ingot dump to the finished product. This control can be seen as a first step to a later control over the total process.

Another measure to attain the full capacity of the train is the prevention of breakdown periods under which the time of changing rolls has to be counted. Modern plants have a roll changing device which makes it possible to change the rolls automatically within 5 minutes. This measure results in a considerable decrease of the interruption period on one side and a decrease of the needed staff on the other one.

In order to keep up the capacity of hot rolling trains, a certain amount of prematerial is necessary which allows at any time to provide the prematerials needed for an order. On the grounds of the experience made with the various rolling trains you can figure a broad strip mill with a monthly output of 250.000 t of hot rolled strip must have a dump of 30 - 50.000 t of slab ingots. This supply is necessary because a missing of slab ingots of the wanted quality and dimension would disturb the program completely and lead to a decrease of capacity.

It should be mentioned that every modern hot rolling train has an automatic control of thickness and shape in order to yield a product with the usual small allowance . Beside these helps result in a correspondingly better product because the amounts of II-a can be kept low. The consumption figures of pusher type furnaces of hot rolling mills are subject to the same influences as the pit furnaces. However, a special criterion of those furnaces is the pushing length which very much effects the investment expenditure and the cost of repairs. Lining the pusher type furnaces you have to watch the fact that heating just with top gas is functional only for low thicknesses of rolling stock. At a thickness of more than 200 mm the length of a pusher type furnace heated with top gas must be increased by 10 - 20 m in comparison to a furnace heated with strong gas or oil. Great pushing length automatically lead to a higher disturbing rate especially when using thick material. The connexion can be seen in graph 20 which differentiates the field of non-troubled operation from the field of low resp. high disturbance.

Hot rolling trains are usually followed by cold rolling mills which work up most of the hot rolled strip to thin or very thin sheets. The latest cold rolling mills have tandem trains with 4 - 6 rolling stands. Older plants still have single revercing stands which, however, have a capacity of only 25 - 30.000 t per month compared to the capacity of modern tandem trains with 6 rolling stands and an appr. production of 100 - 120.000 t per month.

On the field of cold rolling mills it is almost impossible to specify generally fitting techno-economical indices. The structure of the programs with sheets, cold rolled products in rolls, thin and very thin sheets differs from mill to mill and leads to a difficulty in comparing the indices of different cold rolling mills. Nevertheless we shall try it, referring to a cold rolling mill with the following structure: 80.000 t of thin sheets, 25.ooo t of very thin sheets and tinplate, 15.000 t of pickled hot rolled strip.

An analysis of the operating costs of those trains reveals that three kinds of costs make up about 60 % of the operating costs, namely staff costs (20 %), energy costs (15 %), capital costs (25 - 30 %). Very remarkable is the share of the staff costs. It can be explained by the numerous helps needed in those mills for packing the finished products because these works have to be done manually.

Regarding the specific consumptions of a cold rolling mills the current, water, and compressed air consumption are especially interesting. The water consumption amounts to about 9 m^3 per t, the compressed air consumption is about 90-100 Nm^3, and the current consumption amounts to about 130 kWh per t produced. In this connexion we have to pay special attention to the fact that the current consumption, rolling thin sheets, is 1 : 3. Another interesting consumption figure is the amount of mordants used. While pickling with hydrochloric aced one can estimate the consumption at 2,5 kg per strip, with sulfuric acid at 8,5 kg per strip. These figures are true only for the above mentioned average output. Basically the consumption of mordants is in inverse proportion to the thickness of a sheet.

Beside from these pure consumption figures the capital requirement for the installation of a modern cold rolling mill is especially significant. In graph 21 the capital requirement is plotted in relation to the capacity of modern cold rolling mills. Here, too, the strong degression of the specific costs of the plant at an increasing size of the plant is shown. A cold rolling mill in the Federal Republic of Germany with the above capacity requires an investment expenditure of 250 - 300 DM per t and year of production. Comparing the investment of hot rolling mills to the above figures (hot rolling mills require 160 DM per ton and year) you realize the strong influence of a cold rolling mill on a mixed-type metallurgical plant. Because of these high capital costs the call for an optimum balance of trains applies more to cold rolling mills than to other ones.

Beside the indices which are a function of every single plant there are a couple of data which can only be looked at in connexion with the complete steel mill. This applies especially to the techno-economical indices on the field of energy consumption as there are current, compressed air, and oxygen as well as the water economy. Considering that 10 years ago the current consumption of a mixed-type metallurgical plant amounted to appr. 150 - 180 kWh per ton of crude steel while today it has risen to about 200 - 250 kWh per ton of crude steel it becomes obvious how important a good rationing of this capital is. Besides in the course of time the specific current consumption will rise with the widening of the oxygen steel refining process and with another increase of mechanization and automatization. Which possibilities do I have to attain the most efficient cost of current at an average current consumption? Assuming a share of the current consumption to be covered by own generation of current and the rest being purchased you have to watch for a continous use of the purchased current while any peak demand for current within the mill is supplied by the company-owned power station. In that way it is possible to get a relatively high annual rate of hourly current consumption and thus to keep the price of current low. Steel mills depending on purchased current only have to switch off the power at peak demands in order to smooth the graph of the current consumption which yields a high annual rate, too. Both methods lead to a minimum expense at a given current consumption.

It should still be mentioned that 40 % of the current consumption is allotted to the cold rolling mill, about 35 % to the broad strip train, 30 % to the oxygen producing plant. Another important consumer is the blast furnace plant with a rate of 50 kWh per ton of crude steel. The basis for the above shares was generally kWh per ton of crude steel.

Another very important and expensive kind of energy is the compressed air. Today you can estimate the compressed air consumption of a modern metallurgical plant between 100 and 140 Nm^3 per ton of crude steel. Determining factor for the high consumption of compressed air is the share of the produced SM-steel because a large part of the compressed air is used to atomize the oil. In addition to this the cold rolling mill consumes about 28 - 30 Nm^3 per ton while the blast furnaces and the workshop have a total consumption of 20 Nm^3 per ton of crude steel.

The introduction of the oxygen steel refining process is connected with an increased consumption of oxygen. Before the introduction of this process an average amount of 10 - 15 Nm^3 of oxygen per ton of crude steel was needed. Today we can count on a consumption of oxygen between 35 - 45 Nm^3 per ton of crude steel. This consumption figure depends upon the share of the oxygen steel refining process in the total crude steel production. Oxygen converter steel plants have a consumption of 50 - 55 Nm^3 per ton of crude steel while the rest is primarily used for flame scarfing and enriching the blast.

In order to attain low costs in the production of oxygen and compressed air here, too, the tendency to larger plants holds true. This applies especially to oxygen producing plants. Ten years ago oxygen plants with an hourly output around 3 - 4.000 Nm^3 were installed. Today we have plants with a capacity of 20 - 30.000 Nm^3 per hour. The very high capital stress is accompanied by a decrease of the specific costs. The price of oxygen which ten years ago was in the order of 10 - 12 Pfg has dropped to 6 - 7 Pfg per Nm^3 by lowering the costs of current and because of the general degression of costs. With the decreasing price of oxygen the oxygen steel refining process became more and more economical.

Aside from these energies the water economy is extremely significant in the Federal Republic of Germany. This applies especially to so-called dry iron works. The installation of water circulations and the introduction of hot cooling has resulted in an intensive rationing of water which made it possible to lower the water consumption thus drastically decreasing the amount of purchased water and lowering the costs on this field.

All these measures which lead to a decrease of the costs of crude steel can only be guaranteed by a strict control of all consumers. Beside the well organized departments which continously work on these problems we at the same time help ourselves by special accounting systems. Especially to be mentioned is the system of predetermined standard costs which on the basis of given consumption figures and their constant control masters the operation and the emerging consumption at any time.

Now that I have talked about the purely techno-economical indices of production I will consider briefly the optimum size of metallurgical plants since a techno-economical figure is reasonable only in relation to the size of the plant itself. The tendency of decreasing costs with an expansion of capacity observed at special units of a mill is basically the same for the total mill. A steel mill can be optimal only if every single plant is dimensioned at its optimum in relation to the other ones. That is why the trend is going to larger units whereby, of course, the term of the optimum size of steel mills is shifting. Up to 1950, a German steel mill with an annual output of one million tons of crude steel was called optimal. In 1967, the average output of the largest three steel producers in the Federal Republic of Germany amounted to 6,4 million t per year, lying above the average output of the world's important steel mills, the medium capacity of which amounts to almost 5 million t/year today.

The process of expanding the capacity, however, will not yet be finished. Especially "integrated mills" with a production of flat steel bars will still have to grow if their modern production plants are to become profitable. The determining factor for the total capacity will most of the time be a modern hot broad strip train with the possibility of producing 4 - 4,5 t/year and a heavy or medium sheet train with a capacity of 1 - 1,5 t/year. If the mill continous to produce steel shapes it is for commercial reasons suggested to erect several rolling trains side by side in order to distribute the orders optimally according to quality and dimension. Here, too, a capacity of finished products of 1 - 2 million t per year becomes necessary.

Such a high operating capacity allows to compensate market fluctuations which effect certain products differently and to make optimal use of the marketing channels. Assuming a long-range capacity of a steel mill at 7 million t/year, 2 million t of which are steel shapes, you can figure the share of flats to be about 70 % which can definitely be reached.

As I have mentioned in the beginning a considerable increase of the share of flats at the expense of steel shapes and wire rods as well as semi-finished products can be observed during the past years while on the field of flats the share of coils as finished products and of fine sheets has risen most; the share of strip steel, however, is slightly decreasing. This is primarily due to the expansion of economies like automotive engineering, electric machines, and canning. Among the steel shapes especially the share of heavy sections will decrease because of the general reduction of weight in heavy steel constructions.

Finally I want to say a few words about capital investment.

The investments in the iron and steel industry within the Common Market amounted to an annual rate of 580 million $ during the years 1954 - 1959. Between 1960 - 1965 it rose to 1080 million $ per year. During the first period capacities of about 24 million t per year were produced while in the second period they only amounted to 26 million t.

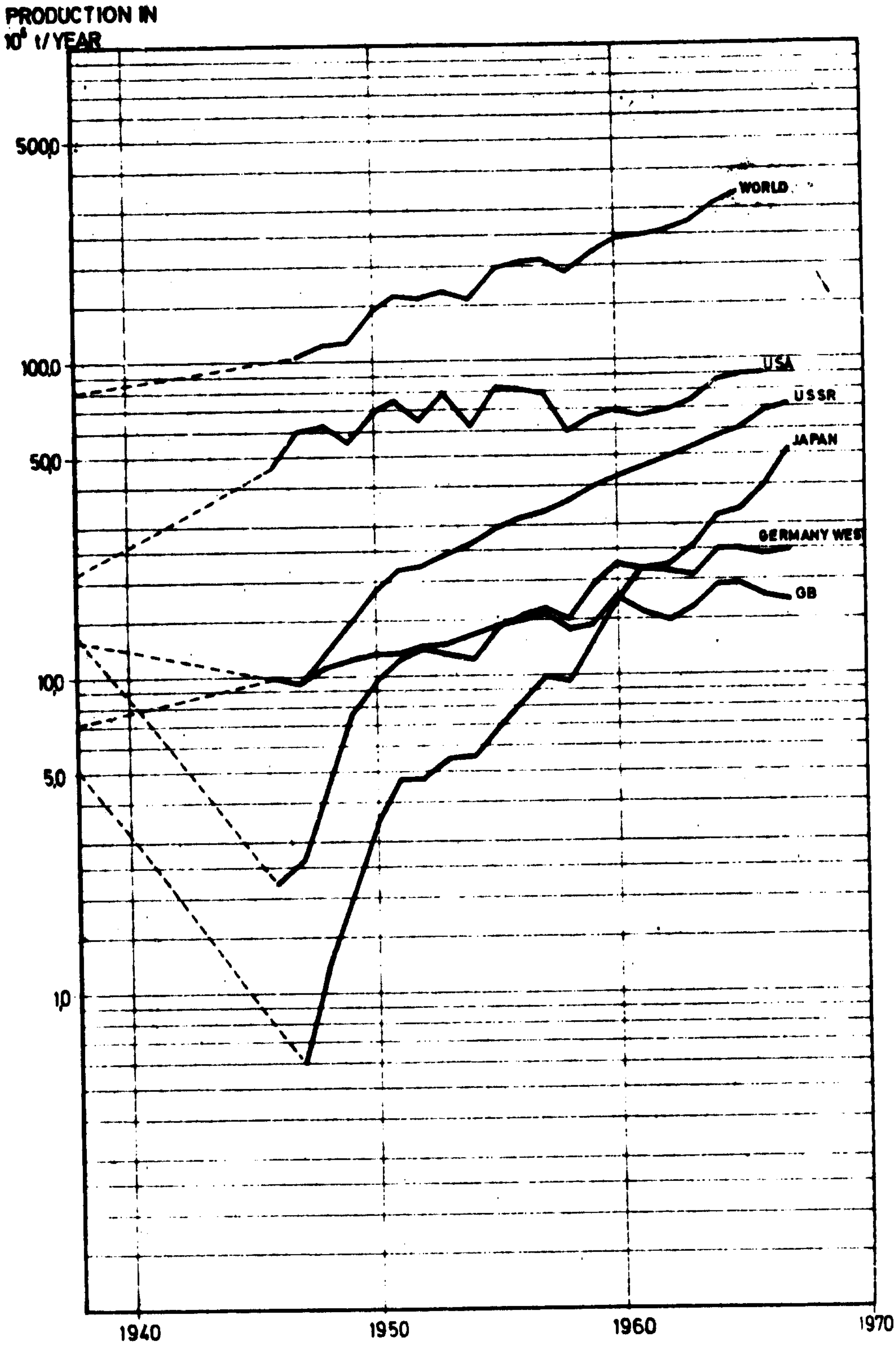
It appears that not only increasing the production capacity required a lot of investment capital but that the already increased capacity was followed by considerably higher maintenance and modernizing costs. Estimating a probable depreciation of steel mill installations in twenty years the maintenance costs would have been 6 - 7 $ per t of crude steel, the cost of expanding and rebuilding would have been 120 - 140 $ per t of crude steel during the above mentioned period of time.

