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OPERATIONAL PLANNING OF A SPONGE IRON AND CONTINUOUS CASTING ROLLED STEEL PRODUCTION PROCESS

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I. Introduction

Industrialization has been the main spring for the rapid economic development in those areas of the world where technologies making this classical growth process possible were supported by large reserves of natural resources.

Yet, vast regions of the earth have not taken part in this advance, and one of the reasons could be the absence of resources which traditionally have sustained conventional industries. In the modern endeavour to extend the benefits of technical development beyond established boundaries a major problem lies with the adaption of classical technical processes to changing patterns of raw materials as well as uncommon economical structures.

This problem assumes major importance in the case of basic industries as, no doubt, is the manufacture of iron and steel products.

II The problems of technology

It has been widely accepted, that the establishment of an iron and steel industry is basic to the industrialization of a country, which intendsto increase the income and thereby the general well-being of its inhabitants. Serious obstacles, however, come in the way of this undertaking due to the very considerable capital requirements of conventional steel plants operating in accordance with the classical process.

This operation - very generally speaking - provides for the reduction of the iron ore in a blast furnace with the help of coke to produce liquid iron. Since these furnaces are very large the carbonaceous fuel has to withstand high pressures of the burden and abrasion during the passage through the shaft of the furnace: only selected grades of coal, i.e. metallurgical varieties can be accepted for this purpose. The modern methods of burden preparation using beneficiation of the ores have not reduced substantially this requirement for selected grades of coal.

Whilst the condition to use specific types of coal renders the conventional iron producing process principally applicable to thoseemerging countries which have a ready and sufficiently large supply of this commodity, the necessity to produce economically and competitively imposes another limitation: the available market has to be large enough to absorb the production of a plant of such size that it can be considered economically feasible. Examples of Indian steelplants suggest at least 1.10^6 yearly tons of steel produced as an economical size. It is evident that what appears practicable for the market volume and conditions in India is not directly applicable to the majority of the industrially emerging countries.

Both reasons - i.e. the technical need to adjust the process of iron making to the available raw materials, and the economic requirement to match the rate of production with the available market conditions - suggest strongly an alternative technology which takes into account the particular conditions of many an industrially less developed area of the world. Thereby the requirement of small capital and production cost per unit of yearly output at the contemplated production volume are of overriding importance.

There seem to be two ways to be investigated when planning the technological process to be applied under circumstances which differ from those of the highly industrialized i.e. steel producing countries: the conventional process could be adjusted in size and if possible, with respect to the conditions defined by the characteristics of available raw materials or else: new processes or at least adaptations of the classical processes must be conceived.

A number of investigations (1)+ have been carried out which, generally speaking, seem to indicate that scaled down units of the blast furnace such as the low shaft furnace, remain quite sensitive to the quality of the fuel used. Although their rate of production is less, and absolute capital requirements are lower, production costs and often also operational reliability are still problematical.

The same conclusion holds for the electric smelting process: conventional processes use coal or coke as the reducing agent as well as the energy carrier unless this latter role is taken over by electric energy. Although demands for the fuel used are less stringent and smaller units can be built the high consumption of electric energy restrict the application to areas where electric energy can be produced cheaply which in turn depends largely on the generating capacity.

[+] Numbers in brackets refer to the list of references.

There are, however, other processes, which use a gaseous reducing agent, which can be derived from natural gas or naphta. It is this type of process which should be considered if a steel industry should be established in areas devoid of sufficient supplies of metallurgical coal.

III Availability of raw materials

Iron ore is fairly well distributed and practically every major region is satisfactorily provided with workable deposits.

Whilst technologically speaking the value of iron ore deposits resides with its iron content and contaminants as also its reducibility, its economic importance rests with its accessibility and the proximity to major centres of production and consumption. This consideration assumes primary importance even for poor deposits as is the case in England and Germany, where ores with only 30 % iron content are economically exploited. Whilst industrialized countries have assessed their reserves extensively major new discoveries such as recently made in Canada, Venezuela and Brazil are likely to become known in future in many still emerging countries. Iron ore is usually sufficiently abundant in these regions to allow the establishment of a steel industry based on local resources.

As has been pointed out the availability of coking coal poses for many areas a serious problem. As an example India can be quoted which has very large deposits of coal but only a small percentage, i.e. 1,5 billion out of 65 billion tons - can be considered for metallurgical use. Similarly, Latin America as also the northern part of Africa are deficient in suitable coal resources. In these countries technology should be adjusted to the raw materials available as has been done for the steel industry in Mexico - although it has coking coal - and in Venezuela.

Natural gas has come to prominence rather later than did petroleum oil and in countries like USA, France, Canada and Italy large pipeline systems transport it over great distances to places of utilization. It should also be mentioned that natural gas can be transported in liquid form at correspondingly low temperatures in tankers.

The occurence of natural gas is closely linked to that of oil since both raw materials are found together. Gas reserves as such have not been assessed precisely although they were inferred from oil resources by assuming ratios of the amount of gas available for every unit of known oil reserve. When this ratio is high, considerable resources of relatively pure gas can be assumed whenever there is an indication of the availability of oil. In view of the possibility to transport gas over vast distances it can, in most cases, be assumed that an indigenous steel industry is feasible where oil in sufficient quantity is found in the geographical region. In particular South- and Middle America as well as North Africa seem to be able to utilize gas reserves for this purpose: in these areas a definite lack of coking coal coincides with the availability of gas as has been shown by recently published estimates of world gas resources and their distribution.(2)

It is, of course, mandatory to insure the supply and the suitability of all raw materials required during the planning stage for industrialization.

IV The HyL-Process

The HyL-process is an example where a new technology which takes fully into account the special circumstances and possibilities with respect to technological and economical factors of an industrially developing country, has been **evolved** by a partnership of entrepreneurs with modern technical know-how, the former being represented by the members of the Garza Sada family, residing in Monterrey, Mexico (3), the latter by the M.W. Kellogg Co. of New York, USA.

This international technical co-operation constitutes an outstanding example for the development of an indigenous non-conventional technology where the industrial project encompassing it has been created by local managerial and financial talent with the participation of industrial and engineering research experience.

The development of the steelmaking facility in Monterrey can, moreover, be considered as a notable example for industrial linkage development: it is closely connected with vast chemical enterprises producing textiles and nylon besides industrial chemicals, glass and paper mills and beer breweries. The latter seem to have initiated the net of production facilities by the desire to become - under the pressure of external war time conditions - independent from imports of glass for bottles, of the caps to close them, and of the paper and cardboard material needed to transport them. Part of this industrial complex is the production of sponge iron.

Since the process itself has previously been described e.g. in the 1963 Steel Symposium of the United Nations(4) it need be characterized only briefly here: High grade lump ore of beneficiated concentrate is exposed in large reactors with a capacity of about 100 tons to a hot reducing gas, containing essentially hydrogen and carbon monoxide, derived in a steam reformer from natural gas. The oxygen is thereby largely, up to 90 percent or more, removed from the ore as, incidentally, is sulfur - the residue being a solid sponge iron.

This represents a high quality feed for the subsequent steelmaking process which as in the case at Monterrey - can be charged to electric or also to open hearth furnaces.+

+ Also other uses are feasible such as in hot blast cupolas with subsequent treatment in oxygen converters to achieve the necessary chemical changes to produce steel with the required analysis.

Apart from the furnace additions dictated by the formation of slag for removal of gangue and other non-ferrous substances, and the requirements of the characteristics of the steel produced, scrap is charged in varying proportions together with sponge iron.

Carrying out the process steps as outlined requires equipment resembling modern oil refineries and this lends itself to centralized controls of reformer and reactor apparatus whereby by virtue of phased operations a maximum of continuity is approached by multiplying the essential elements: thus there are four reactors arranged for carrying out the reduction of the ore.

This feature allows to add to initially installed capacity once the initial economic hurdles are overcome: an important consideration for an industrially emerging country.

Some of the requirements of conventional steel producing technology maintain their important role also for the HyL-process: The ore has to be reducible under the conditions prevailing in the reactor and it s size should allow sufficient penetration by the reducing gas. + Since the removal of the gangue occurs in the refining stage, it is important that the iron content of the ore be high either naturally or be made so by benefication.

The HyL-process thus represents a possibility to utilize widely available or transportable gaseous raw materials for carrying out the basic iron making step in the production of steel. The combination with electric melting and refining constitutes an alternative solution to the conventional steel fabrication technique offering the advantages of flexibility combined with lower production levels. As such it merits

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+ This can be ascertained by tests in or simulating the conditions of, the actual reducing reactor.

serious consideration from the technical point of view for the industrially emerging countries when planning their industrial development.

For the planner of industrialization it is important when deciding on technology to satisfy himself on two more and very decisive criteria, namely:

(1) The process selected should have been demonstrated on a commercial scale in surroundings which should approach as closely as possible conditions prevailing in his own country, and

(2) The process should be established in a manner which the principal financing agencies are prepared to endorse.

