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THE SL/RN PROCESS - KEY TO LOW COST STEEL MAKING[1]

by

A.D. Fisher
Canada

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THE SL/RN PROCESS - KEY TO LOW COST STEELMAKING[1]

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SUMMARY

The SL/RN process is capable of processing a wide variety of ores, using many different coals, to produce a high grade of sponge iron. Extensive pilot plant work has developed this process to the commercial stage and several plants are now under construction.

Numerous tests have been carried out in different ironmaking and steelmaking facilities to demonstrate the technical feasibility, and to determine the economics, of utilizing the sponge iron product of the SL/RN process. Successful tests have been carried out in the blast furnace, the electric smelter, the cupola, the LD converter, and the electric arc furnace.

The SL steelmaking process evolved from the continuous charging of SL/RN sponge iron pellets into the electric arc furnace. In this process the melting of the pellets and the refining of the steel both take place simultaneously, thereby significantly reducing the charge-to-tap time. Refractory consumption and, in some instances, the energy and electrode consumption have been lower than in the all-scrap operation. Compared to the conventional steel plant consisting of blast furnace and basic oxygen open hearths or LD converters, the combination of an SL/RN direct reduction plant and electric arc furnaces using the SL steelmaking process appears to have an economic advantage in many locations.

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INTRODUCTION

Lower cost steelmaking may be expected through the SL/RN direct reduction process. The products of this process have been successfully tested in a number of iron and steelmaking processes, but the real success, economically as well as technically, has been achieved in the continuous charging of SL/RN sponge iron into the electric arc furnace--the basis of the SL steelmaking process.

A growing need exists in the steelmaking industry to obtain a better return on investment than is possible using traditional steelmaking facilities, i.e. blast furnaces in combination with oxygen open hearths or LD converters. The economics of traditional steelmaking operations are such as to demand large-sized equipment, both initially and for expansion, so that capital investment is high and, in some cases, over-capacity may be a problem until the market can absorb the steel at the higher production rate. On the other hand, the SL/RN process, in combination with the SL steelmaking process, offers the advantages of lower capital investment, the ability to tailor the initial plant capacity to the size of the market, and expansion in smaller increments.

The SL/RN process is the result of development work by two groups of companies. The SL group--The Steel Company of Canada, Limited, Hamilton, Ontario, and Lurgi Gesellschaft fur Chemie und Huttenwesen, Frankfurt, Germany--developed a kiln process based essentially on the reduction of high grade iron ore concentrates[1]. Concurrently, the RN group--Republic Steel Corporation, Cleveland, Ohio, and National Lead Company, New York, New York--developed a process based essentially on the reduction of low grade iron ores[2,3]. It was realized that a process worthy of wide application would result if the two processes were combined. Such a combination was effected in 1964, and the Lurgi Company is acting as the world-wide agent for the combined process.

During the various development stages, four pilot plants were built; test results have been published[1-5]. A photograph of the semi-commercial pilot plant located at The Steel Company of Canada, Limited, in Hamilton, is shown in figure 1; it can produce 136 metric tons of iron per day in a kiln having a volume of 123 cubic metres. Three commercial SL/RN plants are under construction and will be in operation in 1969.

The product from the SL/RN process, commonly referred to as sponge iron, has been widely tested in a variety of applications. About 11000 net tons were used in a commercial blast furnace, resulting in a significant increase in production and decrease in coke rate. Other tests have been successfully conducted in the electric smelter, the hot blast cupola, the basic oxygen furnace, and the electric arc furnace. The electric arc furnace work culminated in the SL steelmaking process. The development work on this process involved the production of about 6000 tons of steel and was jointly financed by the SL group and Pickands Mather Company, Cleveland, Ohio.

This paper describes the SL/RN process. The utilization of its product in the blast furnace, electric smelter, cupola, and basic oxygen furnace is briefly discussed, along with some of the economic factors which influence these applications. The SL steelmaking process is described in terms of its operation, improvements over the existing all-scrap practice in electric arc furnaces, and its economics.

THE SL/RN PROCESS

Raw Materials

The basic raw materials for the SL/RN process are iron ore, coal and flux. The iron ore is reduced to metallic iron by reaction with the carbon in the coal as they move together through the kiln. The flux, limestone or dolomite, acts as a scavenger for the sulphur released from the fuels and/or the ore.

The iron ore feed for the SL/RN process can take a variety of forms. It can be as a lump ore or as an agglomerated iron ore concentrate in the form of indurated pellets or green balls (unfired pellets). The preparation of the iron ore is carried out using methods common to the mining industry as indicated in the flow sheet in figure 2. Four examples of ore processed by the SL/RN process are shown in Table I.

Table I shows that a wide range of iron ore can be reduced in the SL/RN process. Similarly to the blast furnace, the SL/RN process performs better with a dust-free, uniformly-sized and high-purity ore, than with an irregularly-sized, low-grade ore. The titanomagnetite, difficult to process in a blast furnace, can be reduced by this process for feeding directly into the steelmaking furnace. The sulphur content of the ore is usually low, but even medium-sulphur ore, as in the case of the magnetite ore of Table I, can be desulphurized during reduction so that the resultant product is suitable for iron and steelmaking.

A wide range of coals from anthracite to lignite can be used in the process. The main criterion in coal selection is that the ash softening temperature must be higher than the temperature used in the rotary kiln so that the coal ash does not fuse during its passage through the kiln. The chemical compositions of three possible types of coal are shown in Table II.

Coals of different classifications contain different percentages of volatile matter and, as this part of the coal represents a substantial fuel value, it is burned in the process as completely as possible to minimize fuel consumption. The sulphur content of the coal is usually less than one percent and at this level it can be readily controlled by the flux addition.

Either limestone or dolomite can be used as the flux with little or no limitation on the quality. The size of the flux, usually less than one millimetre, is smaller than that of the ore and the coal.

Description of the Process

The process is best described with reference to the flow sheet illustrated in figure 3. The iron ore, prepared in some agglomerated form as discussed in the previous section, is fed onto a preheating grate. The hot gases exhausted from the rotary kiln are drawn through the bed of ore and transfer their sensible heat to the ore. The preheated ore is then charged directly into the rotary kiln. The use of a preheating grate, although not essential for most ores, increases the heating efficiency of the process and shortens the length of the kiln required for a given capacity. Furthermore, when the ore used in the SL/RN process is in the form of green balls, the preheating grate serves to strengthen the green balls, thereby minimizing the amount of fines generated by breakage in the rotary kiln.

The preheated iron ore moves slowly through the kiln under the influence of kiln rotation and slope. The hot kiln gases, flowing counter-currently to the iron ore, continue to heat the ore as it travels through the kiln. At temperature (1050° to 1180°C), the iron ore reacts with the reducing gases generated by the coal. The overall reduction reactions may be expressed by the following equations:

$$Fe_xO_y + \frac{y}{2} C \rightarrow xFe + \frac{y}{2} CO_2$$

$$Fe_xO_y + yH_2 \rightarrow xFe + yH_2O$$

In addition to being the reductant, the coal also supplies the fuel to heat the kiln charge. At the end of the kiln opposite from where the ore is charged, the coal is pneumatically injected into the kiln as illustrated in figure 4. When the coal is exposed to the extremely hot kiln atmosphere, its volatile matter is released in the form of gases which are drawn through the kiln by induced draft. The gases formed by the volatile matter, rich in fuel value, are burned when they come into contact with the combustion air injected through the air ports located at spaced intervals along the length of the kiln. The heat thus generated can be precisely controlled by regulating the amount of combustion air entering along the kiln. The temperatures within the kiln, measured by means of thermocouples, are carefully controlled to avoid fusion in the bed while being kept sufficiently high that the ore is reduced as quickly as possible.

Since the heating of the kiln depends upon the volatile matter of the coal, supplemental fuel must be provided if low volatile coals, e.g. anthracite, are to be used. A wide range of auxiliary fuels may be used, including natural gas, fuel oil, or high volatile coal. The natural gas or fuel oil can be added through the combustion air ports thus converting the air ports to burners.

The kiln discharge, containing reduced ore, burnt flux and char (coal minus volatile matter and some carbon), spills continuously into a rotary cooler connected to the kiln by means of a gas-tight chute. A slight positive pressure in the kiln forces sufficient amounts of reducing gases into the cooler that the reduced product is cooled under a non-oxidizing atmosphere.

The product, discharged from the cooler through a gas-tight sealing device, is conveyed to the product separation system. Because of its relatively larger size and magnetic property, as compared to the char and burnt flux, the sponge iron is separated from these materials by screening and magnetic separation. The sponge iron is sent to the ironmaking or steelmaking furnace; the non-magnetic flux and char are further separated by fine screening. The sulphur-ladened burnt flux, because of its finer size, is concentrated in the minus one millimetre fraction and is rejected from the system along with some very fine char and coal ash. The plus one millimetre char still contains a substantial amount of useful carbon and is recirculated back to the kiln as 'recycle char'. This char, fed into the kiln together with the preheated iron ore, supplies the carbon for reduction at the charge end of the kiln where the carbon from the fresh coal is not available.

Energy Consumption

The energy consumption in the SL/RN process depends upon many factors, including the type and quality of the coal and ore, the kiln size and refractory lining, and the efficiency of the operation. As a guide, the approximate fuel requirement and heat consumption of the process, per metric ton of ore, when using different types of coal, are shown in Table III.

