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THE PROCESSING OF RAW MATERIALS

I. FERROUS ORES

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This review paper is prepared pursuant to Agreement No. CLT88/1017 between the consultant and the United Nations Industrial Development Organisation. The terms of reference for the paper are as follows:

1. Brief review of the technology of mining, beneficiation and industrial applications of ferrous ores with special emphasis on new trends in user requirements or processing technologies.

2. The role of mineral research centres and similar R and D institutions in developing countries in promoting a versatile exploitation of the iron and steel industry and an effective co-operation among countries in technology development and dissemination.

3. Review of existing mechanisms for marketing and distribution of ferrous ore in various beneficiated forms and for finished steel products: the obstacles experienced by developing countries when trying to penetrate the international commodity market and the scope for co-operation among them in order to strengthen their position in this respect.

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Introduction

Ferrous ores are utilised almost entirely as the primary raw material for iron and steel production and their exploitation must be considered within this context. The production of iron and steel has world-wide distribution and the industry has major features which give it a different character to that of non-ferrous-metal production.

Iron and steel production is ten times larger than the combined total of non-ferrous metal production and the ferrous ore production required to serve the industry is huge. The world-wide production of iron ore and its concentrates has exceeded 800 million tons/year throughout the past decade. The need to generate these enormous volumes of production has given iron ore mining its dominant characteristics of huge size, huge production equipment and huge financial investment.

High quality iron ore deposits have a world-wide distribution but the best are now located in many of the developing countries. As a consequence the fully industrialised economies of the world, whicn produce the major part of world iron and steel output, are almost entirely dependent on iron ore mining in the developing countries. This is a major contrast with the non-ferrous metal industry where raw material resources are not widely distributed and over 50% of mining production occurs in the industrialised countries themselves.

If the developing countries are to benefit fully from the exploitation of their resources, it is essential that they formulate and pursue a strategy which is both technologically and economically successful.

I. Iron Ore Production and Utilization

Iron ore, because of the relatively low value of its end product iron and the abundance of high grade deposits, is only mined in locations of high metal content and easy extraction. Thus iron ore mines are typically of the open-pit type where large scale earth stripping and earth-moving equipment may be used. The deep shaft mining of low grade ores is only economically viable for the more valuable non-ferrous minerals.

The normal iron mineral exploited is haematite (Fe_2O_3) which has a metal content of 70% iron on a gangue free basis. The actual metal content of iron ores produced is close to the theoretical maximum e.g. the 847 million tons of iron ore produced world-wide in 1986 had a metal iron content of 493 million tons or 58% iron. High grade iron ore deposits are frequently located in regions remote from centres of population and their exploitation depends on the creation of costly bulk transport facilities. Iron ore mining is highly capital intensive and the availability of labour is normally not an obstacle to its development since the mining operations generate relatively little employment. A mine producing several million tons of iron ore/year typically employs a work force of as little as 100 men.

The majority of the iron ore mined throughout the world is destined for use in blast furnaces located in integrated iron and steel production facilities. Most metal ores require some sort of crushing and screening in preparation for further beneficiation, but in the case of iron ores this process is often an end in itself and necessary to prepare the final products for the strict physical and chemical specifications of blast furnace charge. Consequently the processing of iron ore can involve a high degree of technology and control and the ore is commonly pelletised in modern ore treatment plants.

The pelletising process consists of rolling fine ore powder in a drum or disc with water, sometimes with the addition of an inorganic clay binder. The water wets the fine powder particles and capillary forces bind the particles together to produce large porous pellets 10-30mm diameter. These pellets are normally fired to create stronger bonding using a shaft indurating furnace and the strengthened pellets may then be stockpiled or shipped. The world production of pellets in 1986 was estimated at 193 million tons or 23% of total iron ore production.

The main objective in pelletising iron ore is to use the large volume of very fine particles generated in ore crushing operations. This fine powder material cannot be used directly in blast furnace charge for reasons to be discussed later. The pelletising of iron ore may be considered as the first stage of sintering, a process in which the ore is partially melted on a heating moving conveyor or grate and produces a strong but highly porous agglomerate. Successful sintering requires the blending of various reactants in addition to iron ore and it provides a means of upgrading the quality of cheaper ores by mixing with higher grade materials. Consequently sintering is commonly carried out at the iron and steel plant itself where materials from various sources may be stockpiled and graded.

Mining and ore processing carry considerable environmental penalties and their location in remote areas is advantageous in avoiding adverse public reaction. Sintering is a relatively clean operation compared with the dust problems engendered by ore crushing prior to pelletisation.

The world ore trade in 1986 was estimated at 360 million tons of which 84% was sea-borne. Brazil was the leading exporter with 91 million tons. The economies of transporting iron ore by sea have been dramatically improved with the building of large bulk carriers. The cost of shipping iron ore or pellets in a 150,000 dwt ship is one-half to one-third of that for a 50,000 dwt vessel. Consequently much of the world ore trade now travels in large ships and a successful iron ore exporting operation requires transport of the ore to a deep water harbour.

