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The production of steel for flat products in large ultra-high-powered furnaces

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SYNOPSIS

The role of large, ultra-high-powered arc furnaces in a fully integrated steelworks for the production of flat products is outlined, and an account is given of the technological improvements that have been implemented over the past few years to enable the arc furnace to remain competitive against the conventional route using blast furnaces and top-blown-oxygen steelmaking (LD).

Modern secondary refining facilities have been installed, enabling the arc furnace to operate at high production rates in the manufacture of high-quality flat products.

SAMEVATTING

Die rol van groot, ultrahoëkrag-boogoonde in 'n ten volle geïntegreerde staalfabriek vir die vervaardiging van platprodukte word in hooftrekke bespreek en daar word verslag gedoen oor die tegnologiese verbeterings wat die afgelope paar jaar aangebring is om die boogoond in staat te stel om steeds mee te ding met die konvensionele roete wat van hoogoonde en boblaassuurstofstaalvervaardiging (LD) gebruik maak.

Daar is moderne sekondêre raffineerfasiliteite geïnstalleer wat vir die boogoonde moontlik maak om teen hoë produksietempo's te werk vir die vervaardiging van platprodukte van 'n hoë gehalte.

Introduction

The Electric Arc Furnace Shop in Vanderbijlpark forms part of Iscor's largest fully integrated iron and steel works, which has an annual production capacity of 4,5 Mt of bulk-carbon, low- and medium-alloyed structural steel. Flat products are produced exclusively, and embrace the whole spectrum from heavy plate to cold-rolled sheet, galvanized sheet, tinplate, and colour-coated material. About one-third of the steel is produced via the scrap-based arc-furnace route, and is teemed into ingots of between 10 and 25 t. The three arc furnaces have an annual capacity of 1,6 Mt. The plant was commissioned in 1970 with two 155 t arc furnaces (60/72 MVA) and a Dortmund-Hörder (DH) vacuum-degassing facility. In 1975, an identical third furnace was added, and a refining plant employing vacuum arc degassing (VAD) and Thyssen Niederrhein (TN) powder injection was put into operation in 1977. During May 1980, all three furnaces were converted to split-shell design, and were equipped with water-cooled side walls and roofs.

Since January 1981, owing to a lower demand for steel, only two furnaces have been in operation. All preventive maintenance and refractory repairs are carried out on the stand-by furnace.

From August 1984, sponge iron from a coal-based direct-reduction plant (Lurgi-rotary kiln process) with an annual capacity of 720 kt has been charged continuously into the arc furnaces. As envisaged, 30 to 40 per cent of the scrap has been replaced by sponge iron. These are the first large ultra-high-powered (UHP) arc furnaces to utilize sponge iron from a kiln-based process on a commercial basis.

Upgrading of the Electric Arc Furnace Shop

In a major modernization programme at the Electric Arc Furnace Shop, the furnaces were adapted according to the newest technological developments, including the following:

- continuous feeding of sponge iron, lime, recarburizer, and dolomite;
- upgrading of the fourth-hole direct-evacuation system to cope with the increased volume of fume from the use of sponge iron, incorporating forced-draught coolers;
- upgrading of the complete electrical-supply system to the furnaces to 80/96 MVA;
- replacement of the process computer (which was twelve years old at the time);
- erection of an additional teeming bay to utilize the increased melting capacity of the furnaces;
- installation of water-cooled composite electrodes on a trial basis and oxy-fuel burners;
- installation of copper water-cooled tiles in the lower sidewalls, and
- erection of a modern twinstrand continuous slab caster to be operational early in 1987.

Description of the Electric Arc Furnace Shop

The plant which is shown in Fig. 1, is of conventional three-bay design, and is divided into scrap, furnace, and teeming bays. Both the DH-degasser and VAD/TN-ladle refining units are located to the north of the teeming aisle, with the ladles moving on transfer cars into the treatment position.

Fig. 2 shows a schematic layout of the extensions that were implemented during 1984. The upgraded electrical supply system is shown schematically in Fig. 3, and Table I gives design and operating data for the furnaces. Other details of the layout of the plant have been published elsewhere[1].

Conversion of the Furnaces to Water Cooling

From experimentation with water-cooled cast-iron

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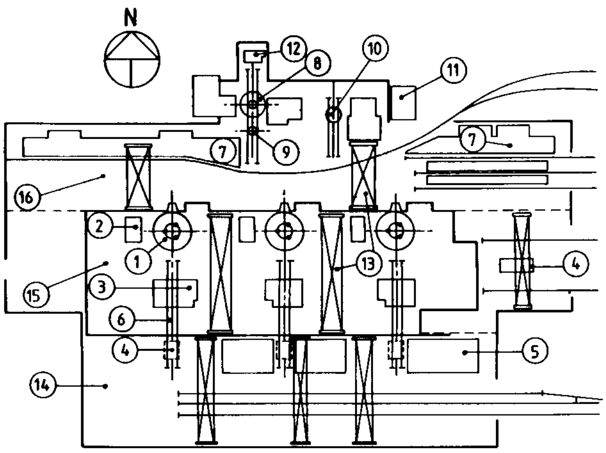
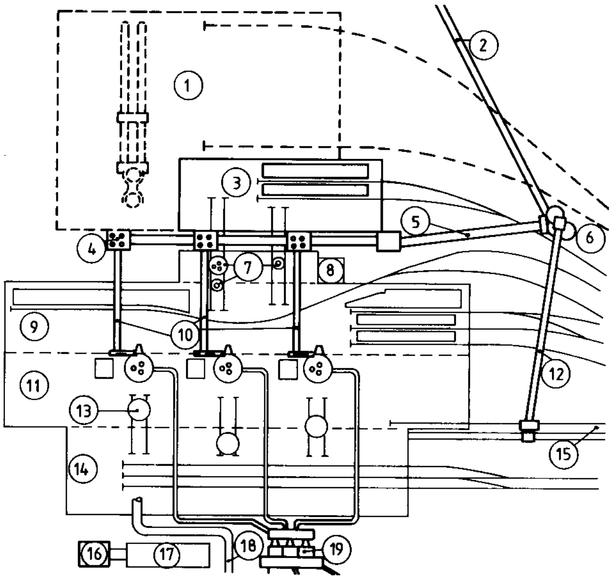


Fig. 1—Schematic layout of the Electric Arc Furnace Shop

1 Arc furnaces
2 Furnace transformers
3 Scrap bucket openings
4 Scrap scales
5 Scrap pits
6 Scrap transfer tracks
7 Teeming platforms
8 VAD plant
9 TN station
10 DH degasser
11 Laboratory
12 Deslagging station
13 Overhead cranes
14 Scrap charging bay
15 Furnace platform
16 Teeming bay

Fig. 2—Extensions to the Electric Arc Furnace Shop

1 Future continuous casting plant
2 Sponge iron conveyor
3 Teeming bay extension
4 Furnace storage bins
5 Sponge iron/additives conveyor
6 Additives day bins
7 DH, VAD, TN bay
8 Laboratory
9 Existing teeming bay
10 Furnace conveyors
11 Furnace bay
12 Additives conveyor
13 Scrap transfer
14 Scrap bay
15 Raw materials conveyor from tippler
16 New computer room
17 Offices
18 Secondary dust extraction
19 Forced-draught waste-gas coolers



