SUB-ARC FURNACE OPTIMISATION AT MIDDELBURG STEEL AND ALLOYS

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ABSTRACT

To utilise the vast resources of Transvaal low grade chrome ores owned by the Rand Mines group, a commercial production plant for the manufacture of low carbon ferrochrome was established in the early 1960's at Middelburg on the Transvaal highveld.

With the advent of the vaccuum oxygen and argon oxygen decarburisation processes in the production of stainless steel during the late 60's, high carbon ferrochrome production at MS&A was initiated in 1969 using unagglomerated low grade Transvaal chrome ore fines.

From humble beginnings, using a 3 000 KVA furnace, the production of charge chrome progressed to the use of a 9 000 KVA furnace and eventually to the installation of two 30 000 KVA furnaces during 1976 and 1977 respectively.

Increasing raw material and power costs made close control of the chemical analysis and physical quality of all raw materials necessary. Optimisation of the power input and control of the large furnaces using an electrode controller designed by MINTEK has improved furnace production substantially.

Further optimisation of power usage through burden pre-heating using the sensible heat in the furnace off-gases is planned. The use of plasma technology so that cheaper, fine raw material can be used is also being researched.

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C O N T E N T S

INTRODUCTION

Brief History

In the early 1950's, the Rand Mines Group who owned large reserves of chrome ore ventured into the production of low carbon ferrochrome alloy utilising Transvaal Chromites with a 1,6:1 Cr:Fe ratio. This ore was at that time only used in the chemical and foundry industries and considered inferior or unsuitable for metallurgical applications such as the manufacture of ferroalloys.

Pilot plant studies on the production of low carbon ferrochrome were carried out at Crown Mines in Johannesburg and the Driehoek works of Scaw Metals in Germiston. These studies proved the viability of producing a low carbon alloy containing ± 55% Cr in competition with the then traditional alloys running at chromium content levels of around 70%.

Market acceptance of this low chrome bearing alloy in the early 1960's proved difficult but met with success to the extent that a commercial production plant was commissioned early in 1964 at Middelburg on the Transvaal Highveld in close proximity to the chrome ore mines.

A logical development from the production of low carbon ferrochrome was the establishment of a stainless steel production facility in 1967 on the same site.

In the late 60's stainless steel production in the U.S.A. and Europe began to swing away from the use of low carbon ferrochrome to the use of high carbon ferrochrome using vaccuum oxygen and argon oxygen techniques. High carbon ferrochrome production at Middelburg using 3 000 KVA and 7 500 KVA furnaces was started in 1969 to meet the changing demands and again a breakthrough was made when this alloy was produced using unagglomerated chromite fines 1,6:1 Cr:Fe ratio.

In 1976 the first and in 1977 the second 30 000 KVA furnace was commissioned to cater for the increased demand for high carbon ferrochrome 6,5 - 8 % C, 51 - 53 % Cr, and 2 - 7 % Si.

MS&A opted for the briquetting route to agglomerate the chromite fines and 100% chromite ore briquettes were used in these furnaces in the early stages.

MS&A's Position Today

MS&A today has both low and high carbon processes running. The low carbon being produced by the two stage process whereby single stage ferrosilicochrome is produced from charge chrome in the first stage and reacted with a chromite-lime slag in the second stage to produce its traditional 56 - 60 % Cr low carbon alloy.

High C ferrochrome (referred to as charge chrome) is produced from 9 000 KVA and 30 000 KVA furnaces in Middelburg and 9 000 KVA and 20 000 KVA furnaces in Krugersdorp.

Increasing raw material, power and labour costs are forcing MS&A to look critically at their labour intensive smaller furnaces and to optimise the operations of their larger furnaces in order to contain costs thereby remaining competitive.

OPTIMISATION TO DATE

It has been stated by many authorities on furnace design and opera= tion that as the size of a furnace increases it tends to behave in a sluggish way, slowly developing deviations that are not easily ob= served or detected by the furnace operator. For this reason it be= comes essential to have tighter controls on both raw material charg= ed to the furnaces and their charging systems and on the electrical parameters affecting the operation of the furnace.