Table III indicates that, when anthracite coal is used, an auxiliary fuel such as natural gas has to be added to supplement the volatile matter in the coal. The use of bituminous and lignite coal, on the other hand, does not require auxiliary fuel; the process heat consumption with these coals, however, is higher than when anthracite coal is used because the combustible gases generated by these more reactive coals are swept out of the kiln before they can be completely burned. With a suitable heat recuperator in the kiln exhaust system, these gases could probably be burned and the heat recovered.

It should be pointed out that the ore upon which Table III is based was in the form of indurated pellets. These pellets have a denser structure and are more difficult to reduce than are green balls or screened ore. The fuel and heat consumptions shown in Table III, therefore, are higher than those required for iron ore in other forms.

Properties of SL/RN Sponge Iron

The reduction reactions effectively remove the major portion of the oxygen from the iron oxide; reduced pellets containing less than one percent residual oxide can be produced consistently. For example, when an iron ore pellet containing 68 percent iron is reduced, the resultant sponge iron normally contains about 93 percent metallic iron and about 0.7 percent residual oxygen as iron oxide, the remainder of the pellet being gangue. When sponge iron is being produced specifically for steelmaking purposes, about one percent of residual oxygen is deliberately retained in the pellet since this was found to provide the best bath action in the steelmaking furnace, as will be explained later.

The gangue content of the sponge iron depends mainly upon the purity of the iron ore fed to the kiln. As it is possible to control the quality of the ore by normal mining and beneficiation techniques, the sponge iron is usually quite consistent in chemical composition. Sponge iron is generally low in tramp elements, such as phosphorus, copper, tin, etc. It is often referred to as a 'virgin metal' since, unlike scrap, it has not been contaminated with tramp elements from some previous steelmaking operation. The purity and consistent composition of the sponge iron make it an attractive feed material for ironmaking and steelmaking furnaces.

The SL/RN pellets are malleable and, consequently, are much more resistant to degradation during transportation and handling than are oxide pellets. This is evidenced by the very high average tumbler index of greater than 99 percent plus 1/4 inch. The compression strength, too, is a measure of malleability, rather than of rupture as is the case with oxide pellets. Reduced green balls average about 105 lb./pellet in compression; reduced oxide pellets average about 245 lb./pellet. During the numerous tests with sponge iron, no problem was encountered concerning the physical strength of this material.

Apart from colour, SL/RN pellets possess virtually the same appearance as oxide pellets, but the bulk density is about 100 to 115 lb./ft^3 as compared to 130 to 140 lb./ft^3 for oxide pellets. They are not abrasive to chutes or conveyors, are easily handled by magnets, and flow readily through bins, chutes, and pipes. Their flow characteristics are well suited to various standard types of volumetric or gravimetric feeders and conveying devices. Hence, SL/RN sponge iron pellets are most amenable to continuous feeding techniques.

The SL/RN sponge iron is highly resistant to oxidation in air unless it becomes wetted. By keeping it dry, sponge iron has been stockpiled for over one year and thousands of tons have been transported by rail to various cities in North America and shipped to points in Europe without any appreciable change in composition. In a commercial operation, this material would probably be shipped in covered railroad cars, water-tight compartments in ships or, if the reduction plant is located adjacent to the ironmaking or steelmaking facilities, on covered conveyor belts.

UTILIZATION OF SL/RN SPONGE IRON

Blast Furnaces

A blast furnace feed which contains sponge iron is called a 'prereduced burden'. Prereduced burdens using SL/RN sponge iron have been tested in experimental and commercial blast furnaces[6-8]. At The Steel Company of Canada, Limited, about 11000 tons of SL/RN pellets were used in the commercial blast furnace described in Table IV.

The test in the commercial blast furnace was divided into four periods during two, of which, oxide pellets were replaced with the metallized SL/RN pellets. The effect of natural gas injection in the blast furnace with a prereduced burden was also examined. The four test periods are outlined in Table V.

The blast furnace operation was held as constant as possible throughout the test, but there were some minor differences between the various periods in wind volume, blast moisture and time-off-wind. These were adjusted to a constant operation in order to determine the independent effect of the sponge iron on the production rate and fuel rate of the blast furnace, which are shown in Table VI.

Table VI shows that significant improvements can be made in coke rate and production rate when SL/RN pellets are charged as part of the blast furnace burden. During the test the coke rate was reduced by 20.4 percent or about 8.2 percent per 10 percent metallic iron in the burden. A further decrease in the coke rate was realized when natural gas was injected into the furnace, but the rewards from prereduction were somewhat lower than when no auxiliary fuel was used. The hot metal production of the blast furnace increased by 22.7 percent or about 9 percent per 10 percent metallic iron in the burden.

The use of sponge iron in the blast furnace offers the possibility of increasing the hot metal capacity of a plant without the major investment associated with the construction of a new blast furnace and coke ovens complex. Although fuel is needed to produce the sponge iron in the SL/RN process, it has been pointed out previously that many types of coal, other than expensive coking coal, can be used for this purpose. Depending upon the local conditions, an

SL/RN kiln--blast furnace combination to produce iron for steelmaking, could offer a distinct economic possibility.

Electric Smelter

In some parts of the world the blast furnace cannot be used for ironmaking because suitable iron ore and coking coals are not available. As an alternative, electric smelting furnaces are used to produce pig iron for steelmaking furnaces. Significant improvements in electric smelting furnace operation can be achieved if the iron ore is first reduced in the SL/RN process. For example, when an ilmenite ore was reduced 80 percent, prior to being charged to an electric smelter, the production rate was increased and the power consumption decreased from 3100 to 1500 KWH per metric ton of pig iron. A plant utilizing this principle is even now under construction in Korea. The flow sheet of this plant is presented in figure 5.

Cupola

SL/RN sponge iron has been tested as a replacement for scrap in the commercial hot blast cupola for the production of pig iron and cast iron. The replacement of scrap by the sponge iron was as high as 100 percent with the sponge iron as briquettes and 70 percent with the sponge iron as pellets. Despite these high feed rates, the sponge iron was melted without creating excessive windbox pressure or adversely affecting the operation of the cupola. Compared to the operation with scrap, a higher coke rate was necessary, primarily to melt the higher proportion of gangue in the sponge iron. For making cast iron, the increase in coke rate was about 4 to 5 percent per 10 percent of sponge iron in the charge.

The major advantage of using sponge iron is that it is a high purity material of known chemical composition. By using this material, the composition of the iron produced from the cupola can be controlled more closely and comprises lower percentages of residual elements than the iron made from scrap. The level of various residual elements in the cast iron produced using SL/RN pellets is shown in Table VII.

In considering the economics of utilizing sponge iron in the cupola, the quality of the product is a favourable factor but the higher coke rate has an adverse effect as compared to the economics of using scrap. The most important considerations, however, appear to be the availability and cost of scrap. If suitable raw materials are available to produce sponge iron at a cost below that of scrap, the use of sponge iron should be economically viable.

LD Converter

A limited tonnage of SL/RN pellets has been charged into a commercial basic oxygen furnace as a scrap replacement. At a pellet addition of about 70 percent of the charge, the LD operated smoothly and the sponge iron appeared to be a more efficient coolant than scrap. More quantitative results, however, are not available due to the limited nature of the test.

Electric Arc Furnace

The investigations into the utilization of SL/RN sponge iron in the electric arc furnace has culminated in the development of the SL steelmaking process[9,10]. This new steelmaking process is based upon the continuous charging of reduced iron ore into the electric arc furnace in such a manner and at such a rate that melting and refining are carred out simultaneously. The majority of the development work was conducted at The Steel Company of Canada's Premier Works in Edmonton, Alberta. Additional tests have also been made at other steel companies in North America on different sizes of furnace. At the time this paper was being prepared another major test was being conducted on a 150 ton furnace, the largest used to date with this process. Table VIII shows the characteristic data of three furnaces used to develop the SL steelmaking process, furnace A being the Premier Works furnace. All three furnaces were equipped with high power transformers relative to their sizes.

Continuous Charging Equipment:

The equipment used for the continuous charging of the sponge iron was of similar design for all three furnaces. The apparatus used with furnace A may be seen in the photograph, figure 6, and, also, in schematic form in figure 7. A belt weigh-feeder conveyed the sponge iron from the storage bunker to a bucket elevator at a controlled feed rate. The bucket elevator discharged the sponge iron into a splitter box which, in turn, distributed the material to three pneumatically retractable feed pipes. The sponge iron fell from the retractable pipes into three furnace feed pipes and then into the furnace through ports located in the roof of the furnace about [illegible]0 centimetres from the electrodes. After a free fall of about 1.5 metres in the furnace, the sponge iron landed in the 'arc flare' region of the steel bath. Gates in the splitter box were used to control the relative amounts of sponge iron being delivered to each electrode area.

Melting Practice:

In the beginning of a heat, scrap and predetermined amounts of carbon and lime or limestone are charged into the furnace in the conventional manner. If a high percentage of sponge iron is to be used, about 15 to 20 percent of the sponge iron is placed at the bottom of the furnace around the furnace periphery. This was done in the test work by using a peripheral charging bucket, shown as a diagram in figure 8.

After the initial charging has been completed, the roof of the furnace is placed in operational position. Full power is applied immediately to melt the charge and bring the bath to about 1560°C. Once the desired temperature has been reached the continuous feeding of the sponge iron is immediately started, with full power being maintained throughout the feeding period. This maximum power input is decreased only after the feeding is finished, at which time the heat should be ready to tap. It must be pointed out that this type of practice, unlike conventional electric arc steelmaking with scrap, requires little or no additional refining period.