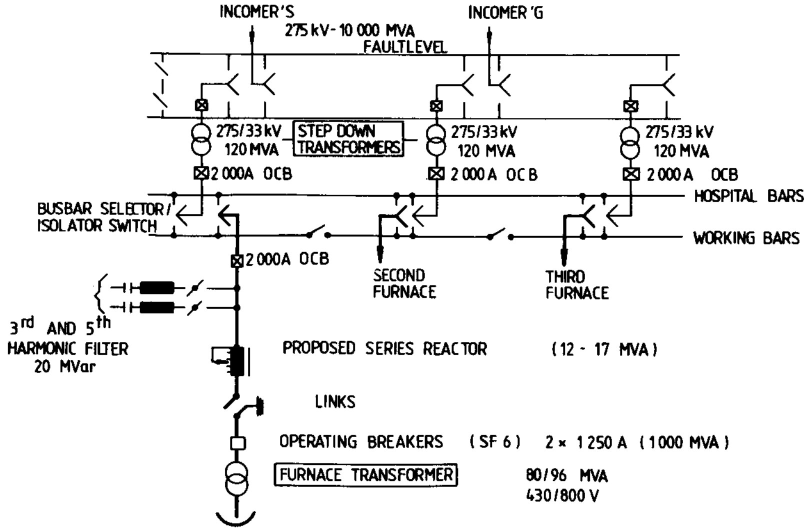


Fig. 3—Upgraded electrical-supply system

TABLE I
MAIN SPECIFICATIONS, CAPACITIES, AND CONSUMPTIONS OF ARC FURNACES

Main specifications		*Average consumptions*	
Arc furnaces			
Number and capacity	3 × 155t	Energy	510 kW·h/t
Manufacturer	Lectromelt	Electrodes	3,5 kg/t
Shell: Diameter	7,0 m	Oxygen	25,0 Nm³/t
Split	Below slagline	Lime	32,0 kg/t
Watercooling: Manufacturer	Korf–Fuchs	Raw dolomite	18,0 kg/t
Sidewalls	16 panels outside	Coke	25,0 kg/t
Roofs	9 panels	Fluorspar	7,0 kg/t
Electrodes: Type	AGX	Refractory bricks: Sidewalls	0,9 kg/t
Diameter	610 mm	Roof	0,3 kg/t
Transformer: Rating	60/72 MVA	Gunning and fettling	4,5 kg/t
Manufacturer	Westinghouse	Yield: Input/output	90,0%
Fume cleaning: Type	4th hole and roof canopies, baghouse collector	Fe yield	94,5%
		Teeming	97,6%
Raw-steel capacity	1,6 Mt/a		
Secondary refining	DH degassing, Vacmetal VAD plant, standard Messo TN plant, standard Messo		

blocks of Iscor's own design for several years, Iscor accumulated sufficient confidence to place an order with Korf–Fuchs in 1979 for the conversion of all the furnaces to fully water-cooled furnaces. The contract included the following modifications:

(1) enlarging the furnace diameter to 7,0 m and implementing a split below the slag-line;
(2) providing a spare shell and bottom to allow for quick turnround;
(3) increasing the inclination of the tapping launder for slag-free tapping with liquid-heel practice;
(4) 16 water-cooled sidewall panels of the outside system for each furnace with water-cooled segment rings below the panels; and
(5) 3 water-cooled roofs with 9 panels each, and 3 spare roofs.

During the conversion, which took 6 weeks (May 1980), the electrical control equipment of the furnaces was modified to programmable controllers (Modicon).

Two months after the conversion, the shop produced a new monthly record of 118 kt, the maximum that the teeming facilities were able to handle.

Scrap-charging Practice

The scrap is made up of fairly large amounts of heavy scrap (≈ 20 per cent) and pit scrap (≈ 20 per cent); sheets and plates make up another 25 per cent, and high-carbon mould or pig iron about 8 per cent, the balance being light to medium purchased scrap (bundles, automotive, etc.), which is delivered in railroad trucks to the plant. Alloy scrap is kept apart in pits and charged on alloy grades as required.

The use of heavy scrap (crop ends from the slabbing mill) in a UHP arc furnace has a number of significant disadvantages including the following.

(a) It causes frequent electrode breakages due to scrap cave-in, which is aggravated by the fairly high furnace shell (Lectromelt design).
(b) The melting rate is slow and may cause cold heats because of stratification.
(c) Long-arc operation and oxygen infiltration are not very effective in melting this type of scrap, which must first drop into the bath.
(d) It delays the opening of the slagdoor to allow early sampling.
(e) It is the reason for heavy blowouts during melting.

The use of heavy scrap has the following advantages.

(i) It is clean scrap with lower residuals and sulphur.
(ii) It has a high iron content and thus improves the yield.
(iii) It allows the charging of two buckets per charge instead of three.

Casting-bay scrap, which originates from both the Arc Shop and the Oxygen Converter Shop, is charged mainly at the arc furnaces to reduce the costs of iron input and to supply additional lime. However, it may cause non-conductor electrode breakages, it has a very low iron content (80 to 85 per cent), and it increases the slag volume considerably.

The slag volumes are over 200 kg/t, which explain the relatively high consumption of energy even though a fairly high amount of oxygen is used. However, under the circumstances, the use of this type of scrap is still economic. Burnt lime and fluorspar are charged into the scrap buckets and help with early slag formation. Coke breeze is charged on top of the scrap to act as a fuel for the oxygen that is blown into the furnace during melt down.

Operating Philosophy

After the furnaces had been equipped with water-cooled sidewalls and roofs, the power input programme was adapted by the application of longer arcs at maximum power input for 80 per cent of the melting cycle. An immediate large drop in electrode consumption to 3,8 kg/t was observed mainly because the secondary currents were lower and the furnace productivity higher. With a furnace of low-reactance design, this operation resulted in a working point away from the electrical optimum (50 MW at 74 kA with a power factor of 0,7). Because the secondary voltage is limited to 560 V, the new operating practice resulted in a reduced real power input. However, it was found that this operating practice was superior to the previous one for the following reasons.

(1) There was a large drop in electrode consumption as a result of lower tip consumption, and fewer electrode breakages and stub-end losses.
(2) The productivity (t/h) was higher, and hence the energy consumption was lower.
(3) The refractory performance was satisfactory.

It was recognized that the large radiation component of the longer arc contributed to the faster meltdown of scrap.

These results were so encouraging that the average secondary currents were reduced further from January 1983. This was possible only through the maintenance of a good foamy slag to cover the longer arcs during flat-bath conditions.

Fig. 4 shows the modified power-input programme. Average secondary currents over the whole melt were 60 kA, and the real power input dropped to 45 MW. The highest transformer tap was used over the entire melting cycle. The furnace transformer was not overloaded, delivering on average 53 MVA during meltdown and 63 MVA during flat-bath conditions.

After two months of operation, there was a further drop in electrode consumption to 3,3 kg/t, including breakages and stub-end losses (Fig. 5). There was no increase in the consumption of refractories and energy, but there was a slight decrease in productivity or increased power on time.

Because of the lower power levels, a higher oxygen rate was used to compensate for the reduced input of electrical energy. The average oxygen consumption increased from 18 to 25 Nm^3/t, and it was increased later to above 30 Nm^3/t by the addition of more carbon to the charge. The existing furnace transformers were designed before 1970 for short-arc operation, a technology that has changed with the introduction of water-cooled furnaces. The furnace transformers were therefore replaced by larger units (the first furnace during October 1984, the second furnace in March 1985, and the third one in May 1985) to allow for maximum power operation at higher voltages and for lower currents at higher power factors (96 MVA maximum, 80 MVA r.m.s. based on 650 V at 71 kA, and maximum secondary voltage of 800 V).