Both these controls are necessary in order to efficiently control the metallurgy of the smelting process if optimum results are to be achieved. To this end, MS&A has, with the aid of the Council for Mineral Technology (MINTEK) (previously the National Institute for Metallurgy - NIM) embarked on a project using computers as an aid to establishing the controls necessary for large furnace optimisation.

Raw Material Control

One cannot economically continuously measure the inconsistent chemical composition of the raw materials charged to a furnace and the compo= sition of the alloy and slag produced. However, we consider the correct quality both physical and chemical, of the raw materials to be the major factor in maintaining optimum production on our furnaces. Since we are committed to the use of briquettes in our furnace charge this area i.e. briquetting, is an area where improvements in quality have been and are being researched on an ongoing basis. Our basic binder is the well proven lime/molasses binder, but these briquettes, especially when carbon is introduced into the mix, tend to disinte= grate prior to being charged to the furnace. Of greater importance is the hot strength of the briquette. By the addition of small quan= tities of bag filter fume from ferrosilicon furnaces we have success= fully improved the hot crushing strength of our briquettes from 30 kg to 200 kg, at the same time adding the stoichiometric requirement of reductant in the form of coal, char or coke fines to the briquettes.

Although our briquette quality has improved markedly and conver= sion cost has been contained in spite of cost increases in line with the high inflation rate over the last 3 years in South Africa, im= proved quality in view of optimum chrome recovery and maximum briquet= te usage is still strived for.

Alternative binders such as lignosulphonates, sodium silicates and bentonites have been tested and are still being tested, with varying degrees of success. Our ultimate goal is to produce a briquette which is at least amenable to successfull pre-heating so that a hot charge can be charged to the furnaces resulting in optimum energy consumption/conservation.

As the size of a furnace increases so the physical characteristics of the raw materials become more critical.

Our 9 000 KVA furnaces can use 60% fines ores (Minus 6mm) in the furnace charge without becoming unmanageble. The larger 20 MVA and 30 MVA furnaces on the other hand can tolerate only 8 - 15% Minus 6mm fines material without upsetting the smooth operation. Eruptions usually occur due to gas entrapped in the impermeable charge.

The size of the raw materials especially the chromite ore or briquettes and the carbonaceous reducing agents control the resistance of the furnace. Since we are in the present market required to pro= duce virtually all our charge chrome with a carbon content of 6,5 - 7% the selection of carbonaceous reductants is of utmost importance. We control the resistance by varying the quantity of the different sizes of reductants available.

Up to 25% of the fixed carbon requirements of the furnace charge is from metallurgical coal. The balance comes from coke in the size range Plus 6, Minus 19mm, Plus 19, Minus 65mm and Plus 65, Minus 110mm These commodities are proportioned into the furnace charge in varying quantities to maintain a resistance in the 30 MVA furnaces of 1,3 to 1,5 Microhm. Since the availability of the correct size and quality (physical, chemical and reactivity) is becoming crucial, MS&A will be building a Char Plant based on the REXCO retort carbonising process to produce char suitable for charge chrome production sized correctly for each furnace.

Carbon Balance

In order to control the carbon balance in the furnace, we are sampling chrome ores being charged twice per shift. A composite sample is analysed the next day. Although we are still basically working on historical information, by using exponentially smoothed values, the furnace operator is provided with far more reliable data for timeous adjustment of mix charged to the furnace.

Batching

Computer controlled batching is regarded as an essential part of the optimisation programme. The recipe for the alloy produced is typed into the batching computer which weighs out the various commodities, correcting for any under or over-shooting in weight, throughout the batching process. The mix to the furnace is free-flow charged through 10 charging tubes, three around each electrode and one in the middle of the furnace. The bins feeding the tubes are on load cells so the mass of the charge to the various zones in the furnace, e.g. the centre of the furnace or around the electrodes is accurately known. This helps to pin point abnormalities in the furnace condit= tion.