II. Iron Production

Iron production in the industrialised developed countries is dominated by the iron blast furnace process. The iron blast furnace has evolved over hundreds of years of development and is now a highly efficient and sophisticated processing system. The characteristics of the blast furnace are its great size and volume of production, its long period of continuous operation, and its very high capital cost.

Modern blast furnaces are capable of continuous liquid iron production at the rate of 6000t/day for even medium-sized furnaces, giving an annual output of 1 million tons/year/furnace. To utilise this huge volume of liquid metal a blast furnace is always linked to a large capacity steelmaking facility in an integrated iron and steel plant.

The efficient operation of the modern blast furnace is critically dependent on the control and quality of the raw materials charged into it, and of these the iron ore and coke are the most important. The high temperature chemical reactions taking place in the blast furnace which convert the iron ore to iron depend on the free movement of reactive gases through the furnace charge burden. To produce this permeability the charge must have the correct ore particle size and distribution and for this reason all modern blast furnaces operate on sintered or pelletised ore. Fine ore particles which would block gas passage through the charge must not be used.

It is equally important that the charge should not be crushed and densely consolidated under its own weight. Hence the ore agglomerate must be strong as well as porous. The crushing strength of the charge is a primary factor in the selection of coke for blast furnace application. Metallurgical coke fulfils several vital functions in the blast furnace:

(a) As a fuel it generates the high temperatures required.

(b) As a reducing agent it converts iron oxide into iron.

(c) As a strong but porous structural material it helps to support the charge burden.

As well as fulfilling these functions, blast furnace coke must have a high degree of purity and not generate high sulphur content or ash in the blast furnace product.

It is difficult to combine the variety of demands on blast furnace coke and the supply of suitable coking coal is limited even on a world scale. Whereas iron ore resources are relatively abundant, coking coal of the highest quality is rare and, in some areas of the world, virtually absent. As a consequence competition for supplies of metallurgical quality coking coal is intense and many of the best supplies are pre-empted by long-term total production contracts with the major steel producers of the industrialised developed countries.

The problems of utilising very large production volumes of liquid iron on a continuous basis, together with the difficulties of coking coal supplies, has led to the development of other ironmaking processes more suitable for use in the developing countries.

III. Steel Production

The major steelmaking process on a world-wide basis is the basic oxygen converter process (BOS). The rise to dominance of this process has been a product of the need to utilise the increasing volume of production of the modern blast furnace and to increase the thermal efficiency of the total process of steelmaking by producing steel directly from liquid iron. The other major steelmaking process in the industrialised developed countries are the electric arc furnace and the open hearth furnace. Their relative levels of utilisation are shown in Figure (1).

Open hearth steelmaking is the oldest process and its use has declined progressively. The majority of these steel plants are now located in the centrally planned economies of Eastern Europe. Both the open hearth process (70% scrap) and the electric arc furnace (100% scrap) can use scrap steel as their raw material whereas the BOS process cannot. The availability of good and cheap sources of scrap are of great importance in the economic viability of the two scrap-using processes. Steel scrap also incorporates the thermal energy expended in the primary ironmaking process. Consequently the overall energy required to produce new steel by remelting steel scrap is much lower than that required to make steel from iron ore. The saving has been estimated as a reduction of 33GJ/ton to only 14GJ/ton.

The final stage in the development of energy efficient steelmaking has been the incorporation of continuous casting as the primary solidification process for liquid steel. By continuous casting to semi-finished billet or slab shapes instead of producing ingots, the energy content of the steel is further reduced with consequent economic benefits.