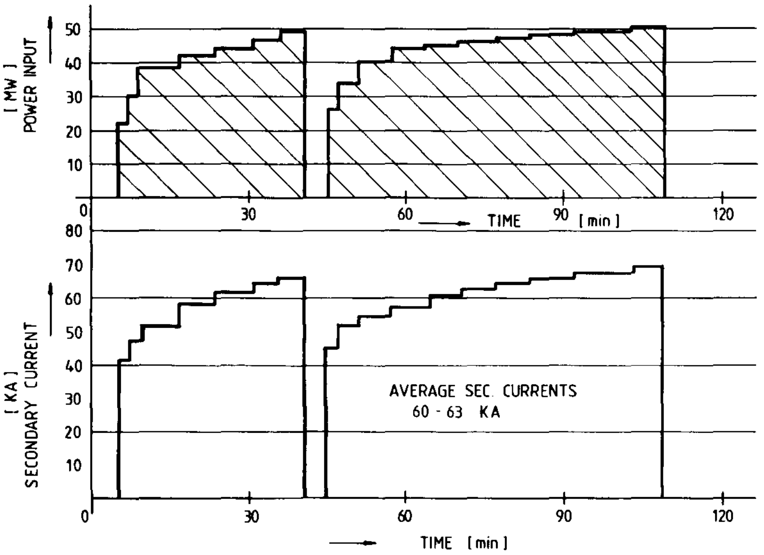


Fig. 4—Schematic diagram showing the modified power-input programme

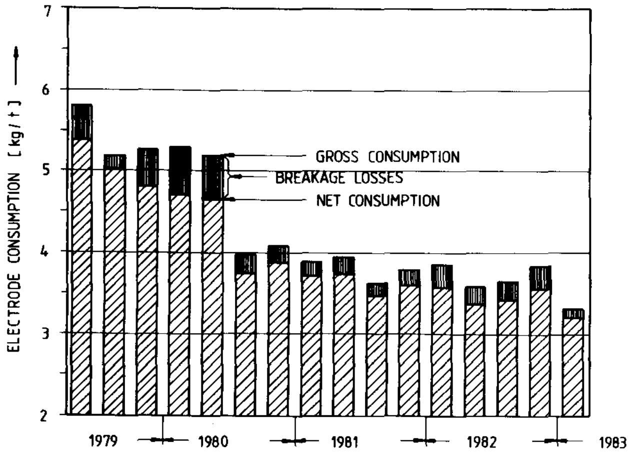


Fig. 5—Electrode consumption

Metallurgical Furnace Practice

There is no distinctive refining period, and all the heats are tapped according to single-slag practice. The same furnace practice is followed on all grades, the only exception being that heats for secondary refining are tapped at higher temperatures. It has been found that it is economical to do more superheating in the furnace rather than in the VAD. As the superheating requires little extra time and is offset by less refining, this uniform practice results in consistent furnace time regardless of the quality requirements, which vary widely.

Slag is flushed off above 1550 °C to achieve low levels of phosphorus. This is an advantage of the arc furnace over the basic-oxygen process. Phosphorus levels can be kept below 0,01 per cent, even after TN or VAD treatment. For the rimming and semi-killed steel grades, the average phosphorus levels are around 0,007 per cent.

Proper scrap-blending and slag practice are extremely important in the achievement of the low sulphur levels that are required for flat products. Since only 15 per cent of the product mix is fully killed, most heats must be tapped within sulphur specification with no possibility of external ladle desulphurization.

As the Arc Furnace Shop is part of an integrated steel mill with basic-oxygen converters, sufficient amounts of clean, low-sulphur scrap are available for the sulphur and copper levels to be kept within acceptable limits (Fig. 6).

By the charging of lime into the scrap buckets, most of the phosphorus and sulphur removal occurs before the first sample is taken. Fig. 7 shows the relationship between basicity and sulphur distribution, and indicates that the slag has a very high sulphur content.

No lime is charged on heats destined for VAD and/or TN; only low-cost raw dolomite is charged to limit slagline erosion due to the higher tapping temperatures. Although desulphurization in the furnace deteriorates, with tapping sulphurs that are 0,012 per cent higher on average, this practice improves the overall economics because of the high desulphurizing potential of the ladle-refining units.

Arc furnaces are known to produce steel of high nitrogen content. However, with oxygen infiltration during melting and a thick foamy slag, the pick-up of nitrogen can be limited to levels that are not usually detrimental to the properties of the final steel (Fig. 8). Since the sponge-iron plant came into operation, the nitrogen levels have been lower, enabling the arc furnaces to produce most cold-rolled qualities.

All steel grades other than high-carbon heats are blown down to below 0,08 per cent carbon (rimming grades to below 0,05 per cent carbon) in the furnace. During tapping, the steel is recarburized and alloyed, while purging in the ladle aids in better mixing. The steel is further purged after tapping in the ladle, resulting in temperature equalization and the flotation of inclusions to the slag. Semi-killed and rimming grades are tapped into sand-slung ladles, in which the supply of oxygen from the ladle lining is not detrimental to the steel properties. All fully killed grades are tapped into basic ladles and are desulphurized during tapping by the addition of a mixture of lime and fluorspar.

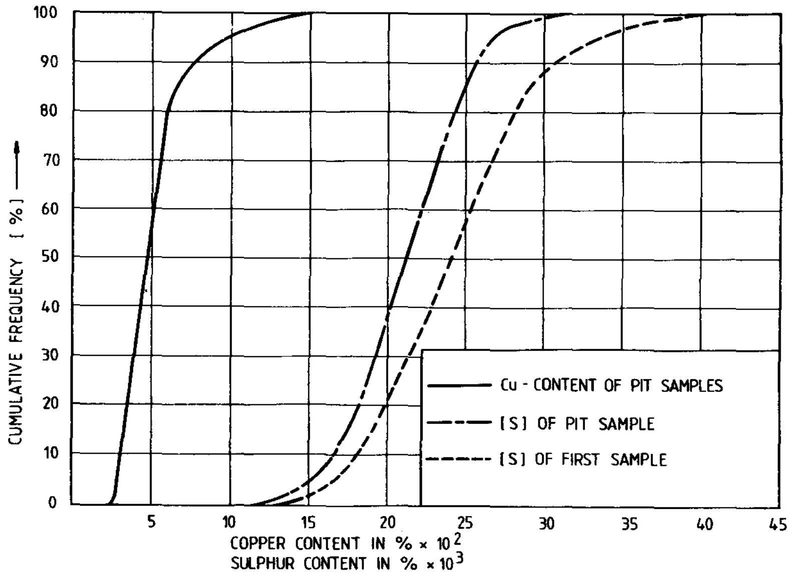


Fig. 6—Distribution of copper and sulphur in rimming and semi-killed steels

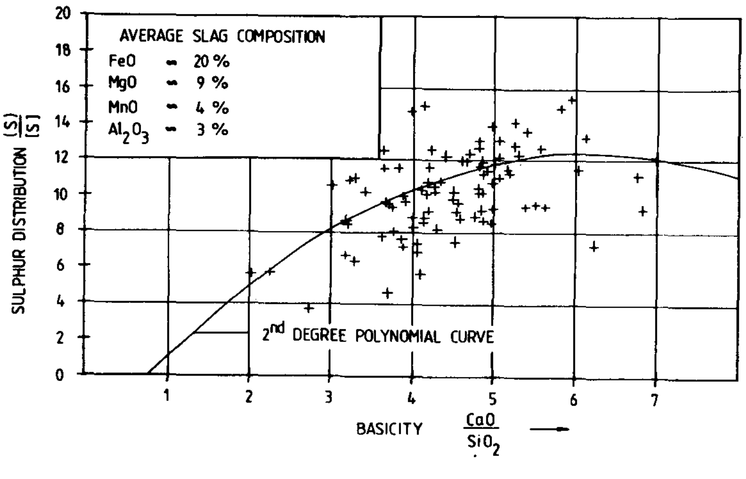


Fig. 7—Effect of basicity on the sulphur-removal potential of oxidized arc-furnace slags