Refining Practice:

As full power is applied to the furnace virtually throughout the heat, the temperature of the steel bath is controlled by small variations in the feed rate of the sponge iron. Temperature measurements, taken by conventional means at predetermined intervals, provide the information for the feed rate adjustments.

The object of the control is to allow the bath temperature to increase gradually so that the desired tapping temperature is reached at the same time that the continuous feeding of the sponge iron is complete. By operating in this manner, the full power of the furnace can be utilized from the beginning to almost the end of the heat. Only a very few minutes are required for final temperature adjustment at lower power, should this be necessary. The conventional practice, on the other hand, depends upon the manipulation of power for temperature control.

For controlling the chemical composition of the steel bath, a sample is taken for chemical analysis at the start of the continuous feeding of the sponge iron. Once this analysis has been determined, the subsequent bath chemistry can be predicted accurately, because of the consistent and known analysis of the sponge iron. As the continuous feeding progresses, samples are taken and analysed, especially for carbon content. Normally, the carbon level decreases gradually until it reaches the desired tapping range at about the same time that the continuous feeding is complete. Towards the end of the heat, if the analysis indicates that the carbon level will be above the desired range, a predetermined amount of oxygen is blown into the bath to effect the necessary carbon correction. The carbon correction, when required, is carried out before the end of continuous charging while full power is still being applied.

Slag basicity is usually maintained in the range of 1.0 to 1.5, the amount of lime fed to the bath being dependent upon the chemical make-up of the gangue in the sponge iron. If the periodic analyses during the heat indicate that the phosphorus or sulphur levels will not meet the desired steel specifications, the lime additions are increased towards the end of the pellet feeding period so that the required desulphurization or dephosphorization can be carried out. The effect of this, as with carbon corrections when needed, is to accomplish all the refining while the charge is still being melted.

About five minutes before the end of continuous charging a final steel bath sample is taken and analysed to determine the required alloying addition. When the continuous feeding is complete and the desired temperature and carbon have been reached, the heat is tapped. The alloy additions can be made either to the furnace or to the ladle as desired.

Heat Time and Productivity:

From the preceding sections it is evident that the melting and refining periods of the new process are carried out simultaneously. Furthermore, the continuous charging of sponge iron permits maximum power to be applied to the furnace virtually throughout the heat. These two factors considerably shortened the heat time in actual practice compared to conventional electric arc steelmaking with the all-scrap charge. A comparison of the heat time between the two practices is graphically illustrated in figure 9. The typical heat times from power-on to start-tap for the three test furnaces are shown in Table IX, with comparative times for the all-scrap heats.

It is apparent from Table IX that the productivity of the test furnaces increased by as much as 65 percent with the continuous charging of SL/RN sponge iron. Not only were the heat times considerably shortened, however, they were also quite predictable and reproducible. In one series of heats made in furnace A, for instance, more than 40 percent of the test heats had power-on to tap times within a range of plus or minus five minutes of each other. Furthermore, by comparing data from the various test furnaces, an empirical relationship has been derived with which the heat time of other furnaces can be established[9].

Heat Transfer and Refractory Consumption:

Because the sulphur, phosphorus, and other residual tramp components of the SL/RN sponge iron are usually very low, a neutral slag can be used which improves the heat transfer from the electrode arc to the bath. The neutral slag, being less conductive than the more basic slag, allows the arc to be submerged into the slag layer. At the same time, the continuously charged sponge iron absorbs the heat from the arc, thereby minimizing the loss of heat through radiation onto the refractory of the furnace. The combined effects of arc submergence, heat absorption by the pellets, and greatly reduced heat time are factors which minimize radiation and refractory burning. The refractory consumption for the continuously charged sponge iron heats was about 27 percent less than that for the all-scrap heats as can be seen in Table X.

During continuous charging the heat transfer in the furnace is further aided by a gentle boiling action caused by the reaction between the bath carbon and the small quantity of residual oxygen (as iron oxide) in the sponge iron. The optimum amount of residual oxygen is about one percent; an excessive amount consumes heat by the oxide reduction reaction and an inadequate amount does not provide the desirable bath agitation.

Energy Consumption:

The energy consumption of the furnace for continuously charged sponge iron depends, to a large extent, on the amount and basicity ($CaO+MgO/SiO_2+Al_2O_3$) of the gangue in the sponge iron. If an excessive amount of gangue is present, or if lime has to be added to make an acceptable slag, the energy consumption increases. The energy consumption may be expressed in terms of the slag made in the furnace, as shown in figure 10.

It may be seen from figure 10 that some of the continuously charged sponge iron heats have energy consumptions below that of the all-scrap heats. In these particular heats, the shorter heat time, more efficient melting, and continuous application of full power are factors that more than offset the extra energy required to form the slag.

For a given transformer setting, a higher energy input rate can be applied with the continuously charged sponge iron than to the melting of scrap, a result of the more efficient heat transfer and the steady heat demand during the continuous charging period. This constant high power demand over a lengthy period, with limited power surges, is viewed most favourably by the power companies.

Steel Grades:

During the development programme a variety of steel grades was produced, including some low alloy, skelp, and low and high carbon merchant bar grades. Using the normal SL/RN sponge iron, which is free of tramp elements, virtually all grades of steel can be made. In Canada, an SL/RN plant is being built to produce a nickel-rich sponge iron[11] which will be used to produce high alloy grades, stainless steels, and steels for use in aircraft.

Economic Aspects

In many situations the economics of new steelmaking installations will favour the utilization of an SL/RN direct reduction plant in combination with electric furnaces employing the SL steelmaking process. Recent studies[12] have shown that the operating costs for this combination are approximately five percent lower for very large installations and more than ten percent lower for smaller ones of, say, one million tons per year or less; capital costs are given more specifically. An example of how the economics of this route to steelmaking might compare to those of the blast furnace--LD converter route has been developed from these studies and is presented in Table XI for four sizes of plant; in this example, the operating costs for both types of steel plant are assumed to be the same. Table XI shows the costs and the return on investment (calculated under Canadian tax laws) to the ingot stage only, a selling price of 65 dollars per ton being assumed for the ingots.

In another economic evaluation[13] a return on investment of 16.8 percent, based upon U.S.A. tax laws, has been reported for the combination of direct reduction, electric furnace, and continuous casting as compared to 9.6 percent for that of the blast furnace, LD converter, and continuous casting. These calculations were made for a plant to produce 1.8 million tons of cold rolled sheet per year.

In addition to having the lower initial capital cost, the SL/RN--SL steelmaking combination has the added attraction of being expandable in much smaller increments. Steel plant expansion based upon the blast furnace--LD converter must be made in large increments out of economic necessity and this, in some cases, could result in undesirable initial over-capacity.

For those countries venturing towards establishing an integrated steelmaking operation, the combination of the SL/RN direct reduction process and the SL steelmaking process could hold the key to low cost steelmaking by offering the advantages of being able to use a variety of ores and coals in the production of sponge iron, lower capital costs for the steel plant, and more flexibility in tailoring the size of the plant to meet the expected market and in expanding to fill increasing market demands.

Continuous Steelmaking:

Continuous steelmaking, even in this day of rapidly improving technologies, is still a rather elusive goal. Certain organizations, notably IRSID in France, are investigating the possibilities of making steel continuously. The high purity sponge iron produced by the SL/RN process, with its good flow characteristics, would appear to be an ideal adjunct to such processes. It should be pointed out, however, that a continuous steelmaking process of any size would probably be best suited to the production of large tonnages of a single grade of steel. Hence, such a process should fit better into a big steel plant than into a small one which must retain considerable flexibility to change grades rapidly to fit the order pattern.

REFERENCES

1. Sibakin, J. G., Development of the SL Direct Reduction Process, American Iron and Steel Institute, New York, May, 1962.

2. Babcock, D. E., The RN Direct Iron Process, American Iron and Steel Institute, Cleveland, October, 1968.

3. Smith, R. F., R-N Rotary kiln Process for the Direct Reduction of Iron Ores, A.I. Ch. E. Meeting, 1962.

4. Fraser, M. W., and Grigg, C. R., The SL/RN Process--Its Place in the Iron and Steel Industry, The Engineering Journal (Engineering Institute of Canada), June, 1965.

5. Meyer, K., The SL/RN Process for Production of Metallized Burden, Ironmaking Proceedings, V. 24, TMS-AIME, 1965.

6. Fine, M. M. et al, Experimental Smelting of Prereduced Iron Ore Pellets, U. S. Bureau of Mines, KI6523.

7. Peart, J. A., Pearce, F. J., The Operation of a Commercial Blast Furnace with a Prereduced Burden, Iron Making Proceedings, V. 24, TMS-AIME, 1965.

8. Peart, J. A., Pearce, F. J., Prereduced Burdens in the Blast Furnace Process, Presented at Congres International sur la Production et l'utilization des Minerais Reduits, Evian, May, 1967.

9. Sibakin, J. G. et al, Electric Arc Steelmaking with Continuously Charged Reduced Pellets, Journal of Iron and Steel Institute, V. 205, October, 1967.

10. Sibakin, J. G. et al, Utilization of SL/RN Reduced Pellets in Electric Arc Furnaces, Presented at the 25th Electric Furnace Conference, AIME, December, 1967.

