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ELECTRIC ENERGY REQUIREMENTS FOR STEEL PLANTS

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SUMMARY

Electricity is one of several forms of energy that can be used to assist in steelmaking. Although steel can be made without the use of electricity, praticality suggests that about 300 kwhr per ton of hot-rolled steel products is a reasonable minimum. Extensive use of electrical energy from ore to final product can lead to consumptions over 2500 kwhr per ton of hot-rolled product. The most efficient and economical use of electricity in most situations is likely to be between these two extremes - for example, over-all average consumptions for 1962 in the U.S.A. and Japan were about 460 and 735 kwhr per ton of product. Emphasis is placed on the point that, taken by itself, the consumption of electrical energy in a steel plant does not tell either the efficiency or the economic soundness of the plant.

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INTRODUCTION

Electricity in some amount can be considered today as a practical necessity for steelmaking, regardless of the location and size of the steel plant. In a completely primitive environment with absolutely no electric power available, a knowledgeable person could make steel (even from ore), but this condition is sufficiently rare that it can be neglected for the present purposes.

A nation or location that is developing its industrial resources usually looks first at a group of activities that includes (1) electric power, (2) transportation, (3) communication, and (4) steel. These activities must be considered together because they are to a large degree mutually interdependent. Undue emphasis on one of these four fields at the expense of the others will lead to imbalance that can inhibit over-all industrial growth.

In a developing nation, electricity for diversion to steelmaking can be either in short supply or can be readily available. Venezuela and New Zealand are two nations in which prior development of sources of electricity made it possible to consider electricity, even for process heat, directly from the start of planning for a new steel industry. In many other developing countries, electricity is less available and must be conserved for the more basic needs of lighting and horsepower.

FRAME OF REFERENCE

The analysis given in this paper concentrates on the use of, and the need for, electricity in steel plants. Electricity is, however, only one form of energy. Other forms are readily interchangeable with electricity. Because of interchangeability, one should not consider electricity except in relation to other forms of energy. However, in this paper we are attempting, to a large degree, to analyse electrical requirements without detailed consideration of alternate forms of energy or of total energy. Because it is vital for the audience to understand this frame of reference, we are illustrating it with the analogy shown in Table 1.

TABLE 1. ANALOGY OF PROBLEM IN TRANSPORT TO A PROBLEM IN STEELMAKING

Nature of Problem	Transport	Steelmaking
Starting point ↓ Finishing point	Small town in Ohio (A) ↓ (B) Small town in Czechoslovakia	Source of iron units (C) ↓ (D) Mixture of steel products
Requirement	Transportation	Energy
Means	Walk Drive an automobile Ride a train ⟷ Ride a boat Ride a bus Ride an airplane	Muscle power Natural gas Electricity Water power Coal Atomic power

In our analogy, consider the problem of a man desiring transportation from a small town in Ohio (Point A) to a small town in Czechoslovakia (Point B). He has available to him several methods of transport (walk, drive an automobile, ride a train, ride a boat, ride a bus, ride an airplane). No single method is satisfactory by itself. Some combination is needed. The man will select the combination which best suits his particular needs and resources at that time. He will make a selection based on a number of factors such as distance, speed, cost, availability, and comfort. Different men faced with the same problem will come up with different combinations, all of which will get all the men from Point A to Point B, but at different speeds, different costs, and different total distances travelled.

In the present analysis of a steel plant, we have a problem of chemical reaction rather than a problem in transport. As shown in Table 1, the problem is to get from a source of iron units (Point C) to a mixture of steel products (Point D). For this, we need energy. We have available several forms of energy (muscle power, natural gas, electricity, waterpower, coal, atomic power). As in the case of the transport analogy, the sources of energy are largely interchangeable, and no source is satisfactory by itself. Some combination is needed. In any particular situation, the best combination will depend upon factors peculiar to that situation.

Continuing the transport analogy, one can analyze railroad transportation as one component in the transport mix. For example, we can analyze transport from Point A to Point B on the basis of the minimum railroad mileage required if our traveller doesn't like railroads; we can analyze on the basis of maximum railroad mileage if the traveller prefers railroads; or we can analyze on the basis of the railroad mileage selected by the average traveller from Point A to Point B. In this analysis of railroad travel, we are recognizing the existence of interchangeable forms of transport, but we are concentrating on one particular form without going into detail on what our selections regarding railroad travel do (for example) to the total distance to be covered or to the total cost of the trip.