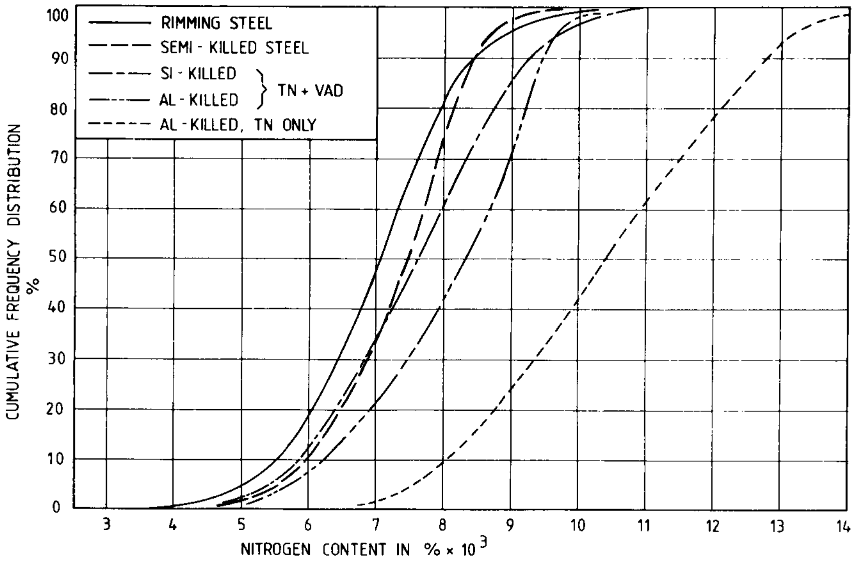


Fig. 8—Distribution of nitrogen in various steels

Refractory Practice

The hearth is rammed and vibrated with dry magnesite material that has excellent sintering properties. This is done on the spare bottom. No preheating is required, and the first heat is started on full power. Hearth refractories are replaced after 1000 heats on average. Fettling requirements for the hearth are low (less than 0,5 kg/t), and it has been found that cold repairs on the spare furnace are more effective than hot fettling.

To optimize the teeming yield, the tapping mass is varied with the type and number of moulds by the keeping back of steel in the furnace after tapping. With the taphole placed low in the furnace, a large runover of slag is prevented. It is important that the taphole should be kept in good condition by being replaced after every 200 heats.

Only two types of brick are used for the lower sidewalls. Tar-impregnated 450 mm magnesite bricks are used in the slagline, followed by shorter carbon-magnesia bricks above the slagline up to the water-cooled panels. Two intermediate repairs, mainly at the hot spots, the taphole area, and alongside the slagdoor, are performed at intervals of 250 heats before relining is done at about 700 heats. The furnace banks are maintained by cold repairs on the spare furnace, and by the addition of dolomite to the charge to maintain the magnesia level in the slag at 8 to 10 per cent. The lower sidewalls and slagline are fettled by the use of either a rotary gunning machine or a batch gun. The total consumption is 4,0 kg/t.

The delta section of the roof is lined with high-alumina bricks and ramming material. The average life is 80 to 100 heats.

Consumptions

The major operating costs are those for electricity, electrodes, and refractories, as clearly shown in Fig. 9.

After the conversion to water-cooling, the consumption of furnace refractories dropped to levels similar to those for the LD converters (Fig. 10). With the improved refractory performance, the furnace availability, and therefore the output, increased. The present two-furnace operation allows refractory repairs to be done on the spare furnace, resulting in a 100 per cent availability of the two operating furnaces.

A large effort was also made to reduce the consumption of graphite electrodes. A reduction to 3,3 kg/t was achieved, a figure that had been thought to be impossible only a few years before. The use of water-cooled composite electrodes resulted in a further reduction of around 20 per cent on a test basis.

The consumption of electricity depends mainly on furnace productivity, slag volumes, teeming temperature, the use of external energy with oxygen or oxy-fuel burners, and the type of scrap and/or sponge iron used. Although an increase in the electricity consumed might have been expected after the conversion to water-cooled panels, the improved productivity more than compensated for the additional energy losses, and a lower consumption was, in fact, realized. Oxy-fuel burners further reduced the electricity consumption, not only by replacing electrical energy but also by clearing cold spots earlier and thereby reducing the total melting time. (Oxy-fuel burners were commissioned during February 1985 at one of the three furnaces.)

Furnace Productivity

The output of an arc furnace is expressed in tonnage per operating hour where all types of delays are included in the operating time. The tonnage per net operating hour indicates the potential of the shop if all delays could be eliminated. The furnace productivity for the years 1979 to 1983 is shown in Fig. 11.

The relationship between power-on time and operating time is commonly referred to as time utilization (TU). The average TU exceeds 74 per cent at Iscor and is a measure of the overall shop efficiency. With the adapted power programme, where the overload capacity of the furnace transformer was not utilized, the effective power input per ton of steel produced was very low at 385 kVA/t. This increased to around 600 kVA/t once the new transformers had been installed.