In the next picture (graph 22: launching cost of modern steel mills) the launching cost of modern steel mills are plotted in relation to their capacity, based on the figures of existing plants. There you can see that an optimal investment expenditure is possible at a crude steel capacity of about 4 million t per year which cannot essentially be lowered, even with larger plants. It has also become apparent that new buildings regarding the capital productivity in comparison to the capital expansion of already existing plants are not necessarily disadvantaged. Besides new plants usually attain a higher productivity in the employment of workers and in the use of raw material.

The shown development of the pig iron and crude steel production and of the rolling technique based on techno-economical indices will not find its end yet at long sight. Considering the present research programs you can rely on large structural changes in the iron and steel industry in the distant future. Beside the trend to powerful large-scale units the technical planning progresses into the direction of a continous conversion of material and thus to an elimination of the still existing separation of blast furnace, steel, and rolling mills. Here the problem of converting pig iron into crude steel - e.g. by the "fresh-spraying process" - is especially to be mentioned. This process - at its fully developed practical stage - could very well be an optimal first step to the continous subsequent treatment of crude steel by continous casting plants.

Graph 1

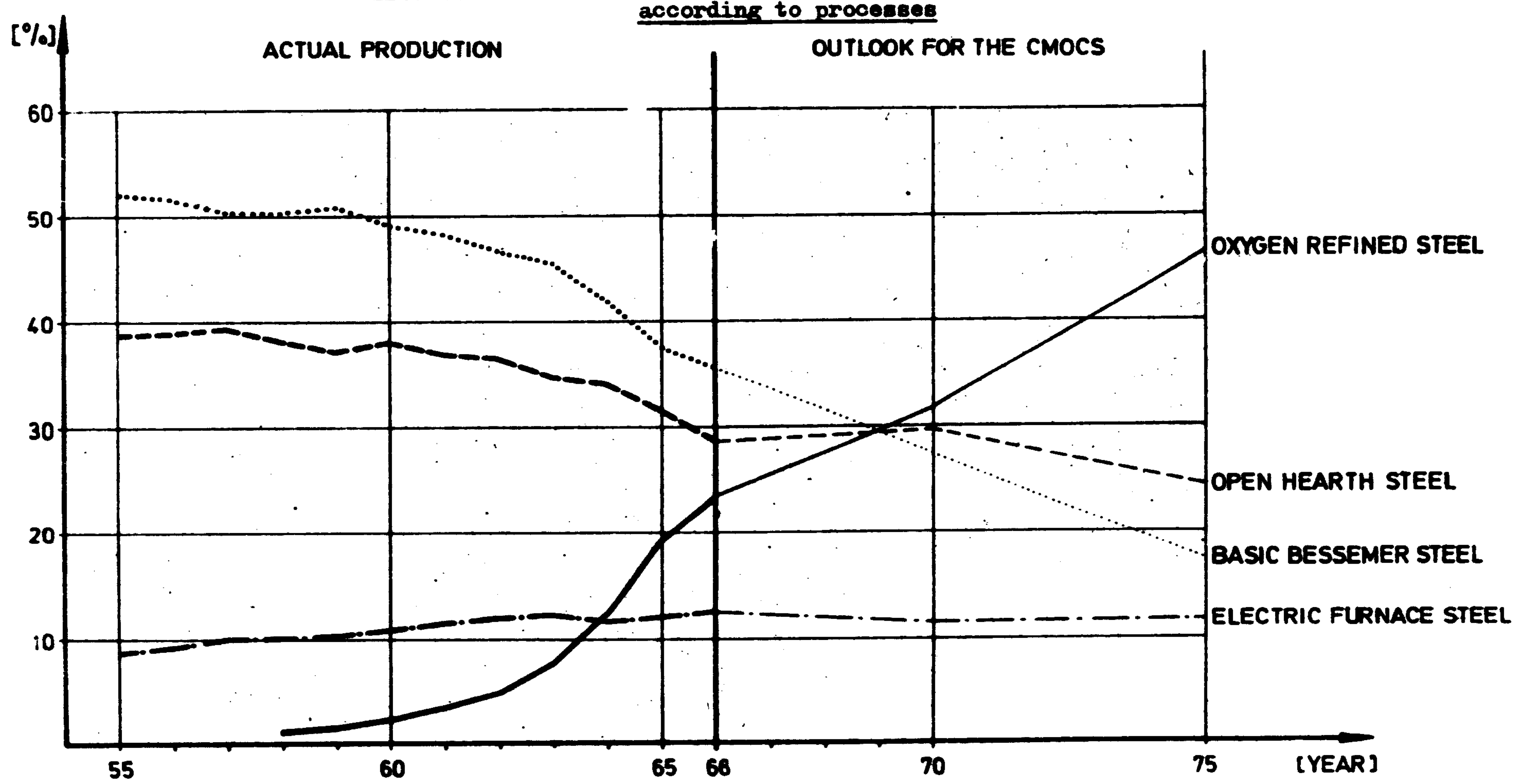
Development of the rolled steel finished production in million t/year



Source: Statistisches Jahrbuch der Eisen- und Stahlindustrie, Duesseldorf 1966 und 1967.

Graph 2

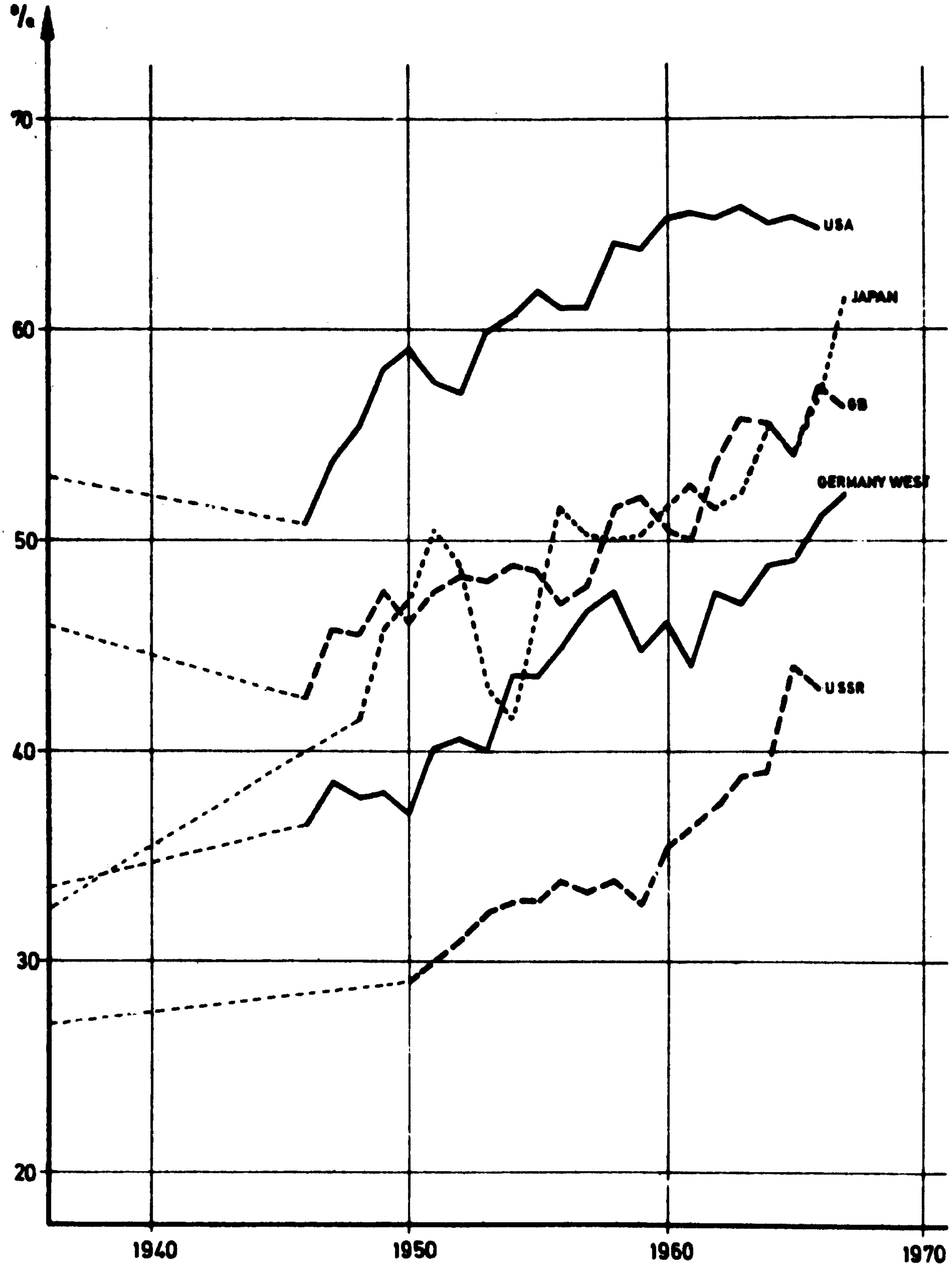
Crude steel production in the common market of coal and steel according to processes



Sources: Statistisches Jahrbuch der Eisen- und Stahlindustrie 1966, Duesseldorf 1967; and Bulletin der EGKS Hohe Behoerde, Allgemeine Ziele Stahl 1970, Luxemburg, 12 Jg.-Nr 1, 1967.

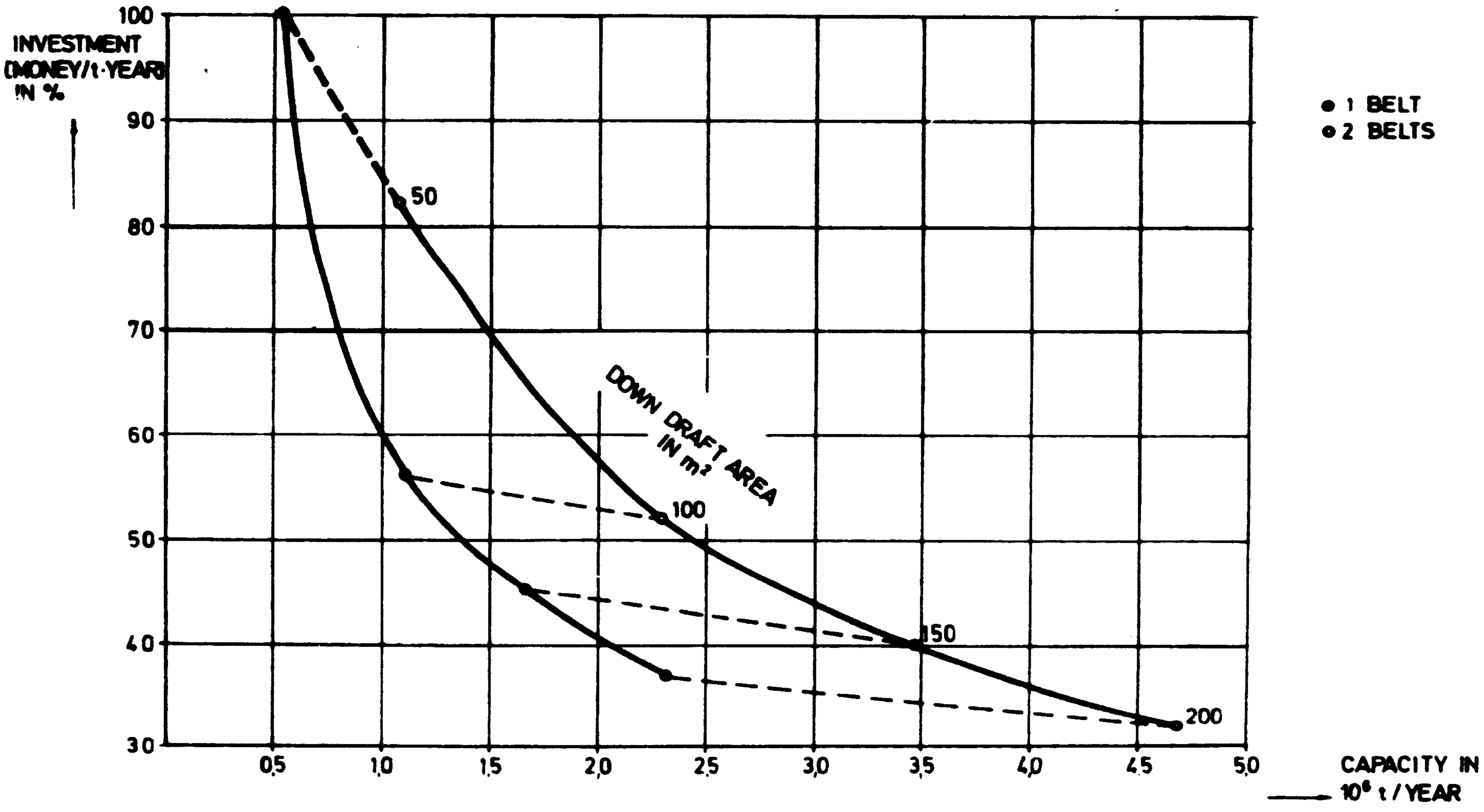
Graph 3

Development of the share of flats in respect to the total production of rolled steel finished products