In the present analysis on steel plants, we are considering the electricity component of total energy just as in the prior problem we considered the railroad component of total distance. Just as our selection to use a train to a larger or lesser degree will change the total distance to be travelled and the cost of travel, so will our selection to use electricity to a larger or lesser degree change the total energy needed and the cost of total energy.

Total energy is the logical basis to consider energy needs for a steel plant. Such analyses have been published and are necessary in the design of a plant. Total requirements are the starting point for analysis of steel-plant energy requirements (just as the distance from Point A to Point B is the starting point for the transport analysis). In the present steel-plant analysis, however, we are for the present purposes relegating total energy to the background and are concentrating on only the one component - electricity. We must recognise this background against which we are working, but we need refer to it no more once the frame of reference is thoroughly understood.

REQUIREMENTS FOR STEELMAKING

The electricity used in a steel plant can be furnished entirely from outside sources, can be generated entirely within the plant, or can come both from outside sources and internal generation. The latter combination is most common.

Drawing on the concept that a steel plant can generate its own electricity if required to do so, one can take the view that an outside source of electricity is not absolutely necessary. With this view, one can list the basic technological needs for steelmaking as follows:

(1) Sources of the elements iron, carbon, manganese, and others that are necessary components of steel, plus necessary fluxes

(2) Suitable equipment, and energy to drive the equipment

(3) A suitable reducing agent (if the starting material is other than metallic iron)

(4) Energy for process heat

(5) Manpower

(6) Suitable working conditions

(7) Suitable knowledge.

None of these basic needs require electricity, but electricity can contribute much to the satisfaction of several of them.

USES FOR ELECTRICITY

What are the most desirable uses for electricity in a steel plant? Three categories cover the situation:

(1) Lighting

(2) Horsepower

(3) Process heat.

Lighting is placed first because it is likely that if only a small amount of electricity is available, the first increment will be used to provide light.

Horsepower via electricity is placed second because of the importance of electric motors to drive all types of mechanical devices. To a large degree, electricity for this purpose is a substitute for manpower. The extent of this substitution depends in each location on the relative availabilities and costs of electricity and manpower.

Process heat via electricity is placed third because it usually enters consideration only if further electricity is available after the needs for light and horsepower are satisfied.

Two general situations can be visualized to illustrate the practical extremes for use of electricity in steelmaking. These will be discussed further, but are summarized here for purposes of orientation.

Conservation of Electricity

The plant is illuminated by electricity. Solid, liquid, or gaseous fuels (e.g. coal, oil, or natural gas) are used to produce process heat. Some of this process heat is converted in the plant to steam for mechanical drives or to generate moderate amounts of electricity for some electric motors. Manpower is presumed readily available and is used freely to minimize the number of electric motors and aids. The plant is presumed to be fairly small (say, 500 tons of steel per day), because this scale of operation is most consistent with the assumed conditions.

A flow sheet for such a plant might well contain the following elements. Ore is handled manually as much as possible. Concentration or grinding (if needed) is done mechanically or hydraulically. The ore is reduced in a kiln using coal or natural gas for heat. The metallic product is melted in a cupola and converted to steel in an air-blown converter or in a small open-hearth furnace. Conventional steel ingots are soaked in fuel-fired pits and are reduced to merchant shapes on conventional but simple mills.

Such a plant would involve a practical minimum of consumption of electricity. Consumption of fuels (coal, oil, or natural gas) and requirements for manpower would be high.

Extensive Use of Electricity

The plant is illuminated by electricity, probably to a higher foot-candle rating than for the prior case. Electric motors are used extensively to speed processing, to reduce manpower requirements, and to improve working conditions. Process heat is furnished electrically wherever it can be used to advantage.

A flow sheet for such a plant would involve a high degree of mechanization of the transport function, even to the use of electric locomotives. The ore or concentrate would be reduced electrically, say, in an electric-arc furnace. The metal from the reduction furnace would be processed to steel in another electric furnace or in an oxygen converter requiring electricity for the production of oxygen. Ingots would be heated in electric soaking pits and worked to high-energy forms such as sheet and strip.

