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THE COMPETITIVE OPEN HEARTH[1]

by

A.D. Fisher,
Canada

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SUMMARY

The modern oxygen open hearth, which evolved through challenge and innovation, enjoys a strong competitive position among today's steelmaking processes. Those open hearth shops which have taken advantage of innovations and changes in technology may be expected to continue as economic producers for many years to come. However, because of lower cost alternatives, it is unlikely that new open hearth shops will be built in the future.

The two major developments that have contributed to the progress of open hearth steelmaking during the past fifteen years are the widespread use of oxygen to speed melting and refining and the evolution of the all-basic furnace. These accomplishments may be described as being equally important because both have been used to attain the impressive results now evident in many open hearth furnaces throughout the world.

Progress is presently being made in the development of new materials handling and control techniques. Rapid charging equipment combined with new devices to speed up physical actions, such as floor clean-up, have greatly reduced congestion resulting from faster heat times. Computer scheduling of raw materials flow has improved the productivity of a number of installations. Also, new process control methods, combined with improved instrumentation, have led to increased production rates and better quality control.

* This is a summary of a paper issued under the same title as ID/WG.14/6.

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Whether [illegible] hearth facility should be modernized to meet expansion or [illegible] requires careful economic analysis. Operating, raw material [illegible] for the two approaches must be studied in detail before [illegible]

The [illegible] process for a "green field" location requires the evaluation [illegible] situation, scale of operation and product mix, cost of raw material [illegible] power costs. The SL/RN direct reduction - electric arc furnace [illegible] is an attractive alternative to the conventional process [illegible] countries now considering the installation of steelmaking fa[illegible] [illegible] established steel producers as well.

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INTRODUCTION

The modern oxygen open hearth, which evolved through challenge and innovation, enjoys a strong competitive position among today's steelmaking processes. Those open hearth shops which have taken advantage of innovations and change in technology may be expected to continue as economic producers for many years to come. However, because of lower cost alternatives, it is unlikely that new open hearth shops will be built in the future.

The two major developments that have contributed to the progress of open hearth steelmaking during the past 15 years are the widespread use of oxygen to speed melting and refining and the evolution of the all-basic furnace. These accomplishments may be described as equally important because both have been used to attain the impressive results now evident in many open hearth furnaces throughout the world. The full benefit of these achievements will be realized when they are matched by new developments in materials handling and control techniques.

This paper outlines the major developments in open hearth practice and describes some very recent work on materials handling techniques and process control. Future developments in open hearth steelmaking are also considered and, in light of this, a discussion on process selection is included.

RECENT TECHNOLOGICAL DEVELOPMENTS

A. Use of Oxygen

The production of steel is essentially a process of high temperature oxidation. The rate of oxidation of metalloids in traditional non-oxygen open hearth refining is governed by the supply of oxygen from the furnace atmosphere and oxide additions across the slag layer to the molten bath. The rates achieved are strongly dependent upon the degree of bath agitation, bath temperature and composition, the nature and quantity of the slag covering and the ability of the furnace to restore heat absorbed by endothermic additions. On the other hand, the injection of gaseous oxygen into the bath results in improved physical agitation, the rapid oxidation of impurities and the generation of heat within the bath due to the exothermic direct oxidation reaction.

Early attempts to apply gaseous oxygen to the direct oxidation of the bath are well described in the literature[1,2]. The major development in the application of oxygen in open hearths was that introduced by The Steel Company of Wales in 1953[3]. Oxygen was injected through retractable water-cooled jet probes running through the furnace roof. This method found general acceptance by open hearth operators and, by 1959, at least 100 furnaces in Canada and the United States were using roof lances[4].

Initial experience was with single orifice probes[5] and indicated that 1700 m^3/h was the upper limit for injection. Excessive splashing and refractory wall deterioration occurred at higher oxygen rates. The introduction of multi-hole probes in roof jetting practice during recent years has proved of great value in extending the utilization of oxygen for bath refining. Typical modern lance nozzle designs are shown in figure 1. This form of probe head with openings diverging from the centre-line to cover a greater bath area reduced the splashing associated with injection and enabled oxygen refining to be carried out at higher carbon levels without excessive refractory consumption. Oxygen rates of up to 5100 m^3/h on a single lance are now being used.

The intensive use of oxygen injection during the refining period has resulted in much lower process fuel requirements and shorter heat times[6]. This, in turn, has decreased the total heat losses per ton of steel. Heat times for modern oxygen open hearths of under four hours, with fuel consumptions of one million Btu's/ton, may be compared with over ten hours for traditional non-oxygen open hearths requiring over four million Btu's of fuel per ton.

The sequencing of fuel and oxygen in a modern open hearth is shown in Table I[7].

During the scrap melting period, fuel is fired at maximum when the efficiency of heat transfer from flame to cold charge is at its highest. Immediately after the addition of hot metal, oxygen injection from the roof jets is commenced; fuel is drastically reduced and, in some cases, turned off completely. Strict temperature control is maintained during this time, bath temperatures being plotted continuously against the carbon content of the bath. These readings are plotted on a graph as shown in figure 2 on which a carbon-temperature curve is reproduced. Corrective steps are taken by the operators when required; ore additions are made when the bath temperature is too high, or the firing rates are increased if the temperature is too low.

In a number of installations[8] the use of gaseous oxygen for end-burner enrichment has yielded beneficial results. Oxygen enrichment of air reduces the nitrogen load in the furnace per unit of fuel burnt; thus, higher fuel rates can be used and production rates increased with lower fuel cost per ton of steel in furnaces previously limited by regenerator and exhaust capacities.

The relationship between combustion oxygen usage and reduced heat time was demonstrated[9] using data collected during the operation of furnaces of 200 tons capacity employing 57 to 65 percent hot metal charges. Heat times were reduced by 20 minutes for every additional 1000 m^3 of oxygen introduced at the burners. The results are shown in figure 3.

Furnaces in one instance[10], were enlarged from an original 80 tons capacity to 170 tons, with little being done to increase the checker capacity or flue sizes. The furnace construction placed severe limitations on the quantity of fuel that could be fired but, by using oxygen, it was possible to increase fuel input and improve furnace productivity. These results were accompanied by a 15 percent decrease in fuel consumption per ton.

The application of oxy-fuel roof burners to accelerate scrap preheating has been widely publicized[11]. The burners, operated through the roofs, provide a means by which separate streams of fuel and oxygen are mixed and fired to provide high temperature flames of great intensity. Fuel is cut off after the hot metal addition and oxygen alone is jetted during the refining period. While scrap melting rates can be increased using this method, it has its limitations. In practice, the operation of oxy-fuel burners raises the temperature of the hearth chamber with a resulting increase in refractory wear. Noise levels created by the burners can be troublesome[12,13], also, the localized nature of the flame from oxy-fuel burners restricts their usefulness in scrap melting.