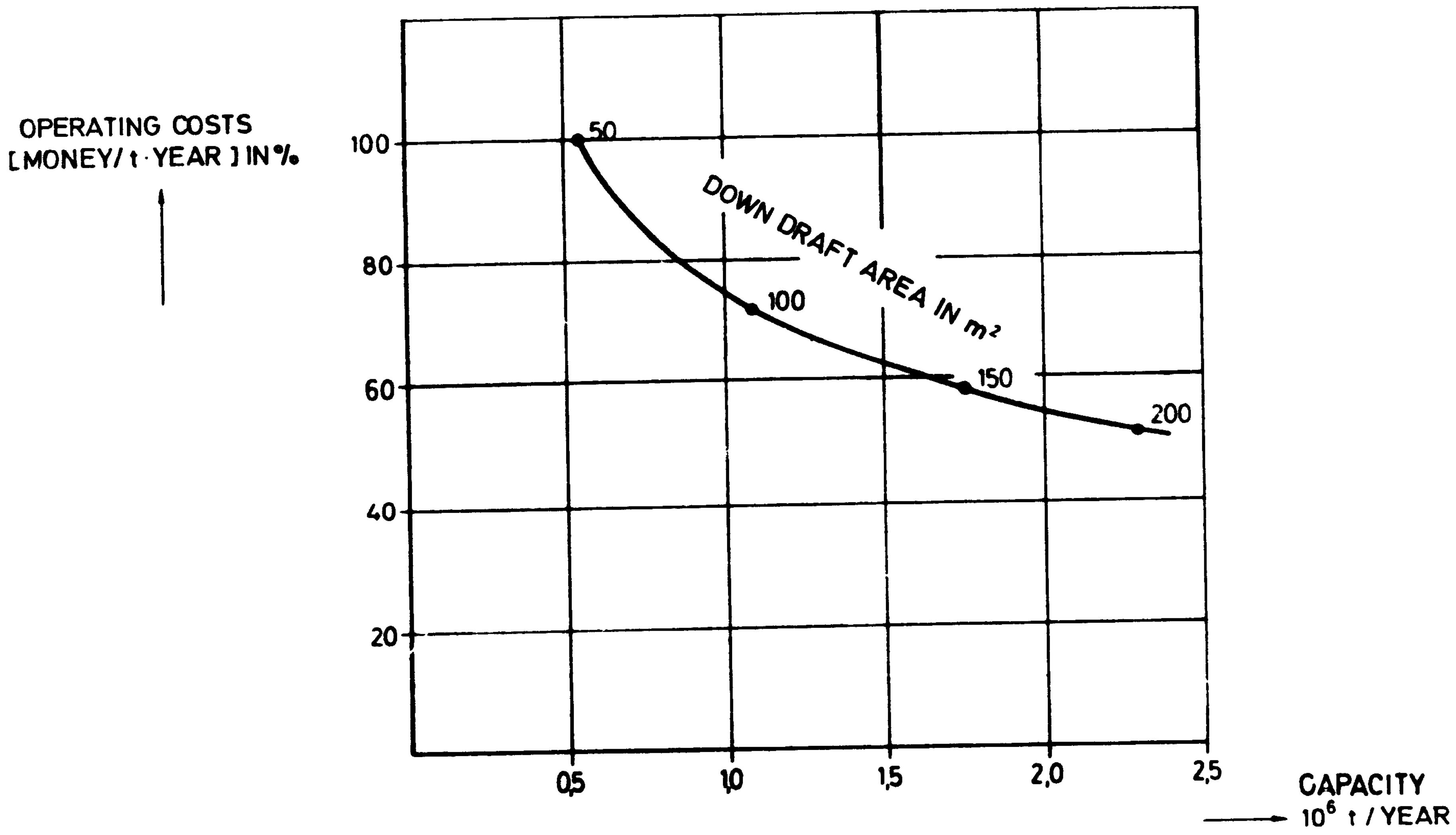
Graph 4

Investment for sintering plants in relation to the capacity



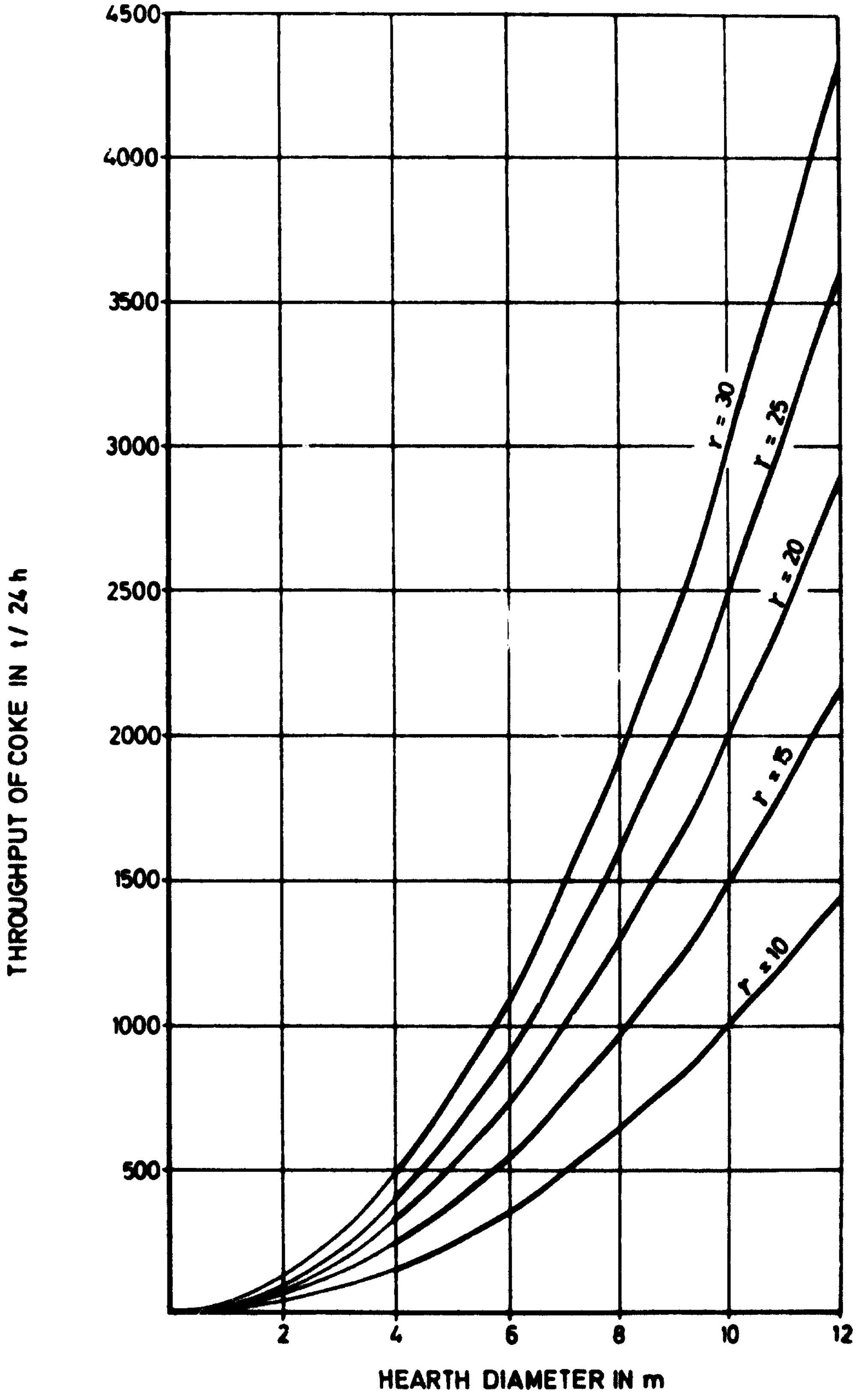
Graph 5

Dependence of the operating costs from the capacity of sintering plants



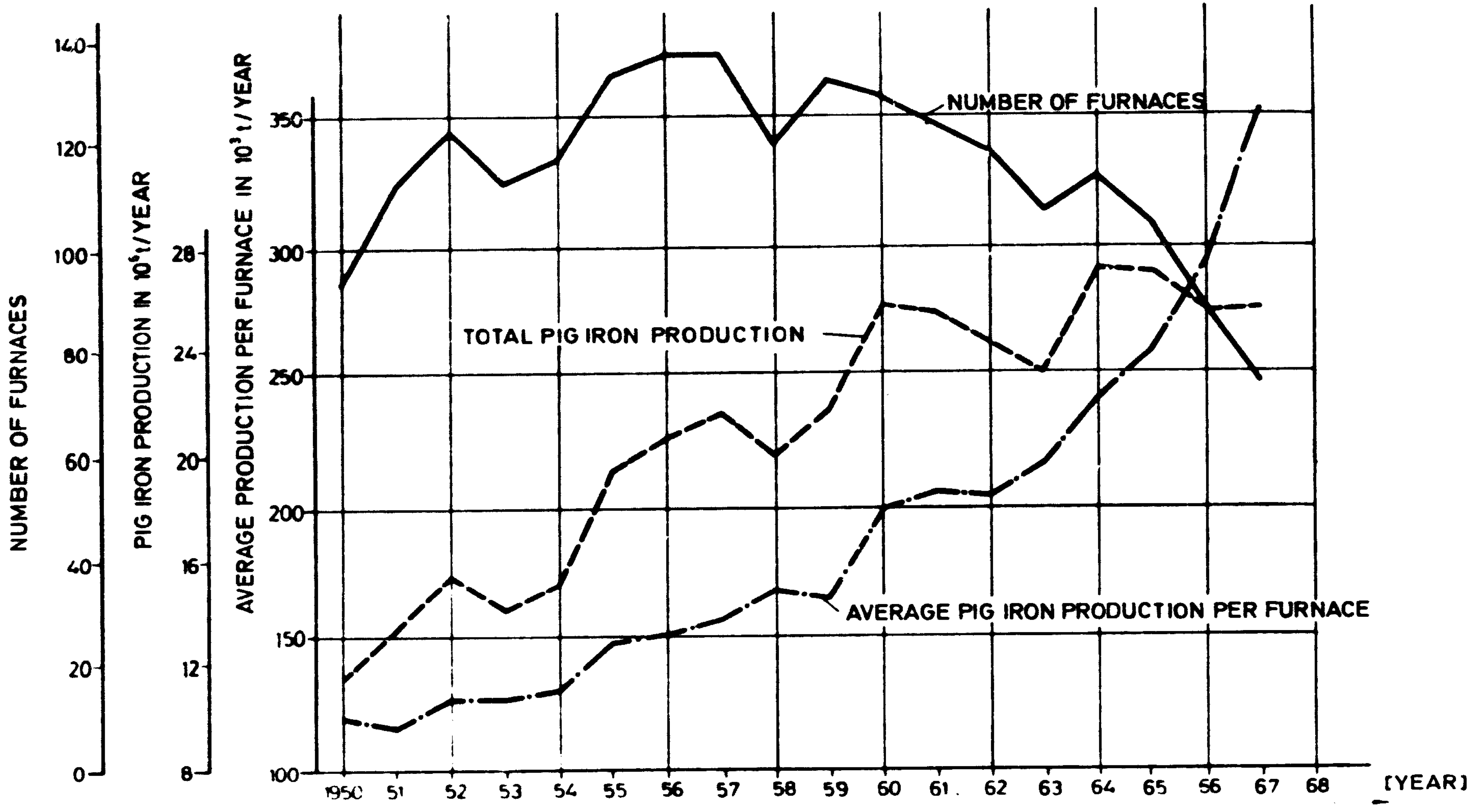
Graph 6

Connexion between the throughput of coke and the hearth diameter at different factors of efficiency