11. Prereduced Pellets: Now They are Nickel Flavoured, Iron Age, February 15, 1968.

12. Dailey, W. H., Steelmaking with Iron Pellets, Presented at the 27th Ironmaking Conference, AIME, April, 1968.

13. Lovgren, G. A., Forces of Economic Change, Steel U.S.A., Presented at the 97th Annual Meeting, AIME, February, 1968.

TABLE I: Properties of Iron Ore Process by the SL/RN Process

Geological form of iron ore	Hematite	Magnetite	Titano-magnetite	Taconite
Agglomerated form of ore fed to the SL/RN Process	lump ore	green ball	green ball	indurated pellet
Size, mm	3-15	5-16	8-15	5-16
Main chemical constituents in agglomerated ore, %				
Fe_2O_3	92.5	2.4	--	90.5
Fe_3O_4	1.9	91.0	79.0	--
FeO	--	--	4.1	--
Gangue	3.7	6.1	8.0	9.2
TiO_2	--	--	8.5	--
S	0.02	0.30	0.01	0.04

TABLE II: Properties of Coals Used in the SL/RN Process

Coal Classification	Anthracite	Bituminous	Lignite
Proximate Analysis*, %			
Volatile matter	7.4	37.5	39.4
Fixed carbon	79.6	56.0	47.8
Ash	13.0	6.5	12.8
S	0.7	0.8	0.3
Heat content*, Kcal/kg	7330	7750	5750

* dry basis

TABLE III: Process Fuel and Heat Requirements With Various Types of Coal

Type of Coal	Anthracite	Bituminous	Lignite
Coal requirement, kg/ton	250	355	665
Natural gas requirement, m^3/ton	84.4	0	0
Heat consumption, 10^6 kcal/ton	2.37	2.62	2.93

TABLE IV: Description of Commercial Blast Furnace Used for Testing SL/RN Sponge Iron

Hearth diameter, m	5.49
Hearth area, m^2	23.60
Working height, m	21.01
Working volume, m^3	587.25

TABLE V: Commercial Blast Furnace Test With Prereduced Burden

Operating Period	Pellets % of Burden		Fuel Injection
	Oxide	SL/RN	
Reference No. 1	100	nil	nil
Test No. 1	70	30	nil
Test No. 2	70	30	natural gas
Reference No. 2	100	nil	natural gas

TABLE VI: Effect of Burden Prereduction Upon the Productio
Rate and Fuel Rate of the Blast Furnace

	Prereduction		Prereduction With Natural Gas Injection	
Test Period	Reference No. 1	Test No. 1	Test No. 2	Reference No. 2
Fe metallic in burden, %	0	25.1	23.1	0
Coke rate (dry), kg/MTHM*	558	444	422	508
Natural gas rate, m^3/MTHM	0	0	33.4	38.5
kg/MTHM	0	0	24.0	29.0
Total fuel rate, kg/MTHM	558	444	446	537
Production rate, MTHM/day	1127	1383	1341	1155

* MTHM = metric ton hot metal

TABLE VII: Residual Elements in Cast Iron Produced Using SL/RN Pellets

Cupola Charge	100 % Scrap	60% Scrap 40% SL/RN Pellets
Residual Elements, %		
Aluminum	0.018	0.011
Arsenic	0.004	nil
Chromium	0.042	0.025
Copper	0.087	0.062
Manganese	0.260	0.120
Molydenum	0.002	nil
Phosphorus	0.035	0.024
Tin	0.011	0.006
Titanium	0.003	0.002

TABLE VIII: Characteristics of Electric Arc Furnaces Used for Developing the SL Steelmaking Process

Furnace		A	B	C
Shell diameter,	m	3.35	3.35	5.16
Normal heat size,	MT*	22.7	22.0	68.0
Electrode size,	cm	30.5	35.5	50.8
Transformer rating,	KVA	8000	5000	18750
Transformer output,	KVA	10000	10500	30000

* MT = metric ton

TABLE IX: Typical Heat Times and Productivities of Test Furnaces

Furnace	A		B		C	
Practice*	Scrap	SL	Scrap	SL	Scrap	SL
Heat time, power-on to tap (hr)	3.00	1.83	2.17	1.55	2.97	1.95
Steel Production rate (MT/hour)	8.4	13.9	10.2	14.5	25.4	40.1

* scrap = conventional all-scrap charge
SL = continuous charging, SL steelmaking process

TABLE X: Refractory Consumption of Furnace A

	All-scrap heats	Continuously Charged heats
Refractory brick consumption kg/MT steel	3.0	2.2

TABLE XI: Economic Comparison of SL/RN - Electric Furnace (SL) Steelmaking To Blast Furnace - LD Converter Steelmaking

Steelmaking capacity, MT/yr	0.5×10^6		1.0×10^6		1.5×10^6		2.0×10^6	
Process Combinations	SL/RN EF	BF LD	SL/RN EF	BF LD	SL/RN EF	BF LD	SL/RN EF	BF LD
Total capital, 10^6 dollars	25	70	40	83	55	95	70	108
Costs per ton, U. S. dollars								
Capital	50	140	40	83	36.6	63.3	35	54
Operating	55	55	52	52	51	51	50	50
Return on investment, %	12.4	1.9	19.6	9.5	22.4	13.6	24.6	17.1