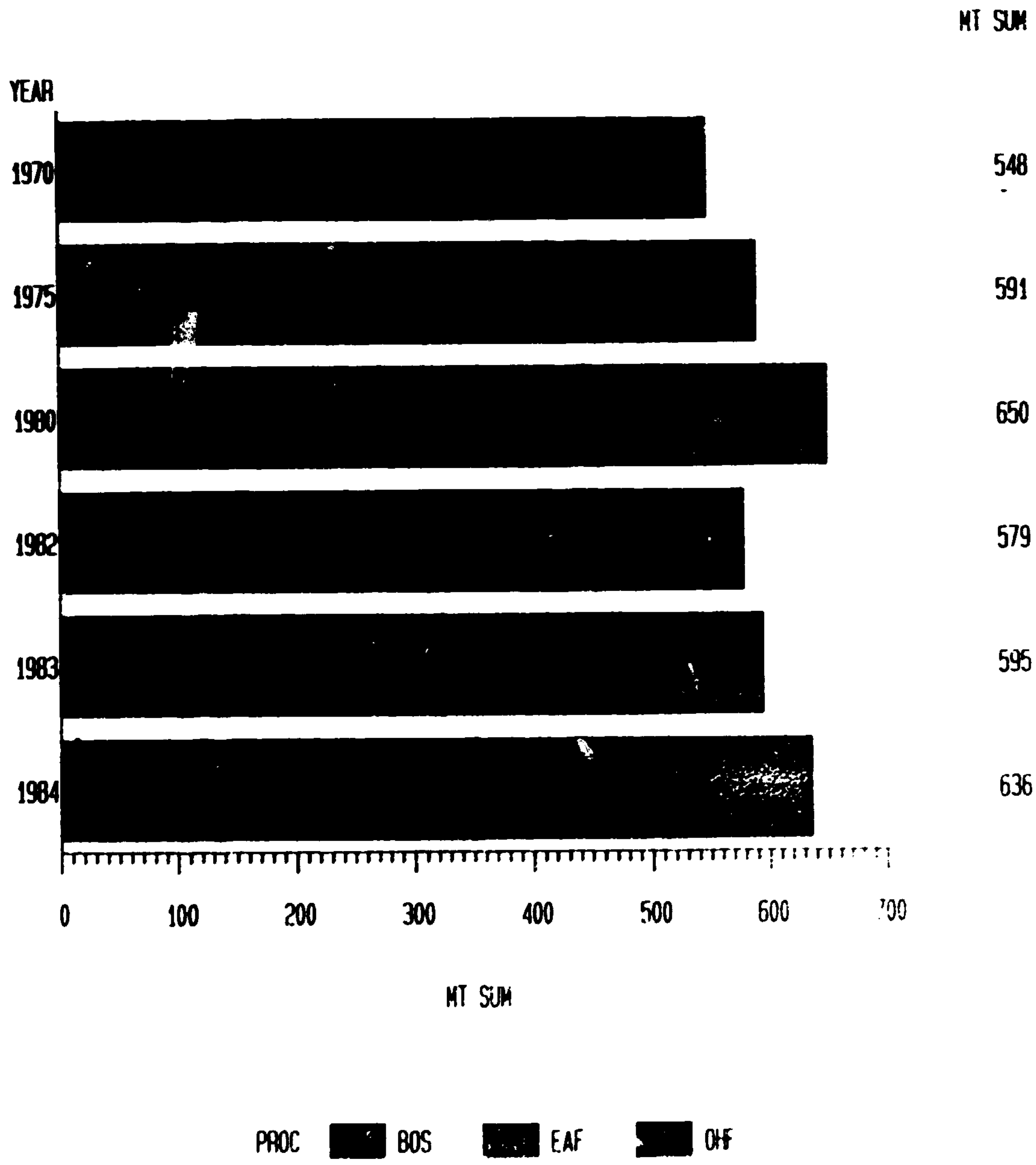

FIG. 1. ANNUAL WORLD PRODUCTION OF CRUDE STEEL
BY MAIN STEELMAKING PROCESSES

As a result of these many technological developments and the impact of intense competition during a period of industrial recession coupled with increasing energy costs, the structure of modern iron and steel plants in the developed industrialised countries has changed considerably.

Old iron and steelmaking plants based on indigenous raw materials and located remote from the coast-line have largely disappeared. They have been superseded by modern integrated plants built on green-field sites beside the sea, with deep water harbour access. These plants import their raw materials by sea and produce large volumes of steel via the blast furnace, BOS, continuous casting sequence.

Although a number of developing countries have built plants of this type their successful operation presents great difficulties. For most developing countries quite different types of iron and steel production are needed and these are largely new forms of technology.

IV. Iron and Steel Production in the Developing Countries - Alternative Technologies

Although the iron blast furnace is by far the most important process for the production of iron, and is likely to continue dominant in the future, alternative methods may have potential under the following conditions:

1. Lack of good coking coals.

2. Availability of other reducing agents such as cheap coal, oil or natural gas.

3. Availability of cheap electric power.

4. Desirability of limited production capacity and great flexibility or intermittent production.

5. Availability of high grade ore concentrates.

In developing countries several of these conditions may co-exist.

Of the alternative ironmaking processes the simplest is:

1. Electric Ironmaking: Electric ironmaking is suitable in countries possessing cheap electricity supplies but expensive coke. The main difference from the blast furnace is that heat is supplied by electricity instead of the burning of coke but the chemical reduction of the iron ore to iron is still done by coke.

A by-product of the process is gas of relatively high calorific value which may be used for heating in other parts of an integrated iron and steel plant. The coke consumed in the process can be made from much cheaper coal than that required for blast furnace coke. Electricity consumption is about 2000KWh/ton but this may be halved if efficient use is made of preheating and pre-reduction of the furnace burden. These operations can be carried out in either a special shaft or rotary kiln.

2. Sponge Iron Processes: In these processes the aim is to reduce the iron ore to iron at a temperature below that at which iron melts. The unmelted product is called "Sponge Iron". Based on a high grade iron ore concentrate this sponge iron may be refined directly to steel in an electric arc furnace. The production of sponge iron by this type of process is called "direct reduction", based on the fact that the blast furnace has been by-passed.