Such a plant would involve a practical maximum of consumption of electricity. Consumption of auxiliary fuels (coal, oil, or natural gas) and requirements for manpower would be relatively low. The plant would be clean, and the process would be amenable to close control.

Intermediate Use of Electricity

Most steel made in the world today involves a usage of electricity intermediate between the two extremes just described. It is likely that future plants in developing countries also will settle on some intermediate usage.

If a developing nation must include extreme conservation of electricity as a requirement for steelmaking, then serious attention should be given to the proposition that a steel plant in this location may be a premature venture.

If a developing nation is blessed with a genuine excess of low-cost electricity, then further serious consideration must be given to how effectively additional increments can be used in a steel plant in comparison to use in other activities (such as reduction of alumina) that consume large amounts of electricity.

ILLUSTRATIONS OF TYPICAL ELECTRICAL USAGE FOR FIVE TYPES AND SIZES OF STEEL PLANTS

The smallest steel plant considered in the present analysis melts steel scrap in an electric furnace and converts this to about 100,000 tons* of merchant products per year. Although processing is fairly simple, the requirements for electricity is about 84,000,000 kwhr per year, or about 840 kwhr per ton of hot-rolled merchant product. As will be seen as the analysis develops, this type of plant consumes a relatively large amount of electricity per ton of product, even though the starting material is metallic (not ore). In this type of plant, the electrical requirements per ton of product will not change much with a change in the size of the plant. This first case is the only one of the five that starts with metal (steel scrap). All subsequent cases start with ore.

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* All tons are metric tons of 2205 pounds.

If we are starting our process with ore instead of steel scrap, various considerations outside the scope of this paper suggest that the plant usually should be larger than for a plant based on steel scrap. For the next three cases, we will consider three possible types of small plants to convert iron ore to 185,000 tons of hot-rolled merchant products per year.

The first of these small ore-based plants smelts the ore in electric furnaces without any prereduction. The hot metal from the electric smelting furnace is used with steel scrap in the ratio of 80/20 to product steel in a basic oxygen (BOF) furnace. Steel ingots are converted in a merchant mill to 185,000 tons per year of simple hot-rolled merchant shapes. The electrical requirement for this plant soars to about 2280 kwhr per ton of merchant product.

In our second ore-based plant we reproduce the first, except that an auxiliary fuel (such as coal) is used in auxiliary equipment (such as a kiln) to do some prereduction and some preheating of the ore before it is charged into the electric smelting furnace. Depending upon process details, we can lower the electrical requirement for the smelting step by one-half or more. In a typical case, electrical usage is lowered to about 1355 kwhr per ton of merchant products.

For the third ore-based small plant, assume that electricity is in short supply. In this case, we can produce briquettes of sponge iron in a kiln from ore, coal, and relatively little electricity. The briquettes can be melted with coke in a cupola, and the hot metal then processed through a BOF furnace and merchant mill as in the prior two cases. The requirement for electricity for the plant now falls to about 370 kwhr per ton of merchant product - only about 16 per cent of our first ore-based plant of the same size. Because this third plant was set up to use fuels such as coal and coke to save electricity, and because these fuels usually cannot be used metallurgically at high efficiency, this plant will generate a considerable amount of "nonmetallurgical" heat. Decisions on whether or not to recover value from this portion by producing steam and/or electricity internally will be a matter for detailed study of the particular situation.

The three versions of the 185,000-ton ore-based plant use 2280, 1355, or 370 kwhr per ton of the same product. This information, however, tell us nothing about which plant is cheapest to construct, which consumes the most energy, or which is the cheapest to operate. These further points of information must be obtained from other analyses. For the present purpose, it is sufficient to have shown that it is possible to make steel over a wide and controllable range of consumption of electrical energy.

For our fifth and last case, we consider electrical usage in a larger more conventional type of steel plant. In this case, we have a blast furnace (and integrated coke plant) producing about 730,000 tons of hot metal a year. This is converted with scrap in open-hearth furnaces to about 1,000,000 tons of steel ingots per year. These ingots are rolled to about 730,000 tons of steel products. Because of the larger scale of operation in comparison to the prior plants, this plant has a wider range of steel products, some of which (for example, sheet) require more energy than merchant shapes for rolling. In such a large integrated plant, the usage of electrical energy is likely to be about 400 kwhr per ton of finished product. A parellel calculation based on the use of BOP furnaces instead of open hearths showed a total electrical usage so close to 400 kwhr per ton as to be judged not significantly different.