Mass and Heat Balances

Two calculations were developed by MINTEK as a first step towards the control of the metallurgical aspects of the process. One calc= ulation is used in the formulation of the feed of the ores, fluxes and carbonaceous reducing agents, and predicts the desired output. In effect this is a performance mass balance.

Secondly, heat-balance caluclations based on the thermodynamic considerations of the chemistry of the process and the total masses of the chemical components of the raw materials entering the furnace were developed by MINTEK. Good agreements have been reached between the predicted furnace output based on the mass balances and that based on the average operating load and the theoretically calculated power per ton of charge chrome.

Using the mass and heat balances in the prediction of alloy prod= uction and comparison of this predicted value with the actual output of alloy from the furnace led to an alloy mass flow model. The alloy produced within a furnace during any time interval does not necess= arily leave the furnace during that same interval. Alloy builds up or is washed out of the furnace. Built-up slag or alloy lead to furnace instability. The mass flow model (see Figure 1 Page 9) is therefore used to forstall a problem before it becomes serious and will soon be incorporated to be an on-line function in the furnace computers therefore aiding the operating staff to maintain optimum operation.

Power Input Control

Power costs have increased dramatically in the RSA from a relatively cheap commodity in the early 70's to one of the most expensive com= modities in 1982. (Refer Figure 2 Pg 10). The company makes use of a computer controlled maximum demand system to control the power demand for the Middelburg complex. Each of our production units on both Alloys and Steel is monitored by the central demand control. The larger 30 MVA units being the greatest consumers of power are used to regulate the demand for the complex.

Although the 30 MVA furnaces were originally equipped with elec= trode controllers controlling the movement of the electrode on sec= ondary current, this system did not necessarily optimise the power input or power usage. Accurate electrical measurements made on the secondary side of the furnace transformers are difficult due to the effect of the strong magnetic fields associated with the high sec= ondary currents. Furthermore as the size of the furnace increases, inductive reactance increases, reducing active power.

MINTEK have shown that inductive reactance is not merely an electrical problem but also affects the metallurgical operation of a furnace. Large furnaces become more easily unbalanced electrically without indication on the instruments of this condition, which event= ually manifests itself in rough furnace operation when for instance the furnace taps eratically.

For this reason, MS&A installed and commissioned an electrode controller designed by MINTEK and produced by SIEMENS. This control= ler makes all its measurements on the primary side of the furnace transformers, no connections to the metal bath of the furnace being necessary. Direct control of electrode movement is exercised based on the comparison between resistance setpoints entered into the controller and resistances calculated by the controller computer from primary electrical measurements.

Certain design limitations place constraints on furnace operation. Transformer ratings in MVA should not be exceeded and the current through electrodes is defined. To operate a furnace at maximum power the design limitations must apply and these are entered in the controller.

Since the commissioning of the controller in December 1981, prod= uction has improved to 170 tons per day for the first 6 months of operation compared with 157 tons output per day for the second half of 1981. This overall improvement stems from the following advantag= es gained:-

- Load factor improvement
- Higher power input
- Improved furnace power factor.

Furnace Uprating

Pollution control legislation compelled MS&A to install expensive gas filtration installations. To absorb these additional running costs and improve our profit margin, several alternatives were con= sidered. Among these were to use the off-gas to pre-heat the furnace charge, to use the off-gas to generate electricity or to uprate the two 33 MVA furnaces.

Uprating of the furnaces was decided upon for the following reas= ons; increased furnace output would dilute plant fixed costs and company allocated overheads. Secondly, maintenance costs would not rise substantially and operating staff would not increase. Thirdly, relatively minor modifications were necessary to the furnace water cooled roof and canopy to allow for a different electrode spacing. Fourthly, downtime for uprating would not take longer than 6 weeks per furnace.