The problem of localized flame impingement and inefficient melting using roof burners has been solved to some degree by altering lance design and positioning. In some cases angled exit lances were used which improved melting efficiency and reduced disruptions to normal furnace gas flow patterns. On a 400-ton furnace, it was determined that the most effective lance height was 1 to 1.3 metres above the scrap. Using a greater lance jet height (2.3 to 3 metres) a greater area was heated; however, the heating efficiency was greatly reduced. When the jet was placed closer to the scrap (0.3 metres above the scrap), melting took place rapidly but only a small area was melted and small particles of molten metal were blown against the roof and walls of the furnace with resulting refractory damage.

The Inland Steel Company[12] reports a 15 percent increase in productivity and 12 percent decrease in fuel consumption with oxy-fuel burners and even more impressive results have been described elsewhere. It is felt, however, that some of the figures are optimistic. The difficulties outlined previously, particularly the refractory problem, have limited the application of oxy-fuel burners at The Steel Company of Canada, Limited, (Stelco). It is suggested that when intensification of scrap melting becomes necessary, an increase in end-burner capacity is preferrable to the adoption of oxy-fuel roof burners.

Dual Hearth Furnaces

The possibility of economically increasing ingot capacity with a minimum of capital expenditure generated interest, at Stelco, in the operation of an open hearth furnace with a split, or dual, hearth. In 1964 a furnace of 270 tons capacity was converted to a dual hearth furnace. The basic concept, of course, was the simultaneous refining in one hearth and preheating scrap in the other hearth by burning the CO-rich off-gases from the refining phase, thereby increasing furnace productivity. It was realized from the start that the success of the dual hearth operation depended, in large measure, upon the rapid charging of tonnage scrap and a system, described later in this paper, was developed which enabled the scrap to be charged regularly in an average time of 5 to 8 minutes.

Structurally, the furnace remained unchanged from other furnaces so far as the uptakes, checkers, and boiler were concerned. The basic differences in the dual hearth design, apart from the centre bridgewall dividing the two hearths, included additional reinforcing of the hearth, increasing the door size to accommodate the rapid charging, equipping each hearth of the furnace with its own jib crane and reagent-handling system, the use of more extensive water cooling in the furnace construction, and the installation of more cooling fan capacity. In addition, each half of the furnace was equipped with three moveable lances located along the vertical centre-line of the roof--one straight oxygen lance for refining purposes located centrally over each hearth and two oxy-fuel roof burners located on either side of each refining lance. The conventional end-burner fuel system was left undisturbed.

The initial operation of this furnace with its problems, their solutions, and some of the operating results of the first five campaigns has been described elsewhere[14]. In general, it may be stated that the dual hearth furnace gave an increase in productivity of about 30 percent over the same furnace operated in a conventional manner, the input heat consumption was about 20 percent lower, and the oxygen consumption was about 150 percent higher because of the use of oxy-fuel burners.

The dual hearth furnace at Stelco was re-converted late in 1967 to a single hearth. As far as this Company is concerned, the principle behind the dual hearth is good in theory, but the difficulties imposed by this type of operation are not compatible with the existing open hearth shops at Stelco.

B. Open Hearth Refractories

The development of the all-basic open hearth was of no lesser importance than that of the practice of using tonnage oxygen in open hearth steelmaking. High oxygen blowing rates became economically possible only with the adoption of basic refractories throughout the furnace.

The history of refractory consumption in North American open hearths is shown in figure 4. For many years following its inception, the open hearth furnace was lined predominantly with silica brick in the front, back and end walls. The roofs, too, were almost universally constructed of silica brick. Clay brick found extensive use at points which did not demand the high refractoriness of silica, especially below floor level, although, in some cases, clay bricks were used as back-up for the silica brick. Basic refractories were used very sparingly, being largely confined to use in subhearth construction and at the slag line. It was not until around 1940 that basic brick began to be substituted for silica in any quantity, first into the front and back walls, and later into the end walls. By 1946, basic wall construction was firmly established as an economical practice[15] and the first basic roof trials in North America were well underway; European open hearths had had basic roofs for some time.

Following the early work on the installation of oxygen roof lances, it became quite apparent that changes in furnace design and construction were absolutely necessary if furnace life was to be maintained or improved. Silica brick, even in its high purity form was incapable of withstanding the high driving practice accompanying the use of lances. Naturally, then, a more intensive look was taken at the use of basic brick in the roofs.

The first basic roofs, in Europe, had been of sprung arch construction, with fired chrome-magnesite brick. This construction, while quite satisfactory for small open hearth furnaces resulted in failure by buckling or collapsing when used on larger furnaces. Of the new roof designs developed to overcome this problem with basic refractories, probably the most important emerged in 1958--the Fairless hold-up, hold-down roof design[16]. The increase in the number of heats on the basic roof with this design above that normally obtained on silica roofs was significantly greater than the economic break-even point. Consequently, the installation of similar roofs in other plants, including Stelco, followed rapidly.

Other design changes, too, were gradually evolved to overcome the increased gas volume and splashing that resulted from the use of roof lances. These included raising the roofs higher above the bath, widening the port ends, enlarging the slag pockets at the expense of the checker chamber, whilst maintaining the regenerative capacity of the system by improving gas flow distribution[17], enlarging the checker chimneys to reduce the rate of plugging, and encasing the slag pockets and checkers in steel housings to decrease leakage[15].

At the time of the rapid swing to basic roofs in the late 1950's, the basic brick available was predominantly chemically-bonded and silicate-bonded. In many shops neither of these bricks proved to be completely satisfactory as open hearth practice moved to higher levels of temperature and oxygen usage; it became imperative for these shops that improved basic brick become available. The critical improvements were soon recognized to be in the direction of lower silica content, lower porosity, and higher strength at operating temperatures. These requirements led to the development of direct-bonded[18-24] brick which has been commercially available since about 1964. This brick has gained an increasing acceptance by the industry, especially in some of the high-productivity furnaces operating under the severest conditions. On the basis of individual shops, there are indications that direct-bonded brick provides the most economic refractory roof system[25]. At Steloo, however, good roof life, up to 1200 heats on the 460 ton furnace, has been obtained using 77 percent magnesia, chemically-bonded, brick. The relative economics of the two brick types has not yet been resolved in the context of Stelco's operations.

Another refractory product which has appeared recently on the market is the fused-cast basic brick. As the name implies, the constituents are melted completely and cast into shape. These bricks possess a very low porosity and very high hot strength; they are also very expensive. Tests are still being made with this brick to determine whether the increased service life will justify the higher cost. Even if fused-cast brick should not meet the desired economics of refractory costs to enable it to supplant other common refractories, it may be that its role will be to complement these other refractories in attaining the 'balanced furnace'.