There are two main groups of sponge iron processes; those based on solid fuel and those based on gaseous reducing agents.

(i) Solid Fuel Processes

The fuel used in these processes may be cheap coal, coke breeze or lignite but in all cases the reducing agent is solid carbon. Since a high temperature (1000°C) is needed for the carbon to reduce the iron oxide to iron, the process requires heat to operate. However, combustion reactions generate oxidising atmospheres and this would negate the primary reducing reaction.

The problem is solved in processes such as the SL-RN process by using a rotary kiln into which combustion air is introduced along its length in controlled quantities. This allows a temperature of 1000°C to be maintained while preserving a reducing atmosphere at the discharge end of the kiln.

(ii) Gaseous Reducing Agents

Suitable reducing agents for iron ore may be derived from either natural gas or oil. They may also be produced from solid carbon in a gas producer. Gaseous reduction occurs at relatively low temperature and requires little heat input for the reaction itself, but it produces an excess of reducing gas which must find other uses for full efficiency.

In the Hyl process sintered iron ore is preheated by the [illegible] excess gases, and at a temperature of 1100°C reduced by partially oxidised natural gas. Gas consumption is high but this is offset by the [illegible] of the process if cheap natural gas is available.

Direct reduction can also be achieved in shaft furnaces using an iron ore pellet charge and a reducing gas. The reducing gas must be pre-heated to a temperature of 900°C to generate the reaction and cover heat losses in the process. The process resembles the upper part of the normal blast furnace and is typified by the Midrex process, developed in the U.S.A., but now widely used in developing countries.

All sponge iron processes suffer from the common problem that the product rapidly rusts during storage and transportation. Consequently the processes should preferably operate in direct conjunction with a steel plant.

The development of direct reduction processes utilising cheaper raw materials is likely to continue, particularly in the area of substituting raw coal for more expensive coke. It is also possible that processes involving the production of liquid iron using fluidised bed technology may become available in future years. If the reactions which are combined in the conventional blast furnace can be separated and carried out in separate stages using cheaper sources of heating, then liquid iron production is feasible.

3. Charcoal Blast Furnace: The charcoal blast furnace has been developed as an alternative to the production of sponge iron via direct reduction. The development is suitable for developing countries lacking a supply of normal blast furnace coke but with an abundance of forest or land. The process involves the use of a small shaft furnace capable of production rates up to 800t/day and has been exploited principally in Brazil.

The process is labour intensive in terms of its raw material, charcoal, and the trees needed to supply the charcoal are a renewable resource. The land required for such energy plantation is large but land unsuitable for agriculture may be used. Fast growing trees, such as eucalyptus, appear particularly suitable for cultivation.

4. Steelmaking

No small-scale steelmaking processes have been developed which would supersede the electric arc furnace. The EAF provides a flexible and efficient method of producing steel from sponge iron in an integrated plant. Where sponge iron is not available semi-integrated steel production may be achieved using steel scrap and, in these cases, other fuel sources besides electricity may be used for furnace heating.

V. Research and Development Institutions in Developing Countries

For a developing country to fully exploit its indigenous natural resources and gain the full economic benefit from them, it must possess and use all the relevant technical and scientific information available. To create an industry based on these resources and run it successfully the country must also have a skilled and educated work force.

In addition to dealing with the immediate practical problems of its day-to-day running, an industry must have other capabilities:

1. It must be able to solve problems requiring deeper analysis and scientific investigation than can be applied on-site.

2. It must be able to deal with longer term problems which may arise from difficulties specific or unique to its own operations.

3. It must have the capacity to carry out forward planning for future technical development.

4. It must remain aware of technical development elsewhere in the world which it can make use of, or which may threaten it with obsolescence.

To meet these requirements an industry must possess, or have access to, some type of research and development (R and D) centre.

In order to create and apply indigenous research and development expertise, developing countries have three basic options:

1. They may transfer or adopt the technology used in industrialised countries in well-defined areas, while making appropriate changes to suit local conditions. Local conditions may involve raw materials, equipment, manpower and other specifics such as the scale of operation or market.

2. They may transfer or adopt the appropriate technology from another developing country, thereby minimising the problem of technology transfer and accelerating their own development.

3. They may create their own indigenous research and development activities, with the necessary supporting services and institutional arrangements for co-operation with industry.

The level of technical development in a country will have an important influence on which of these various options can be used. The transfer of advanced technology may be possible where only relative underdevelopment exists, but in cases of total underdevelopment a country must create its own indigenous research and development capabilities if only in selected areas of science and technology.

An R and D centre may cover broad sectors of the mineral and metallurgical industries or it may be confined to a specific subject such as iron and steel or aluminium. The specific technical areas covered would normally include ore beneficiation, metal extraction, refining and processing into finished shapes and forms. A centre should also undertake the evaluation and testing of raw materials and it should be involved in any exploration of a country's mineral resources and reserves.