Although the furnace tank and crucible dimensions might not be optimum for the higher power input, the decision was taken at the end of 1981 and the first furnace was switched in after uprating during May 1982. The electrode diameter was not regarded as critical as these were originally designed for charge chrome and ferrosilico= chrome production.

The most costly items were three new 16 MVA single phase trans= formers per furnace. Having had the cooperation of the original transformer suppliers, it was possible to design new transformers that could be installed with only minor modification. Transformer installation took only 2 days to effect.

With the power input increased from 33 to 48 MVA, secondary current values were selected at 12% higher and secondary voltage on the transformers was selected to effect higher power input. This obviously necessitated uprating of the primary electrical cables between the sub-station and the furnace air-breakers situated on the furnace building ground floor.

The first furnace was uprated over two months (March and April 1982) and by the third month after commissioning 35% higher power input was achieved maintaining the same power and production efficiencies as before. It is planned to uprate the second furnace during October and November 1982.

This uprating exercise is regarded as the single best productivity improvement yet achieved considering the very low capital investment. Refer product cost increase versus consumer price index - Figure 3 Pg 10. Refer also Figure 4 Pg 11 for productivity improvement.

PROCESS IMPROVEMENTS THAT AFFECT THE SCOPE FOR OPTIMISATION

Although Southern Africa has the largest known reserves of chromite ore only 25 - 30% of the run of mine ore can be considered to be truly lumpy material. The majority of Transvaal chrome ores are extremely friable. Agglomeration by briquetting the fines, as we do at MS&A or by pelletising the fines as is carried out by CMI in Lydenburg are both costly and both processes introduce additional foreign material into the furnace charge. This material must be fluxed off in the furnace and in addition consumes energy which could be used in the smelting process to produce charge chrome.

It was also pointed out earlier that our power costs have risen from a point where we generated the cheapest power in the world from coal, to today, where our power is becoming as expensive as that of other ferroalloy producing countries. Many countries are already making use of sensible heat in the furnace off-gases to produce steam as in the Vargon plant or to generate electricity as at Bjolvefossen in Norway.

We at MS&A see future process improvements in both the abovemen= tioned fields i.e. the use of more fines, both ore and reductant as well as progressing towards energy conservation processes.

Preheating of the Charge to the Furnace

MS&A is researching the possibility of preheating the charge of ore, briquettes, fluxes and carbonaceous reducing agents prior to the charge entering the furnace. The Outokumpu process appears to be most suitable to achieve this end. Closed top furnaces would be used and the carbon monoxide produced would be used to pre-heat the charge in a rotary kiln. Although the process lends itself well to pelletised ore, we would like to apply the process to our briquettes which in our view has definite advantages over pelletising.

The Development and Use of Plasma Processes in the Production of Ferrochrome

The plasma processes lend themselves to the production of ferrochrome from fine Transvaal chromites and cheap, fine metallurgical coals. Slatter defines a plasma as consisting of a gas which is at a sufficiently high temperature to be ionised. At this stage it is electrically conductive and will allow the stable transfer of elec= tric power between two or more electrodes. Furnaces utilising this principle would subject the materials being treated to temperatures in excess of 2500°C. Material in this high temperature plasma feed would react rapidly, depending on the residence time within the field, and the composition of the material. The molten metal and slag re= sulting from the reaction would collect in the hearth of the furnace and remain molten due to the heat radiated from the plasma before being tapped from the furnace.

MS&A has been researching plasma arc technology over the last 36 months and has evaluated the possibility of applying the plasma pro= cess to the production of high carbon ferrochrome. Research work has been carried out at Tectronics Research and Development at Ferrington in the United Kingdom where the economic feasibility of the process has been proven.

Clearly the advantage of this process in not only the use of fine materials, of which South Africa has an abundant supply, but the greater efficiency of power utilisation.

The potential this process has could open up a new field in ferroalloy technology and the realisation thereof is only a question of time.