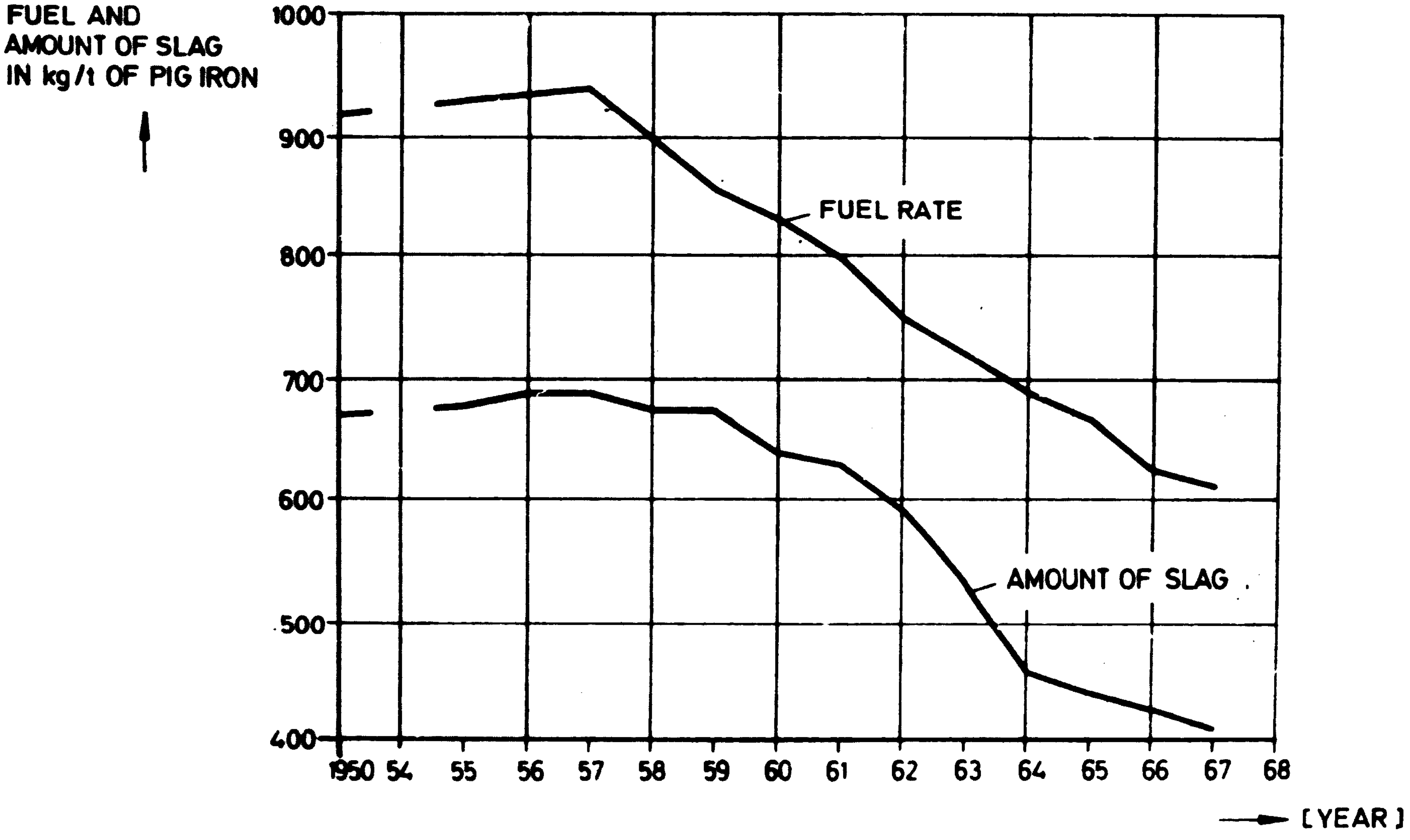
Graph 7

Number of blast furnaces in operation at the end of each year, pig iron production per year, and annual production per furnace in the Federal Republic of Germany