An R and D centre should deal with such problems as the standardisation of products, fuel and energy conservation, environmental aspects and it should be able to undertake consultancy work for local clients. R and D centres also have an important function as the focus for activities such as the collection, cataloguing and dissemination of technical information and documentation. As an information resource they are well placed to prepare feasibility studies, market surveys and project reports for industry.

The technical development of a country is critically dependent on the creation of an educated work force and, in this area of technical training, an R and D centre has another vital role. It should have the necessary facilities, and be expected to provide technical training for industry and research personnel. High level overseas education and training may be appropriate for a small number of key personnel in an industry but the majority of the work force will also benefit greatly from technical training and this can only be carried out within the developing countries own institutions. A centre should have available, and regularly run, both in-house training programmes and appropriate courses in industry.

The creation of a successful R and D centre which can undertake the many functions described is clearly a major investment and requires careful planning. A R and D centre must be large enough to be viable; small, understaffed and ill-equipped institutions are a poor investment. Much of the equipment of an R and D centre will have to be imported and the overseas training of personnel represents another potential foreign exchange drain. For a small developing country there may be greater benefits in co-operating in the creation of a regional R and D centre.

The equipping of an R and D centre also requires careful forward planning and attention to the special problems of operating advanced scientific equipment in a developing country. Scientific apparatus is not as well developed nor as robust as industrial equipment. It can therefore be expected to develop minor faults at frequent intervals and, in the absence of adequate maintenance or servicing facilities, equipment may become inoperative for long periods and rapidly deteriorate. It is therefore important that equipment should only be bought from manufacturers able to provide servicing back-up at a reasonable cost, and that every effort should be made to develop maintenance and servicing expertise within the R and D centre itself.

The scientific and technical training function of an R and D centre should be regarded as a long-term investment with valuable spin-off benefits for the country beyond those accruing to the specific industries it serves. The creation of scientific and technical awareness and competence within the community as a whole is a necessary element in the industrial development of any country.

R and D centres are best located in or near the industries they serve in order to maximise personal contact and technical interchange. It is often very difficult to conduct research and carry out experiments in an operational industrial plant. Hence R and D centres must often build their own larger-scale pilot plant facilities and these also benefit from location close to the appropriate industry.

The recruitment and retention of trained staff is also easier if the centre is near a major population centre. The training of staff represents a considerable investment for a developing country and every effort should be made to encourage them to stay in the developing countries. In this respect the creation of regional R and D centres, with good resources and a wide range of scientific and technical activities, would help to reduce competition for trained staff between the developing countries themselves.

VI. Ferrous Ore Exploitation and Iron and Steel Development

Any discussion of the exploitation of the ferrous ore resources of a developing country and its intimate link with the national and international iron and steel industry is complicated by the major differences between the individual developing countries. They differ in stage of development, size and type of natural resources, size of population and internal market structure. In addition to these individual differences, there are also major distinctions between the main geographical regions of the world.

The level of industrial development in a country is commonly judged on the basis of its consumption of steel per capita. For the fully industrialised developed countries the value is in the range 200/600Kg/head. A number of the major developing countries of Latin America and the Far East have values of 100Kg/head and some of the North African and Middle East Arab States are similar. The values for the developing African countries are generally much lower.

The relationship of steel consumption to Gross National Product is also used to judge the stage of development of countries and this steel "intensity" has been used to identify four stages of development:

(a) Developing countries and conditions for take-off.

(b) The stage after take-off.

(c) The levelling-off phase and the timing of the peak.

(d) Mature economies with a declining steel intensity.

This latter stage is also marked by a decline in steel consumption/capita and, over the past decade, this has been a feature of all the major industrialised developed countries.

Projections of steel demand on a world-wide basis indicate that growth in consumption will occur only in the developing countries and that demand in the industrialised economies will decline. At present the developing countries, including the centrally planned economies of Asia, produce about 20% of total world steel output. The aim of all developing countries should be that they themselves are the main beneficiary of their own development. The strategies by which this aim may be achieved are best discussed on a regional basis.

1. Africa

Africa is so large and composed of such a diversity of countries that it is usually analysed in terms of three geographical regions - West, East and North Africa. This division is, to an extent, justified by the physical barriers which make land transport between these regions difficult but, in the context of iron ore exploitation, the availability of bulk sea transport provides an alternative link.

Africa has great natural mineral resources of which iron ore is a major component. The region cannot utilize much of its iron ore production and 70% is exported, mainly from Liberia and Mauritania who, together, produced 25 million tons in 1986. The abundance of good quality iron ore would normally be expected to lead to the development of an indigenous iron and steel industry but this has only happened in Nigeria and Zimbabwe. Development elsewhere has been constrained by the lack of coking coal, poor sub-regional communications and lack of infrastructure and a small market potential for products in low population regions.