The index of productivity is a better measure of plant

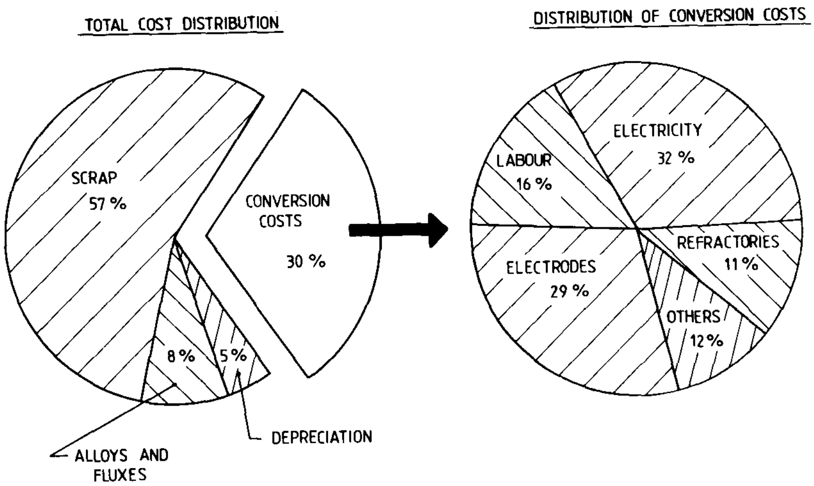


Fig. 9—Distribution of costs for arc furnaces

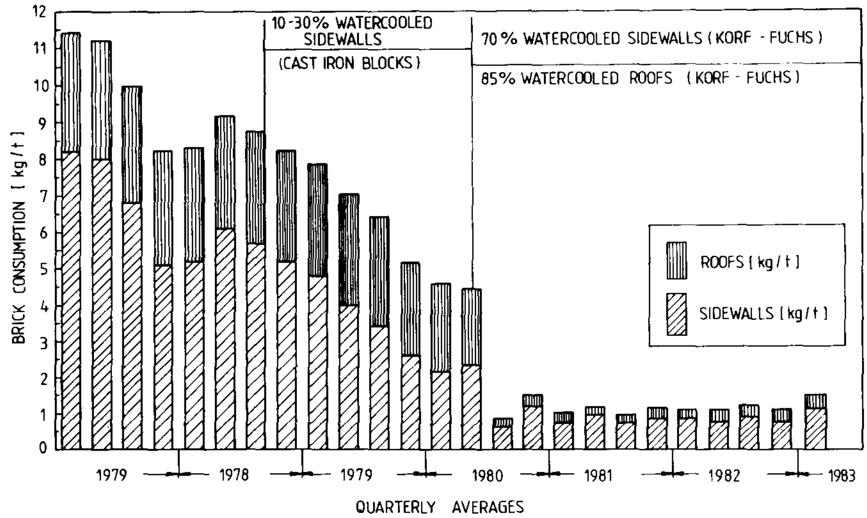


Fig. 10—Reduction in the consumption of refractory bricks, 1977 to 1983

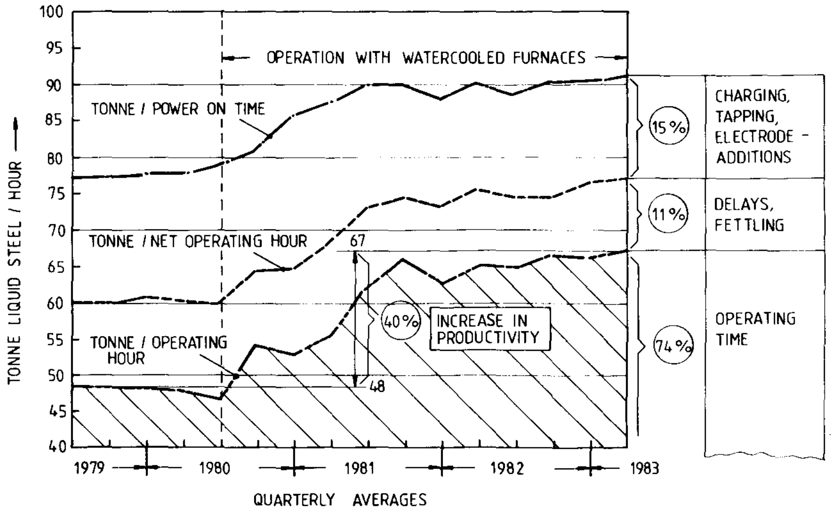


Fig. 11—Increase in productivity, 1979 to 1983

efficiency since it relates the furnace output per hour to the maximum power input of the transformer. The average index before the new transformers were installed was 1,45 (67 t/h:45 MW). With the new transformers, the performance has approached 100 t/h, or tap/tap times of 1,5 h for 155 t heats.

The Role of the Process Computer

Full automation of all the functions in the Arc Furnace Shop is not yet possible because there are too many variables that cannot be predicted with sufficient accuracy. Important decisions on matters such as the grade to be produced can be taken only after a representative sample from the steelbath has become available. The predictability will improve with a greater percentage of sponge iron because the properties of a portion of the input material will then be known in advance. Continuous feeding of sponge iron will thus be used in the future to control the final stages of a heat in conjunction with control of the power input in order to achieve the desired end-point.

The process computer is at present used mainly for the control of the power input and the arc length based on a static model. As the arc furnaces are the largest consumer of electric energy, it also functions to control the maximum demand of the Works. A data link between the process computer and the Works central computer provides the plant with a 24-hour production schedule. All the relevant heat data, such as the final analysis, ingot masses, and teeming times, are transferred to the central computer for the planning of the subsequent rolling operations.

One of the most important functions of the computer is to supply immediate feedback of the process parameters and of relevant data to the operators, and to group and summarize the data to form the basis of a comprehensive plant-management information system[2].

Secondary Steelmaking

Extended refining times with low power utilization become very expensive in the type of highly productive furnaces described. To improve the economics of these primary melting units, they can be combined with various secondary facilities where refining tasks can be carried out more effectively, and therefore at lower cost.

As a producer of flat products, which often require high standards of cleanliness and analysis control (including hydrogen), Iscor's Vanderbijlpark Works installed a DH-degassing unit in 1970 together with its first two arc furnaces. Although this plant made possible the successful production of boiler plate such as BS 1501/224 and boron steels equivalent to ASTM A517, it was soon recognized that there were two serious shortcomings.

(1) The sulphur content could not be decreased to the low, and later even ultra-low levels required for certain grades.
(2) No heating was possible after tapping, which demanded high accuracy and thus extra time for the primary furnaces.

Despite the fact that only 15 per cent of the production of the Arc Furnace Shop is fully killed, ever-increasing quality and productivity demands have prompted Iscor to install a combined VAD/TN-ladle refining plant, which was commissioned in 1977. In 1981, argon/nitrogen purging in the ladle was initiated on all grades of steel, finally leading to the decommissioning of the DH-degassing unit in 1982.

As the requirements for degassed steel will exceed the VAD plant's capacity once the continuous caster comes on line early in 1987, the DH unit will by then have been modernized and recommissioned.

Layout of the VAD/TN-ladle Plant

The plant (Fig. 12), built by Standard Messo Duisburg, has a transfer car to carry the vacuum tank in which the ladle is placed. From the teeming bay, the ladle can be moved to three positions, namely slag-off station, VAD station, and TN station.

At the slag-off station, the whole tank with the full ladle can be tilted 30 degrees. Argon purging pushes the slag towards the slag spout, and deslagging is assisted by a mechanical scraper. Thicknesses of approximately 4 cm are easily achieved in the remaining slag. This facility leaves the furnaces free to allow some carry-over of slag and maximize the furnace yield. However, the temperature losses are about 15 °C.

At the VAD station (Table II), the electrodes are mounted in vaccum-tight telescopic tubes on top of the vertically moving vacuum cover, and heating is carried out under a pressure of approximately 300 torr (40 kPa). No electrode breakages have occurred since 1978. Arcing on the lowest parts of the electrode tubes, where they are not insulated, caused waterleaks on a number of occasions, but without serious consequences. During degassing, pressures of typically 0,6 torr (80 Pa) are reached with a four-stage steam-ejector system. Samples and temperatures are taken outside the treatment position. The thermocouples, like all the instruments, are connected to the process computer, and during treatment the temperature is calculated continuously and displayed with a good degree of accuracy. A sophisticated alloy system allows automated additions to be made during heating, as well as during degassing.

At the TN station (Table III and Fig. 13), the carriage with the injection lance and conveying equipment moves only vertically. A small overhead hoist transports the lances. Fumes are captured and led into the secondary emission-control system of the furnaces. Alloys can be added through an additional hole in the hood. After disappointing results with CaC_2, the use of CaSi led to the anticipated success. Since 1982 the material has been injected with 12 mm lances (previously 9 mm). Either 180 kg (0,35 kg of calcium per ton) or 270 kg (0,52 kg of calcium per ton) is injected with an average blowing rate of 35 kg/min.

Steel Qualities

The use of purging bricks on all the ladles, as well as the use of a TN and a VAD plant, permit various ladle treatments, depending on the widely varying requirements.