Figure 1

SL/RN Pilot Plant at The Steel Company of Canada, Hamilton, Ontario

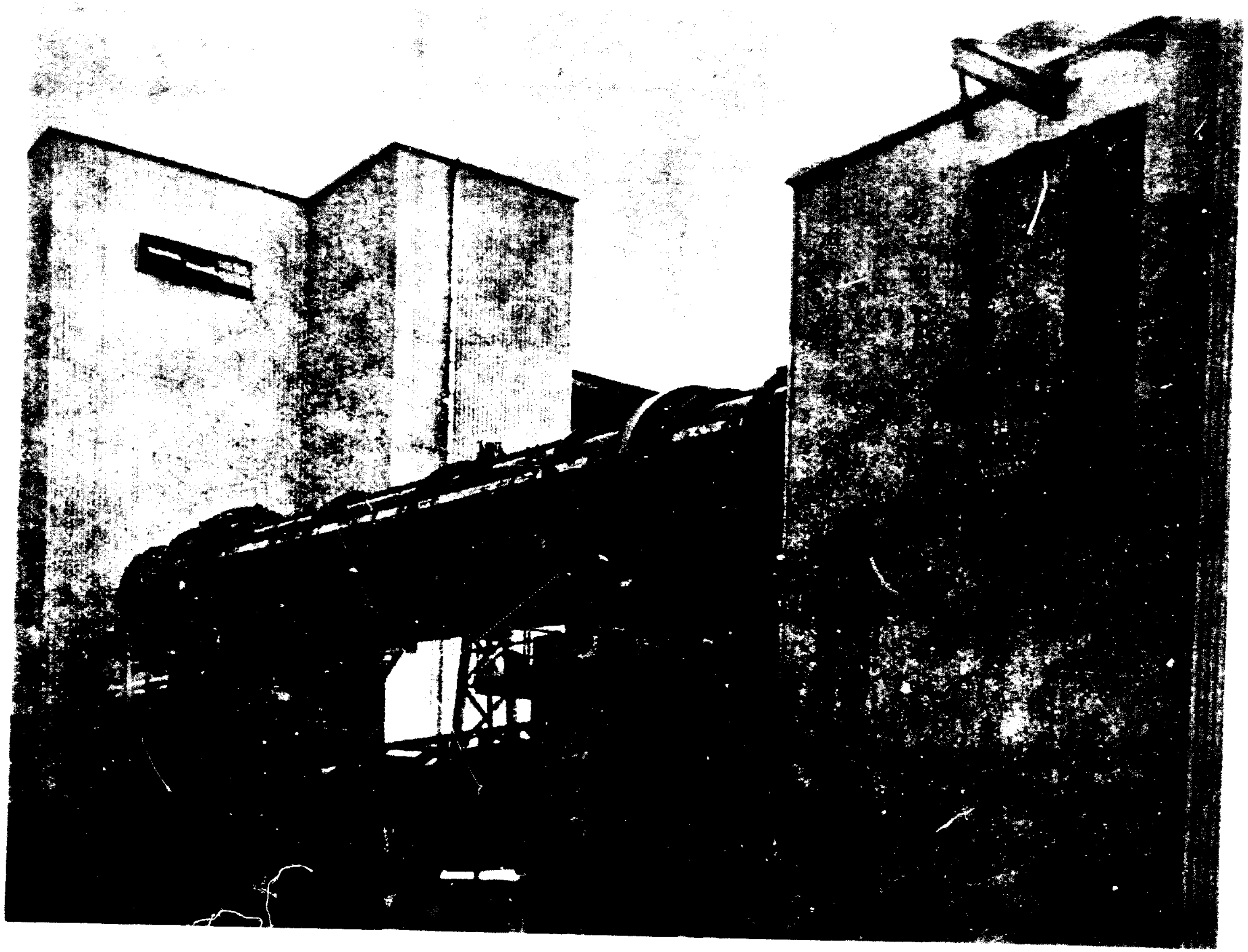


Figure 2

Preparation of iron ore feeds for SL/RN process

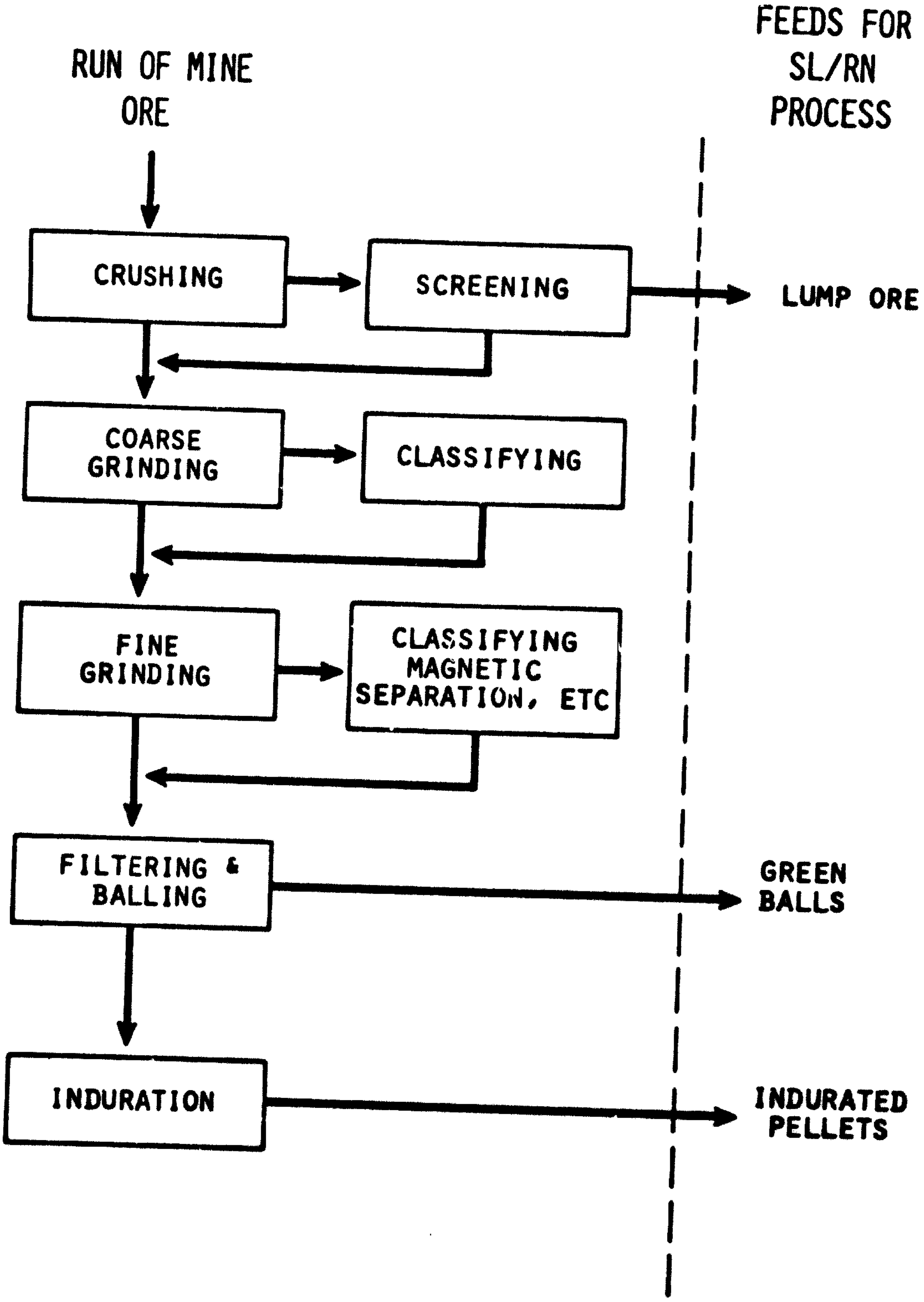


Figure 3

Flow sheet of the SL/RN process