The development of ironmaking processes using high grade ore and gas reduction has changed this situation. Many countries in the region now have direct reduction plants, particularly where natural gas is produced as a by-product of oil production. Previously this gas was often flared off and wasted.

The potential for co-operative development in Africa is very great and the region has all the natural resources to become self-sufficient in iron and steel products. The greatest value the developing countries of Africa could derive from their iron ore resources would be to convert them into higher grade engineering products which are currently imported. The technology for this already exists, even on the scale of mini-plants where a country's domestic market is small.

2. Latin America

Several countries in Latin America are major producers and exporters of iron ore, some in pelletised form. Brazil is the largest producer with 130 million tons in 1986, making it also the second largest producer in the world. The availability of large bulk ore carriers, some of which it has invested in itself, has enabled Brazil to ship iron ore all over the world at low cost. Brazilian pellets can be landed at coastal steel plants in the U.S.A. at lower cost than domestic products and Latin American countries are developing important supply arrangements with a number of other developing countries, such as China and Libya.

Several Latin American countries have diversified iron and steel production and are now active in the production of capital goods. Argentina, Brazil and Mexico are examples of this advanced stage of development and the associated high value added aspect of the iron ore production.

3. Asia

The developing countries of Asia have made great progress in the creation of large scale iron and steel industries. India, Korea and China are all examples of this and both India and China are major producers of iron ore for domestic consumption and, in the case of India, for export also. India exports both iron ore concentrates and pellets to a variety of industrialised and developing countries.

VII. Summary

The relative abundance of high grade ferrous ores, coupled with a declining market for iron and steel products in the industralised countries of the world, will continue to keep basic mineral prices low. Mineral processing in the developing country of origin carries some financial benefit in that iron ore fines, the lowest valued product at $15 per ton, can be converted into pellets worth $24 per ton. The metal content of iron ore demanded by consumers has risen progressively over the years and can now only be obtained in high grade deposits. Consequently the exploitation of low grade ore for export has little potential other than as a blending constituent for sinter production.

The major consumers of iron ore will remain the large integrated iron and steel plants around the world based on the blast furnace. However, in the majority of developing countries this type of large scale plant is unsuitable and the use of direct reduction ironmaking will continue to grow.

There is great scope for regional self-sufficiency in iron and steel products among the developing countries through co-operative development. This is particularly evident in the case of the developing countries of Africa, where raw material resources are good and the market for finished iron and steel products is still at an early stage of its potential growth.

Technological development will continue to depend on the creation of an educated and trained work force and such investment has permanent long term benefits. Regional co-operation in such training should also be advantageous.

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3. Review of existing mechanisms for marketing and distribution of non-ferrous metals in various beneficiated and fabricated forms, the obstacles experienced by developing countries when trying to penetrate the international commodity market and scope for co-operation among them in order to strengthen their position in this respect.

C O N T E N T S

Introduction

The mining of non-ferrous ores and the production of non-ferrous metals from them is closely linked to their consumption levels by world-wide industry. In terms of annual production the most important non-ferrous metals are aluminium, copper, lead, zinc and tin which, together, have an annual production averaging 35 million tons. Non-ferrous metal production is therefore less than 10% of world steel output but the higher value of the non-ferrous metals balances this effect and makes them of major economic significance.

The higher value of non-ferrous metals has a significant effect on both their production and usage. Although non-ferrous ores are widely distributed on a world scale, they are generally not available now in deposits with high metal concentrations. Consequently the trend in non-ferrous ore exploitation has been one of developing more low grade and secondary resources, whereas in ferrous ore exploitation the trend has been the reverse.

The uses of a metal in industrial applications is generally inversely proportional to its price and this effect is seen in the utilisation of non-ferrous metals. Since metal prices are based on weight and not volume, the denser metals are less attractive than the lighter and the scale in utilisation of a metal is, in fact, related more to price/volume rather than price/mass. This accounts for the higher level of consumption of aluminium, which is the only non-ferrous metal to seriously compete with steel as a structural material. The use of the most expensive non-ferrous metals such as tin, is confined to applications such as thin coatings where the volume required is very small.

The scale of production of the major non-ferrous metals has fluctuated over the past two decades closely in line with the level of economic activity in the major industrialised countries of the world. The overall use of metals in all forms of engineering tends to decline with the impact of newer and lighter designs but the non-ferrous metals have many non-structural applications based on their unique physical and chemical properties. Consumption in these areas is likely to continue to increase and with higher and higher added value.

I. The Mining and Processing of Non-Ferrous Ores

The progressive depletion of high-grade base metal ore bodies and the necessity to mine lower grade ores on a greater scale for the same level of metal production has escalated costs over the past two decades. As a consequence the mining industry has undergone major changes in its efforts to streamline operations and improve technology to remain competitive.