Both conditions say, in fact, that a process not yet or not sufficiently tried out in large scale industrial and economic operation is not considered "bankable". Loans might not be granted for it nor is the availability of multi- and mostly also bilateral technical assistance assured.

On both counts the HyL-process qualifies since in its most recent stage of development ranging from a pilot plant establishment about 10 years ago to a 200 ton-a-day full scale operation it has achieved in an improved new design of an industrial and economically sound plant, operating since 1963, a production of 500 tons of sponge iron per day.

For the question of actual capital and production costs as also details of the process reference may be made to relevant sources (5) of information.

V. Continuous casting of steel

If the principal viewpoint for choosing suitable technologies for industrial development are essentially technical and economic in nature these criteria must also be applied to processes downstream of the reduction and refining stages i.e. to the casting and forming process of steel.

At least in the steel casting process more recent advances lend themselves to the particular situation of developing economies offering, as they do, economic solutions for medium and small output levels, combined with reliability, flexibility and ease of gradual expansion of production.

Whatever process is chosen for the manufacture of steel it has to be transferred from the vessel containing the liquid metal to a form where it solidifies in preparation to being formed to the shape suitable for its final use. In a steel-plant this intermediate operation is carried out in a melt-shop to which the metal normally travels in a teeming ladle the capacity of which is determined by and normally coincides with, the output per heat of the refining vessel.

The conventional processing of steel from the liquid state in the electric furnace - to which the further treatment is confined - into usable shapes occurs by casting ingots from the ladle. These, after reheating in soaking pits, are rolled to improve the grain structure and thereby the strength of the steel, and to form them ultimately into standardized sections. Large amounts of heat and rolling energy are necessary to obtain in rolling mills the large reduction of cross sectional area between the ingot and even the semi-finished state of the steel product in the form of billets, blooms or slabs.

The process of continuous casting (6) represents in comparison an essential simplification: the hot metal ladle after receiving the contents of the steelmaking furnace, is emptied either through a special opening or by tilting, into a tundish which distributes the metal to one or several strands each capable of carrying out in its vertical downward extension a sequence of processes delivering a semi-finished solid product of suitable size which by conventional means and after reheating, can be rolled and processed further. Each strand, consequently, is provided with a mold on top receiving liquid metal from the tundish. By intense cooling and, usually, by virtue of vertical **oscillations** it releases at its exit a **partially** solidified steel bar held and transported downwards by externally driven rolls at a closely controlled continuous rate of motion. Additional cooling occurs further down until complete solidification is assured when, normally, the bar is bent into the horizontal direction and there, cut into pieces of desired length. Cross sectional dimensions vary from below 50 mm (2 inches) to 300 mm (12 inches) square but slabs are cast with widths up to 1650 mm (65 inches).

The advantage of continuous casting as compared with conventional methods of steel casting and shaping can be summarized as follows:

1. Since the pouring into ingot molds, ingot stripping, the reheating in soaking pits and rolling in primary mills are eliminated, corresponding capital and operating costs are saved, and especially, energy requirements for this equipment are eliminated; mold melting, casting, repair and transport become unnecessary.

2. The yield of the semi-finished product from molten steel is about 2 % higher than for conventional casting and consequently, the amount of steel produced to obtain a required product tonnage can be lessened which, in turn, diminishes the equipment capacities involved, including the iron making capacity. Energy requirements are reduced proportionately.

Electrical energy requirements for continuous casting machines are small - much smaller than for the rolling operations they replace - and so are the needs for tundish preheat for which oil and off-gas can be used. Besides this, only oxygen is used for cutting purposes, and propane to shield the free liquid metal surface and the metal jets.

In less general terms, the following points can be cited as advantages of continuous casting:-

1. Yield, i.e. the ratio of usable product weight to the weight of metal accepted by the casting machine, is high. Values of 96 % and higher can be achieved.
2. Small sections can be cast thus eliminating heavy rolling operations and equipment. Sections cast may be shaped to accommodate the needs of the rolling process.
3. Quality of cast material is good requiring little or no surface dressing prior to rerolling, and its properties make it suitable for hot working procedures, with generally lower levels of admissable working intensity.
4. The cast product is hot and only small amounts of reheat are necessary before rerolling provided the timing of the processes involved can be governed closely enough.
5. Casting machine operations can be automated.
6. Product characteristicscover common as well as alloyed steel qualities.
7. Capital costs of casting plants are low.
8. Operating costs are low, compared with the respective expenditure for conventional methods.

The timing of the continuous casting operation is determined by its own operational requirements: Although the tendency for high throughput is acknowledged, there is a serious limitation since withdrawal speeds depend on permissible cooling rates consistent with product quality: they are high for small cross sections and vice versa. The corresponding limitations in the throughput of one strand for small sections are compensated for by arranging several strands in one casting machine although due to technical reasons only up to about six strands are normally combined in one machine. With two ladle outlets or with a further provision to distribute the metal, however, two casting machines can be used simultaneously.

Due to the fact that the metal in the teeming ladle cannot be kept at a sufficiently high temperature too long, the casting process is strictly limited in time. Thus an intricate interdependence exists between the ladle capacity, i.e. the output of the steel making process and the capability of the casting machine to absorb and process this given amount of liquid metal within the time allowed, to shapes of widely varying sectional forms and areas. Beyond this, there is the problem of matching the operational sequences in time, of the electric melting unit especially, if there are several furnaces engaged in the melting and refining of steel and co-operating with one casting machine.

It is this problem of operational scheduling, essential for the industrial project planner, which is now taken up.

VI. Characteristics of the continuous casting operation

The production capability of a continuous casting machine depends basically on factors residing with its design features. It is, however, also determined by the mode of its operation, i.e. the frequency of the operational cycle or the availability of the machine and, in addition, by the degree of its integration with the operational cycles of those processes governing the supply of the materials fed to the casting machine, i.e. the steelmaking process. Production rates of the casting machine are not radically influenced, however, by operational factors "downstream" of the product flow, i.e. the rolling mill, although the latter is decidedly affected by the production cycle the continuous casting machine performs, and its product.

Production of a given continuous casting machine depends on the time required to get it ready after the completion of one casting process for the beginning of the next. If for cleaning the machine 20 minutes are required, the availability would be 75 % for the case that an assumed limit of casting time of one hour is just utilized. In such a case, 18 complete casting processes could be carried out during a three-shift operation covering 24 hours. For higher availability, more casting cycles should be completed and vice-versa, and thus, the daily production depends, for a given machine and casting speed, critically on the availability of the continuous casting machine.

The availability has a limit which depends on operational factors, labor force, number of units, e.g. of tundishes or other parts, which have to be prepared for each heat, the duration of such preparation and of the pre-heating period, etc. For the actual operational cycle, a close analysis of the time required for resetting the machine must be made which should take into account the complete range of auxiliary services. It should be noted that the volume of preparatory services is likely to be larger for a larger number of strands.

The correlation between availability and production rate is superimposed on the interdependence of casting speed and the casting rate for a given section, which can be achieved with a given metal capacity of the ladle. This relationship is outlined in Table 1 offering calculated though operational values.+ Two assumptions are made for the availability, namely 50 and 80 % and for both sets, a yield of 95 % is assumed. Thus, Table 1 shows the possible daily production for billets (above) and slabs (below). Highest and lowest numbers of strands are taken into consideration as they were determined by average lowest and highest casting speeds, respectively. Where the range of casting speeds due to its small spread resulted in but a single number of strands, the production was calculated for average casting time.

A demarcation line between technically feasible and not

+ Values in the table should be considered as indicating examples. For a more rigid analysis data can be obtained from manufacturers.

recommended solutions, has been drawn in Table 1.

Table 1 underlines the advantages of a high degree of availability as also, again, of high casting speeds since these are capable of increasing the production of a given machine, even beyond another with a larger number of strands but more conventional casting speeds.

It should be understood that Table 1 is based on low carbon steels and a casting time not exceeding one hour which represents the practical maximum for bottom pouring ladles. If, say, for smaller ladle capacities, lippour ladles are used, the casting time can be extended to about 75 minutes. For the very small size of billets, e.g. the 50 mm squares, lip pouring is to be preferred if a special machine is used.

It is economically advantageous to use large ladles since the number of furnaces are thereby reduced as are initial investments in consequence of this.

To allow a qualitative assessment of average operational performance of casting machines maximum ladle sizes for twin-strand machines casting square sections of billets ranging in sizes up to 300 mm (12 inches) are plotted in Fig. 1 for lip pour and for bottom pour ladles.
Fig. 2 represents an indication of the possibilities of producing square billets ranging up to 300 mm (12 inches) sections from a given ladle size and type - lip pour and bottom pour - in casting machines with single, twin or four strands. It can be seen that for a bottom pour ladle capacity of 60 tons no smaller billets than 150 x 150 mm (6 x 6") could be cast with a four strand machine or, alternatively, 300 mm (12") blooms could be produced with a twin strand machine.