According to the 'balanced furnace' concept, differential wear between various parts of the furnace should be nullified, as far as possible, by assigning the proper refractory materials and thicknesses to various zones of the furnace on the basis of wear pattern. The operating conditions of each open hearth shop, both in operating techniques and physical limitations, are peculiar to that shop and the refractory utilization pattern must be tailored to that shop. Work towards the 'balanced furnace' at Stelco has evolved to the following. Roofs are mainly constructed of chemically-bonded brick containing 77 percent magnesia and all of the oxygen furnaces are equipped with extensive fan installations over their roofs to ensure that the outer face of the brick is kept clean, i.e. no insulating build-up of dust. The furnace walls, which employ extensive water cooling, e.g. the [illegible] ton furnace uses 17000 litres/min., are of burned basic brick containing 40 percent magnesia, although burned brick containing 96 percent magnesia is used at the slag line. The protection of the checker brick from the high temperatures of the waste gases has required the use of water sprays which are activated by radiomatic 'eyes' sighted on the brick[26]. The hearth bottoms are now being constructed of burned 97 to 98 percent magnesia brick, replacing the former rammed bottoms[27]. This construction is somewhat more economical and, so far, its performance appears to be better. Another type of bottom is currently being successfully tested in the United States--high fired dolomite rammed into place. The dolomite is considerably less expensive than the magnesite usually employed for this purpose.

Spray maintenance is a very important supplementary aid in achieving the 'balanced furnace'. Gunning is probably the most popular procedure and both hot and cold (below red heat) gunning are possible. Traditionally, the aggregate refractories used in this application are more expensive per cubic foot of material than the equivalent brick would be. The cost savings in gunning lie in the lower labour costs, the more complete utilization of the total furnace refractories, through running repairs to balance out the wear pattern, and increased furnace availability. Any gunning programme, of course, needs to be continuously reviewed on the basis of economics. The importance of gunning in open hearth maintenance is evidenced by the number of gunning programmes described in the literature[28-32]. The gunning programme at Stelco has extended roof life by at least 20 to 25 percent. Roof gunning is begun when the roof first begins to show severe wear areas, as evidenced by hot spots observed during furnace top inspection. These areas are selectively gunned, at first infrequently, and then more frequently and more extensively as the furnace gets older. The roof life is prolonged to match the wear life of the other refractories in the furnace. As an example of the amount of roof gunning required, the average life of the 460 ton furnace over the past four campaigns was 1144 heats and this required less than 1 Kg/ton of gunning refractory.

The refractory consumption for Stelco's oxygen open hearth shop may be seen in Table II. Promising new refractories and refractory practices are continuously being tested and developed and those which show an economic advantage are adopted so that the figures shown in Table II can only be expected to decrease.

C. Materials Handling

As discussed earlier, the intensive use of oxygen in modern open hearths has led to significant increases in furnace productivity. As heat times become shorter and shorter an ever-increasing need for improved materials handling and shop scheduling techniques has become apparent. In fact, these factors now represent the principal hurdle in increasing the productivity of modern open hearth shops.

The first, and probably most significant development arising from intensive oxygen usage, has been the trend towards larger heat sizes. Fewer furnaces producing the same total tonnage reduce logistic problems and, ultimately, the operating cost per ton. An added benefit of larger heats is reduced heat loss and resultant lower fuel consumption per ton of steel. During the period from 1950 to 1960, for instance, the number of open hearths operated by the United States Steel Corporation[15] decreased from 305 to 250, yet their open hearth ingot capacity increased from 26 million tons to 36 million tons. Over the same period the average heat size increased from 134 tons to 188 tons and the average tap-to-tap time decreased from 12 hours and 5 minutes to 9 hours and 43 minutes. A similar trend has been experienced in the U.S.S.R.

During the period from 1950 to 1966 the average open hearth heat size has increased from 115 tons to 216 tons[33] and furnace sizes of up to 900 tons are now in use.

To take advantage of the potential gains from the application of gaseous oxygen a number of shops have introduced new techniques and equipment to increase the rate of scrap charging to the furnace. In most cases, more charging buggies and boxes and additional floor-type charging machines have been added to reduce delays in scrap charging. A novel charging technique has been developed in Czechoslovakia[34], in which scrap is discharged into the furnace by large buggies equipped with tilting and shaking devices. Perhaps the most significant development to arise from Stelco's experience with the Dual Hearth Process was the introduction of a rapid-floor charging mechanism. A diagram of the box used is shown in figure 5.

These boxes have a volume of 8.5 cubic metres and are operated by the standard floor charging machine. The box is positioned in front of the furnaces and is emptied of its contents by the action of the charging car ram pushing the rear movable wall through the box discharging the scrap over the front lowered ramp into the furnace. Larger furnace doors were installed in conjunction with this technique. The charging rate using these boxes is 12 tons/minute. A Germany company is presently using a roof charging technique which has the added benefit of reducing floor congestion[35].

In addition to these developments, other materials handling facilities have been improved in modern open hearth shops. Additional hot metal cranes and new ladling stations have been added to handle incoming materials. Extra pit cranes, ladles, preheat stations, ingot buggies and mould service have been installed on the pouring side. A significant development in materials handling has been the elimination of slag pots for either front or rear flushing furnaces[15]. Front flushing for example, when followed by slag removal from beneath the furnace by loaders and subsequent withdrawal from the pit in trucks or rail cars has greatly reduced confusion in the pit areas.

Computer scheduling of materials flow has also led to production increases. Computers are presently being used at the Yawata Steel plant in Japan[36] for inventory control of raw materials, efficient utilization of hot-metal transport ladles, scheduling of tapping times and regulating mould shop and stripper operations. At the Kawasaki Iron Works[37] computers being used for materials flow and process control have increased operational efficiency, reduced the number of furnace additives and have produced a higher uniform quality of products.

D. Instrumentation

Coupled with faster refining and the introduction of process control computers has been the development of rapid sensing and control devices. In some cases, combustion and waste gas control systems have been completely automated[7].

The development of the immersion thermocouple and rapid carbon analysis techniques such as the thermo carb[38] and the thermal arrest carbon determination have resulted in improved process control. Rapid response vacuum spectographs are becoming a standard tool for melters programming ladle additons.

E. Stelco's 460 Ton Furnace

By way of a summary for this discussion of recent technological developments in open hearth steelmaking, reference is made to Stelco's experiences with the 460 ton oxygen open hearth. Table III shows the operating performance of this furnace from 1962 to 1967.

This example demonstrates the ever-changing nature of oxygen open hearth practice and the benefits to be realized through experience and progressive innovation. Modifications to the furnace operation are continuing and will result in further improvements in its performance.

FUTURE TECHNOLOGICAL DEVELOPMENTS

The improvements in open hearth practice over the past ten years have indeed been impressive. As this paper has indicated, these gains have been due primarily to the application of gaseous oxygen and the use of basic refractories. Although improvements have been made in materials handling and process control procedures, it is felt that their development has not kept pace with the major innovations. The full benefit of faster heat times will be realized with the optimization of these procedures.