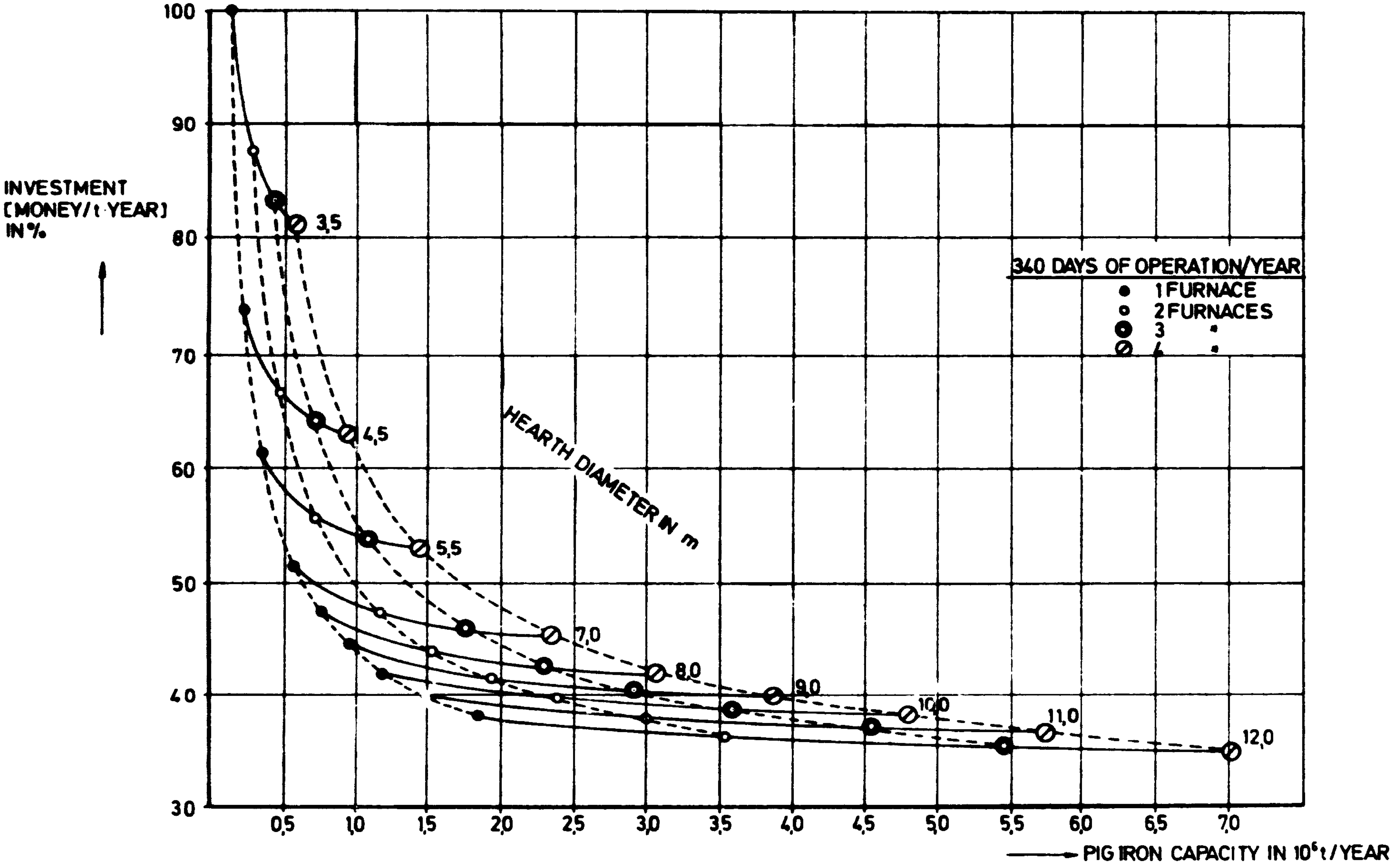
Graph 8

Development of the coke rate and the slag volume of German blast furnaces



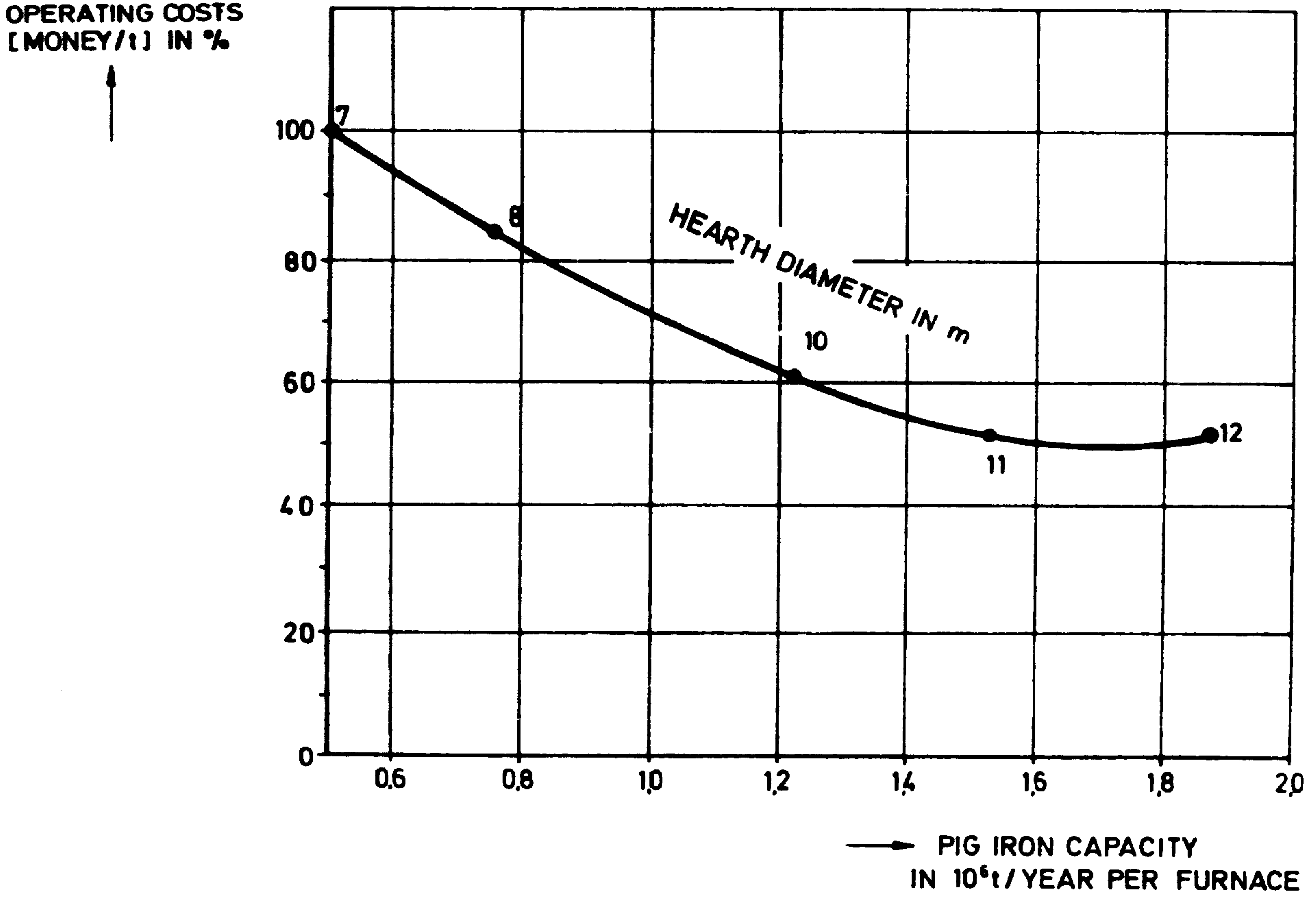
Graph 9

Investment of blast furnace plants in relation to the capacity



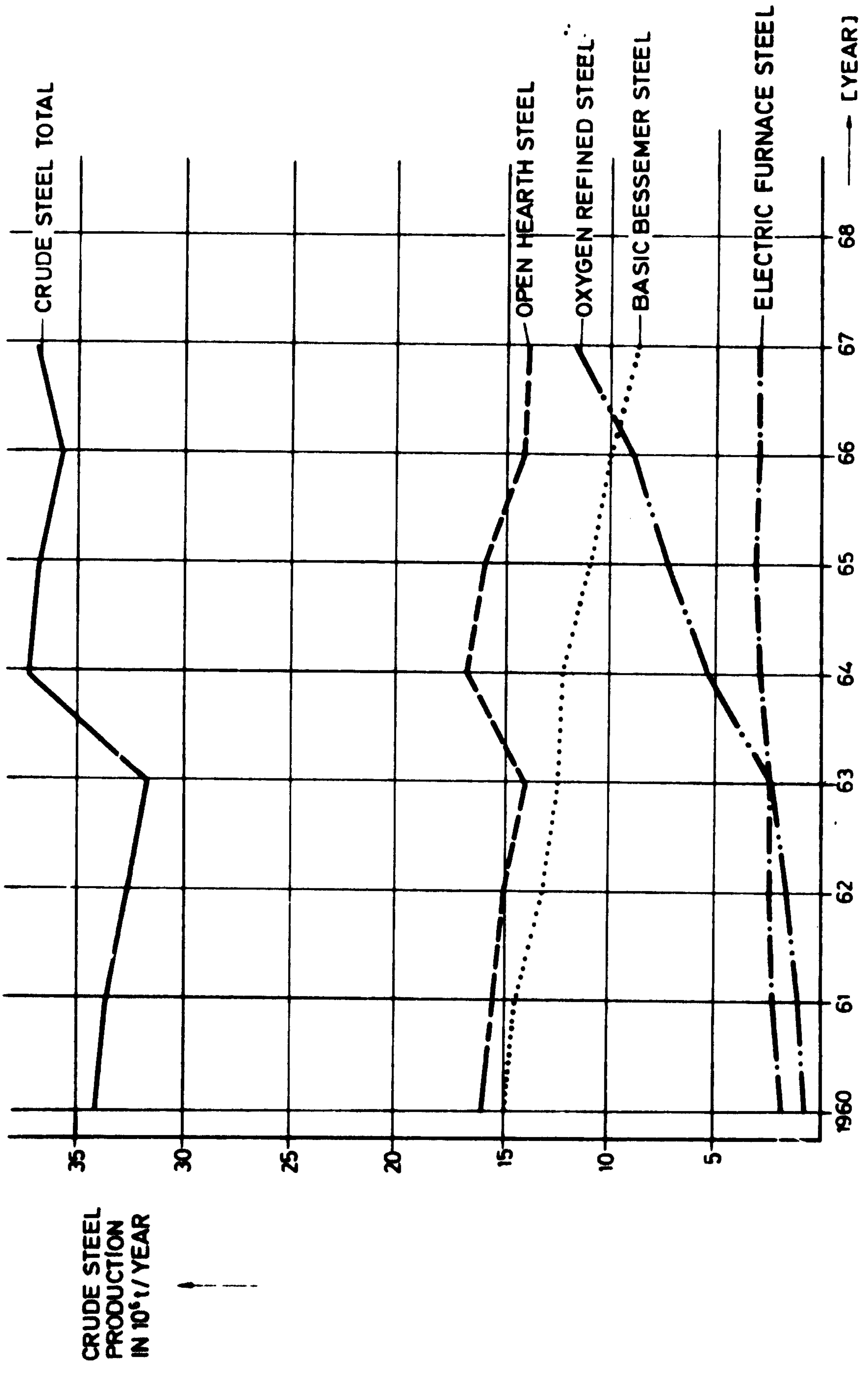
Graph 10

Operating costs of blast furnaces



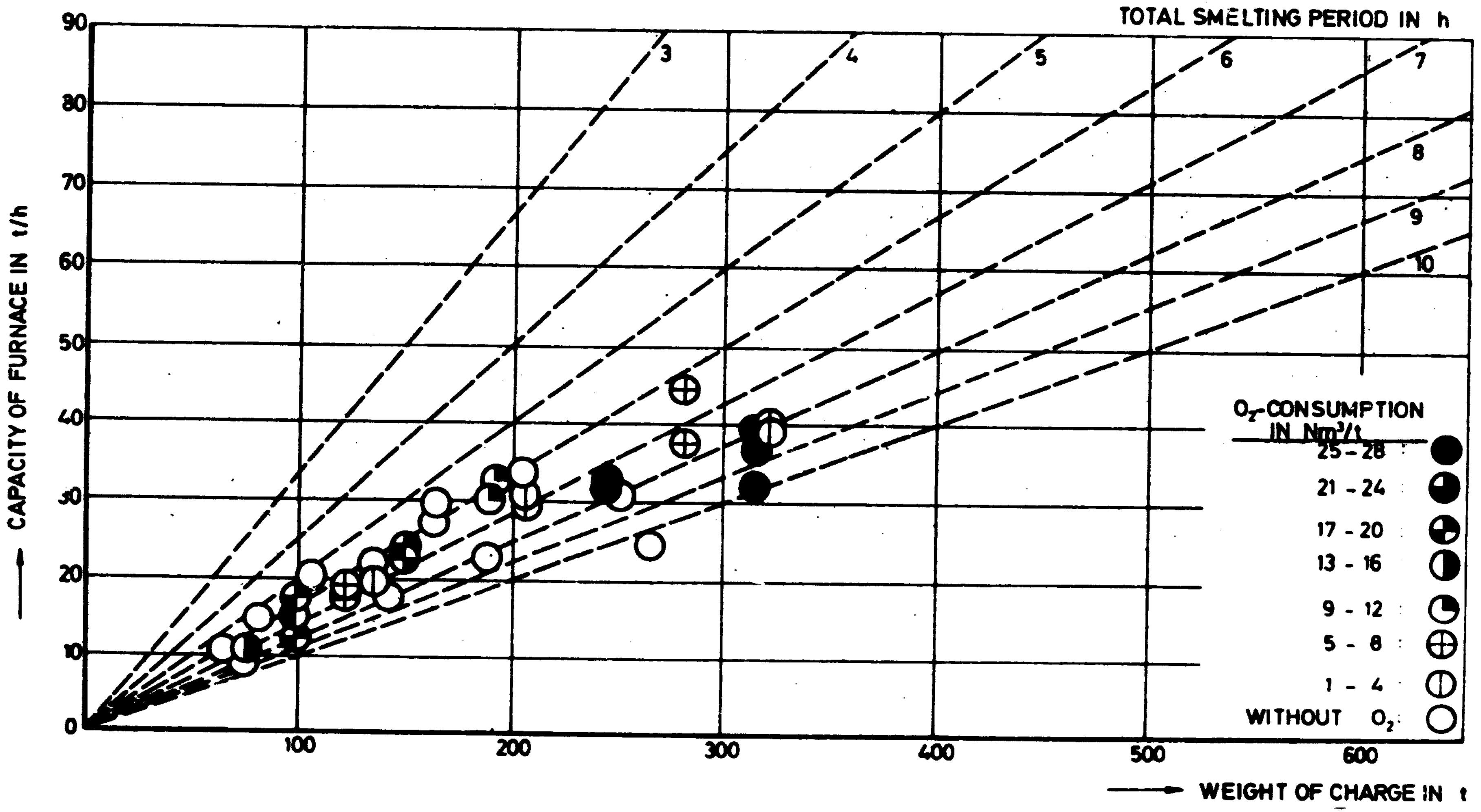
Graph 11

Development of the crude steel production in the Federal Republic of Germany



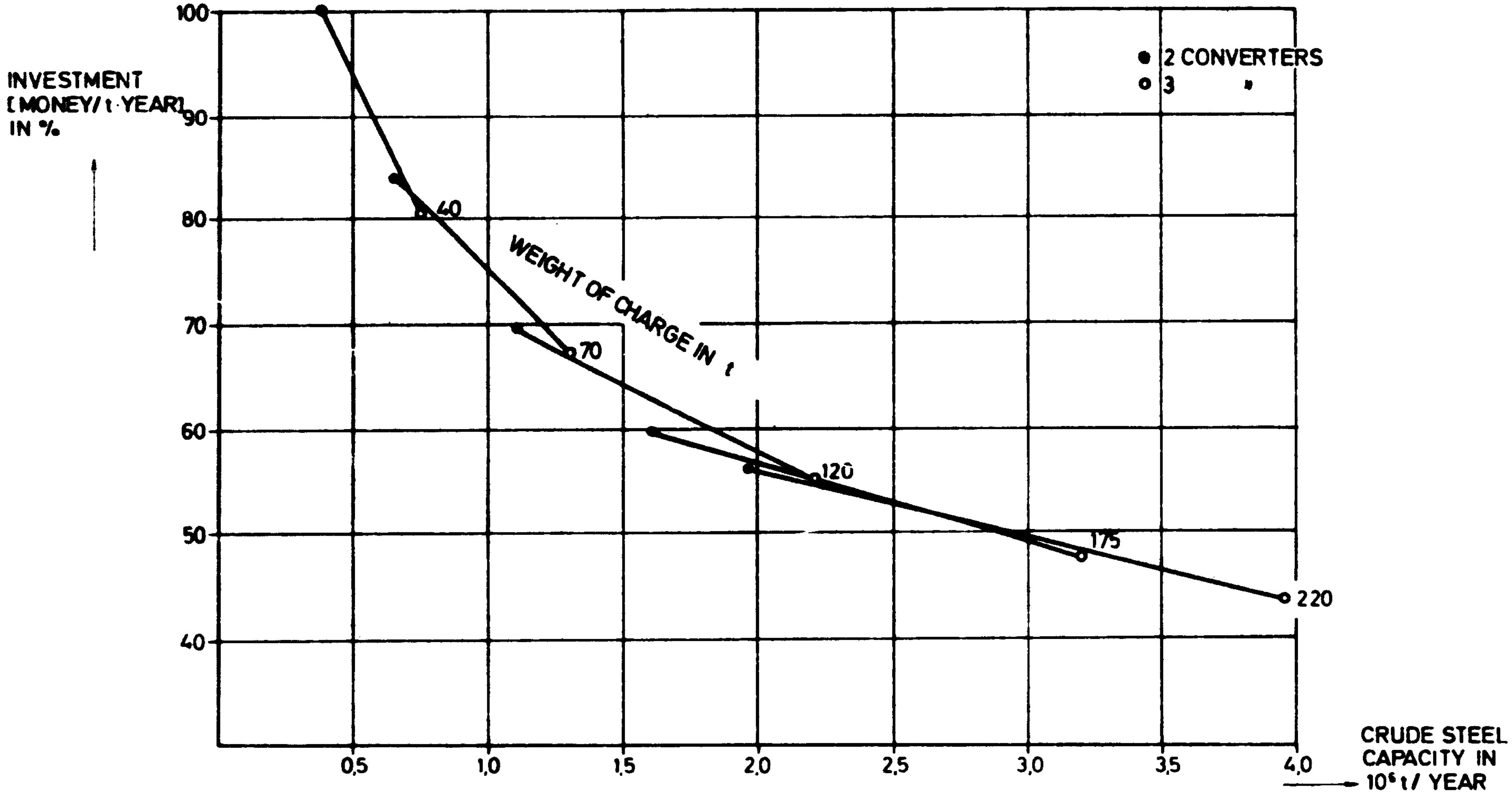
Graph 12

Data referring to the output of open hearth furnaces in the Federal Republic of Germany