Fig. 2 may be used for a first assessment of machine characteristics with a given output target.

Fig. 2 acknowledges the longer casting time for lip pour ladles as shown in Fig. 1 in its effect on possible ladle capacities, by assuming a maximum casting time of 75 minutes as compared to an assumed restriction to 45 minutes for bottom pouring ladles. Furthermore, it is based on casting speeds and rates related to hot metal, as shown in Fig. 3 for a one strand machine.

With multiple furnace operation there might be a compulsion to reduce the duration of casting in order to assure sufficient time for servicing the machine before handling the next heat.

From Fig. 2 and 3, it can be seen that for small sections conventional arrangements severely restrict the ladle size and thus furnace size as well. In such instances, it is necessary to install more than one casting machine unit and to possibly split the heat to keep the number of furnaces as low as possible.

VII. Steelmaking and Casting Process integration

The need to closely assess production quantities when matching the steel producing and especially the HyL-process with continuous casting derives from the necessity to determine the output and thus size and cost of the individual sets of equipment. For this it is necessary, to take into account the timing of each component and their combined operation and the material flows to be handled individually as well as collectively -. Lastly the demands of the special situation of emerging countries should be kept in mind by remembering the need for comparatively small output levels for the processes in question.

The production rates, as they are determined by factors residing solely with the continuous casting machine, cannot be surpassed but should be met as closely as possible with respect to material flow and timing by the steelmaking process equipment. The ideal would obviously be established if a perfect and continuous synchronization of tapping of steel with the readiness of the casting machine to start casting could be achieved. Reality, however, would demand a certain waiting period between the time all preparations of the machine are completed and the moment casting can start. This time reduces the availability of the machine.

Electric furnace operations require careful operational planning for meeting the demands of continuous casting plus steelmaking installations for casting small heats at frequent and sufficiently small intervals. The total time required for a complete heat varies widely say between three to six hours and depends on the charge characteristics, e.g. the ratio of scrap to sponge iron, and the gangue content of the latter. Thus, there should be more than one furnace to reduce the time between casting operations and, generally, their number tends to be higher for longer lasting individual heats.

Ideally, the number of heats per day for all electrical furnaces should be equal to the number of casting operations possible during the same time, each process taken to include preparatory intervals. The number of possible casting processes depending on availability can be deduced from Table 1 by simply dividing the daily production by the ladle capacity, see Fig. 1 and 2. The number of heats per day to be refined is proportional to the number of furnaces, and decreases with increasing tap-to-tap time. Assuming the individual metal capacity of both processes to be the same, the necessary number of furnaces "n_f" for the given ladle capacity L (t) and daily production capability Pcd of the continuous casting machine (Table 1) is:

$$n_f = \frac{P_{cd} \cdot t_h}{24\ L} \qquad (1)$$

whereby the tap-to-tap time t_h (h) has still to be determined.

As an example, we assume at first, an availability of 50 % for the casting of 100 mm squares from a 100 t ladle. In Table 1 the possible casting machine production figure P_{cd} is 1220 t/d, with an assumed tap-to-tap time t_h of 6 hours, three furnaces would be required. In this case the molten metal becomes just available when the casting machine is ready to receive it. This condition would be synonymous with the highest possible output which could be realized only with perfect scheduling and synchronization of both processes: $n_f = n_{f\ max}$, i.e. the casting machine could not accomodate more furnaces if the chosen availability is upheld.+

In reality, the number of casting processes per day necessary to obtain the production given in Table 1 for the availability chosen,

$$n_c = P_{cd}/L \tag{2}$$

will differ from the possible number of melting heats per day

$$n_h = 24\ n_f/t_h \tag{3}$$

by a margin which should cover deviations from exact operational scheduling. As a rule, less furnaces should cooperate with a casting machine as is indicated by the above mentioned Eq. 3: $n_f < n_{f\ max}$. As a consequence of $n_{cc} \neq n_m$, the daily resulting production now becomes

$$P'_{cd} = P_{cd}\ n_f/n_{f\ max} \tag{4}$$

+ The daily production of 1200 t could be achieved, according to Table 1, in nine strands. It is not materially changed if eight strands are adopted at a slightly higher casting speed as is indicated in the table by the fact that for six strands, the production rises only to 1220 t if the highest casting speed is adopted.

i.e., 800 t in the example for two furnaces.

The number of casting processes n_c changes to

$$n_c' = n_c \quad {}^{n_f/n_{f\,\mathrm{max}}} \tag{5}$$

or, from the possible number of twelve to eight, in the example.

One consequence of the adjustment of the number of casting processes to the frequency of furnace heats is that a "waiting time" is interspersed between the end of the preparatory treatment and servicing of the casting machine, and the on-set of the new casting cycle. These intervals will individually be small; yet, in the course of the day, they accumulate finally to:

$$t_w = 24 \; {}^{(n_c - n_c')}/{}_{n_c} \tag{6}$$

i.e., eight hours in the example. This represents a loss in production and should as far as is practically possible, be avoided.

On the other hand, it should be noted that increasing the production by utilizing the excess output possibilities moves the operation closer to the limit where perfect timing is required for both the steelmaking and the casting facility. It is obvious that this approach to the limit can, for practical reasons, not be carried too far especially where operational experience is still to be gained.

The excess of casting capacity

$$P_{ex} = P_{cd} \; (1 - {}^{n_f}/{}_{n_{f\,\mathrm{max}}}) \tag{7}$$

which exists if less than the maximum number of furnaces is employed, can be utilized for any expansion of the melting capacity either by overloading the already existing furnaces, or by the addition of further furnace units. Increased waiting time, i.e. time in excess of the absolutely necessary preparatory period for each casting process as it is determined by availability, can often also be utilized for easing the casting machine preparations. Thus, for a sufficiently long down-period, the tundish can be preheated in the casting set-up after each casting process and, in this case, it would not be necessary to exchange the used tundish against one preheated in advance.

In the case of a more sophisticated operation, the ratio of actual casting time to the duration of the operational cycle without waiting time, can be chosen higher, i.e. 80 % instead of 50 % assumed so far. This would allow four furnaces to be installed to supply the casting machine which would produce 1600 tons of liquid metal in 16 heats.

It is evident that this extension of production calls for high precision in scheduling the operations.

Customarily, two furnaces cooperate with one casting machine but this rule should be accepted with caution since, as the relations shown above indicate, a number of features such as tap-to-tap time variations and machine availability, enter the consideration. Besides, the type of production is important since for the coverage of an extremely wide range of products, more than one machine might be required. This case would exist if the production program would call for small billets, large billets and slabs. In all probability, one casting machine for each category is required, and the furnace capacity would, therefore, be determined by the requirements of each category.

The integration of casting with steelmaking facilities is a multifaceted problem. Technically, uncertainties are introduced by e.g. the casting speed and machine availability, i.e.

factors which depend on machine operation. On the other hand, economies of investment and operation should decide the optimum solution from among the number of technically possible solutions.

So far our treatment of melting and casting operation scheduling has been quite independent of the operational "personalities" of the processes involved, i.e. the nature and quantity of the charge to the furnace namely sponge iron and scrap which, essentially, determine the tap-to-tap-time. This can vary over a wide range either due to the characteristics of the sponge iron charged which depends on the ore used, or due to the proportion of scrap in the furnace charge. The furnace operation is carried out with the addition of foreign scrap and/or of scrap resulting from cropping of the metal strands in the casting machine, or from the rolling and finishing operations downstream of the casting machine. Each of these processes is afflicted with non-recoverable losses which determine the individual process yields.

This complex is represented in Fig. 4: The charge to the electric furnace consists of sponge iron (C_{sp} , on a yearly basis since we deal with a planning procedure) and scrap from foreign sources (C_{sf}) to which return scrap (C_{sr}) is added which becomes available from other operations of the process. The electric furnace produces liquid metal (M_1), which is transferred to the casting machine to be turned into a semifinished cast product (M_c). Both operations have losses accounted for by yield figures (η_f, η_c). The cast product is assumed to be finished in two operations each accepting a portion of the total material (ϵ_A,ϵ_B) processing it with individual yields (η_A,η_B) to final products (P_A,P_B) whereby non-recoverable losses (L_A,L_B) occur, which are expressed as portions (λ_A,λ_B) of the respective total losses: Their recoverable portions add to the return flow of home scrap from the casting machine (S_c) individual quantities (S_A,S_B) which together enter the furnace again (C_{sr}). Other non-recoverable iron losses occur to the slag in the furnace (L_F) during the refining period.