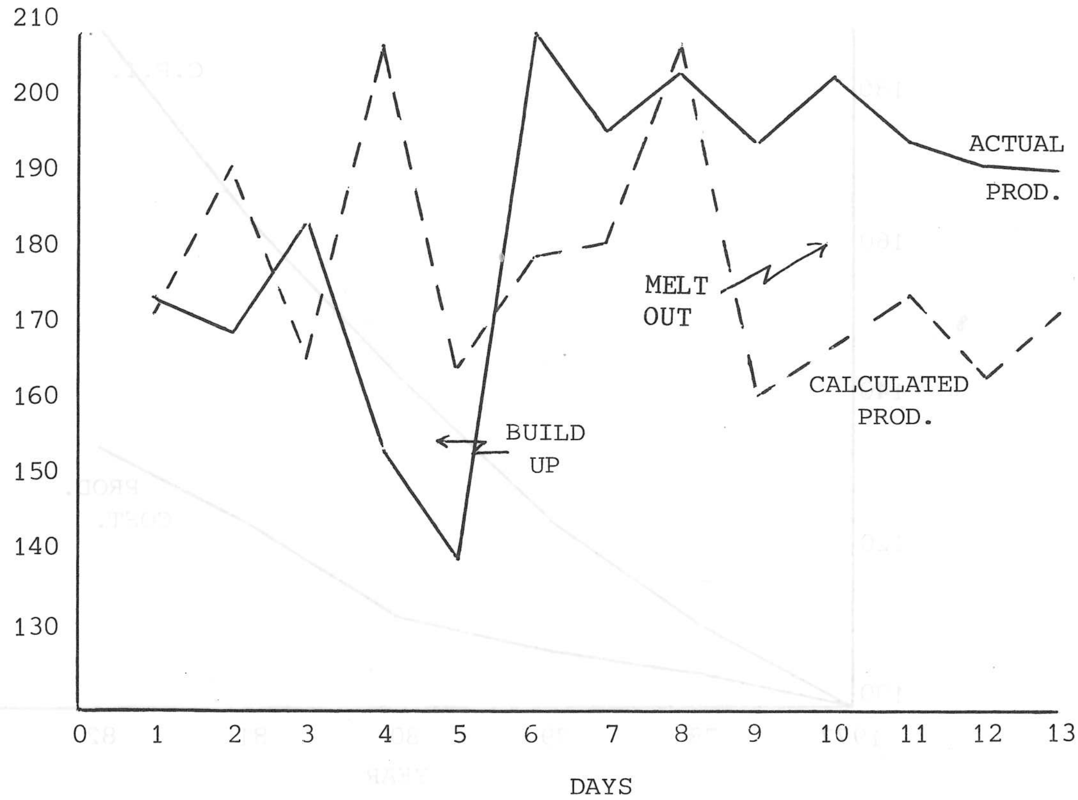
Reference

1. The Development and Use of Plasma Processes in Metallurgy
Slatter, D de L, Chamber of Mines Journal.
May 1961, Pg 61 - 67.