The trend towards computer control of materials flow is certain to continue and will further improve the efficiency of modern oxygen open hearth operations. The scheduling of operations from the blast furnace through to the finishing mills will soon become commonplace. The role of the melter in the open hearth is changing rapidly from that of an artisan to that of a communications and control expert. His experience is still required for bottom repair and assessment of furnace condition but, in a modern shop, this is his only direct association with the furnace. The melting and refining is carried out by the first helper using push-button controls. The 'melter', on the other hand, is spending more of his time co-ordinating furnace operation and materials flow using modern communication systems. Incidentally, the control system for a modern open hearth need not be an elaborate computer centre. At Stelco, it has been found that rapid communication and simple print-out of essential data to the appropriate personnel are paramount in establishing an efficient practice. For instance, automatic weighing of blast furnace hot metal with simultaneous teletype print-out of the weight and cast analysis in the melter's office can lead to much improved operating control. The complexity of the optimum control system, of course, will depend largely on the number of furnaces operating in a shop, the number of physical actions required and certainly the shop product mix. Monte Carlo[39] simulation methods can be of great assistance in sorting out materials flow patterns and in choosing a control system.

Further modernization of the techniques and equipment used in performing physical actions in or about the furnace is required. Certain fixed or 'furnace inactive' periods, such as the fettling time, are now receiving serious attention. In non-oxygen open hearth practice, where 12 hour heat times are encountered, a one-hour fettling period represents a mere eight percent of the heat cycle. In modern shops, the same operation represents 25 percent of the heat time. Thus, seemingly minor improvements, such as spring-loaded pay-out wheels for oxygen scarfing hoses, larger diameter throwing wheels for dolomite machines and new techniques for rapid tap hole repair, can lead to significant productivity gains in oxygen open hearths.

Oxygen furnaces with high firing capacities, using high percentages of hot metal, have encountered another fixed or 'inactive' furnace period. The period 'start charge to hot metal addition' becomes shorter with higher hot metal percentages. The optimum time is governed by the time required to adequately preheat the scrap charge. The optimum and actual start charge to hot metal times for Stelco's 460 ton open hearth are shown in figure 6.

Above 60 percent hot metal the actual meltdown period becomes longer than the optimum. Two operations, scrap charging and cleanup (30 minutes) and building furnace banks (30 minutes) become rate-controlling above 60 percent hot metal. Fast charging, which is not used on this furnace would reduce this period by about 12 minutes. Work is progressing on the design of rapid banking machines and the use of heavier and speedier equipment for floor cleanup. The ultimate solution, of course, would be a furnace having permanent banks. Such a furnace, equipped with rapid charging, could produce heats every three hours. For the 460 ton furnace this would mean a productivity of approximately 155 ingot tons per hour (tap-to-tap).

Process control techniques have been initiated, as discussed earlier, and will continue to develop. A simple control device (in the form of a slide rule) has been developed at Stelco. It enables the melter to regulate his scrap melt fuel rate depending on the percent hot metal in the charge, the percent silicon in the hot metal, the hot metal track time from blast furnace to open hearth and the scrap melting time. Conversely, if the melter wishes to fire fuel at maximum, the rule can be operated in the reverse direction, using the same parameters, to determine the optimum hot metal percentage in the charge. The use of this slide rule (the calculation is also available to the melter on a computer) has resulted in lower fuel consumption, and fewer corrective actions during the refine period.

It is doubtful that the open hearth will require the same degree of end-point prediction control that is now being exhaustively tested in the LD process. The slower oxygen blowing rates and the greater accessibility of the open hearth bath for regular sampling and temperature measurement gives the open hearth a type of 'built-in' dynamic control. New techniques for the controlled addition of cooling additions, such as lime, recycled open hearth precipitator dust, ore, or reduced pellets, through oxygen lances or separate mechanisms will undoubtedly be developed. This type of cooling correction in combination with the existing fuel source will be used to keep the carbon temperature relationship on line during the refining period. Within a few years devices for continuously measuring and recording bath temperature, carbon and oxygen[40] will be available to steelmakers and these combined with refined corrective techniques, will place the open hearth on full dynamic control.

PROCESS SELECTION

A. Open Hearth Modernization or Replacement

Progressive industries are continuously faced with expansion and replacement decisions. If the Industry as a whole and individual organizations within the Industry are to remain competitive, the costs of producing a particular product or products must be kept to a minimum. Each producer must be aware of the ever-changing technology and should be assessing his operation in relation to others on a continuing basis.

Those companies with modern open hearth facilities faced, and will continue to face, a rather complicated decision process. The situation is summarized in the following example. Consider a company which is presently producing 1,000,000 ingot tons per year using modern oxygen open hearths and whose expected demand requires that the company expand its steelmaking capacity to 1,500,000 ingot tons per year. Engineering estimates for increasing the open hearth capacity by 500,000 tons, principally through the modernization of materials handling techniques and equipment, are $7,500,000. The alternative is to replace the open hearths by an LD shop consisting of two 150 ton converters, one operating, with an annual capacity of 1,500,000 tons at a cost of $33,000,000. A summary of the expected production costs of these two approaches is shown in Table IV.

In the example cited in Table IV, the raw materials costs for the open hearth are lower due to its greater use of scrap; 60 percent hot metal practice versus greater than 70 percent for the LD. It is assumed that the present blast furnace and coke oven facilities can handle either approach. If not, capital charges for increasing the capacities in these areas must be included in the raw material charge. This additional cost would be less for the open hearth because of its lower hot metal requirements. The operating costs for the two processes are expected to be approximately equal. The capital charges at 12 percent interest are, respectively, $0.6 per annual ton for the open hearth and $2.60 per annual ton for the LD. The expected total production costs ($49.60 vs. $52.10) would favour expansion via increased open hearth capacity.

The example, of course, is hypothetical and does not mean that modernization of existing oxygen open hearth facilities is always the best alternative. Each open hearth operation is characterized by its own cost situation. For instance, if expected operating costs of the open hearth were $17.00, instead of the $13.00 cited above, the decision would be reversed. In any event, it is essential that an analysis of this sort be performed before modernization or replacement of existing operations takes place.

B. Green Field Locations

The process of selecting steelmaking facilities for green field sites also requires careful analysis. The market situation, availability and costs of raw materials, power costs, scale of operation and location of plant site must all be thoroughly studied before an evaluation of the steelmaking alternatives can commence. The large capital costs of new open hearth installations rules out the selection of this process. The choice of an LD operation versus an electric furnace installation, or even a combination of the two, is another matter.

The LD process is a hot metal user and, as such, must be linked to coke oven and blast furnace facilities. To realize the economies of modern blast furnace--LD combinations it is generally considered that the facilities must have a minimum annual capacity of 1,000,000 tons. Operations smaller than this are seriously challenged by modern electric furnace operations using 100 percent scrap. The answer, of course, is not as simple as the above statements would indicate. The majority of the statistics on steelmaking facilities have their origin in large developed countries where huge hot metal oriented steel complexes are producing the major portion of the hot and cold rolled products, with the smaller electric furnace operations producing mainly specialty grades. The wider use of electric furnaces has been limited by power costs, their complete dependence upon scrap and their inherent inability to produce low-nitrogen deep drawing steels.