The model scheme is designed in such a manner that it should be possible to cover most cases by adjusting the variables describing the details. A brief description is given in the Appendix of this report.

List of data

The following data (all on a yearly basis) define the system at hand.

1. Basic Quantities

In most projects the amount of sponge iron entering the melt shop on a yearly basis is given (C_{sp}), as well as the amount of foreign scrap to be admitted (C_{sf}).

Charge to Furnaces : Sponge Iron (C_{sp});
Foreign Scrap (C_{sf});
Return Home Scrap (C_{sr});

2. Process Variables

Yield of Casting Machine : y_C
Portion of Cast Product M_C diverted to Finishing Process A : ϵ_A
Portion of Cast Product M_C diverted to Finishing Process B : $(\epsilon_B) = 1 - \epsilon_A$
Yield of Finishing Process A : y_A
Yield of Finishing Process B : y_B
Non-Recoverable losses of Finishing Process A : $L_A = \lambda_A S_A$
Non-Recoverable losses of Finishing Process B : $L_B = \lambda_B S_B$

where S_A and S_B denote the amount of return scrap from the respective finishing operations, as does S_C for the casting process.

3. Assumed Value

Yield of Electric Furnace to Liquid Metal : y_F

Basic Calculation

With an assumed value of y_F (which is subject to further consideration), the yearly liquid metal output M_l is calculated[+] first with the help of the quantities listed above:

$$M_l = y_F \frac{C_{sp} + C_{sf}}{1 - y_F y_C \left[\frac{1}{y_C} + \epsilon_A \frac{1 - y_A}{1 + \lambda A} + (1 - \epsilon_A) \frac{1 - y_B}{1 + \lambda B} - 1 \right]} \qquad (8)$$

With M_l determined, the relation

$$r_{sp} = y_F \frac{C_{sp}}{Ml} \qquad (9)$$

gives the percentage of sponge iron in the total charge, with which the earlier choice of y_F can now be verified.

Recourse can also be made to the graphical representation Fig. 5, whereby the transition is made from annual material quantities of the iron flowsheet to the consideration of individual furnace data.

Furnace Data

In order to denote practical limits, two different basic types of sponge iron are considered:

[+] See Appendix for derivation.

1. Sponge Iron - Type A[+]

3.2 % SiO_2, 0.7 % Al_2O_3, 90 % O_2 removed, 2 % C, P < 0.100 %, derived from an ore (all Fe exists as Fe_2O_3) of roughly 66 % Fe, 2.5 % SiO_2, 0,7 % Al_2O_3 for which, available information suggests the following furnace data:

Table 2

Percent Sponge in Charge r_{sp} (%)	Fe-Yield Charge to Liquid Metal y_F	Tap-to-Tap Time t_h (min)
0	95	240
25	94	270
50	92	300
75	89	330
100	86	360

2. Sponge Iron - Type B

Similarly, the other limit is characterized by: 7 % SiO_2, 2 % Al_2O_3, 90 % O_2 removed, 2 % C, P < 0.10 %, derived from an ore with about 62.5 % Fe, 5.2 % SiO_2, 1.5 % Al_2O_3, with the following furnace data[+] :

Table 3

Percent Sponge in Charge r_{sp} (%)	Fe-Yield Charge to Liquid Metal y_F (-)	Tap-to-Tap Time t_h (min)
0	95	240

[+] Data given refer to low carbon steel and to electric furnaces with 60-80 metric ton liquid metal capacity, as exemplified by Monterrey practice. The author wishes to thank Mr. E.A. Bryan for his assistance in specifying the two characteristic types of sponge iron.

cont. Table 3

Percent Sponge in Charge r_{sp} (%)	Fe-Yield Charge to Liquid Metal y_F (-)	Ta-to-Tap Time t_h (min)
25	90	290
50	85	330
75	79	360
100	73	400

These data have been plotted in the lower part of Fig. 5 (Section 1) for both types of sponge iron+ .

To the right-hand side, Section 2 of Fig. 5 shows for the limiting sponge Types A and B, the tap-to-tap time (t_h) and the corresponding number of heats (n_h) possible for one furnace on the average during a 24 hour period.

Thus, with the value r_{sp} as found in the basic calculation and the appropriate sponge characteristics, the number of heats (n_h) per day is now known.

Both Sections 1 and 2 of Fig. 5, together with an assumption of the number of furnaces (n_f) provided in the melt shop and the number of operating days per year (n_d), yield the capacity of liquid metal for one furnace per heat.

$$F_{lh} = \frac{M_l}{n_d \cdot n_f \cdot n_h} \qquad (10)$$

with M_l being known from the basic calculation above.

Reverting to Fig. 5 and the assumed value of y_F on the appropriate scale in Section 1 - which might entail a repetition of the calculation enumerated so far with a second or

---

+ For intermediate types, an assumption has to be made as to what value of y_F could be expected for a given sponge: scrap combination in the furnace charge.

third value of y_F different from and corrected with respect to the first one assumed - the diagonal line starting from this final value of y_F is followed into Section 3 upward to a point vertically under the F_{1h} value calculated above by Eq. 3. This intersection enables one to read (on the left-hand scale of Section 3) the total iron charge per heat to one furnace (F_{ch}). Besides,

$$F_{ch} = \frac{F_{1h}}{y_F} \qquad (11)$$

For the daily material flow of one furnace unit, the values F_{1h} and F_{ch} have to be multiplied by n_h; for the material flow for the melt shop, they have to be multiplied by the product $n_h \cdot n_f$, i.e. the total number of heats per day (see example in Appendix).

Matching the Casting Machine

With F_{1h} located in Section 3, the question now arises as to the capabilities of the casting operation.

Section 4 of Fig. 5 is designed to answer this question for bottom pouring ladles in the upper part and for lip pouring ladles in the lower part.

It is assumed that billets with square cross-section are produced and cast on either a one, twin or four strand machine. In each case, the line for the longest possible casting time (t_c = 45 minutes for a bottom pour; t_c = 75 minutes for a lip pour ladle) denotes the largest possible and acceptable ladle capacity (L_1 or L_b).

Smaller casting times (t_c) correspondingly entail smaller ladle capacities. As an example, values of t_c = 30, 35 and 40 minutes, and t_c = 50 and 60 minutes are entered in the bottom pour and lip pour compartments, respectively.

The assumption, that what the furnace holds constitutes also the capacity of the ladle (L) furnishes

$$L = F_{1h} \tag{12}$$

and forms the basis for matching melting and casting.[+]

Thus, continuing vertically upward from the F_{1h} or L value, the points of intersections with the lines for the casting times denote the range of billet sizes which can be produced on the machines fitted with varying strand numbers.

If the results are acceptable, some further check has to be made on the availability of a sufficiently extended servicing period for the casting machine. To this end the total number of heats per day, namely, n_h (from Section 2, top scale) has to be multiplied by the number of furnaces (n_f as assumed) to obtain the total time - Σt_c - occupied by casting within a period of 24 hours:

$$\Sigma t_c = t_c \cdot n_h \cdot n_f \tag{13}$$

with t_c taken from Section 4. The average available servicing time, t_s, is found to be

$$t_s = \frac{1440 - \Sigma t_c}{n_h \cdot n_f} \tag{14}$$

Generally, this should not be less than about 40 minutes at least for the beginning of the operation and until the personnel has been trained although this can be tolerated for smaller casting machines.

With the assertion that t_s or the corresponding availability $t_c/(t_c + t_s)$ is acceptable, the process of planning casting

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[+] Any difference between furnace and ladle capacity, e.g. when "splitting the heat" may be accounted for by taking readings in Section 4 of Fig. 5 at values $L < F_{1h}$.

and melting operations is completed.

Iron Balance

In the following the calculations to establish the yearly ferrous material flows of melting, casting and finishing operations, is given.

1. Production

Endproduct $P_A = M_1 \; y_C y_A \epsilon_A = (I) \cdot y_A \epsilon_A$

Endproduct $P_B = M_1 \; y_C y_B (1 - \epsilon_A) = (I) \; y_B (1 - \epsilon_A)$

where the symbol

$$(I) = M_1 \cdot y_C .$$

2. Non-Recoverable Iron Losses to Slag in the Furnace

$$L_F = (C_{sp} + C_{sf} + C_{sr}) (1 - y_F)$$

or

$$L_F = M_1 \left(\frac{1}{y_F} - 1 \right)$$

3. Non-Recoverable Iron Losses of Finishing

$$L_A = \lambda_A \cdot (I) \cdot (II)$$

$$L_B = \lambda_B \cdot (I) \cdot (III)$$

where the symbols

$$(II) = \epsilon_A \frac{1 - y_A}{1 + \lambda_A}$$

$$(III) = (1 - \epsilon_A) \frac{1 - y_B}{1 + \lambda_B}$$

The contribution to the total return scrap (C_{sr}) which was used above, is given by:

4. Recoverable Losses of Finishing

$$S_A = (I) \cdot (II)$$

$$S_B = (I) \cdot (III)$$

5. Recoverable Losses of Continuous Casting

$$S_C = M_L - (I)$$

These values allow the completion of the iron balance for the system. An example is given in the Appendix of this report.