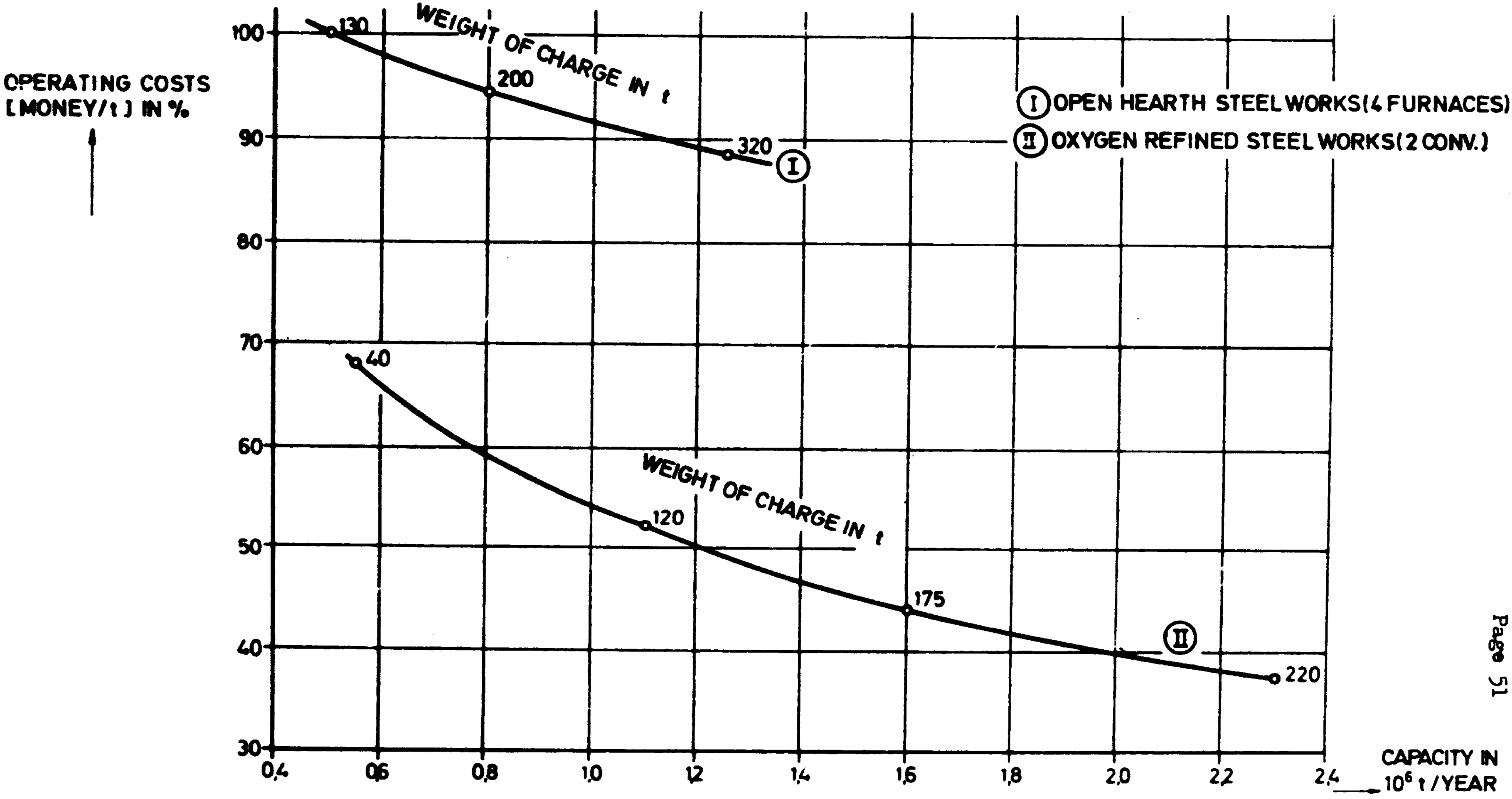
Graph 13

Investment of oxygen refined steel works in relation to the capacity



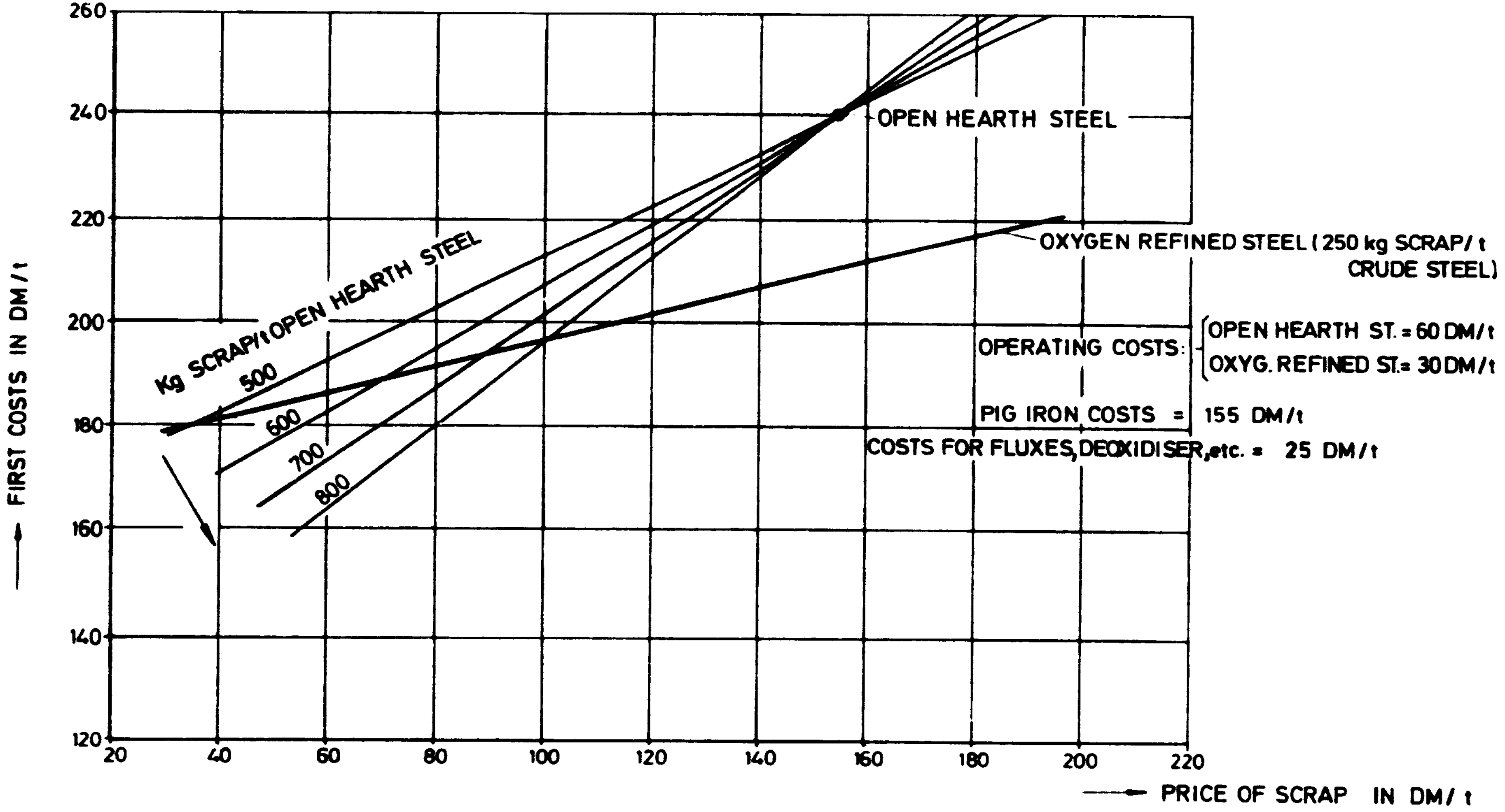
Graph 14

Connexion between operating costs and capacity of open hearth and oxygen refined steel works



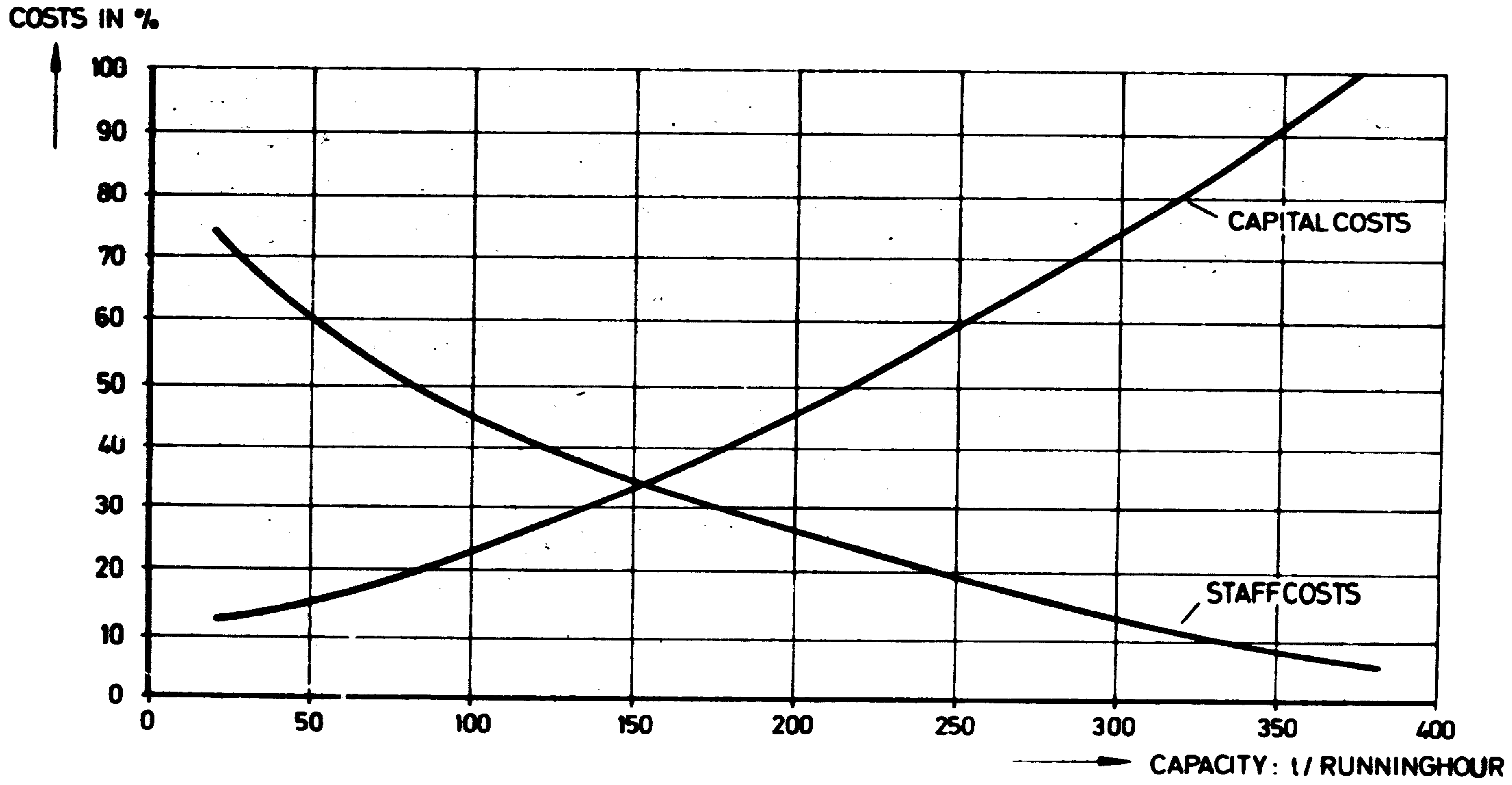
Graph 15

First costs of open hearth and oxygen refined steel in relation to the price of scrap



Graph 16

Staff and capital costs at different rates of mechanization (blooming and slabbing mills)



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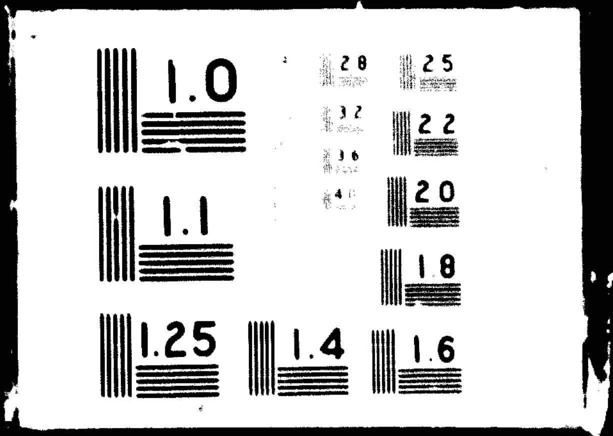
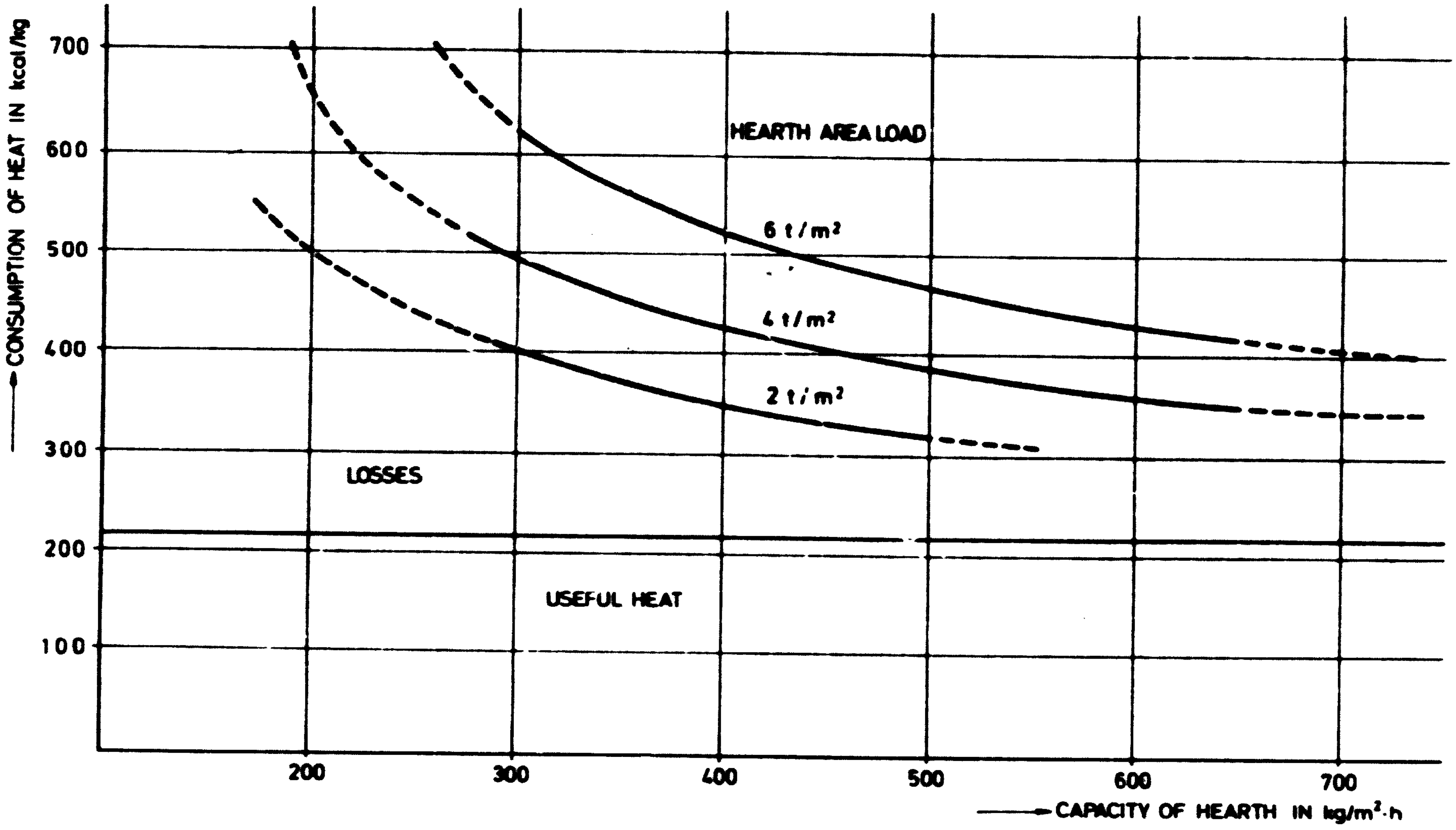