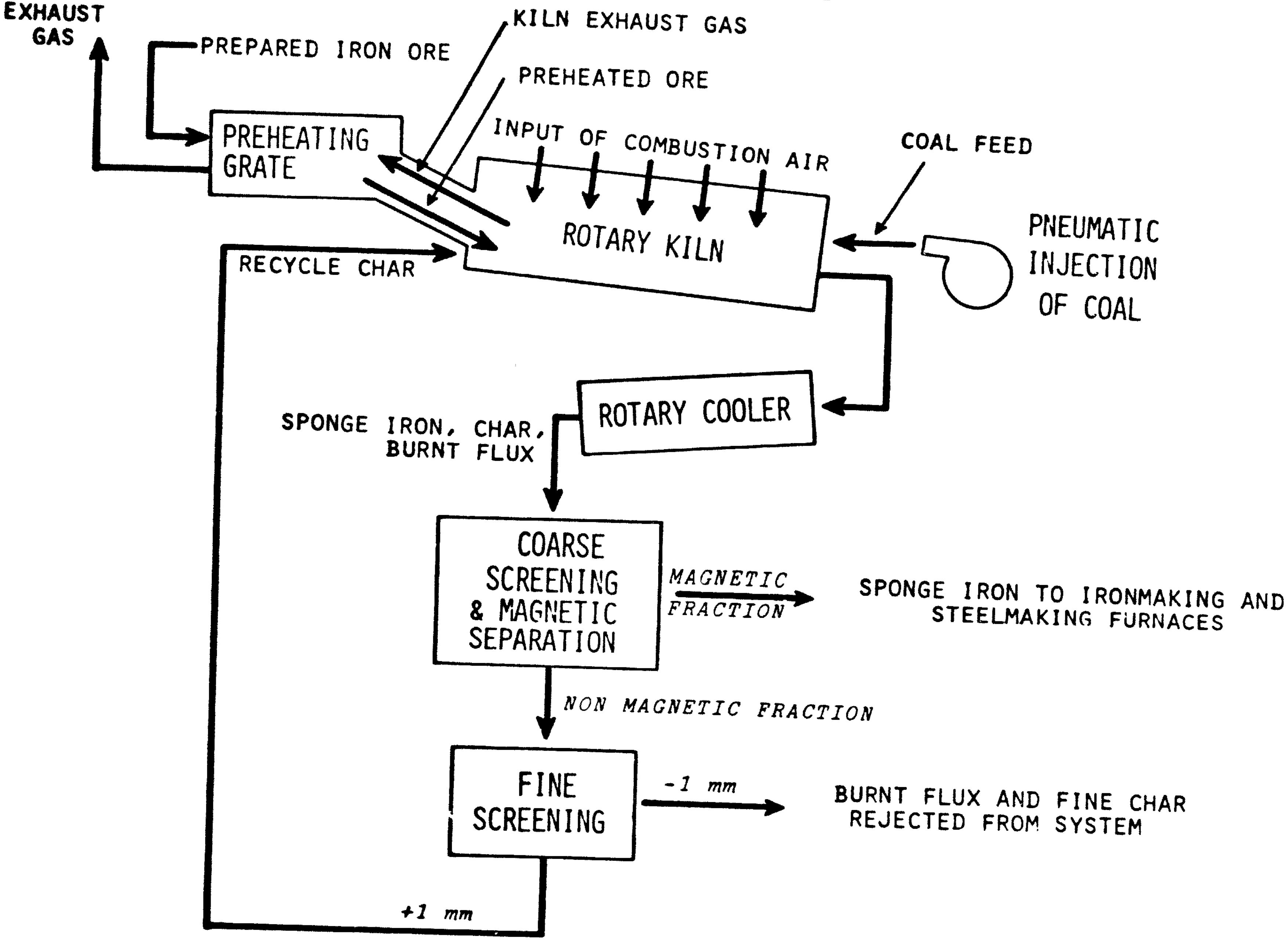


Figure 4

Injection of coal into the rotary kiln

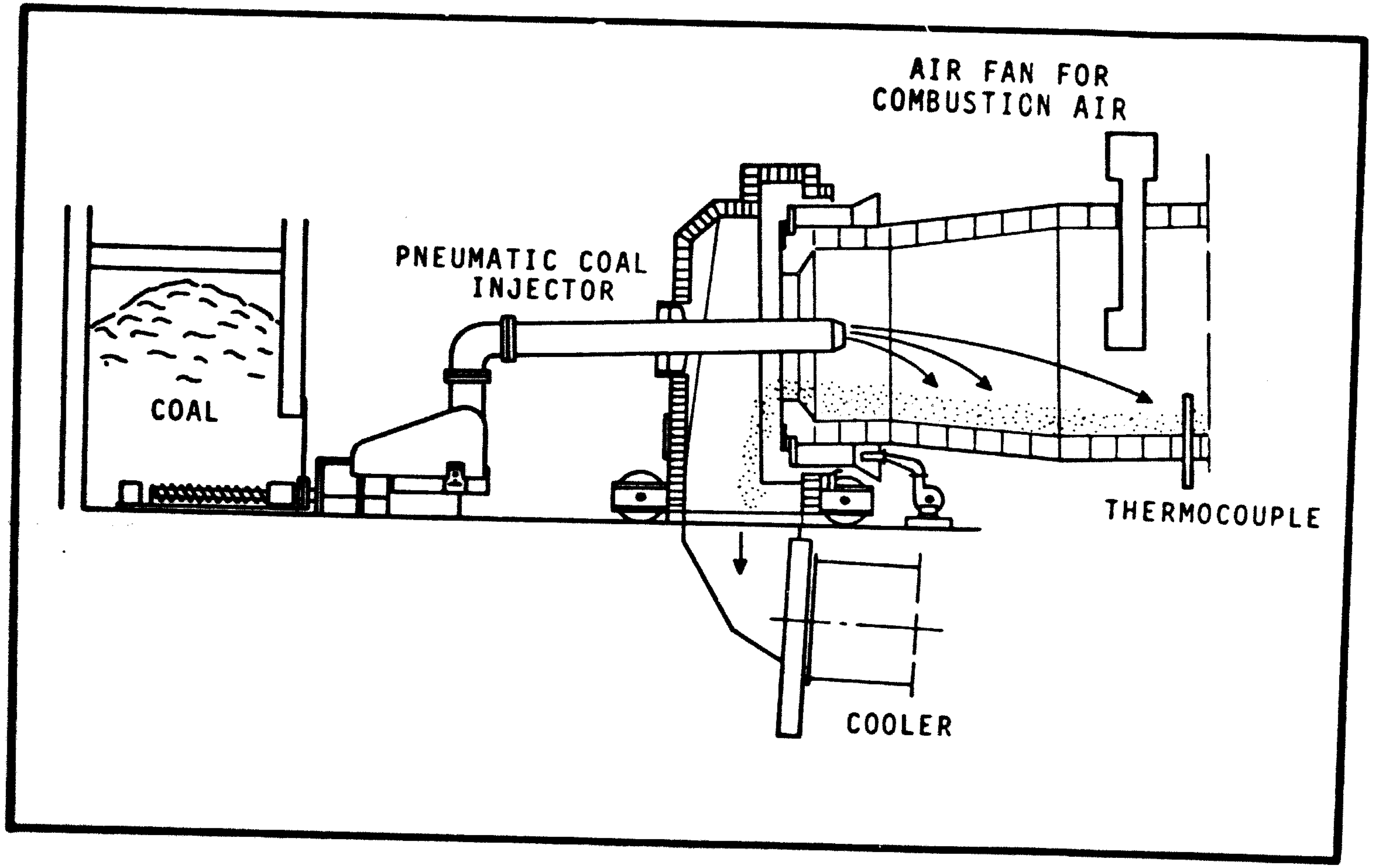


Figure 5

Flow sheet of the Inchon Steel Works in South Korea

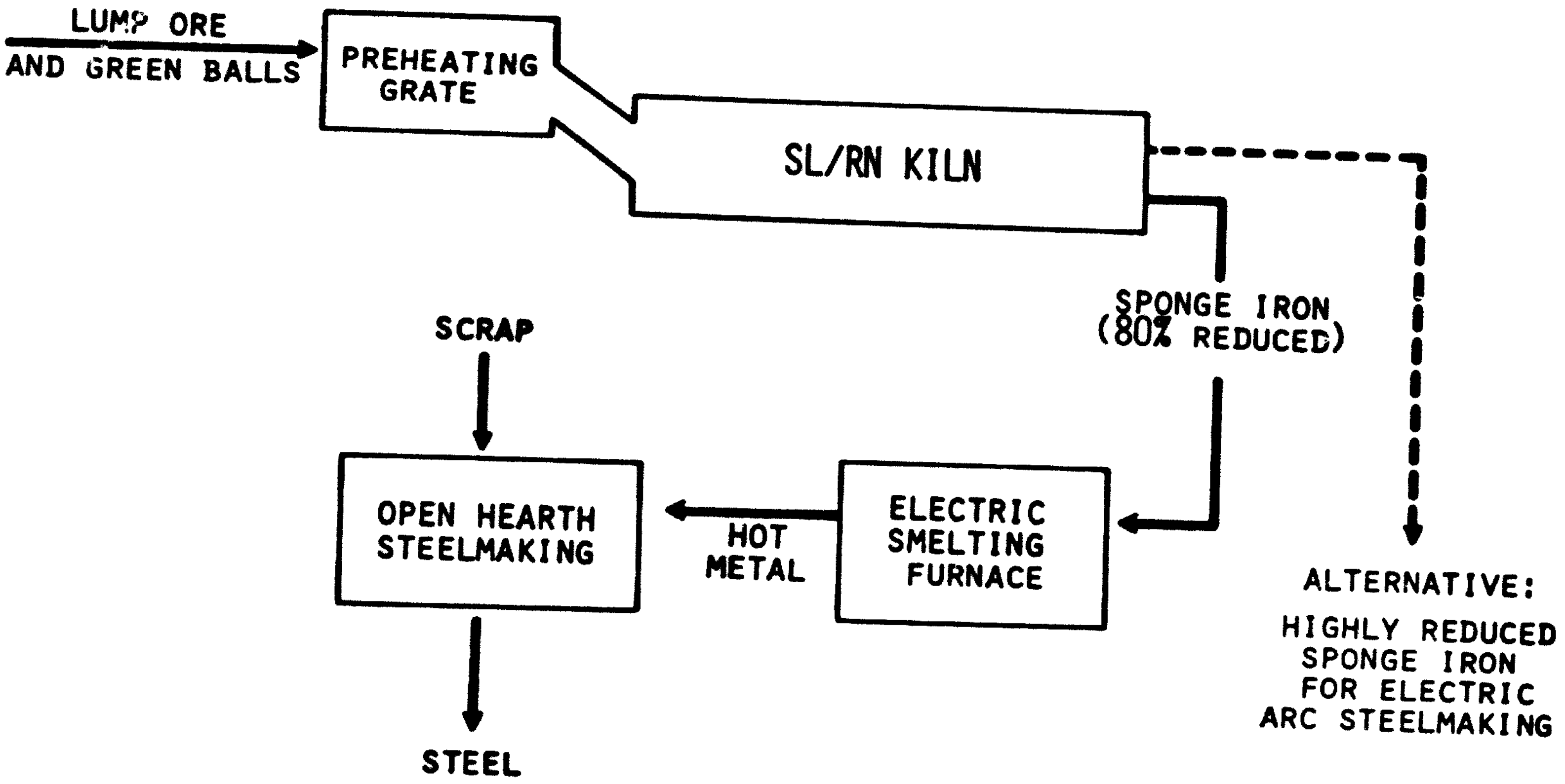


Figure 6

The continuous charging apparatus used for furnace A