VIII. Technological outlook

The pressure of economics of the steel producing process imposes especially in areas where industrial development is essential for economic growth the need to economize in every possible way. Apart from the requirement of utilizing indigenous raw materials it is this need which exerts a strong influence on technologies in emerging countries.

Considering the example of sponge iron manufacture and processing to steel products two major areas of development can be discerned: The adjustment of the reducing step to a still greater variety of basic materials perhaps with the help of economical gasification processes of lower grade liquid or even solid fuels. The **other** area of potential advance appears to be the extension of the continuous casting method which in itself is proven in industrial applications operationally as well as economically (7) to a semi-permanent process whereby the heat stored in the metal is utilized (8) to a larger degree as is the case now, for the shaping and forming of the final product (9).

II. Acknowledgement

Thanks are due to the M.W. Kellogg Company of New York and its associated company, the Swindell Dressler Corporation of Pittsburgh for permission to use some of their material for the preparation of this paper.

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Appendix

A. Casting

Ladle capacity L is given for a predetermined casting time t_c by

$$L = A \cdot g \cdot c_{sp} \cdot t_c \qquad /1/$$

for square billets or blooms, where:

A = Cross-sectional area of cast section.

g = Specific weight of casting material at casting temperature +.

c_{sp} = Casting speed e.g. as given in Fig. 3 for square billets.

t_c = Casting time.

L becomes a maximum for largest possible t_c which, in Fig. 5, is taken as 45 minutes for bottom pour and 75 minutes for lip pour ladles. (Consistent dimensions to be used.)

For a machine with i strands, the resulting ladle capacity L_i is given by

$$L_i = i \cdot L \qquad /2/$$

For a smaller casting time t'_c, the resulting allowable ladle capacity L' becomes

$$L' = L \frac{t'_c}{t_c} \qquad /3/$$

which, for the same product dimensions, allows to determine t'_c for values L' other than those given for t_c in the graph.

\+ It is often overlooked that g changes appreciably with temperature and somewhat with composition.

For constant ladle capacity, the casting time changes with product size in accordance with the respective casting rates:

$$t'_c = t_c \frac{A \cdot c_{sp}}{(Ac_{sp})'}$$

Their ratio can be taken from the respective curve in Fig. 3.

B. Iron Flowsheet

Applicability of the system shown in Fig. 5 has been attempted by providing, apart from the intake of sponge iron (C_{sp}) and foreign scrap (C_{sf}), a certain amount of return scrap (C_{sr}) from operations from the melting stage onward, all constituting the furnace charge. With a yield (y_F) of the furnace the liquid metal capacity (M_1) and the non-recoverable losses of slag (L_F) are given, the former determining the capacity of the casting machine. With its yield (y_C) the cast metal flow (M_C) is fixed and assumed to be split into two lines; one ($\epsilon_A \cdot M_C$) constituting one type of finishing operation A producing P_A tons/year with a given yield (y_A); the second ($\epsilon_B \cdot M_C$) constituting another operation B producing P_B tons/year with a given yield (y_B).

While it is believed possible to return all of the losses of the casting process (S_C) some portions ($\lambda_A \cdot S_A$, $\lambda_B \cdot S_B$) of the losses might prove non-recoverable while by far the larger parts (S_A, S_B) of the losses in operations A and B add to the amount of return scrap entering the furnace charge.

Utilizing the following definitions:

-1- $(C_{sp} + C_{sf} + C_{sr}) \cdot y_F = M_1$

-2- $M_1 \cdot y_C = M_C$

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-3- $M_A = \epsilon_A \cdot M_C; \quad M_B = \epsilon_B \cdot M_C; \quad \epsilon_A + \epsilon_B$

-4- $P_A = M_A \cdot y_A; \quad P_B = M_B \cdot y_B$

-5- $L_A = \lambda_A \cdot S_A; \quad L_B = \lambda_B \cdot S_B$

-6- $S_A + L_A = M_A - P_A; \quad S_B + L_B = M_B - P_B$

the yearly liquid metal capacity becomes:

$$M_1 = y_F \frac{C_{sp} + C_{sf}}{1 - y_F y_C \left[\frac{1}{y_C} + \epsilon_A \frac{1 - y_A}{1 + \lambda_A} + (1 - \epsilon_A) \frac{1 - y_B}{1 + \lambda_B} - 1 \right]}$$

where the fraction behind y_F represents the total yearly charge to the furnace, according to the first calculation above. The different flows of return scrap are:

$$S_A = M_1 \cdot y_C \cdot \epsilon_A \frac{1 - y_A}{1 + \lambda_A}$$

$$S_B = M_1 \, y_C \, (1 - \epsilon_A) \frac{1 - y_B}{1 + \lambda_B}$$

$$S_C = M_1 \, (1 - y_C)$$

adding up to:

$$C_{sr} = S_A + S_B + S_C = M_1 \, y_C \left[\epsilon_A \frac{1 - y_A}{1 + \lambda_A} + (1 - \epsilon_A) \frac{1 - y_B}{1 + \lambda_B} + \frac{1}{y_C} \right.$$

so that relation -1- above can now be checked.

This set of relations can be simplified by introducing abbre

Relations:

-7- $(I) = M_1 \cdot y_C$

-8- $(II) = \varepsilon_A \frac{1 - y_A}{1 + \lambda_A}$

-9- $(III) = (1 - \varepsilon_A) \frac{1 - y_B}{1 + \lambda_B}$

so that:

$$M_1 = y_F \frac{C_{sp} + C_{sr}}{1 - y_F y_C \left[\frac{1}{y_C} + (II) + (III) - 1 \right]} \qquad /5a/$$

$$S_A = (I) \cdot (II) \qquad /6a/$$

$$S_B = (I) \cdot (III) \qquad /7a/$$

$$S_C = (I)(\frac{1}{y_C} - 1) \quad \text{or,} \quad S_C = M_1 - (I) \qquad /8a/$$

$$C_{sr} = (I)((II) + (III) + (\frac{1}{y_C} - 1)) \qquad /9a/$$

The ratio (r_{sp}) of sponge iron to total scrap is given by:

$$r_{sp} = y_F \frac{C_{sp}}{M_1} \qquad /10/$$

For the iron balance of the material flows the relations are enumerated in the body of this report.

C. Furnace Data:

In order to get the furnace data from the set of values derived above, the number of furnaces (n_f) and the number of operating days per year (n_d) have to be estimated while the determination of the number of heats (n_h) one furnace can complete in one day (depending on the ore properties and sponge:scrap ratio in the charge - percent r_{sp}) follows from Section 1 and 2 of Fig. 5.

For one heat, one furnace has the liquid metal capacity

$$F_{lh} = \frac{M_l}{n_d n_f n_h} \qquad /11/$$

where $n_f n_h$ is the total number of heats per day in the melt shop.

The charge is correspondingly

$$F_{ch} = \frac{F_{lh}}{y_F} \qquad /12/$$

with the composition of sponge, foreign and the different types of return scrap calculated by dividing the respective annual figures by $n_d n_f n_h$.

D. Example

Reverting to the iron flow diagram in Fig. 5, a numerical example is worked out for which are given:

Main Annual Quantities

C_{sp} = 264,000 tons sponge iron

C_{sf} = 6,000 tons foreign scrap

Process Variables

y_C = 0.94 Yield in Casting Machine

ϵ_A = 0.35 of Cast Metal to Production of A

$\epsilon_B = 1 - \epsilon_A$ = 0.65 of Cast Metal to Production of B

y_A = 0.90 Yield of Finishing Process A (e.g. Tube Mill)

y_B = 0.95 Yield of Finishing Process B (e.g. Small Section Mill

λ_A = 0.10 Non-Recoverable Losses of Finishing Line A

λ_B = 0.10 Non-Recoverable Losses of Finishing Line B

with an assumed value of $y_F = 0.88$ for the furnace yield to liquid metal in the furnace.

Basic Calculation

With Eq. 5, the yearly liquid metal capacity (M_1) becomes 280,000 tons. For further use, it is noted that

$$(I) = M_1 \cdot y_C = 263{,}500 \text{ tons}$$
$$(II) = 0.0318$$
$$(III) = 0.0886$$

Further with Eq. 10,

$$r_{sp} = y_F \frac{C_{sp}}{M_1} \qquad \text{i.e.,} \qquad r_{sp} = 0.88 \frac{263{,}500}{280{,}000}$$

$$r_{sp} = 0.830$$

Furnace Data

For the Type A sponge iron chosen, the choice of $y_F = 0.88$ is confirmed in Section 1 of Fig. 5.