The majority of the production, being rimming and semi-killed steel, has no ladle treatment prescribed, although nitrogen purging in sand-slung ladles is usually carried out for homogeneity and temperature control. A

Fig. 12—Schematic layout of VAD ladle refining

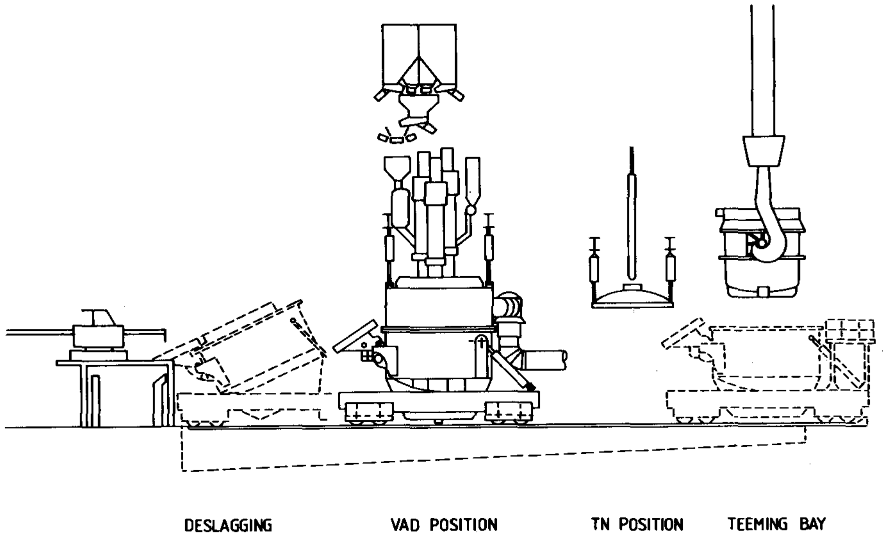


TABLE II
MAIN SPECIFICATIONS OF VAD PLANT

Vacuum vessel		*Heating system*	
Inside diameter	5750 mm	Transformer	15 MVA
Inside height (tank)	4306 mm	Primary voltage/current	11 kV/800 A
Inside height (cover)	2240 mm	Secondary voltage	164,5 – 308,5 (7 taps)
Cover lifting and lowering	Hydraulic system	Working voltage/current	269 V/33 A (tap 6)
Stroke	1900 mm	Electrodes grade	AGX
		Diameter and length	406,5 × 1880 mm
Ladle		Length per column	4 to 5
Top outside diameter	4311 × 3714 mm (oval)	Lifting and lowering	Hydraulic system
Outside height	4550 mm	Pitch-circle diameter	1000 mm
Nominal steel capacity	155 t	Distance electrode ladle	750 mm
Free board	960 mm		
Working lining	Dolomite except floor (60% Al_2O_3)	*Alloying system*	
Vacuum system		Bunkers with vibrators	10
Stages	4	Capacities and contents	10m^3(CaO), 3 m^3 (FeSi), 2 m^2 (CaF_2, SiMn, FeMn, FeCr, FeV, FeMo, electr. Mn, FeSiZr)
Steam ejectors	5 (incl. 1 for heating)		
Intercondensors	3 (incl. 1 for heating)		
Lowest treatment pressure	0,4 torr (50 Pa)		
Steam consumption	16 t/h		
		Bunkers for special alloys	2 (0,5 m^3)
		Bunkers with rotary feeders	2 (1 m^3), C and Al
		Weigh hoppers	2

few non-critical killed grades, such as abrasion-resistant plate, also fall into this category. An exception is semi-killed steel for pressure vessels and micro-alloyed structural plate, for which a purging time of 10 minutes is prescribed for enhanced cleanliness and compositional control.

For the majority of killed steel, use is made of one of the following options: purging, TN treatment, VAD treatment, or combined TN/VAD treatment (Table IV).

Apart from the benefits of purging stated above, gas (usually argon) stirring also serves to shift the burden of refining from the furnace to the ladle. Sulphur specifications of 0,02 and even 0,01 per cent are easily met.

Where high standards of cleanliness and isotropic or near-isotropic properties are required for strip, sheet, and thinner plate (below 25 to 50 mm, depending on the type of steel), TN treatment is done. TN treatment may be chosen instead of gas purging when tap sulphurs are very high.

Where hydrogen is of concern and isotropic properties are not required, vacuum degassing in the VAD takes place. It is used for heavy plate, usually of structural quality. As most of the material is tested ultrasonically, sulphur limits of either 0,02 or 0,01 per cent are set, ensuring low oxygen levels as well. Again, the furnaces are not restricted in tap sulphur. In isolated cases, the VAD is used to heat TN purged heats, and as a holding furnace to either overcome delays or prevent furnace delays when other heats have to be tapped and teemed.

The combined TN/VAD treatment is applied for the

TABLE III
MAIN SPECIFICATIONS OF TN PLANT

Dust cover		*Pressure vessel*	
Suspension	Chains	Pressure	1400 kPa
Movement	Hydraulic system	Capacity	670 litre
Suction	From secondary furnace system		
Ladle		*Alloy hopper*	
As for VAD		Number/capacity	1/1 m³, with vibrator
Lance		*Practical*	
Total length	5400 mm	Material injected	CaSi
Type of refractory	Monolithic	Argon flow	750 l/min
Size of refractory	178 dia. × 3000 mm long	Material flow	35 kg/min
Blow-pipe diameter	12 mm inside	No. of heats per lance	8 (average)
Blowing depth	2300 mm		

TABLE IV
LADLE TREATMENTS OF KILLED STEEL

Treatment	Gas purging	TN	VAD	TN/VAD
Primary objectives	Sulphur removal Improved cleanliness Homogenization	Sulphide shape control	Hydrogen control	Highest cleanliness Isotropic properties Hydrogen removal
Other objectives	Composition control	Sulphur removal Cleanliness Composition control	Sulphur removal Cleanliness Composition and temp. control Holding	Composition control Temperature control Holding
Typical applications	Light plate, sheet strip Corten A and B RR ST 37 3 RR ST 52 3 C35 Plough steel	Forming qualities Corten A–F Supraform TM CK 60 (mod) H.S. C.R.	Medium to heavy plates BS 4360 RR ST 37 3	ASTM A 514 to A 517 BS 1501 PT 1 and 2 H II and 17 MN 4 BS 4360 GR 55 E Lloyds CMN LT 60 (Arctic–D)

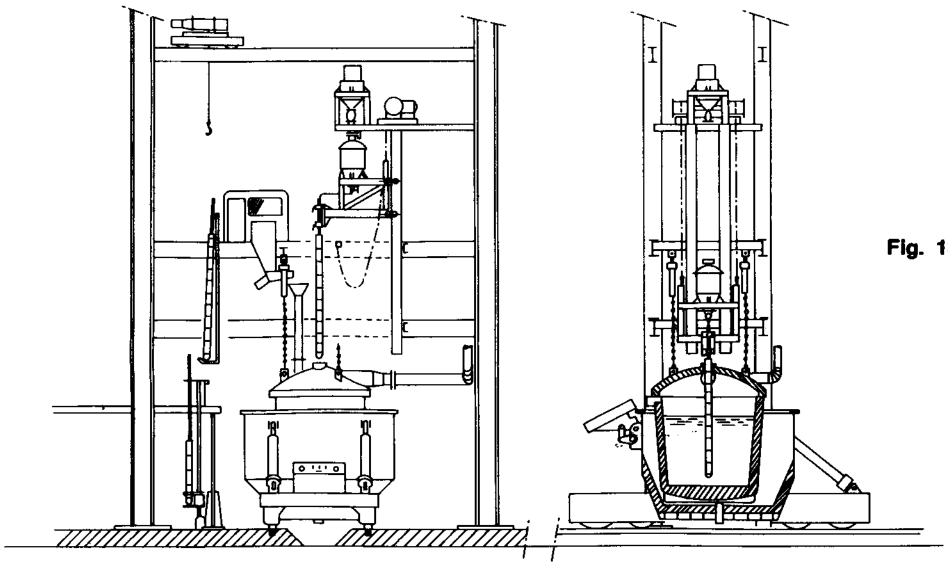


Fig. 13—Layout of the TN (VAD) injection plant

highest cleanliness, isotropic properties, and—owing to the very low sulphur levels—hydrogen control. It is used for all killed boiler plate, roller-quenched and tempered plate, and structural steel with severe toughness requirements at very low temperatures.