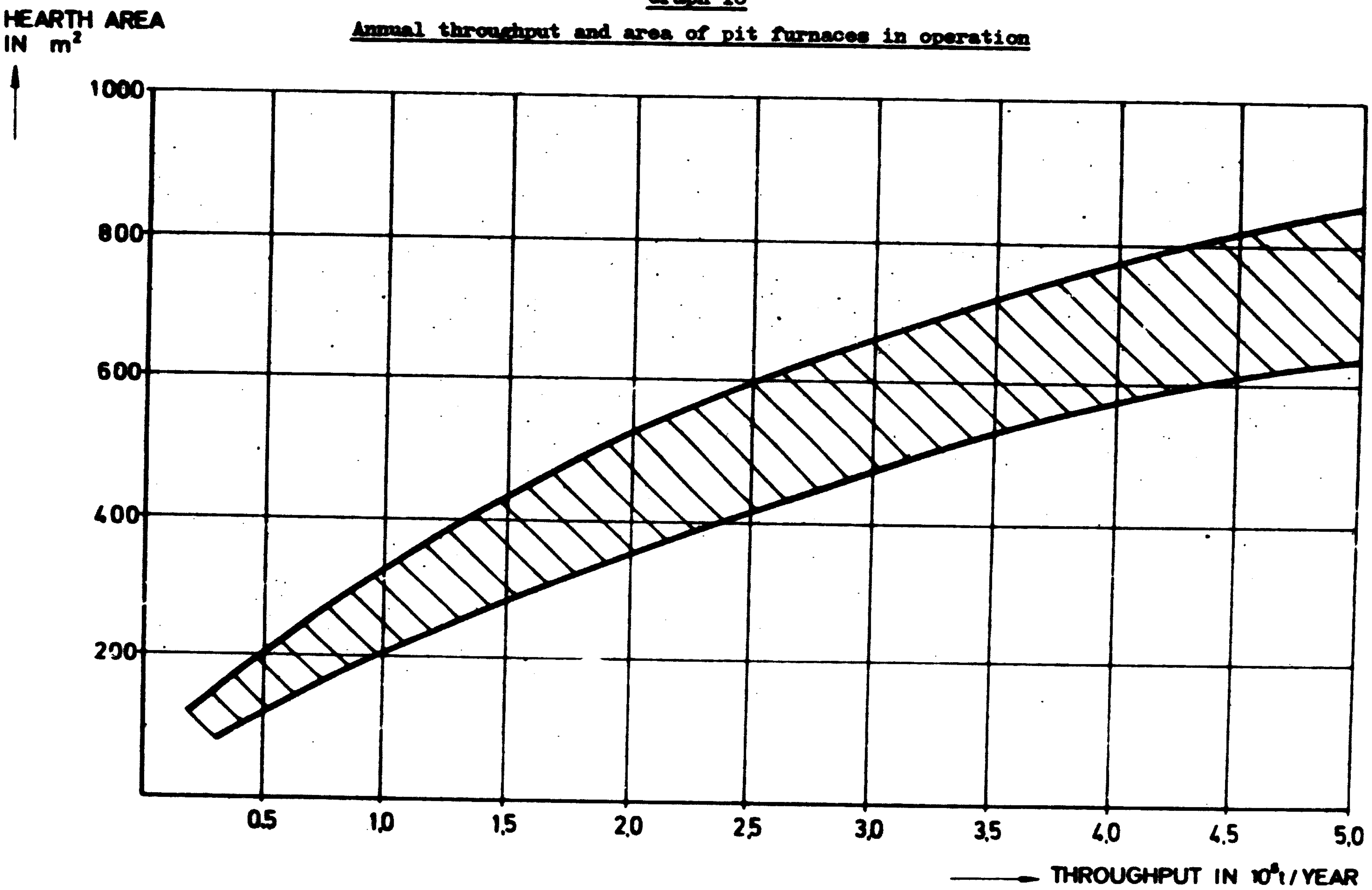
Graph 17

Heat consumption of a pit furnace (top gas) cold charge



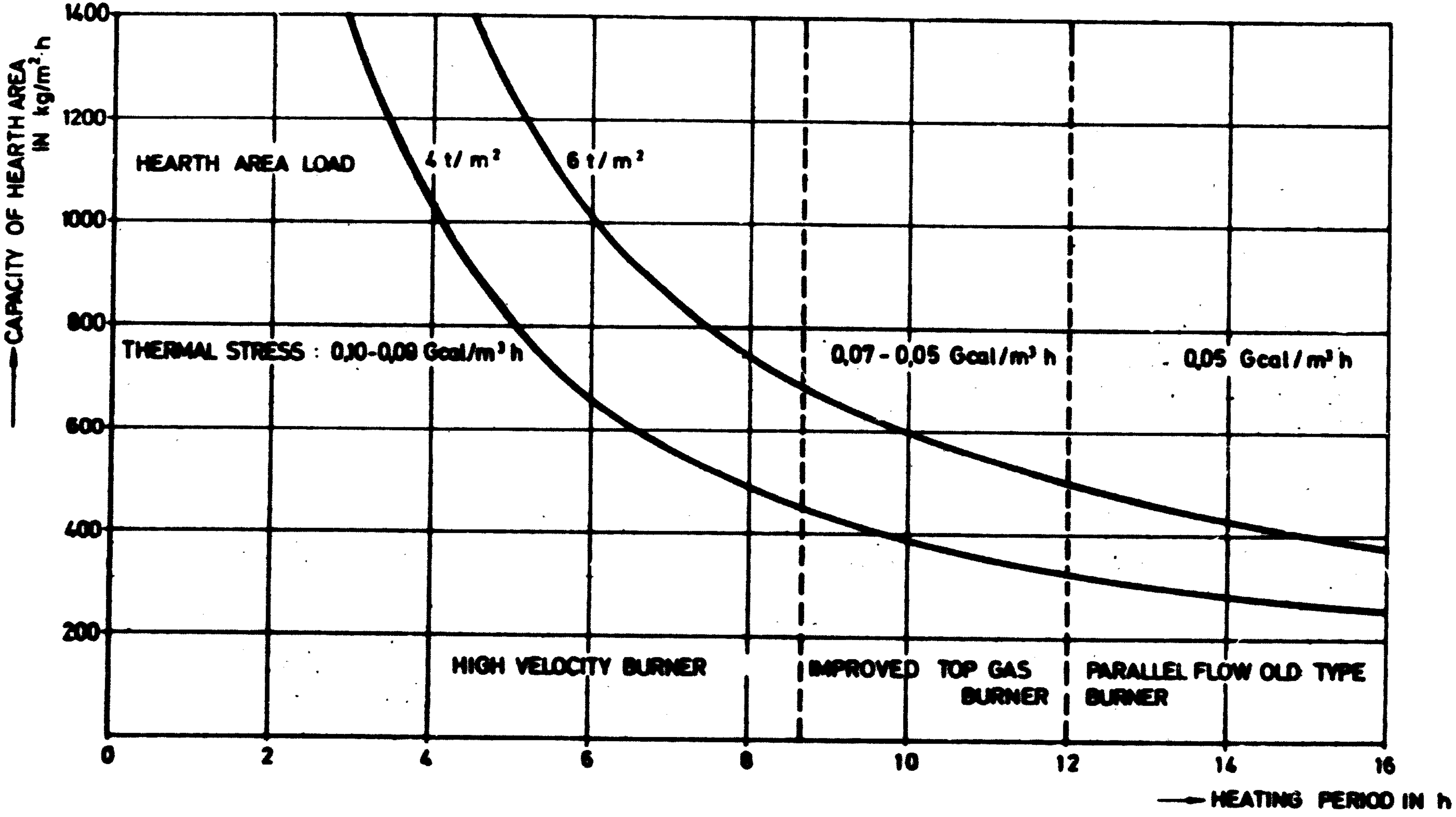
Graph 18

Annual throughput and area of pit furnaces in operation



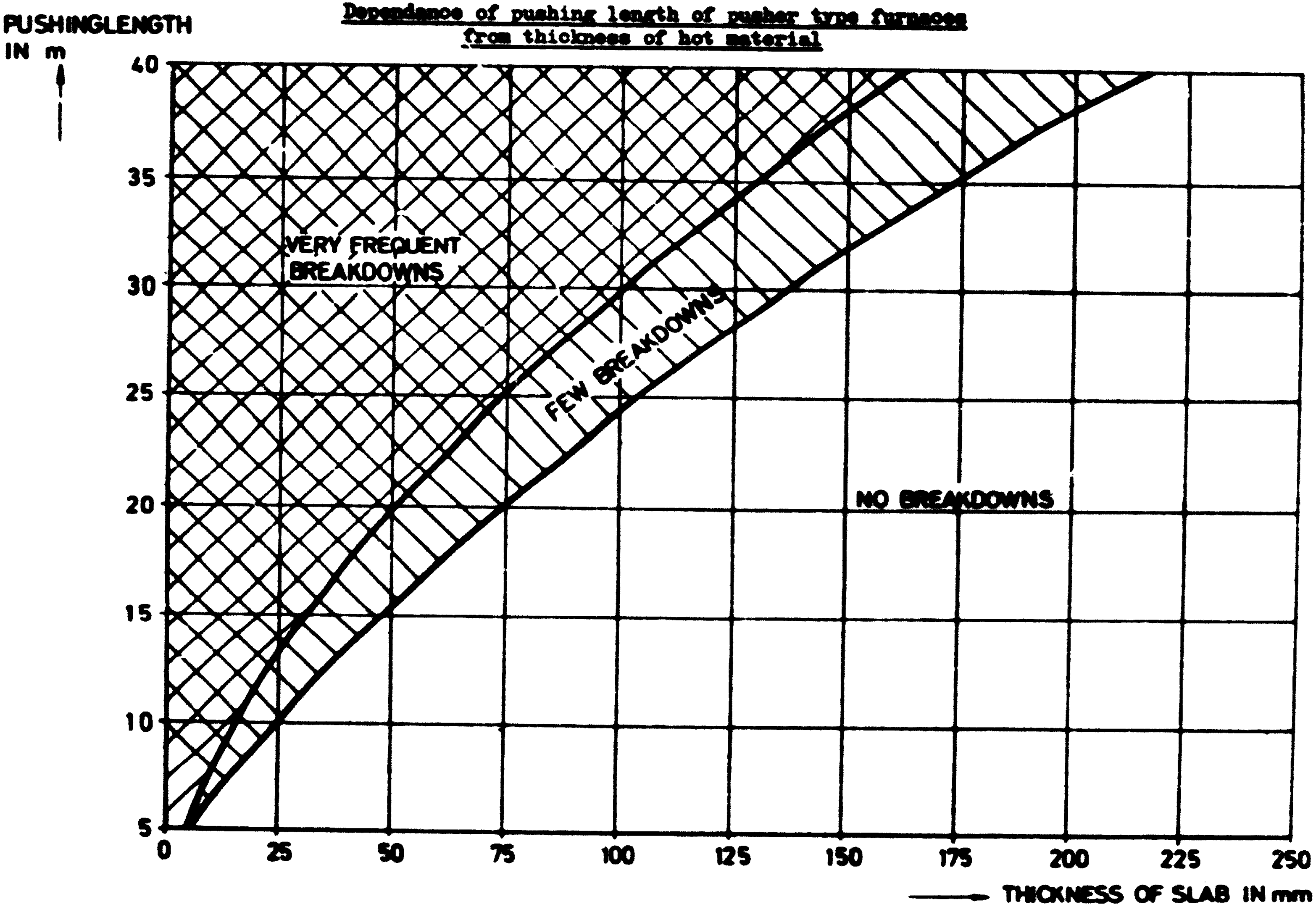
Graph 19

Connexion between heating period and capacity of hearth area of pit furnaces



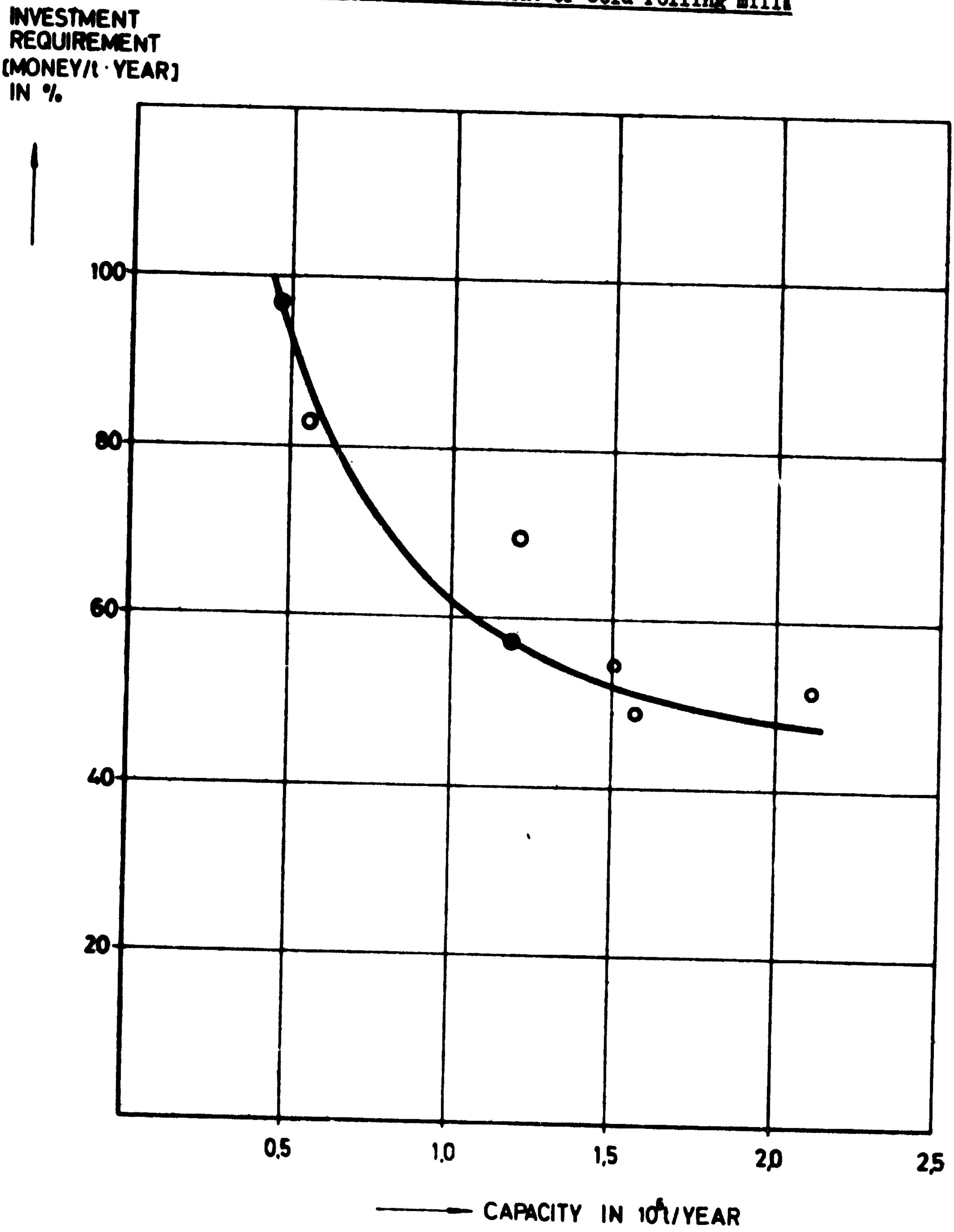