By transition to Section 2 of Fig. 5 from r_{sp} in Section 1 the intersection with the appropriate "ore line" there allows to read at the upper scale the number of heats/day for one furnace, n_h, as 4.25 and also, the tap-to-tap time, t_h, at the lower scale - 5 hours and 40 minutes.

Assuming the number of furnaces (n_f) to be three, the capacity of the furnace should then be:

$$F_{1h} = \frac{M_1}{n_d \cdot n_f \cdot n_h} = \frac{280{,}000}{330 \cdot 3 \cdot 4.25} = 66.5 \text{ tons}$$

if it is assumed that the melt shop operates 330 days/year (n_d).

The total charge per heat would be

$$F_{ch} = \frac{F_{1h}}{y_F} = \frac{66.5}{0.88} = 75.6 \text{ tons}$$

This can be read by following the diagonal line in Section 3 denoting $y_F = 0.88$ upward until a vertical line drawn from the F_{1h}-scale downward at 66.5 tons is met, and reading the ordinate of the point of intersection on the F_{ch}-scale.

Casting Operation

With the ladle capacity for liquid metal given by $F_{1h} = 66.5$ tons, desired to be a maximum, 4" billets could be cast on a four strand machine (as shown in Section 4 of Fig. 5), with a casting time $t_c = 75$ minutes with a lip pour ladle. For a larger product but the same ladle size, the casting time would be shorter, i.e. approximately 50 minutes for 6" billets, but four strands would still be required.

Following the ordinate further, it is seen to intersect the line for maximum ladle capacity of a twin-strand machine for billets about 8" square, with the casting time being again 75 minutes. Such a machine could produce up to 12" blooms from the given lip pour ladle.

Alternatively, for a bottom pour ladle, the maximum casting time - 45 minutes - as the upper part of Section 4 shows, would allow the production of only much larger sections on a four strand machine, i.e. about 7" square billets minimum, or larger billets with consequently smaller casting time t_c. If 4" billets are to be produced, more than four strands have to be used.

This example clearly shows the difficulties involved in casting small sections from large furnaces.

The total number of heats per day is $n_h \cdot n_f = 4.25 \cdot 3 = 12.75$. With this the available servicing time for the casting machine can be found for the lip pour ladle, which would cast for a total of

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$$\Sigma t_c = t_c \cdot n_h \cdot n_f = 75 \cdot 12.75 = 975 \text{ minutes/day}$$

and the bottom pour ladle would cast for a total of

$$\Sigma t_c = t_c \cdot n_h \cdot n_f = 4\text{[illegible]} \cdot 12.75 = \text{[illegible] minutes/day.}$$

The servicing time for the casting period would, on the average, last

for the Lip Pour Ladle:

$$t_s = \frac{1440 - \Sigma t_c}{n_h \cdot n_f} = \frac{1440 - \text{[illegible]}}{12.75} = \text{[illegible]}7.\text{[illegible] minutes}$$

and for the Bottom Pour Ladle:

$$t_s = \frac{1440 - \Sigma t_c}{n_h \cdot n_f} = \frac{1440 - \text{[illegible]}}{12.75} = 67.\text{[illegible] minutes}$$

While the lip pour ladle is more accommodating to casting smaller sections, service periods tend to decrease [illegible] and, thus, the task of minimizing expenditure for casting equipment for a given furnace outlay is more complex for it than for the bottom pour ladle.

Iron Balance

If satisfied with the casting aspects, the yearly material flows can be calculated.

Production:

$$P_A = M_1 y_C y_A \epsilon_A = 280,000 \cdot 0.90 \cdot 0.94 \cdot 0.35 = 8\text{[illegible]},000 \text{ Tons}$$

$$P_B = M_1 y_C y_B (1 - \epsilon_A) = \ldots\ldots\ldots\ldots\ldots\ldots\ldots = 14\text{[illegible]},000 \text{ Tons}$$

Non-Recoverable Losses to Slag:

$L_F = M_1 \left(\frac{1}{y_F} - 1\right) = 280,000(1/0.88 - 1) = 38,000$ Tons

Non-Recoverable Losses of Finishing:

$L_A = \lambda_A \, (I) \cdot (II) = 0.10 \cdot 263,500 \cdot 0.0318 = 840$ Tons

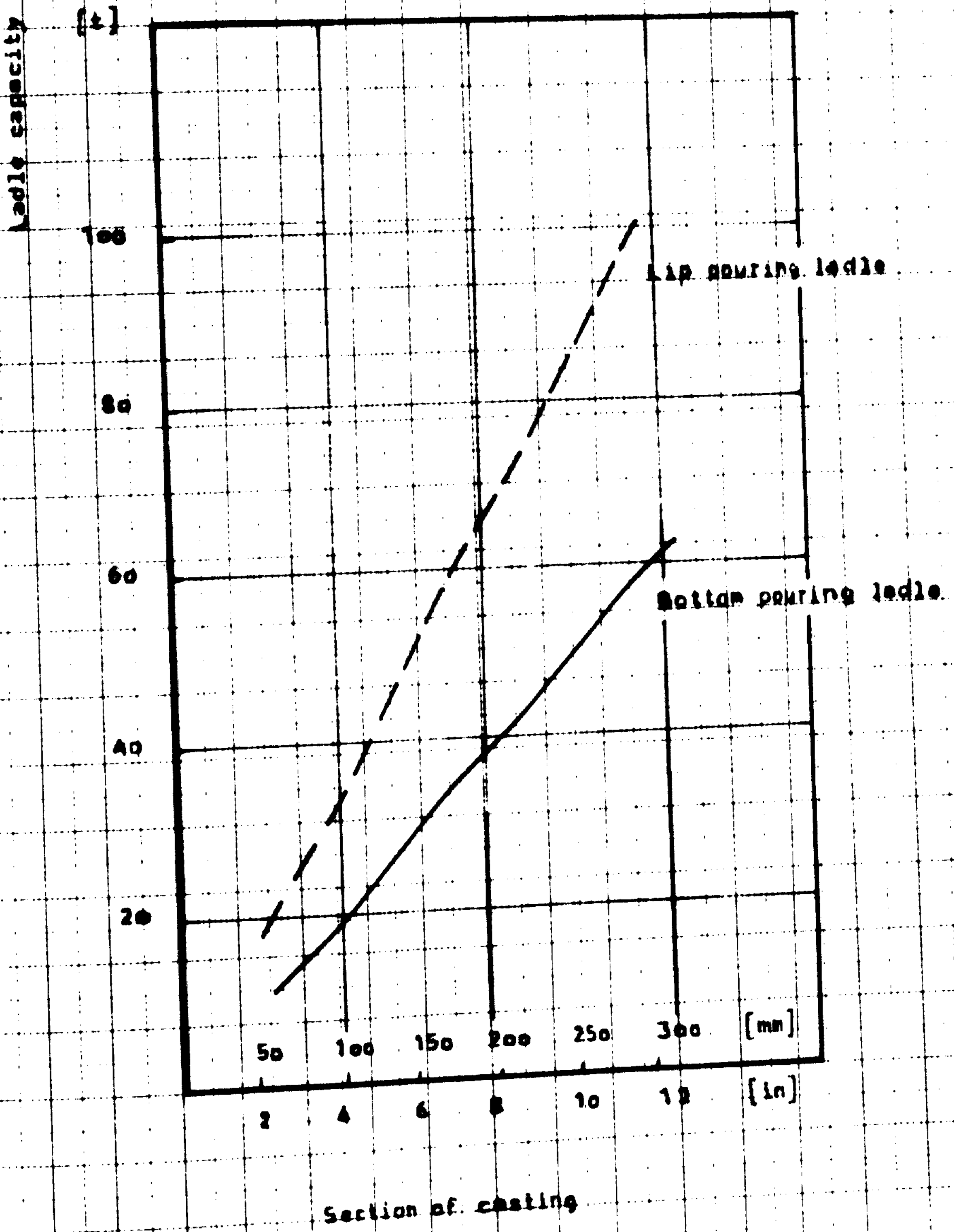
$L_B = \lambda_B \, (I) \cdot (III) = 0.10 \cdot 263,500 \cdot 0.0886 = 2,340$ Tons