This set of circumstances presents a quandary to the developing nation which wishes to produce a wide range of products but has a small total market and virtually no scrap supply. Perhaps the most attractive approach to steelmaking in this situation is the continuous charging of reduced iron ore, possibly in the form of pellets, into an electric arc furnace[41]. This process has just been developed at The Steel Company of Canada's Premier Works and would appear to offer operating and capital costs per ton of steel which are more than competitive[42] with those enjoyed by large-scale steelmaking complexes based on the traditional combinations of blast furnace and oxygen open hearths or LD converters.

Moreover, this approach solves the problem of insufficient scrap availability, does not require expensive coking coals and coke plants and provides the possibility of gradually escalating the production capacity as the demand for steel increases, thereby avoiding at all times, excessively large outlays of capital and over-capacity situations. This new steelmaking process is expected to become completely competitive, even to the production of deep drawing steels, and could become a standard practice not only in those countries just beginning to produce their own steel but, also, in those nations whose steelmaking industries are already well established.

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TABLE I: Operations Sequence for a Modern Oxygen Open Hearth

	Fuel Use, MM Kcal/hr.	Oxygen Input, m^3/min.
Start charge to first hot metal	94	0
First hot metal to finish iron	62	136
Finish iron to 0.50 carbon	0-25	227
0.50 carbon to 0.20 carbon	62	141
0.20 carbon to 0.10 carbon	75	70
5 minutes before tap	88	0

TABLE II: Refractory Consumption, Stelco Oxygen Open Hearths[7]

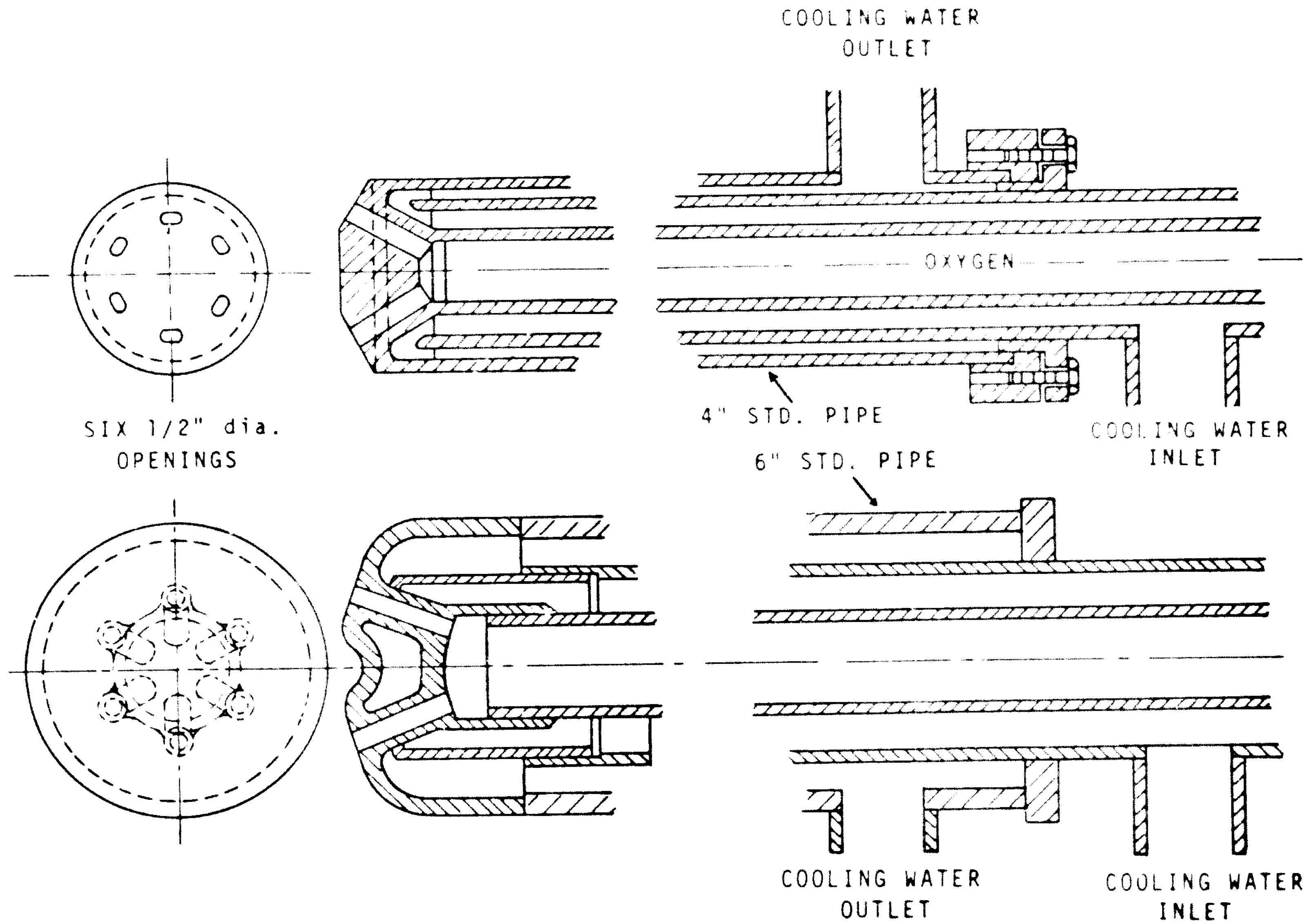
Refractory	Consumption total Kg/ton
Basic brick	3.60
Clay brick	0.99
Total brick	4.59
Basic spray	3.00

TABLE III: Summary of Operating Data for Stelco's 460 Ton Furnace Over 14 Campaigns

Campaign	Heats	Tons	Heat Size	C-T	T-T	Interval	Tons/hr	% Metal Hot	% Metal Cold	Yield	Kcal x 10^6	O_2 m^3/ton
4	412	190,000	462	3:20	4:39	1:19	99.5	54.1	4.1	86.0	0.535	33.3
5	445	201,500	452	3:19	5:02	1:43	89.6	55.1	4.6	87.3	0.543	31.2
6	434	199,500	460	3:19	4:43	1:24	98.0	55.4	4.4	86.4	0.496	30.7
7	609	281,000	462	3:18	4:36	1:18	100.5	53.0	5.7	86.8	0.516	33.4
8	540	251,000	464	3:14	4:20	1:06	107.5	56.8	3.4	87.8	0.472	34.3
9	525	240,000	458	3:14	4:12	:58	109.0	56.2	2.9	87.2	0.442	35.3
10	406	186,000	459	3:18	4:14	:56	108.3	55.5	3.7	87.6	0.498	38.4
11	649	297,000	458	3:37	4:34	:57	100.0	53.6	4.1	88.1	0.587	37.7
12	774	351,000	454	3:38	4:35	:57	99.2	52.7	7.4	87.7	0.574	36.1
13	639	295,000	462	3:32	4:28	:56	103.1	55.9	3.7	88.4	0.551	35.0
14	1123	522,000	464	3:15	4:05	:50	113.2	56.4	4.8	88.9	0.483	35.1
15	1085	498,000	460	3:23	4:12	:49	109.6	57.3	3.7	88.8	0.447	33.9
16	1290	586,000	454	3:18	4:15	:57	106.8	56.8	5.6	88.3	0.472	34.4
17	1077	489,000	454	3:15	4:13	:58	107.6	56.4	4.3	88.4	0.457	34.1