Graph 20

Dependance of pushing length of pusher type furnaces from thickness of hot material



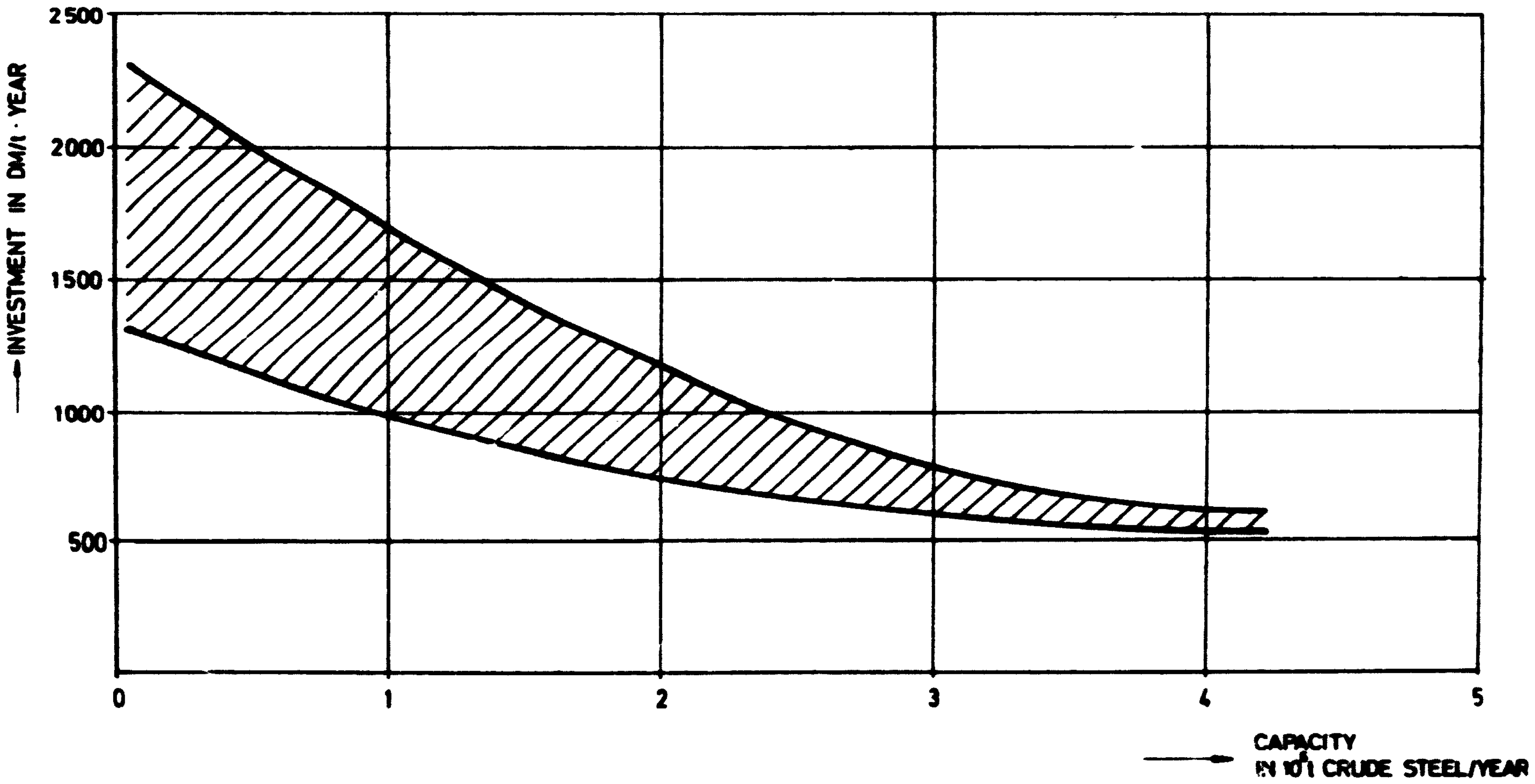
Graph 21

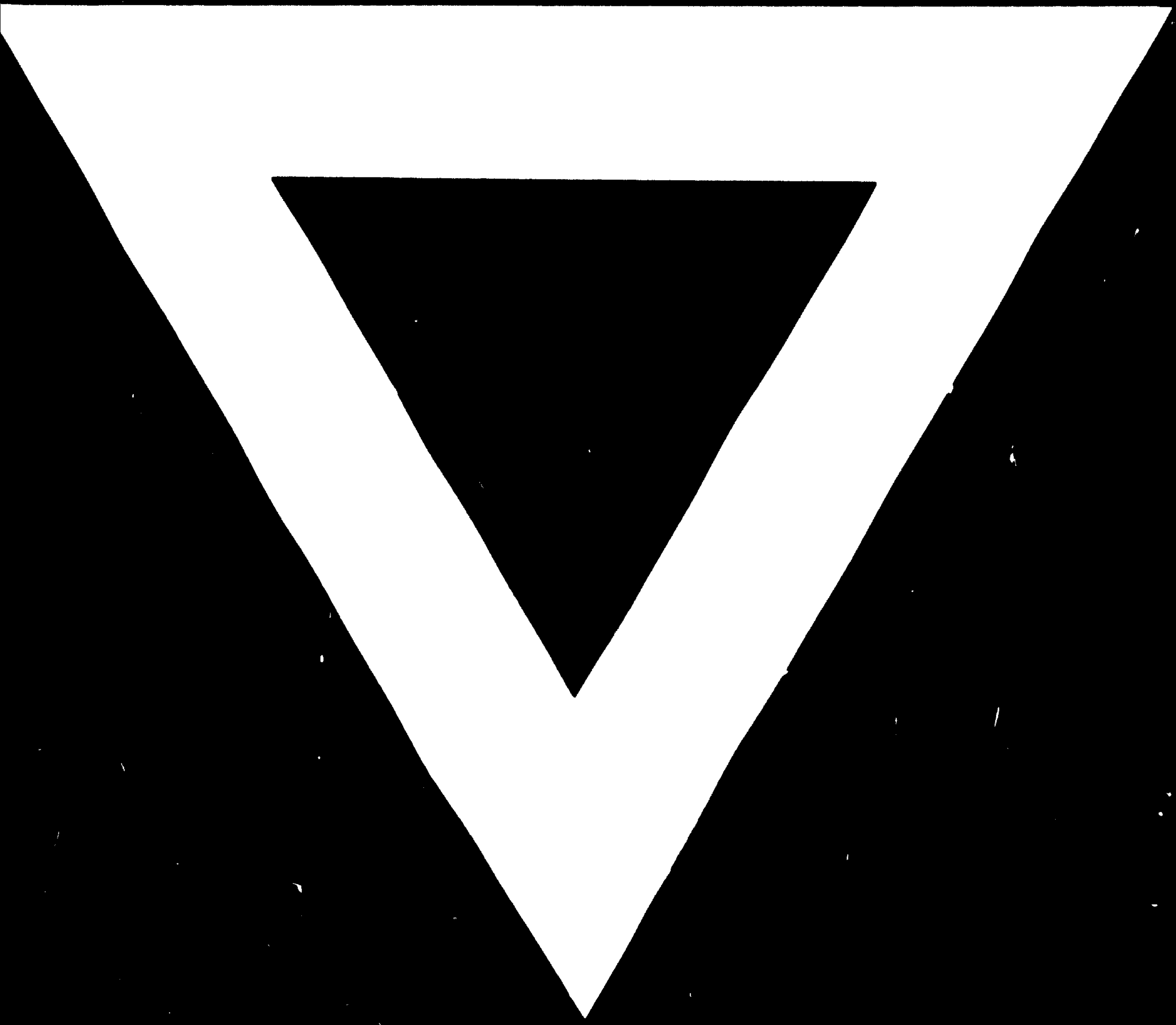
Specific investment requirement of cold rolling mills



Graph 22

Investments of modern iron and steel plants





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