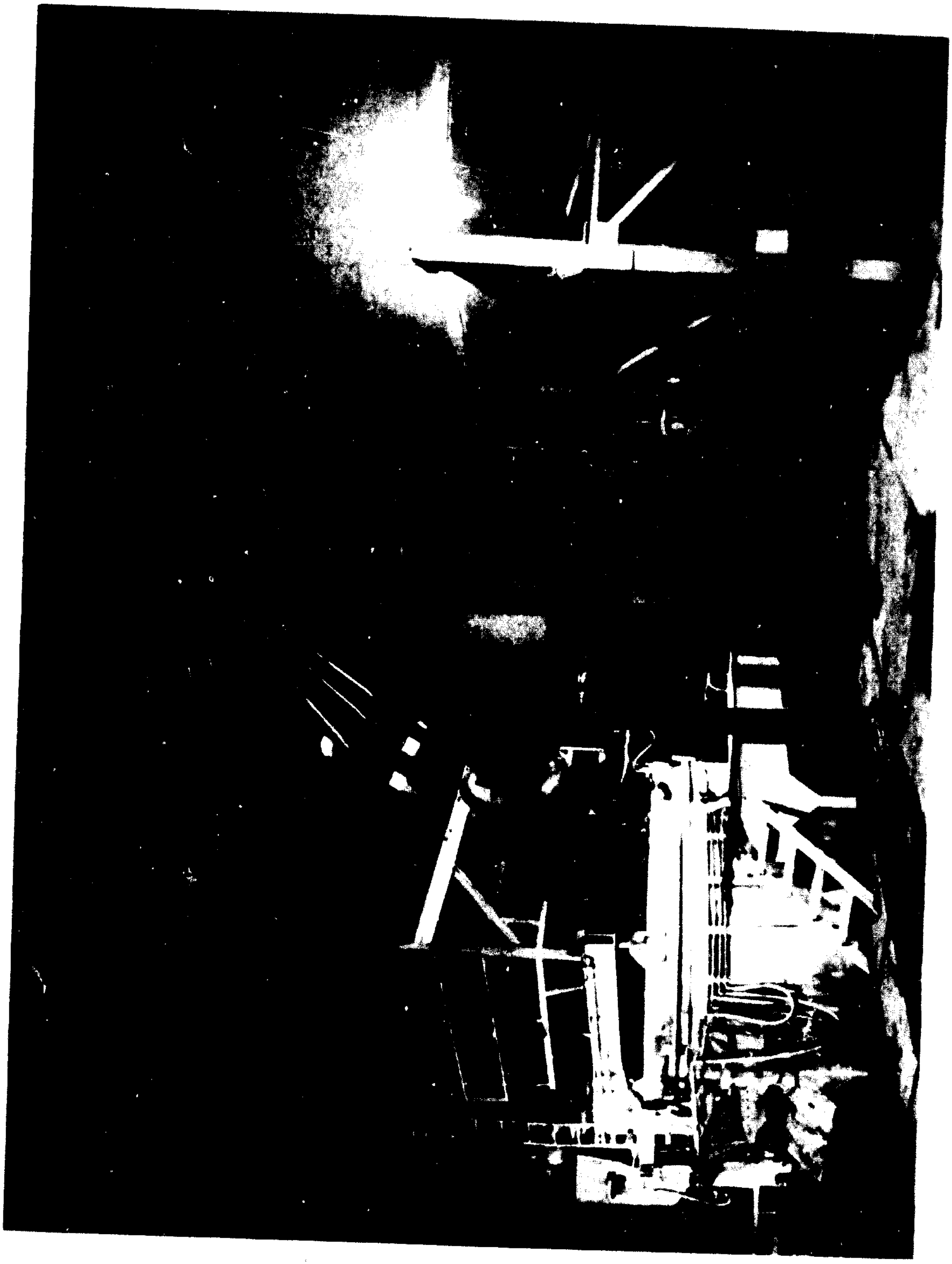


Figure 7

Schematic diagram of continuous charging apparatus

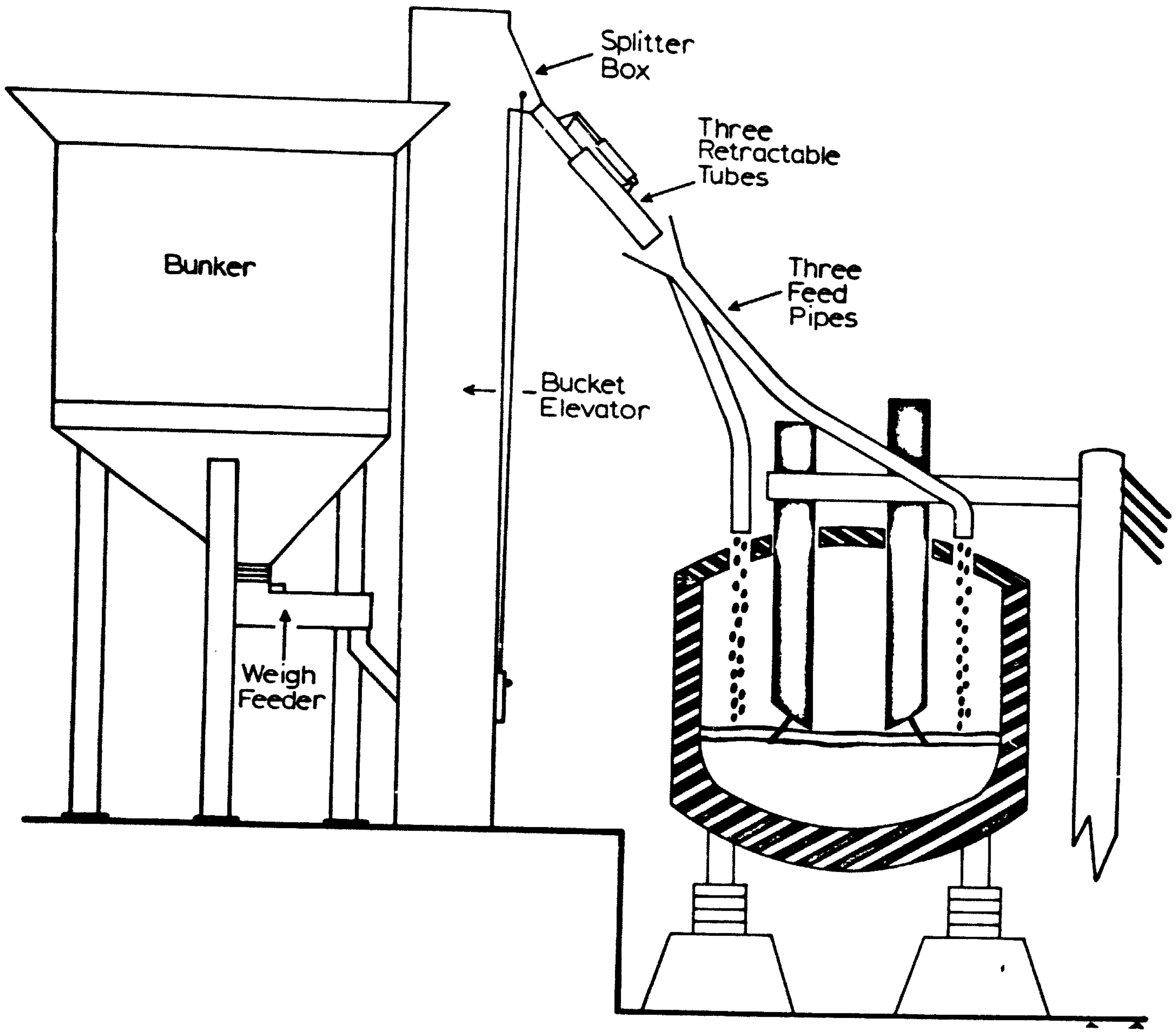


Figure 8

The peripheral discharge bucket

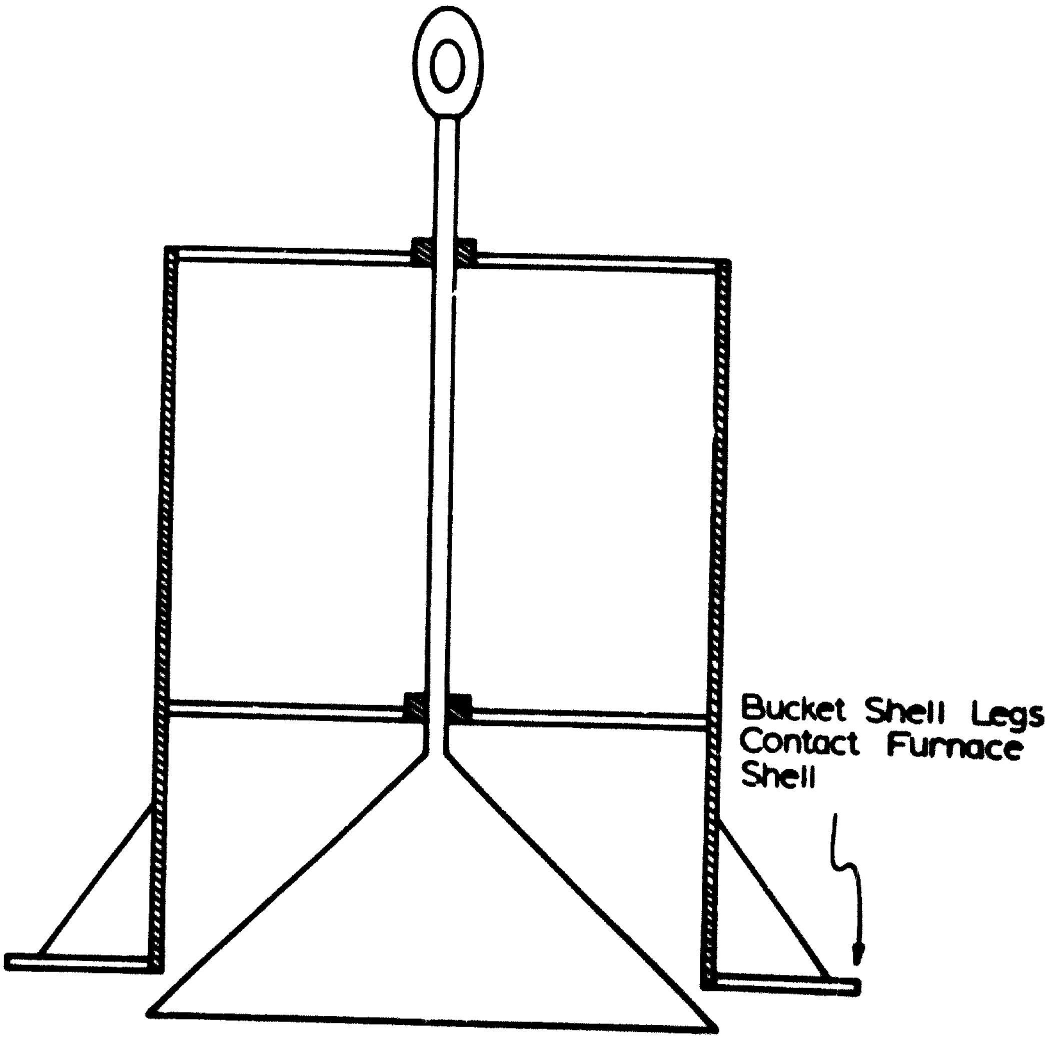
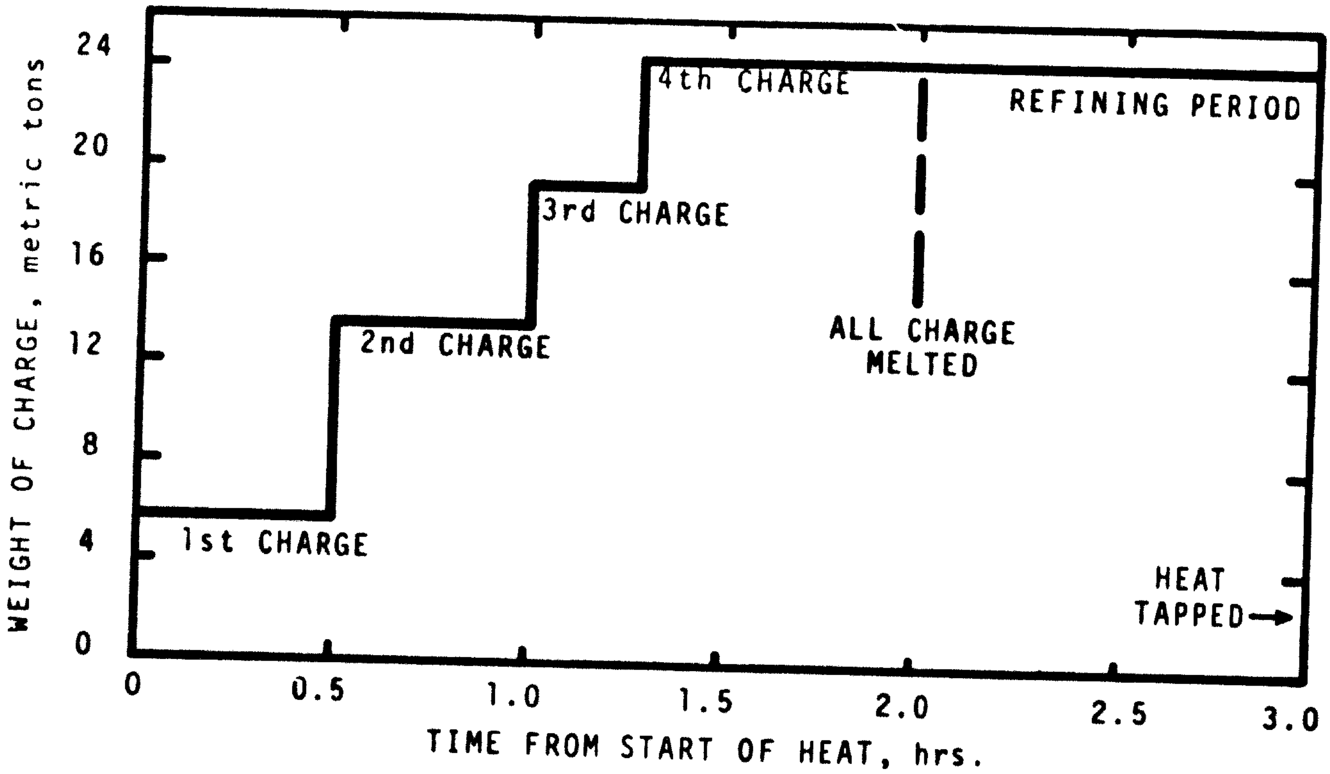