FIGURE 1

MASS FLOW MODEL

CALCULATED VS ACTUAL PRODUCTION

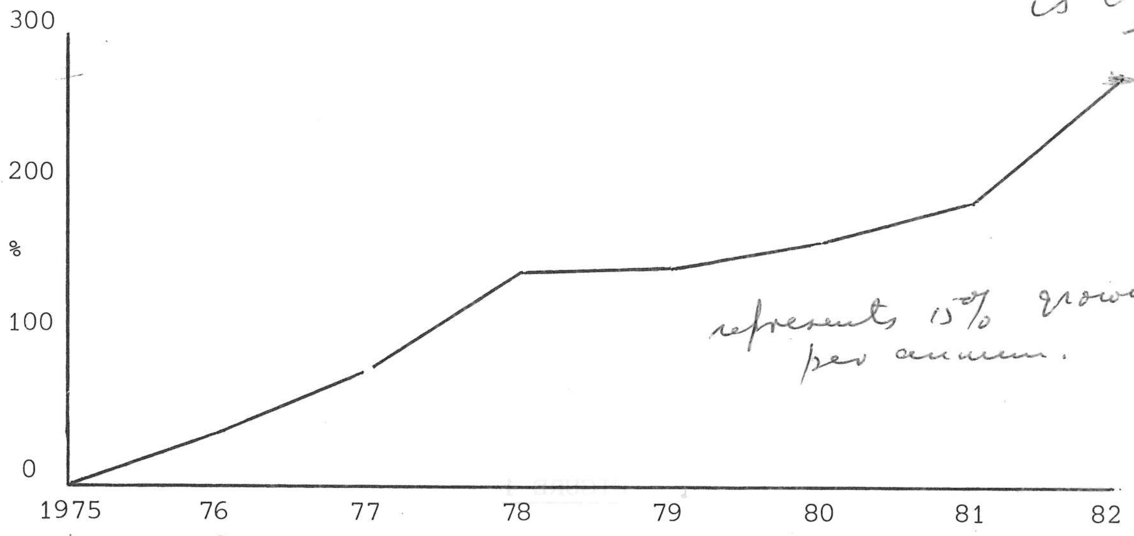


8 yrs at 15% gives $(1.15)^8 = (1+.15)^8 \approx 2.6$

FIGURE 2

ELECTRICAL POWER INCREASE - 1975 TO 1982

Brian - is this true



Cost .75c per kwhr if 2.6c now ie 1982.