The bases used for the calculations given in this section are summarized in Tables 2, 3, 4, 5, and 6.

TABLE 2. TYPICAL ELECTRIC-ENERGY USAGE FOR PLANT PRODUCING 100,000 TONS PER YEAR OF MERCHANT PRODUCTS FROM SCRAP USING COLD-MELT ELECTRIC FURNACE

Item	Output, metric tons/year	Kwhr/ Metric Ton	Million Kwhr/Year
Electric steelmaking furnace	115,000	550	63
Merchant mill	100,000	80	8
Plant and auxiliary power	--	--	13
Total			84
Average = 840 kwhr/ton of product			

TABLE 3. TYPICAL ELECTRIC-ENERGY USAGE FOR PLANT PRODUCING 185,000 TONS PER YEAR OF MERCHANT PRODUCTS FROM ORE USING ELECTRIC SMELTING FURNACE WITHOUT PREREDUCTION

Item	Output, metric tons/year	Kwhr/ Metric Ton	Million Kwhr/Year
Electric smelting furnace	160,000	2200	352
BOP furnace (excluding oxygen)	200,000	20	4
Merchant mill	185,000	80	15
Plant and auxiliary power (including oxygen)	--	--	50
Total			421
Average = 2280 kwhr/ton of product			

TABLE 4. TYPICAL ELECTRIC-ENERGY USAGE FOR PLANT PRODUCING 185,000 TONS PER YEAR OF MERCHANT PRODUCTS FROM ORE USING ELECTRIC SMELTING FURNACE WITH PRE-REDUCTION WITH CARBON

Item	Output, metric tons/year	Kwhr/ Metric Ton	Million Kwhr/Year
Electric smelting furnace with prereduction	160,000	1200	192
BOP furnace (excluding oxygen)	200,000	20	4
Merchant mill	185,000	80	15
Plant and auxiliary power (including oxygen)	--	--	40
Total			251
Average 1355 kwhr/ton of product			

TABLE 5. TYPICAL ELECTRIC-ENERGY USAGE FOR PLANT PRODUCING 185,000 TONS PER YEAR OF MERCHANT PRODUCTS FROM ORE USING CARBONACEOUS REDUCTION TO SPONGE IRON IN A KILN

Item	Output, metric tons/year	Kwhr/ Metric Ton	Million Kwhr/Year
Sponge iron plant	200,000	150	30
Cupola	200,000	10	2
BOP furnace (excluding oxygen)	200,000	20	4
Merchant mill	185,000	80	15
Plant and auxiliary power	—	—	17
Total			68
Average = 370 kwhr/ton of product			

TABLE 6. TYPICAL ELECTRIC-ENERGY USAGE FOR PLANT PRODUCING 730,000 TONS PER YEAR OF STEEL PRODUCTS FROM ORE USING BLAST FURNACE AND OPEN HEARTH PROCESSES

Item	Output, metric tons/year	Kwhr/ Metric Ton	Million Kwhr/Year
Blast furnace and coke plant	730,000	26	19
Open hearth	1,000,000	27	27
Rolling (bar, plate, sheet, structurals)	730,000	188	137
Plant and auxiliary power	—	—	107
Total			290
Average = 400 kwhr/ton of product			

USAGE OF ELECTRICAL ENERGY FOR STEELMAKING IN HIGHLY DEVELOPED COUNTRIES

The foregoing calculations based on hypothetical installations can be compared with actual electricity usage for large steel industries in highly developed countries.

In the United States, the reported annual usage of electrical energy by the steel industry has varied over the period from 1958 to 1962 from about 416 to about 457 kwhr per ton of product, with no consistent pattern of increase or decrease during this period. In 1962, the manufacture of about 68 million metric tons of finished product required about 31 billion kwhr, or about 457 kwhr per ton of finished product. Of this total usage, about 21.2 billion kwhr (or 68 per cent) was purchased, and the balance was generated internally. This average electrical usage for the entire United States is for an industry that does practically no reduction of iron ore by electricity and uses electric steelmaking furnaces for about 9 per cent of its total steel production.