Secondary Metallurgy

The general sequence of the major metallurgical steps is as follows:

(a) maximum precipitation deoxidation during tapping, which, although the recoveries are low, creates ideal conditions for the further treatment steps;
(b) tap desulphurization, followed by gas stirring;
(c) deslagging of heats to be vacuum degassed;
(d) as far as necessary, additions of lime/fluorspar with simultaneous heating and alloy additions at the VAD (second desulphurization step);
(e) if required, injection of calcium at the TN plant;
(f) if necessary, heating to an aimed temperature, possibly with minor additions of lime/fluorspar, sand, or bauxite;
(g) when required, vacuum degassing for 10 or 20 minutes after reaching 2 torr (270 Pa) with trimming and additions of micro-alloys; and
(h) soft purging for 5 to 15 minutes, depending on the temperature.

Results Obtained

Figs. 14 to 16 show the desulphurization of the VAD, TN, and TN/VAD heats during March 1983. In all cases, the desulphurization of silicon-killed heats was nearly as good as that of the aluminium-killed heats, although with a somewhat higher consumption of lime and, especially, fluorspar.

With an injection of 0,35 kg of calcium per ton of steel, the sulphides in aluminium-killed sheet material that have retained a globular shape amount to about 90 per cent, the remaining sulphides having short 'tails'. For applications where this is considered insufficient, 0,52 kg of calcium per ton is injected, giving a modification of almost 100 per cent. After TN treatment, neither heating (under partial vacuum) nor degassing appears to influence the shape of the inclusions, but their quality is reduced.

On silicon-killed steel with its higher oxygen level, the ratio of length to thickness in the sulphides improves by

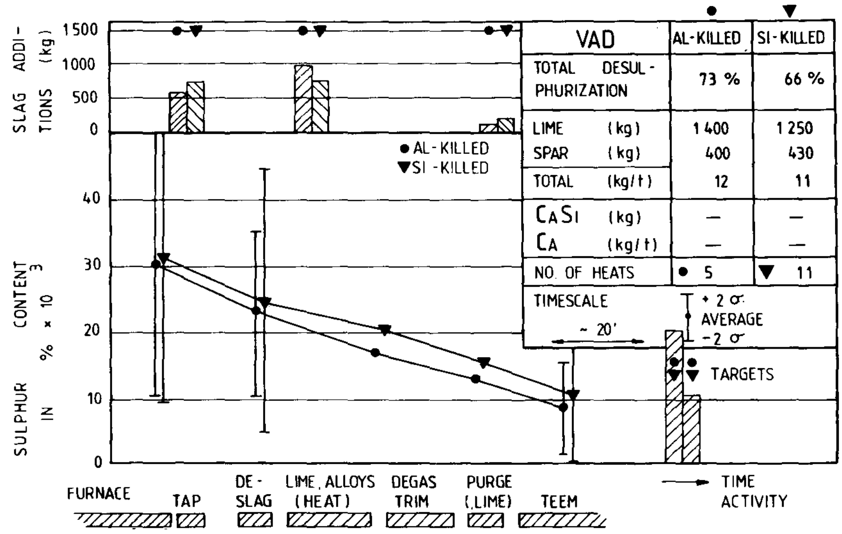


Fig. 14—Desulphurization of VAD heats

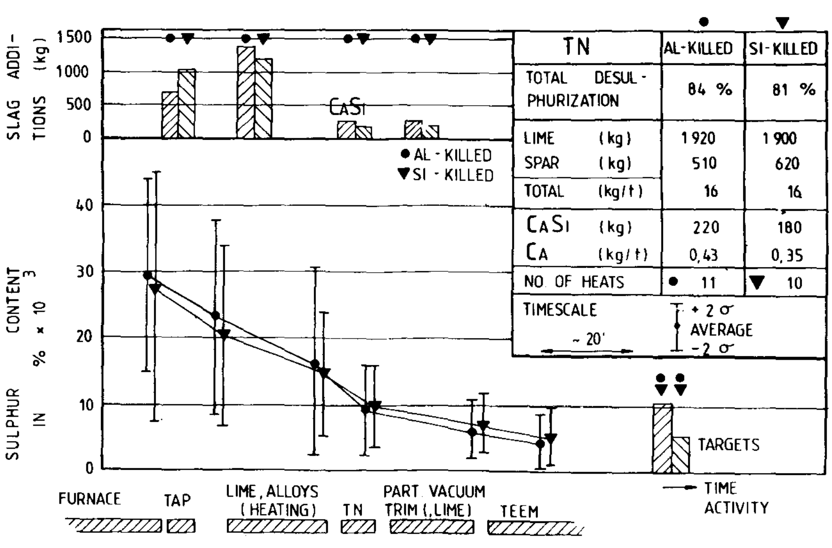


Fig. 15—Desulphurization of TN heats

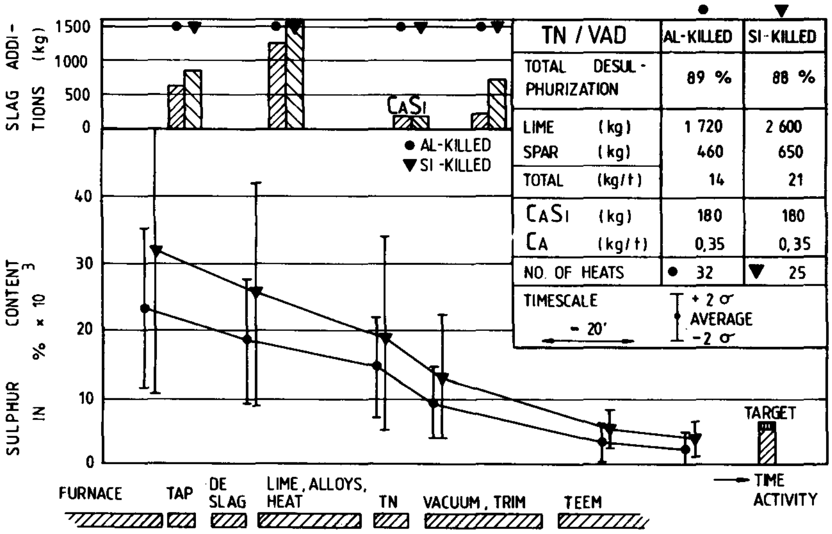
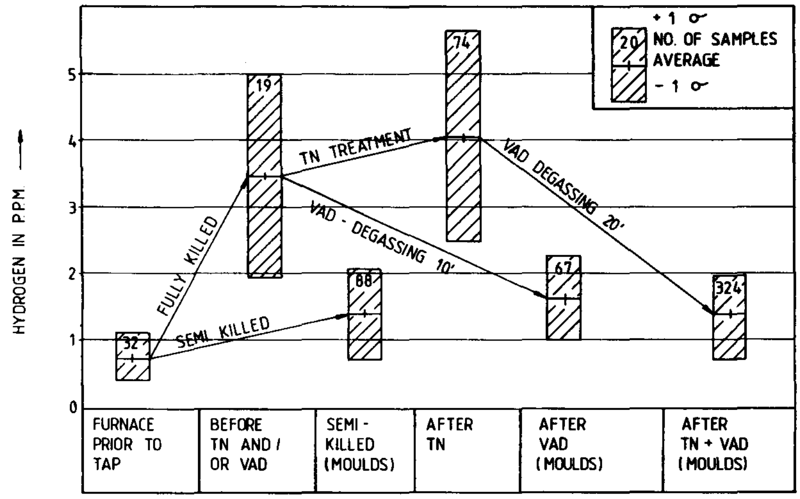