TABLE IV: Production Costs; Open Hearth Modernization vs. Replacement by LD

Process	Open Hearth	LD
Annual capacity, tons	1,500,000	1,500,000
Raw materials costs	$36.0	$37.0
Operating costs	$13.0	$12.5
Capital charge (12%)	$ 0.6	$ 2.6
Total production costs	$49.6	$52.1



COOLING WATER
OUTLET
OXYGEN
SIX 1/2" dia.
OPENINGS
4" STD. PIPE
COOLING WATER
INLET
6" STD. PIPE
COOLING WATER
OUTLET
COOLING WATER
INLET

Figure 2

Typical carbon-temperature control chart for a modern oxygen open hearth

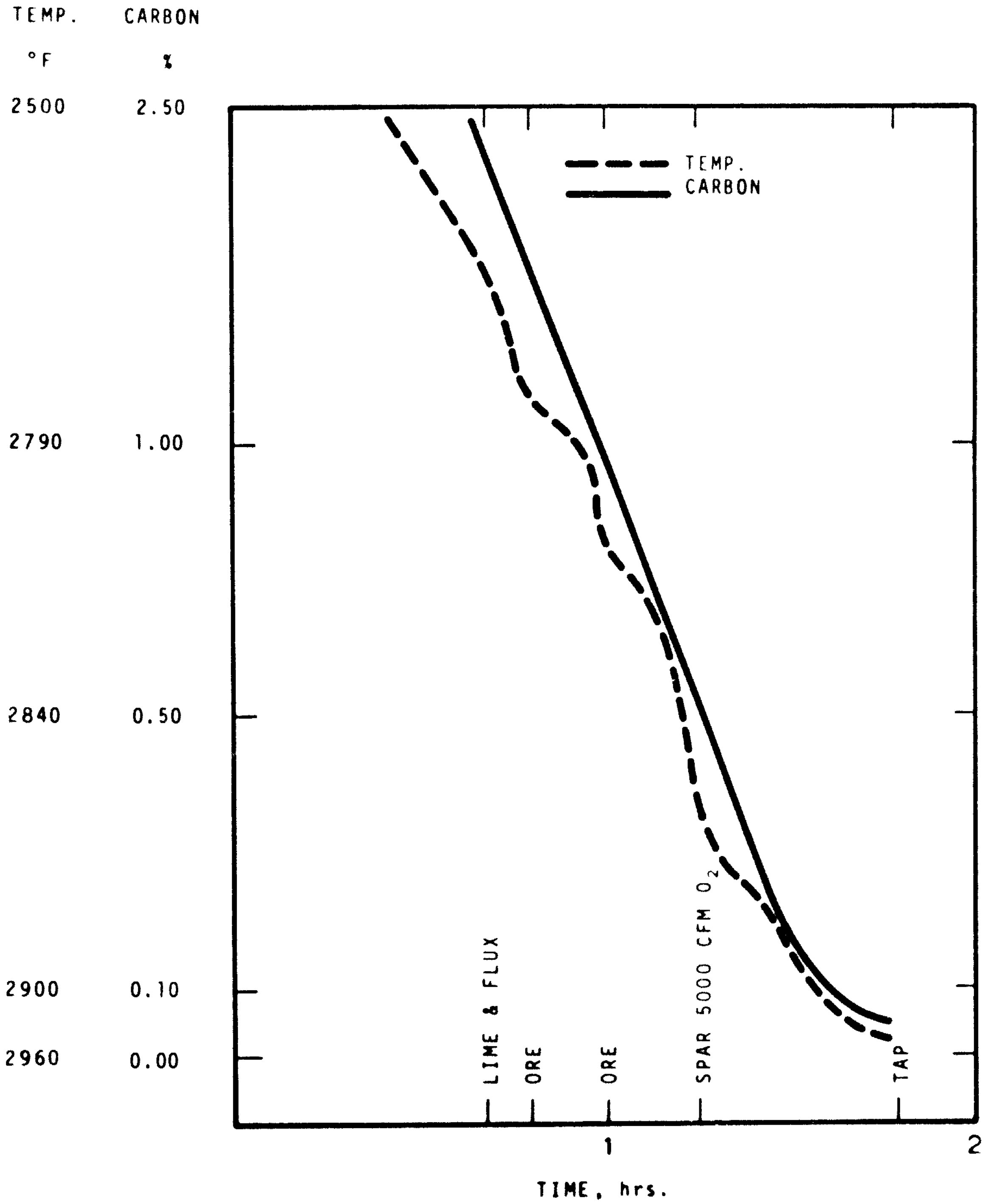


Figure 3

Ratio of melting time to oxygen consumption

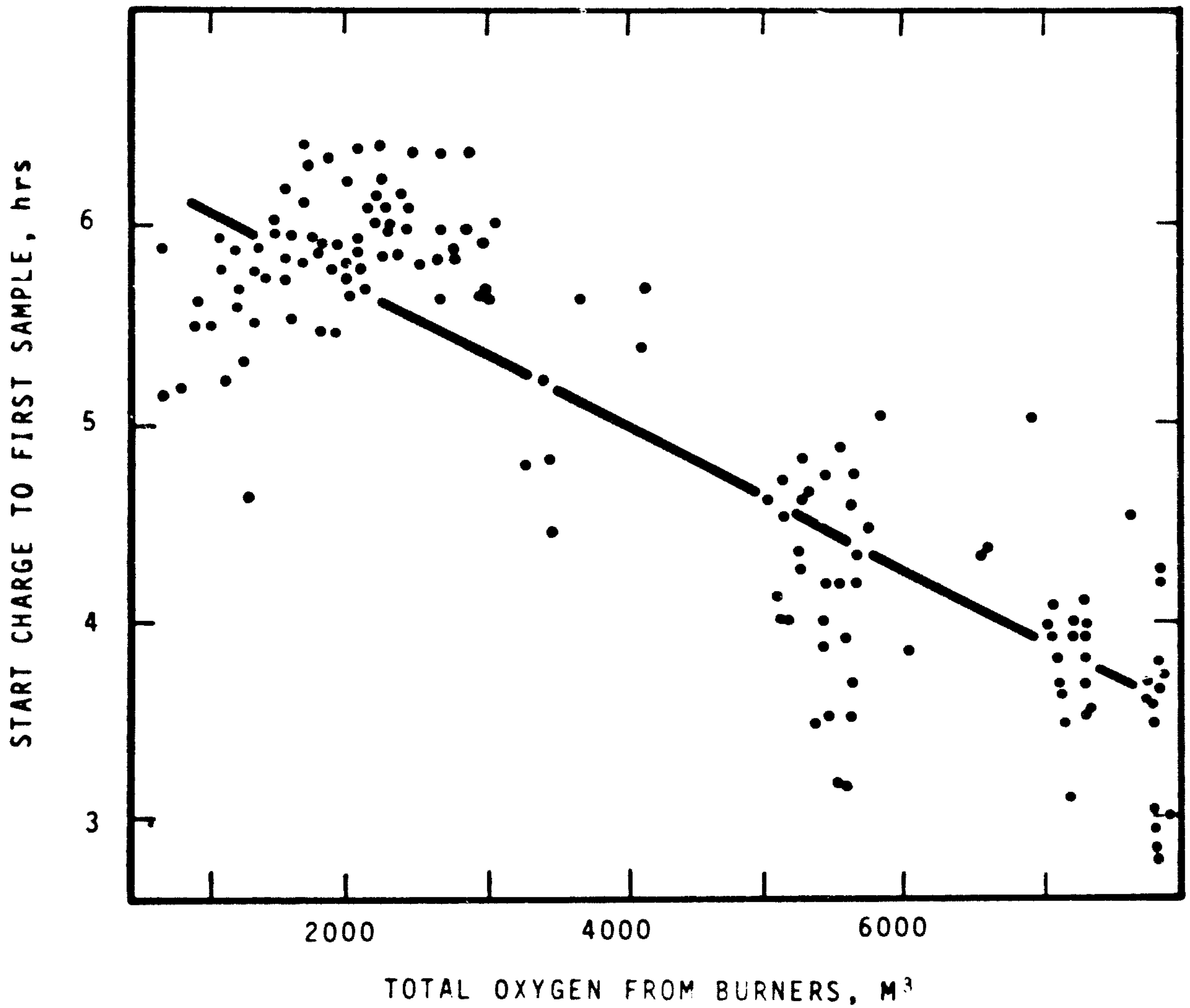
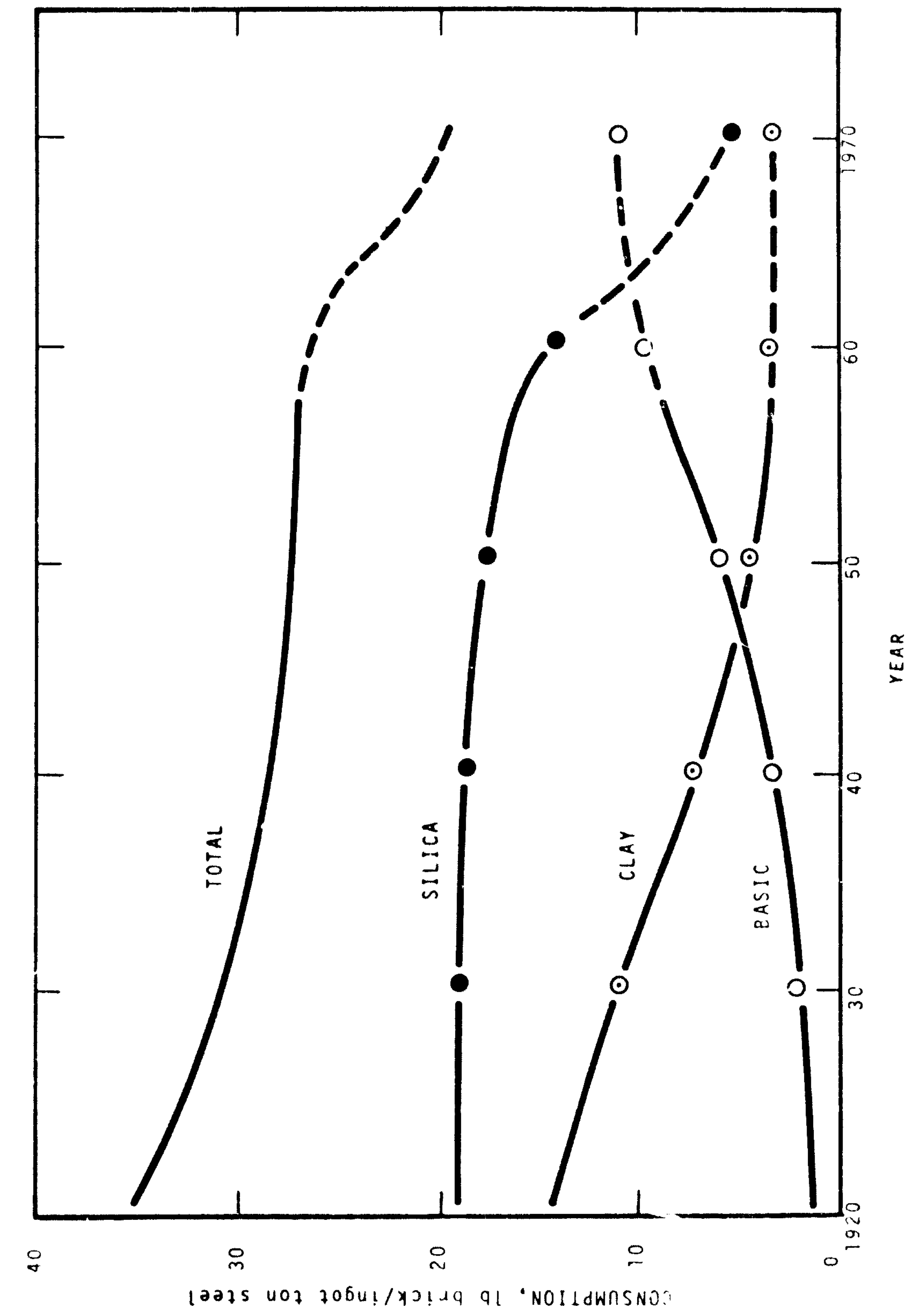


Figure 4

Trends in open hearth refractory consumption (Debenham[3])