In Japan, more use is made of electric energy in steelmaking. Some iron ore is reduced in electric furnaces, and about 21 per cent of total steel is made in electric furnaces. For this reason, their consumption of about 16 billion kwhr for about 21.7 million tons of finished products averages about 735 kwhr per ton of finished product.

These two examples, based on statistical summaries for two large national steel industries, illustrate the considerable magnitude of variation of electrical usage actually encountered in practice when local conditions are taken into account in determining the most economical and most effective balance between optional sources of energy.

ELECTRICAL REQUIREMENTS FOR SPECIFIC PROCESSES

As one breaks the problem of electrical usage into small units for consideration, the dependability and comparability of data degrade. In dealing with complete plants or national industries as we have to this point, differences between specific operations tend to average out. In dealing with specific processes, however, variations between different units of the same process can be large. For example, in blast furnace practice, electrical usage will be affected by furnace size, quality and nature of ore and coke, injection of hydrocarbons or oxygen, and other factors. For this reason, the electric usage figures given in Table 7 are illustrative of typical practices, and are subject to considerable variation in specific cases. Data of the type given in Table 7 are useful mainly to indicate the order of magnitude of likely electrical consumptions for typical items in typical plants. These data suggest the processes that are high consumers or low consumers of electrical energy. In no way do they tell which processes are "most efficient". Such decisions on efficiency must be based on the interrelation of processes and units as they are actually assembled into the plant.

Presentations such as Table 7 must not be used to estimate total electrical needs in any particular plant. The data are not sufficiently coherent for this purpose. For example, the nature of the denominator of the relationships (energy/product) changes in Table 7 with the nature of the product. Determination of a common denominator requires consideration of the whole plant as an integrated whole, not as a series of unrelated processing steps. This situation is illustrated also by the large value and wide variation listed in Table 7 for "plant and auxiliary power". This component of the total energy mix can be either relatively large or relatively small in any particular plant, and any general statement on how to estimate it would be of questionable value.

One final illustration shows the type of hazard inherent in dealing in generalities. Consider a hypothetical but not unusual situation where we want to minimise electrical usage in the production of hot metal from ore because electricity is expensive in the particular case under discussion. Examination of Table 7 might lead to the general statement that electric smelting ought to be avoided because it requires a large amount of electricity and, hence (in this case) leads to high cost. This generality is based on the correct idea that the relationship between process cost and the percentage of metallic iron in the charge to an electric furnace is about as shown schematically in Figure 1a. The electrical requirement and the cost of operation of the electric furnace drops from a maximum when the furnace is charged with ore to a minimum when it is charged with metal. The generality says "use only metal in the electric furnace". Forgetting the generality for a moment, we can now ask a question about the cost of obtaining this metal. If we

TABLE 7. ILLUSTRATIONS OF TYPICAL ELECTRIC USAGE FOR SPECIFIC OPERATIONS

Item	Typical Electric Usage	
	Kwhr	Unit[1]
Sintering of ore	15 to 40	Ton of sinter
Coke plant for blast furnace	13 to 18	Ton of hot metal
Blast furnace (exclusive of coke plant)	10 to 15	Ton of hot metal
Electric smelting (without prereduction)	2000 to 2500	Ton of hot metal
Electric smelting (with prereduction)	1000 to 2000	Ton of hot metal
Sponge iron (kiln reduction with carbon)	100 to 200	Ton of sponge iron
Basic oxygen furnace (excluding oxygen)	15 to 25	Ton of molten steel
(including oxygen)	50 to 60	Ton of molten steel
Open hearth furnace (without oxygen)	7 to 15	Ton of molten steel
(with some oxygen)	15 to 30	Ton of molten steel
Electric steelmaking furnace (scrap charge)	500 to 700	Ton of molten steel
Cupola	5 to 15	Ton of hot metal
Small merchant mill	70 to 100	Ton of product
Blooming mill	20 to 40	Ton of blooms
Billet mill	25 to 45	Ton of billets
Bar mill (12 inch)	65 to 85	Ton of bars
Plate mill	80 to 110	Ton of plate
Electric soaking pits	30 to 35	Ton of ingots
Plant and auxiliary power (for complete plant)	100 to 300	Ton of product

(1) All tons are metric tons of 2205 pounds

think for the present in terms of doing some or complete prereduction in a prior step, we might come up with a pretreatment cost similar to that shown in Figure 1b. By itself, this tells us little except that pretreatment also can be expensive. When the costs in 1a and 1b are added, the result for this particular situation is something like Figure 1c. The generality ("use only metal in the electric furnace") works out for this particular example to give us the highest cost for the combined processes. The lowest cost for this example falls somewhere between all-ore and all-metal.