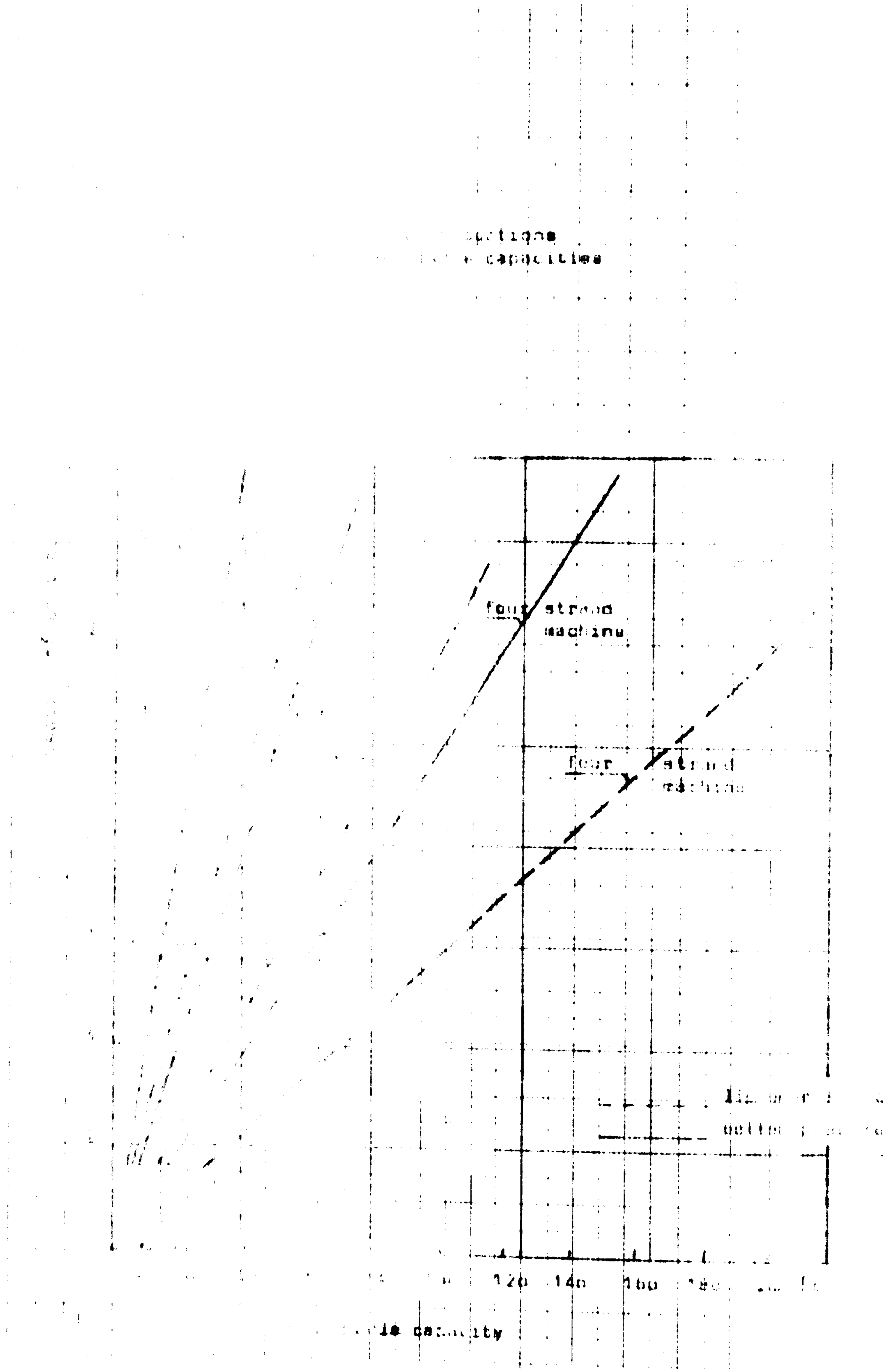
Recoverable Losses of Finishing:

$S_A = (I) \cdot (II) = 8,000$ Tons
$S_B = (I) \cdot (III) = 23,000$ Tons
$S_C = M_1 - (I) = 17,000$ Tons

with a total of 48,000 tons of return scrap re-entering the system.

Fig. 1 Ladle capacities for twin-strand continuous casting machines for different square sections

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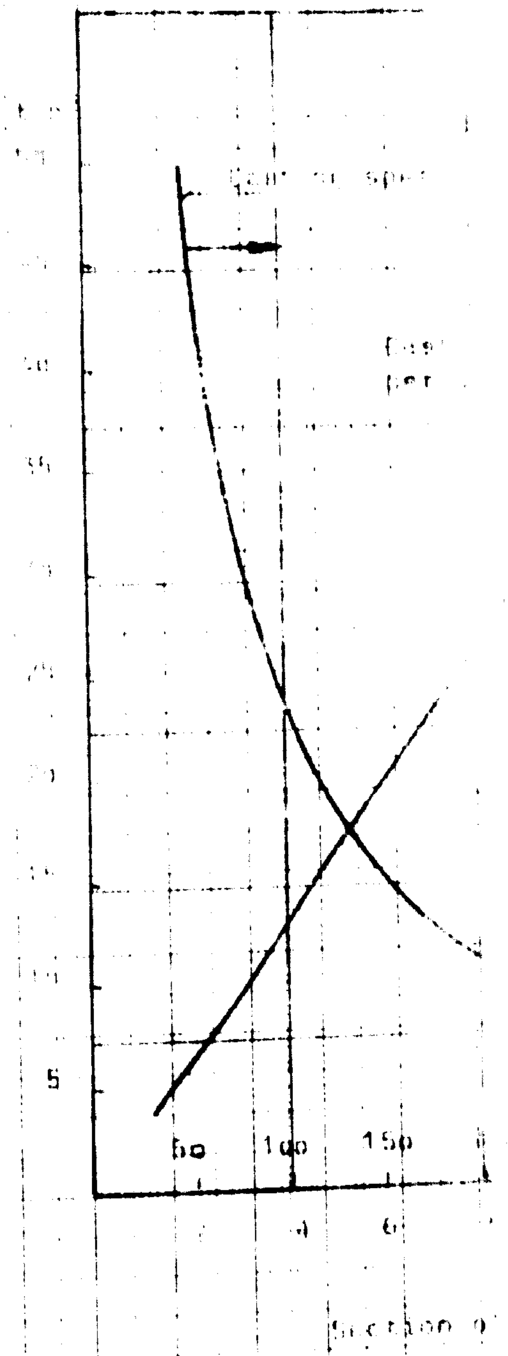

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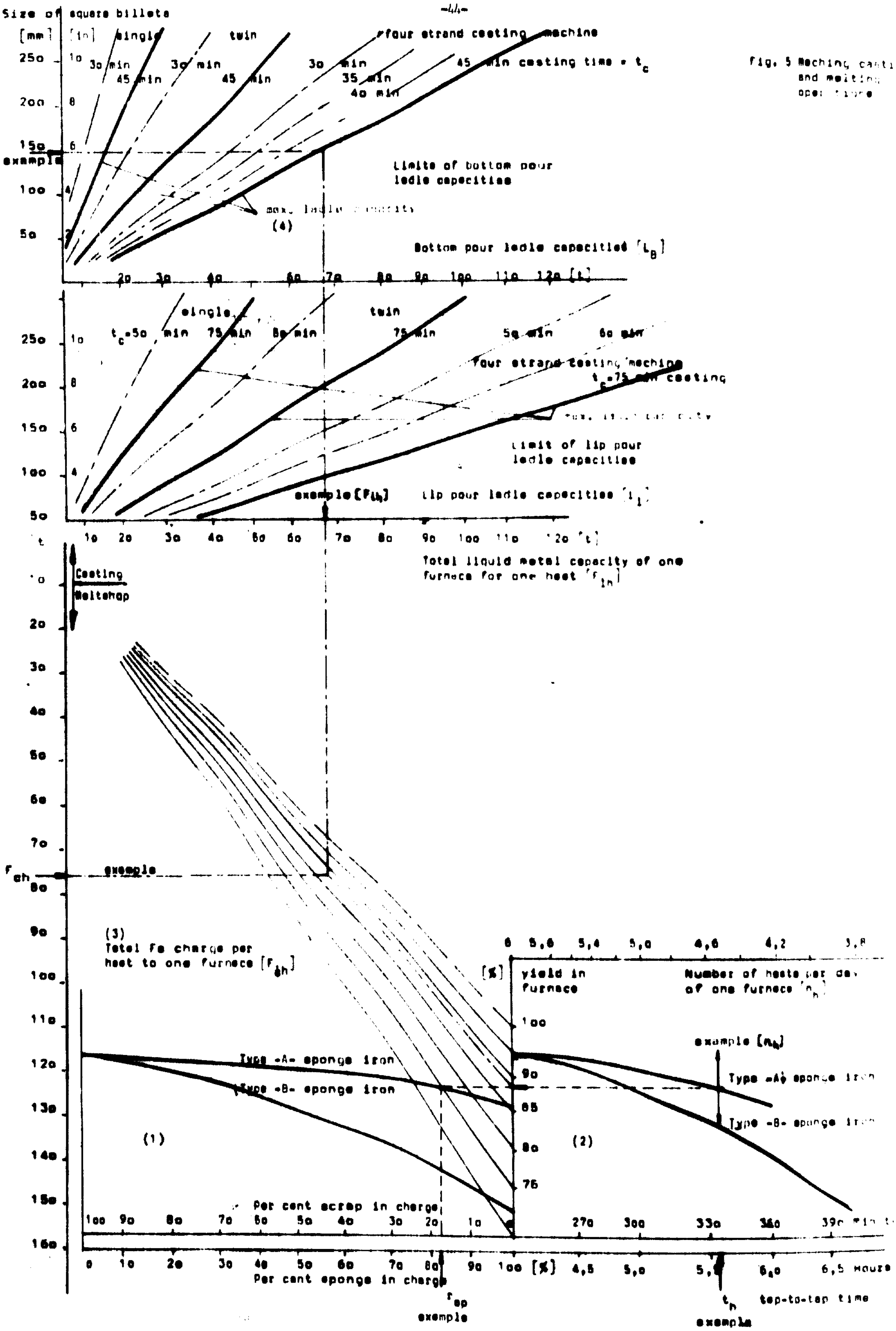