There has been a general trend towards larger scale mining using much larger equipment and the development of open-pit mines where lower grade ores can be more easily exploited. Progress in deep-pit underground mining has also taken place but the sector is likely to decline further in the long term.

There has been substantial progress in the processing and beneficiation of non-ferrous ores. In pyrometallurgical processes the use of oxygen injection to speed chemical reactions and increase furnace capacity has been developed but these processes will always be fundamentally energy intensive. Consequently there has also been considerable development of the less expensive hydrometallurgical processes for the processing of very low grade ores.

Pyrometallurgical processes are responsible for much of the cost of extracting metals where the conventional comminution-concentration-smelting sequence is used, e.g. 60% in the case of copper. Hydrometallurgical extraction processes are generally cheap and require simple technology. They are particularly convenient for developing countries in that the plant used requires minimum capital, is cheap and fast to construct and can be amortised very quickly. Although the technology of mineral leaching has not yet been universally accepted, the situation is changing rapidly.

Mineral leaching can be carried out in situ on fractured or fragmented ore material which is not excavated. Alternatively, broken ore rock may be leached in heaps or dumps and sprinkled with leach liquors using a recirculatory system. Leaching may be chemical using acid, caustic soda or cyanide or biological using particular strains of bacteria. The bacteria do not actually leach the ore material themselves but they accelerate the process by regenerating the chemical leaching agent.

The current and alternative technologies for non-ferrous ore exploitation are best analysed under the headings of the individual metals.

1. Aluminium: Aluminium is the most abundant metal in nature and makes up 8% of the earth's crust. It is a common constituent of many minerals, in combination with various other elements, but only one of these, bauxite, is the main source of the metal. Bauxite contains at least 50% aluminium oxide or hydroxide and its first stage of refining involves the production of alumina (Al_2O_3) via the Bayer process. Of the known world bauxite reserves 70% are concentrated in four countries - Guinea, Australia, Brazil and Jamaica.

(i) Bauxite: Bauxite ore is generally mined by open-pit methods from sites capable of producing several million tons/year. World-wide production in 1987 was over 95 million tons. Where beneficiation is necessary bauxite is generally treated by wet processes to remove silica, iron and clay. Most bauxites require crushing for ease of processing and may be dried at the mine to reduce transport costs if shipped large distances. The first stage in the extraction of aluminium from its ore involves the production of refined alumina.

(ii) Alumina: Alumina production on a world scale was 28 million tons in 1987 and 95% of this was derived from bauxite. Alumina production from bauxite is almost exclusively carried out using the Bayer process in which high-grade bauxite is digested with caustic soda solution and separated from waste residues (red mud) as a solution of sodium aluminate. The aluminate solution is decomposed and precipitates aluminium trihydrate which is subsequently calcined to alumina.

Alumina plants can have capacities up to 1 million ton/year and require considerable space. For the production of 1 ton of alumina 3-4 tons of material must be removed and, for this reason, alumina plants are often located at coastal sites. The waste product (red mud) from alumina production presents a major environmental problem since, in quantity, it equals or even exceeds that of the alumina produced.

Although much of both bauxite and alumina production is directly exported from the mining country, present day trends are to establish integrated plants including aluminium smelters.

(iii) Aluminium Smelting: Primary aluminium world production in 1987 was over 15 million tons with a further 4 million tons being derived from scrap recovery. All this primary production was derived from the 100 year old Hall-Heroult process in which Al_2O_3 (alumina) is electrolysed in a cryolite melt (Na_3AlF_6) using a carbon anode and aluminium pool cathode.

The economics of aluminium production are dominated by its energy consumption (50% of production costs) and this relates mainly to its use of electricity both as a heating agent and for electrolysis. Smelters are ideally located where both cheap electricity and good bauxite reserves are close to one another but this combination is rarely found. In practice in the past smelters have been mainly sited in the developed countries, close to their aluminium markets and running on cheap electricity sources. Bauxite or alumina were imported. In more recent times smelter location appears to be most strongly influenced by the availability of low cost energy and new facilities are almost always based on hydro-power, as in Canada and Brazil, or on cheap coal, as in Australia.

The availability of low cost sea-borne transport of raw materials through the use of large bulk carries has favoured the location of smelters on coastal sites. There remain many undeveloped energy sources in the world where hydro-generation or flared gas could be used for cheap electric power.

2. <u>Copper:</u> Copper is a very important base metal in the mining production of the developing countries. Large copper ore resources exist in many of the countries of Latin America as well as in Central Africa. The bulk of copper ore deposits in developing countries are of two types:

(a) the porphyry ores of the American continent, and

(b) the sedimentary deposits of Africa.

The deposits have common characteristics and can be exploited using similar mining and metallurgical strategies. Consequently there is considerable scope for co-operative research and development on an inter-regional basis.