Figure

Rapid charge box developed by the Steel Company of Canada

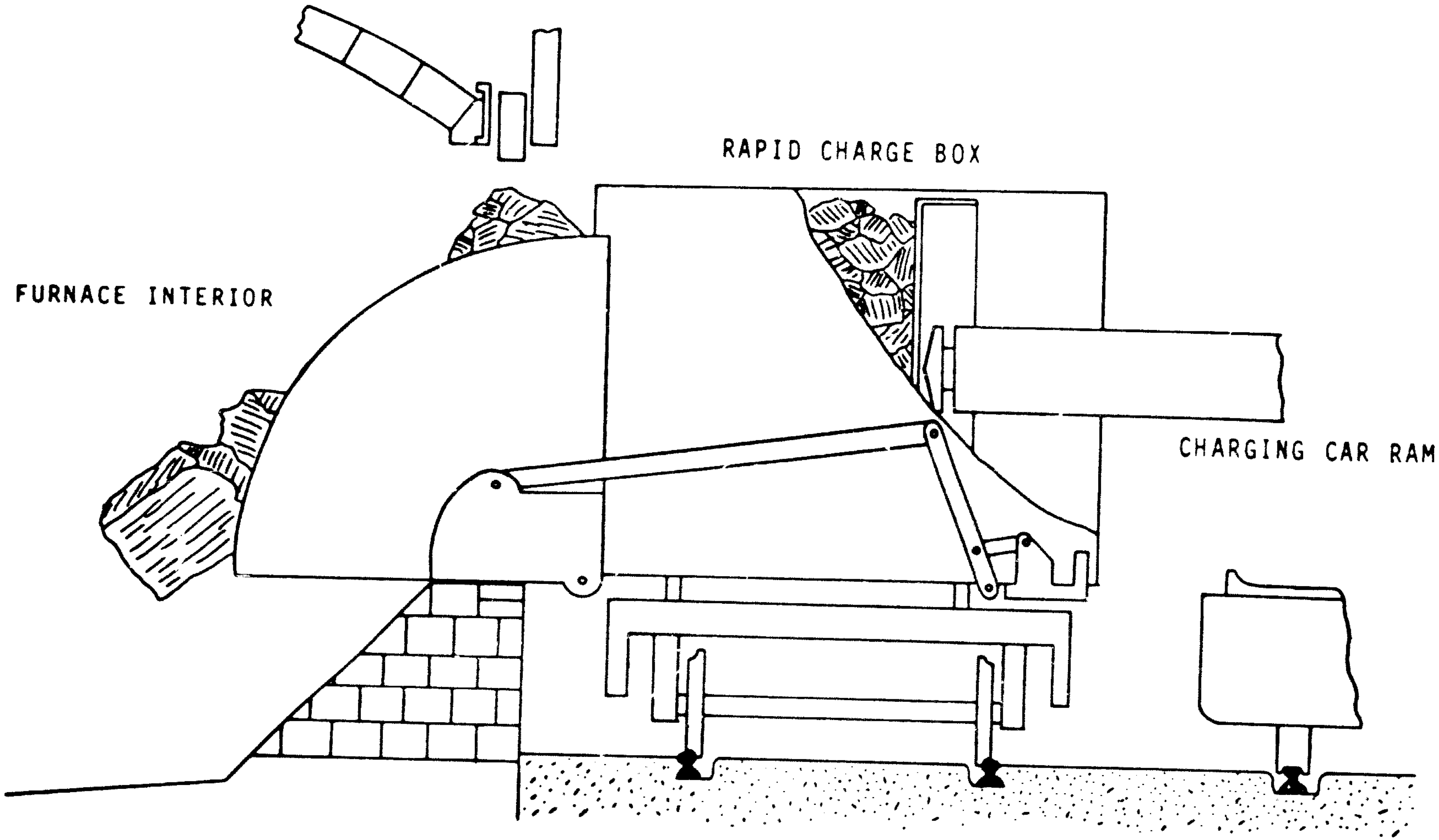
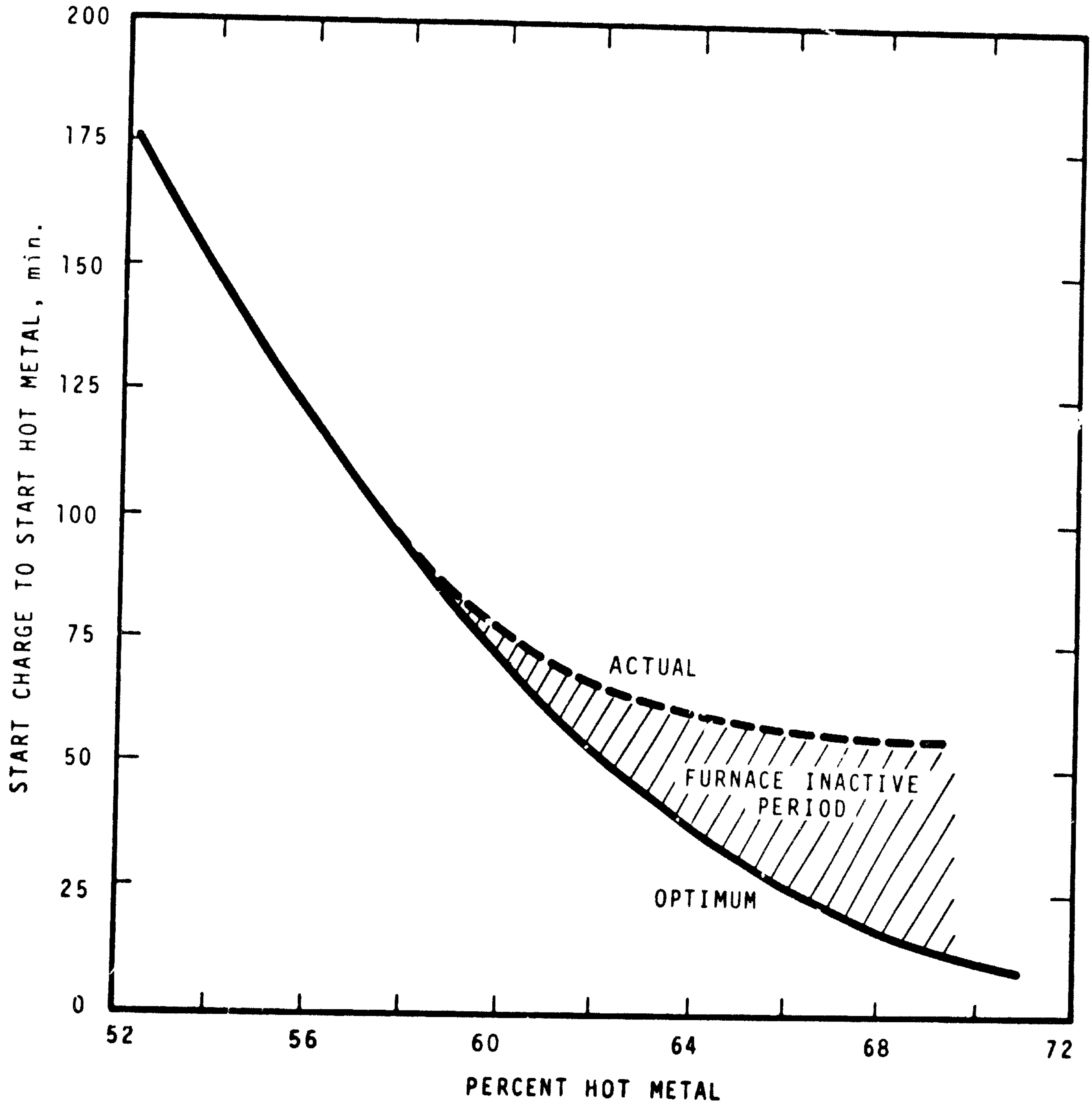


Figure [illegible]

Optimum and actual melt-down period vs. percentage hot metal for Steel [illegible] No. [illegible] Furnace



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