Fig. 5 Maching casting, and melting operations

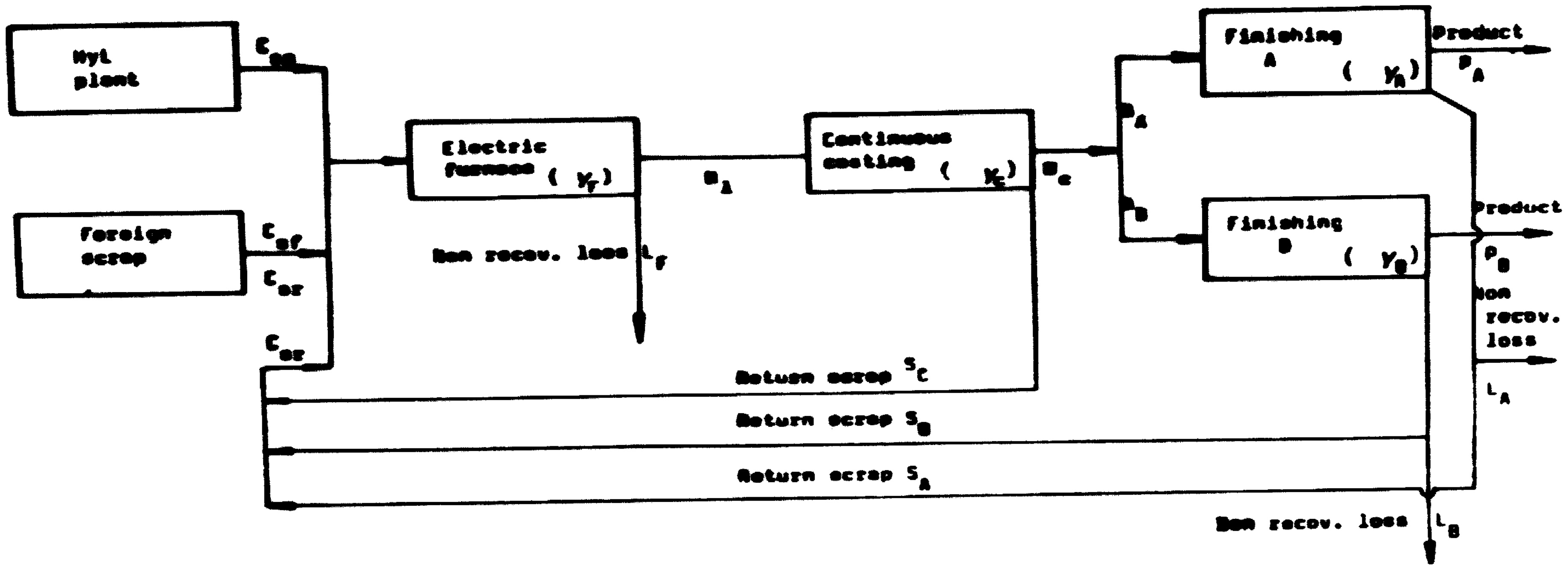

Fig. 4 Iron flow sheet

[illegible]

[illegible]

Sections	Strand [illegible]	[illegible]	[illegible]	[illegible]	Strand [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	- 1	[illegible]	[illegible] 34	- [illegible]	3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	9
[illegible]	1	3	[illegible]	[illegible]	4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	1	42	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	-	3	[illegible]	[illegible]	[illegible]	[illegible]	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]					-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible] x 7	1	43	[illegible]	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
400 x 7	-	-	-	-	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
600 x 165	-	-	-	-	-	41	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1000 x 165	-	-	-	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1200 x 165	-	-	-	-	-	-	-	-	1	46	[illegible]	[illegible]	-	33	[illegible]	331	-	40	[illegible]	3270
1500 x 200	-	-	-	-	-	-	-	-	1	37	1200	[illegible]	1	33	1200	2060	1	[illegible]	1310	2180

We regret that some of the pages in the microfiche copy of this report may not be up to the proper legibility standards even though the best possible copy was used for preparing the master fiche

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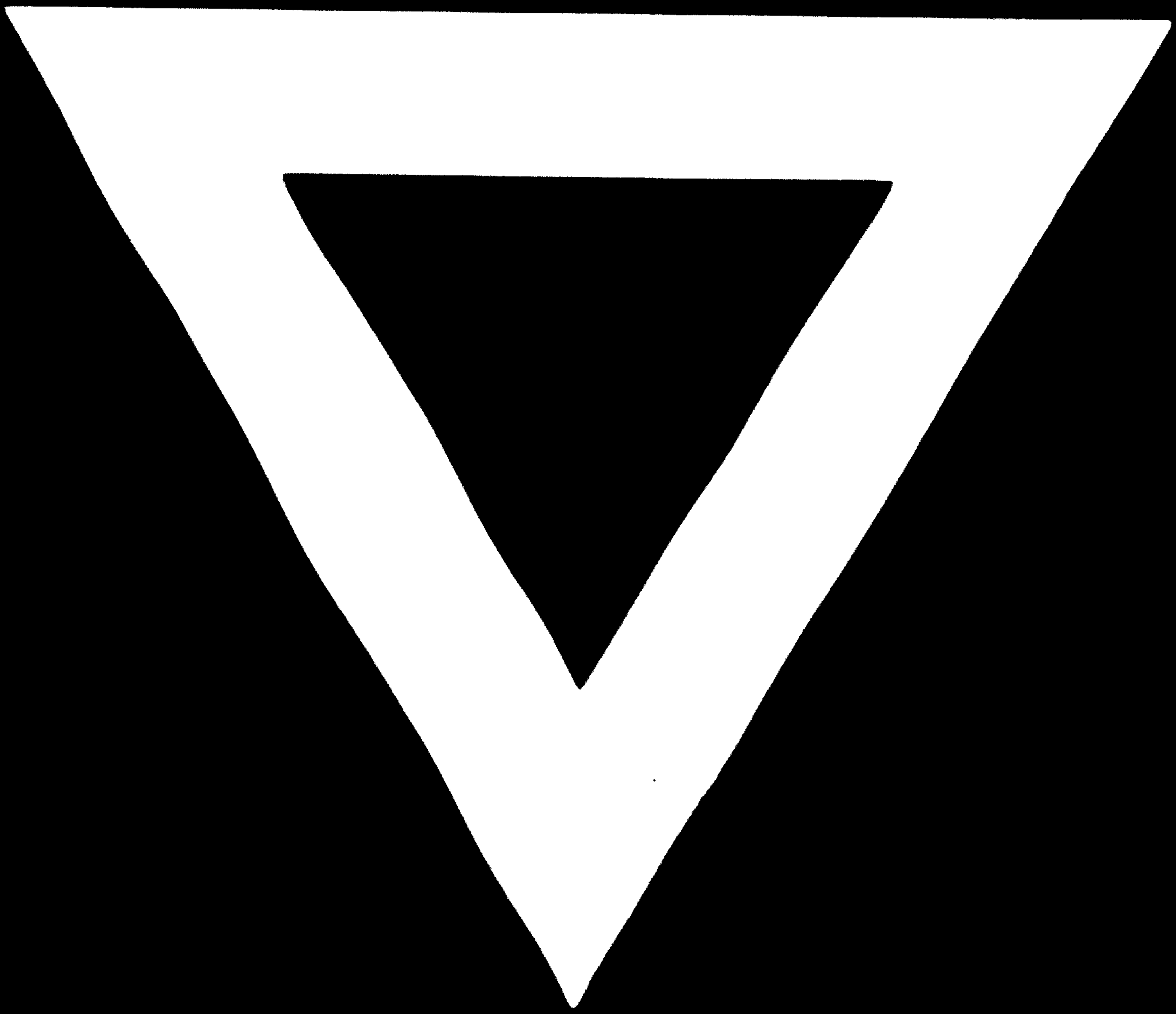

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