Figure 9

Comparison of heat time -- conventional all scrap practice vs. continuously charged sponge iron practice

CONVENTIONAL ALL SCRAP PRACTICE



CONTINUOUS CHARGING OF SPONGE IRON

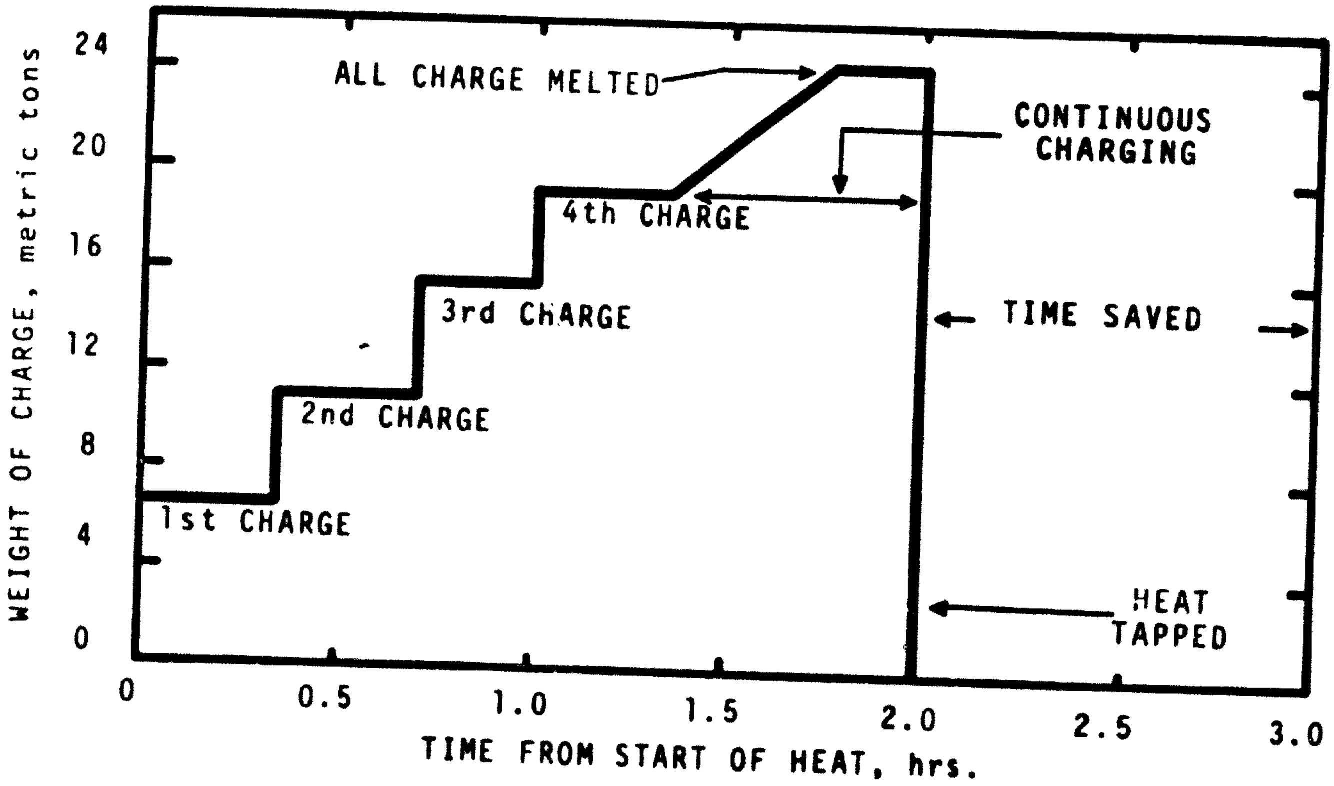
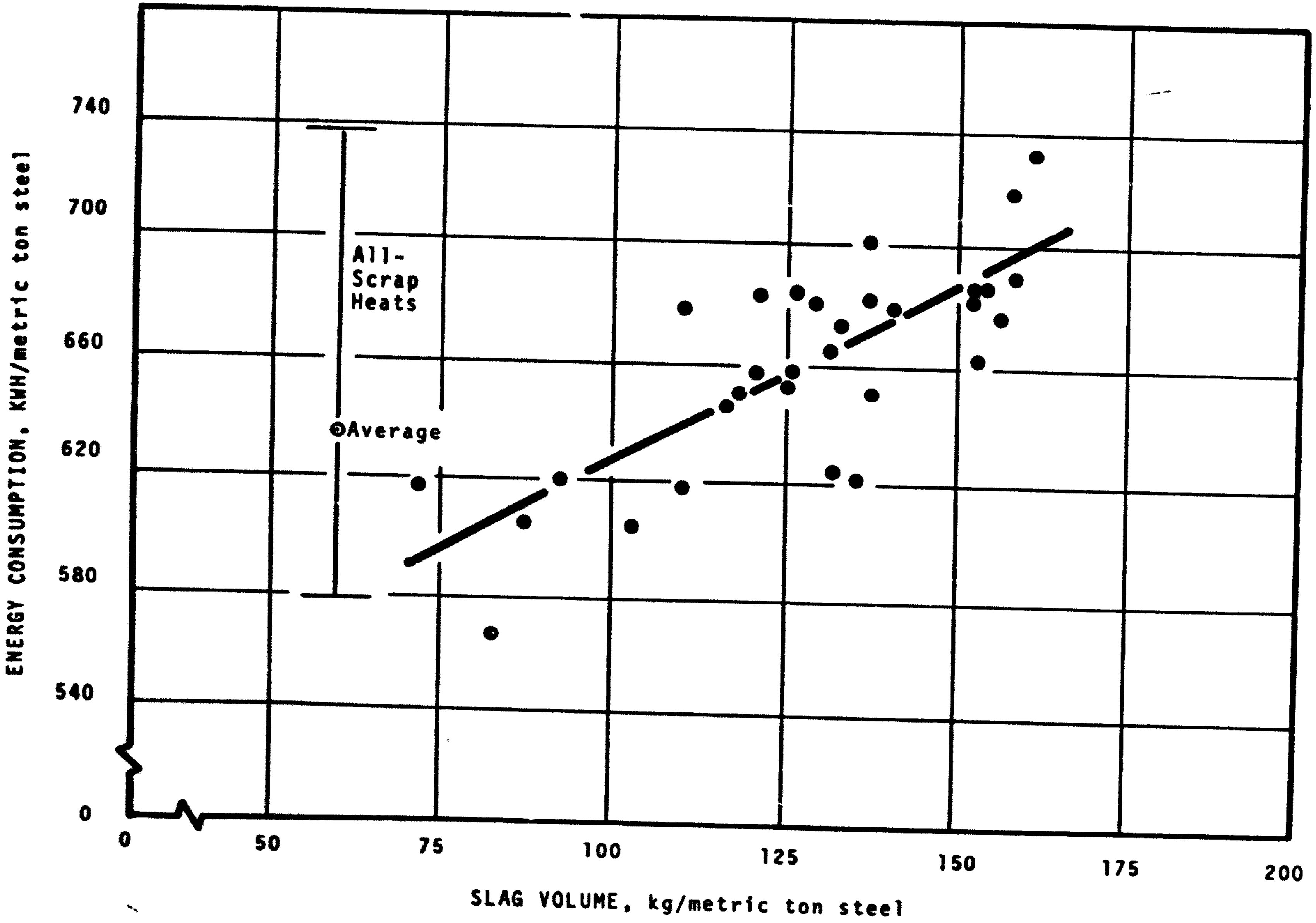


Figure 10

Effect of slag volume on energy consumption



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