This type of analysis involving the combining of process steps should be continued for the particular situation. When other appropriate factors and alternatives are fed into the problem, we may find that for the over-all plant our best solution is to use all-ore, all-metal, or some mixture in between; or we may find that it involves some entirely different processing route.

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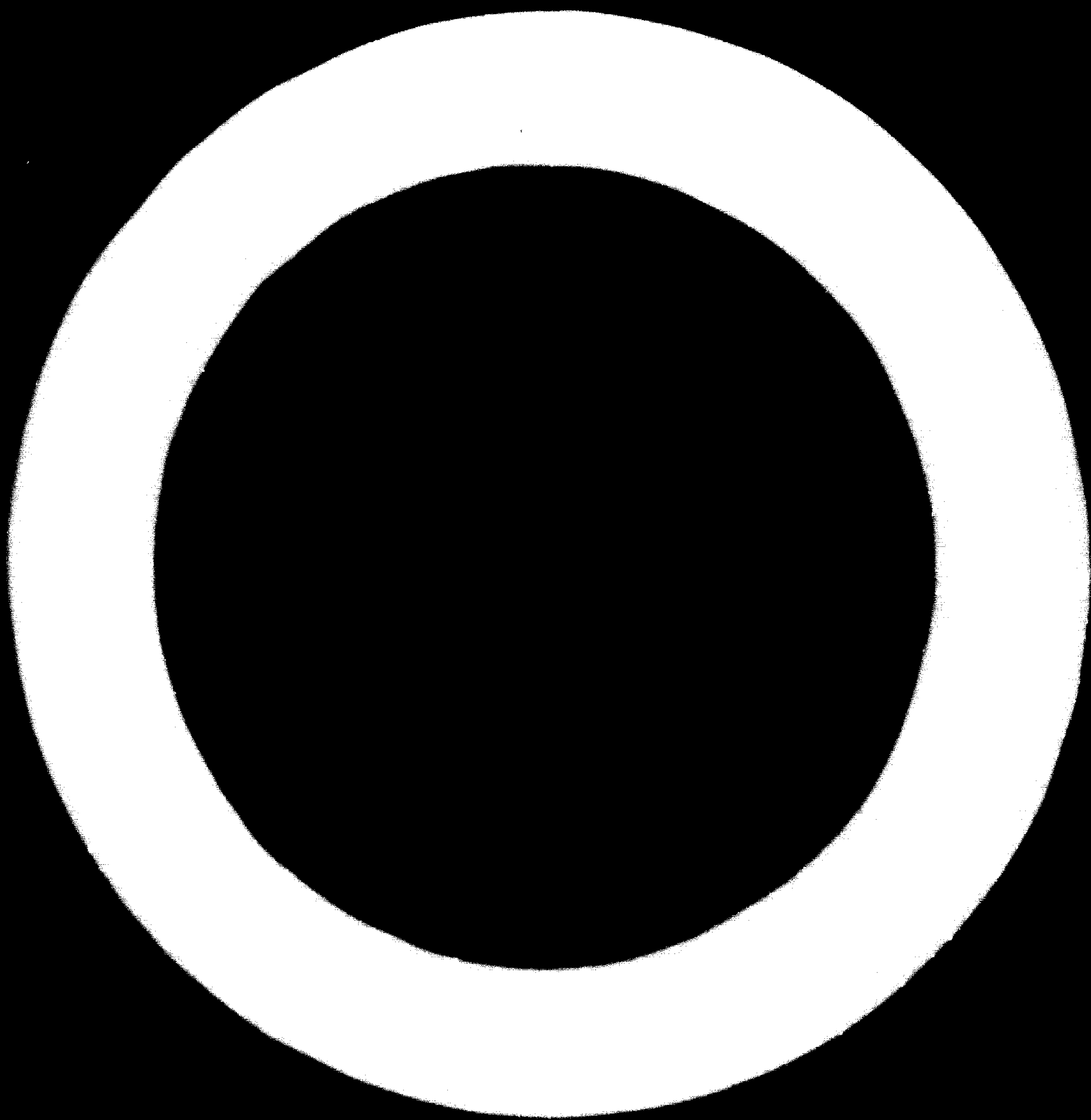
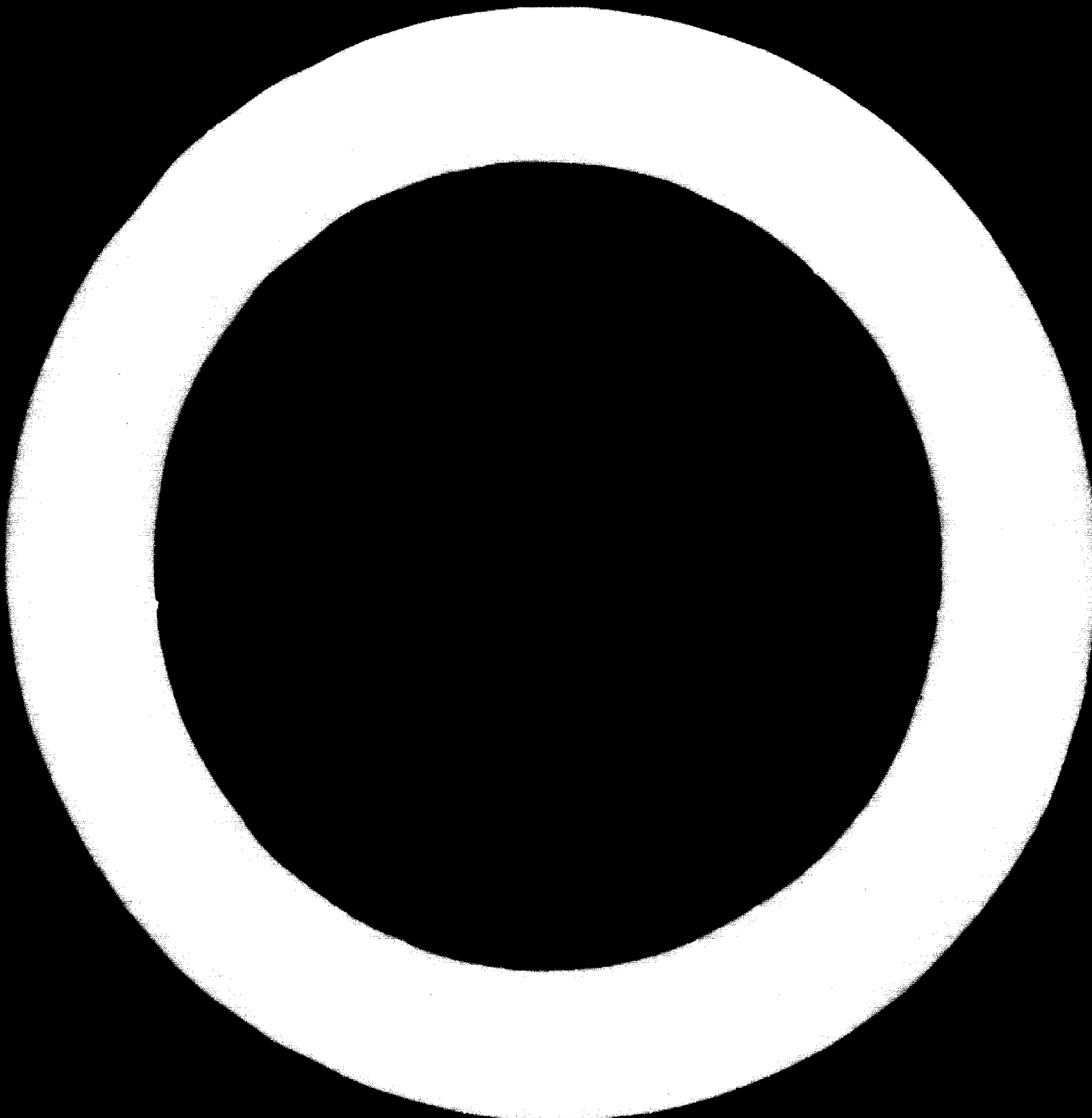