Fig. 16—Desulphurization of TN/VAD heats

Fig. 17—Hydrogen contents in steel



a factor of approximately 5. Although still rather elongated, this shape appreciably improves the manufacturing of products such as dished ends for heavy boilers.

Owing to the dry climate, as well as the foamy-slag practice, the hydrogen levels prior to tapping are very low, less than 1,0 p.p.m. (Fig. 17). Semi-killed steel on average picks up 0,7 p.p.m. during tapping and teeming, presumably mainly from the alloys added, whereas killed steel picks up an average of 2,7 p.p.m. Although in the latter case more alloys are added, the addition of burnt lime/fluorspar, containing some 1 per cent water, is considered to be the major source. Endeavours to improve this situation are in hand. The injection of calcium under a hood causes a modest pick-up of hydrogen (Fig. 17).

The degassing capacity of the VAD is clearly demonstrated by the subsequent drop in hydrogen content, with a hydrogen removal rate of 50 per cent for 10 minutes, and 65 per cent for 20 minutes, after pump down. As the samples are taken after teeming, these figures include the pick-up during teeming.

The total oxygen contents of aluminium-killed TN/VAD steel are usually below 20 p.p.m.

Fig. 8 shows the nitrogen contents after TN treatment, and after subsequent VAD treatment. The pick-up during the injection of calcium is effectively reversed during vacuum degassing, so that the final values approach those of rimming and semi-killed grades.

Teeming

Interstop slide gates type 4C with interchangeable collector nozzles of various bore sizes are used on all the casts. The average plate life is 4,3 casts. All rimming and semi-killed steel is top-poured. Bottom-pouring was developed during 1981, and over one-third of the killed steel, mainly of TN/VAD quality, is poured in this way. A decrease by a factor of 5 in the ultrasonic reject rate for inclusion clusters was realized, and the incidence of surface defects was approximately halved.

All the killed casts are left at the teeming platforms for the full solidification time.

Conclusion

After the three 155 t arc furnaces had been converted to water-cooled sidewalls and roofs, changes in the operations (among others) of scrap charging, melt-down operation, oxygen blowing, and slag practice brought about an average tap-to-tap time of around 2 hours. The replacement of the 60/72 MVA transformers with 80/96 MVA transformers and the addition of oxy-fuel burners further reduced these times.

The same furnace operation is followed for every steel quality, and the first steps to the desired quality are taken during tapping. By the utilization of various ladle treatments (purging, TN, VAD, and combinations) and teeming practices, the desired quality is obtained at the lowest overall cost.

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PROTEC deserves your support*

by Cliff McMillan†

Most readers will be aware by now of PROTEC—The Programme for Technological and Engineering Careers. Started by the engineering profession some four years ago, it is an enrichment programme for selected high-school students, and is aimed at increasing the pool of matriculants from all population groups who are capable of tertiary education and of careers in engineering and technology.

This is a further appeal to individual engineers to support PROTEC with financial contributions as well as personal assistance. With the support of the Federation of Societies of Professional Engineers, over 18 000 letters of appeal went out in April to engineers of all disciplines. The appeal was for every engineer to make a small monthly or annual contribution to this worth-while programme. So far the response has been poor.

PROTEC's achievements are most encouraging. We have groups of over 100 selected students in each of Standards 8, 9, and 10 participating in our Soweto–Alexandra pilot project. These students constitute a highly motivated and hard-working group who are becoming increasingly realistic about the career choices available to them. They regularly attend Saturday school-enrichment programmes and vacation activities, and are of above-average ability in mathematics, science, and problem-solving.

Our first group of 67 students, who participated in the enrichment programmes from 1982, matriculated at the end of last year. Their results were most encouraging: 83 per cent passed and 45 per cent obtained matriculation exemption; and 33 received bursaries for tertiary education or were placed in employment and training positions in engineering.

PROTEC aims to become a country-wide non-racial programme. Branches have already been established on the East Rand and at Mmabatho, and discussions are under way with groups in other centres.

To succeed PROTEC needs your financial support. Last year we raised R220 000. In view of our growing range of activities, student numbers, and staff requirements, as well as inflation, our budget for 1985 is R500 000. This still makes PROTEC an extremely cost-effective means of selecting and developing for engineering careers the best potential students from disadvantaged communities.

PROTEC is a long-term project and an investment in the future. We address the projected future shortage of skilled manpower in South Africa and the need to draw increasingly from all population groups. It is sometimes difficult to motivate such endeavours in the current climate of recession, when the construction industry is severely affected and engineers in some instances without work. But the short-term problems cannot be allowed to divert our efforts to build a sound base for South Africa's future.

The engineering profession and industry have supported us from the start. As a result we were able to go to the private sector at large with a confident appeal, and are raising funds from major companies, some not related to engineering.

Even a contribution of R5 to R10 per month would, if given by many of the engineers in South Africa, constitute a major proportion of our required funds. This in turn would strengthen our hand enormously in appealing to the private sector and to Government.

Your support will be gratefully acknowledged. Kindly reply to PROTEC, P.O. Box 52657, Saxonwold, 2132 Johannesburg (Tel: 447-2063), giving your name and address. If you wish to make a one-off annual contribution, please enclose a cheque in favour of PROTEC. Alternatively, if you would prefer a monthly stop order, please supply the following details: name, address, and branch of your bank; your account number and your monthly/annual contribution; and the date of the first payment. Note that PROTEC's constitution enables your contribution to be tax-deductable.

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* Released by the Federation of Societies of Professional Engineers (FSPE), P.O. Box 61019, Marshalltown, 2107 Transvaal.

† Chairman of PROTEC.

Rebates for safe firms

Some 89 583 employers qualified for a special merit rebate totalling nerly R44 million for the three-year cycle 1980–82, according to the Workmen's Compensation Commissioner, Hennie du Toit. He was speaking to over 500 delegates at the annual awards function of the National Occupational Safety Association (NOSA), which was held in Cape Town towards the end of May.

[illegible] during the 1980/82 cycle despite the fact that the majority of them were classified as extremely hazardous. These included industrial plants and firms handling the dismantling and erection of steel structures, shuttering, and scaffolds, including the demolition of buildings. Mining firms and municipalities had also achieved high standards.

The Commissioner concluded by saying that the most important aspect of a safety programme was the safeguarding of workers against accidents. 'It is not just the pain, suffering, and hardship our workers are spared, but also the disruption, sorrow, and grief their families may suffer, expecially in fatal accidents.'

The Workmen's Compensation Commissioner, Hennie du Toit