FIGURE 3

PRODUCT COST INCREASE VERSUS CONSUMER PRICE INDEX

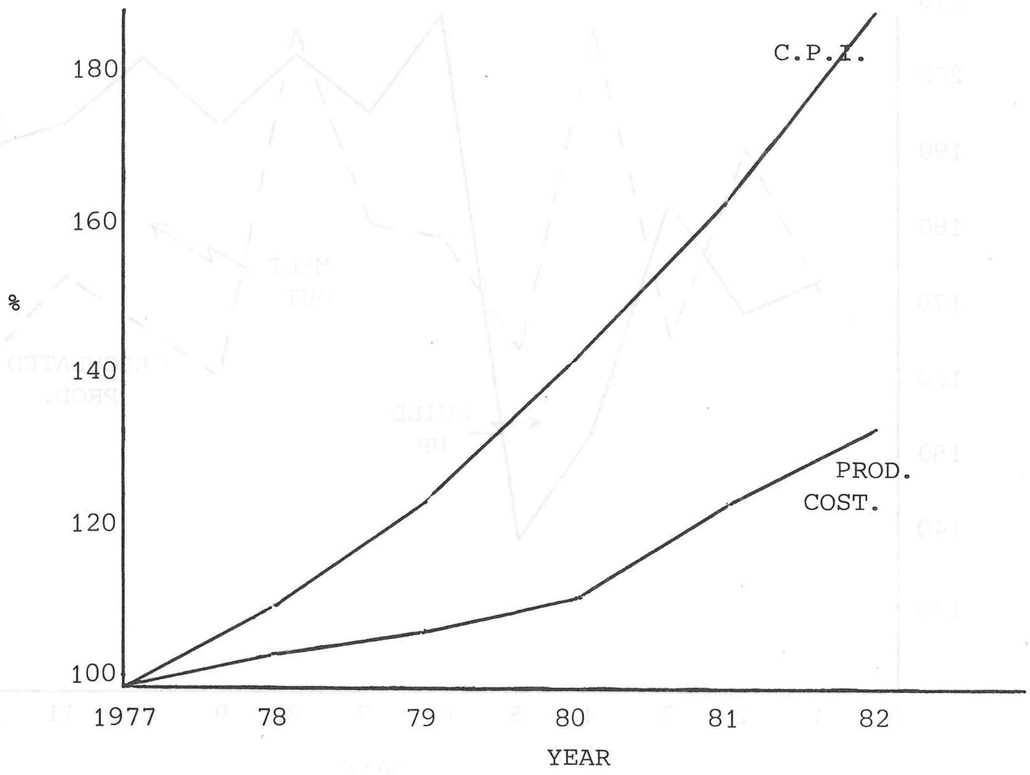
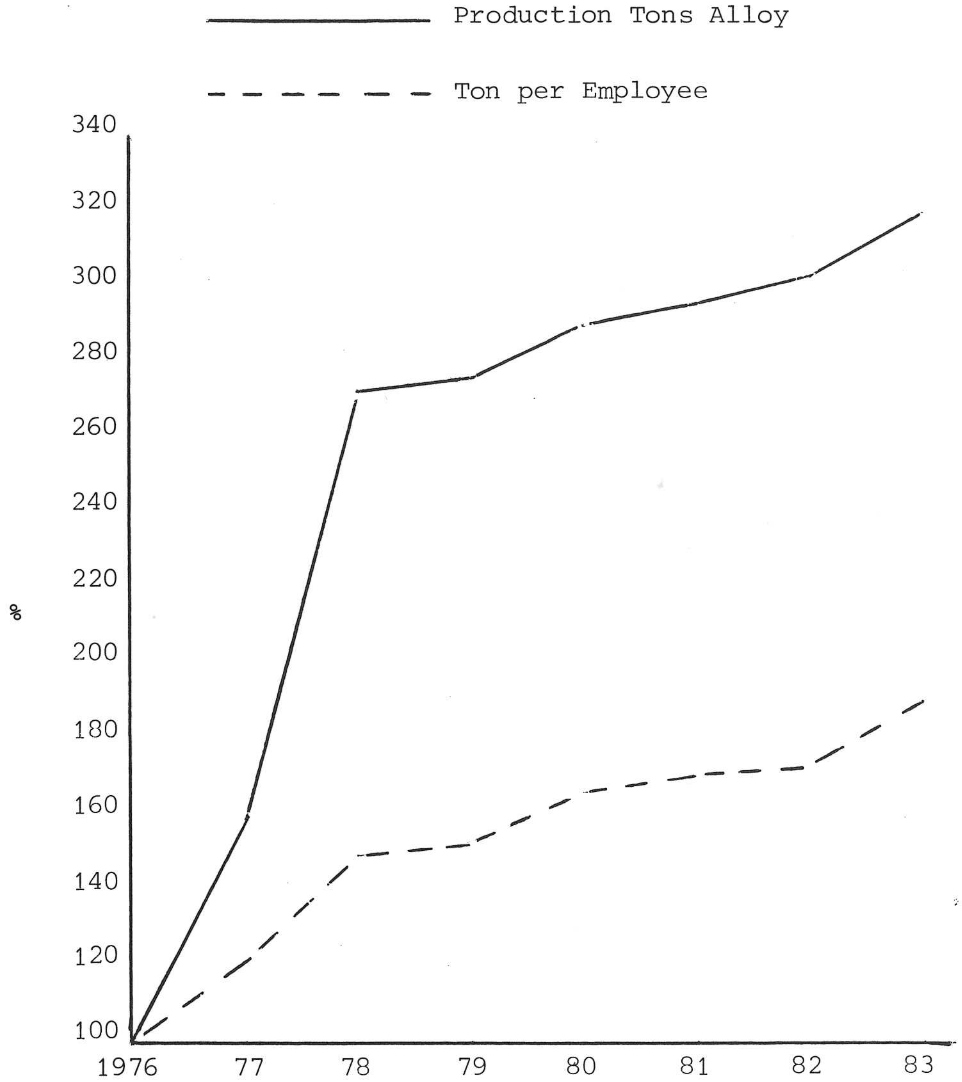


FIGURE 4

CHARGE CHROME PRODUCTIVITY CHART

ANNUAL PERCENTAGE INCREASE



1976 TO 1977 - 1 x 30 MVA FURNACE RUNNING

1978 TO 1981 - 2 x 33 MVA FURNACES RUNNING

1983 - 2 x 48 MVA FURNACES RUNNING

(As budgeted June 82 reflecting downtime for uprating and market demand).