FIGURE



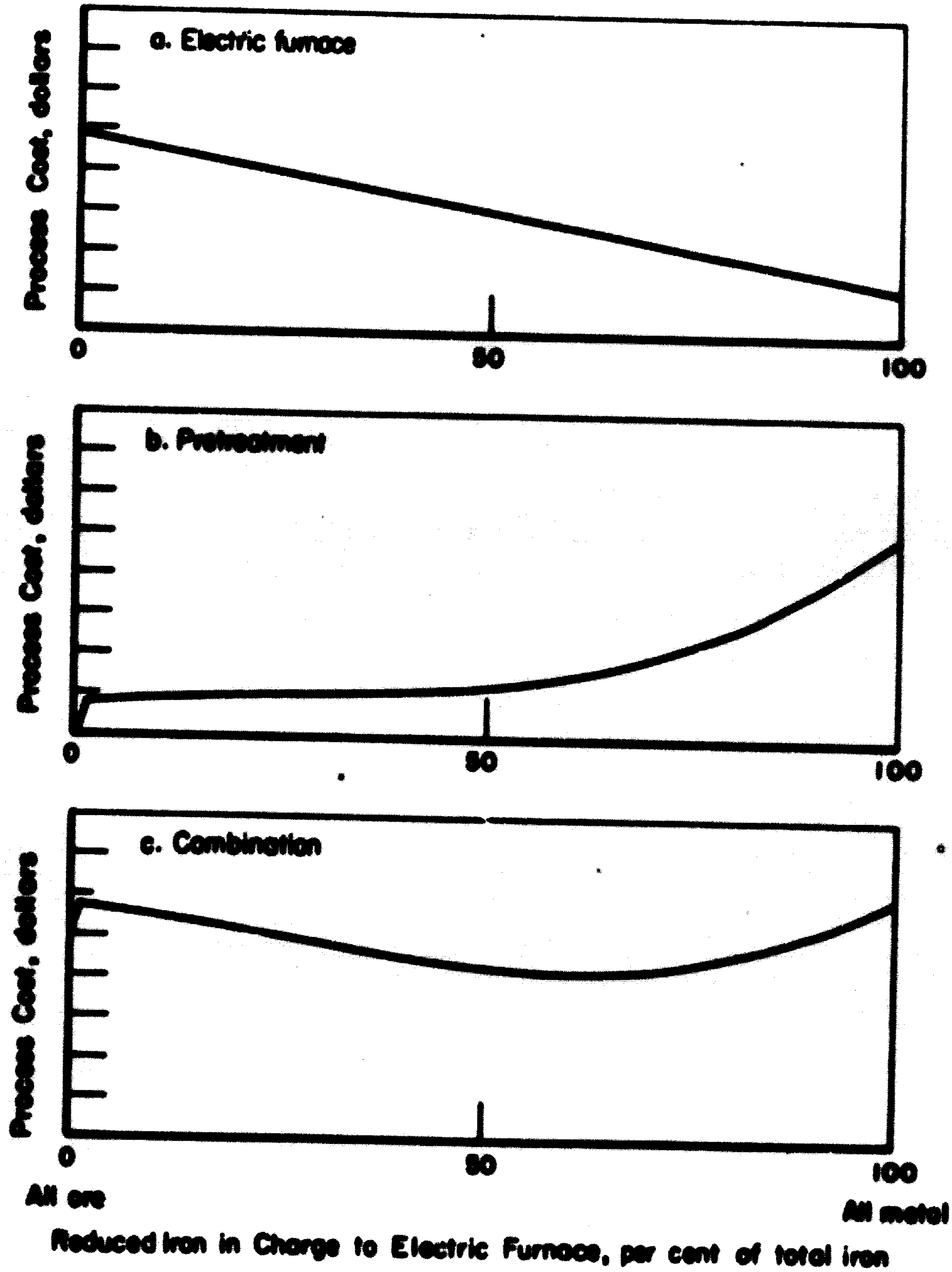


FIGURE 1. SCHEMATIC REPRESENTATION OF COST OF PROCESSING IRON IN ELECTRIC FURNACE

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