(i) <u>Bacterial Leaching:</u> The need to process low grade copper ores, which cannot be used with more expensive standard flotation techniques, has led to the increased use of bacterial leaching as a means of treating copper sulphide ores. The process is simple and cheap and it produces solutions which can subsequently be conveniently processed. Bacterial leaching is well suited to the treatment of sulphide ores since they are less soluble than oxide under normal conditions with conventional solvents.

The bacteria responsible for the leaching effect are autotrophic, i.e. they can live in the absence of organic matter, and they act by accelerating the oxidation and solution of the sulphides present in ore, mine waste and tailings. The bacteria are naturally present in sulphide mine waters and these are added as the activator to dilute sulphuric acid for the leaching reaction. The oxidising conditions necessary for the leaching is principally provided by atmospheric oxygen but oxidising bacteria can also improve this aspect of the process.

(ii) Solvent Extraction - Electrowinning (SX/EW): The SX/EW process is a direct and effective process for the recovery of cathode copper from leached solutions. The process has a relatively low investment cost and low operating costs. The combination of leaching with solvent extraction and electrowinning provides a good alternative to conventional ore crushing operations with their high energy and material requirements. The expensive flotation process is also avoided. Most important of all the most expensive of the conventional operations, smelting, is eliminated.

The plant required for SX/EW processes consists of simple mixers and settlers instead of the traditional grinding mills, flotation machines and furnaces. The final product, cathode copper, is obtained in a 99.9% purity which is the same as that produced in classical electrolytic refineries. The process is based on the use of organic reagents which have selective solubility for copper ions and remove them from the leached solution. Subsequently the copper is stripped from the reagent by strong sulphuric acid and this acid solution is electrolysed to produce high purity cathode copper.

(iii) Pyrometallurgy: Scientific research and technological advance has produced important results in pyrometallurgical copper smelting. The most successful new smelting process is that of Flash Smelting and this success has been enhanced since the 1970s by the introduction of oxygen injection.

In flash smelting the earlier process sequence of roasting, melting and partial conversion of sulphide ore is combined into a single operation. In the original flash smelting process the high temperature required for the process was generated by a combination of pre-heated air, exothermic oxidation and burning fuel oil. With the advent of oxygen injection the process becomes autogenous and the copper content of the matte product rises to 70%.

3. Lead and Zinc: Lead and zinc ores generally occur together in ore deposits and most of these ores are complex. The economics of lead and zinc extraction are consequently influenced by the possibility of recovering more valuable by-products, of which silver is particularly significant. Ore separation and concentration is normally carried out by conventional flotation methods but since the mineralisation of each ore body is usually unique, the flotation reagents and techniques normally have to be tailored to the specific case.

Lead and zinc frequently occur in association with copper and the copper and zinc must first be separated since they interfere with one another. Consequently the first stage of processing is normally the floating-off of lead and copper concentrates from the zinc.

There have been no major advances in flotation technology but there remains a major difficulty in the separation of lead, zinc and copper into individual concentrates. Metal recovery rates are usually no more than 80% and the metal losses occur mainly in the secondary separation rather than the primary bulk flotation. Since bulk flotation is a relatively efficient process (90% reco ry) the processing of primary concentrate is often pyrometallurgical smelting.

The dominant smelting process is the Imperial Smelting Process.

This process involves the use of the blast furnace principle in which oxide ore is reduced by a carbonaceous combined heating and reducing agent. The process is designed to recover lead and zinc simultaneously from low grade ore concentrates. The high solvent action of lead means that it is also possible to recover silver, gold and bismuth and a substantial part of any copper. It is ideal for dealing with lead-zinc-copper concentrates and produces an overall recovery of 95% of these metals.

There are some 13 plants of this type around the world producing 14% of the world zinc production. The zinc blast furnace is a large production unit producing up to 300 tons/day and involving major capital investment. As a consequence the plants are best run as a regional facility taking concentrate from various sources.

In the area of the direct smelting of concentrates two approaches are under current development. Bath smelting in the QSL process involves the use of a horizontal kiln reactor equipped with bottom injectors through which oxygen is introduced. The kiln has a graded oxidising/reducing zone combination and liquid lead is tapped from the bottom. The process is claimed to give flexible continuous operation at low capital cost and may be suitable for use in the developing countries in the future.

The alternative smelting process is an adaption of the flash smelting technique used for copper extraction. The flash smelting reactor generates a lead-rich slag which is skimmed to an electric furnace where it is reduced using coal injection. Zinc is volatilised into the off-gas from the furnace and an 80% recovery claimed.

Neither of the recent pyrometallurgical processes is fully proven and both involve high technology and control. They are therefore as yet not suitable for developing country application. Die casting and galvanising, two of the principal end uses for zinc, require metal of HG (High Grade) quality and this is produced directly by hydrometallurgical extraction methods. The zinc produced in the blast furnace requires further refining and hydrometallurgical processes now account for 70% of world zinc production.

4. Tin: Traditional methods of tin extraction rely on the use of high grade concentrates from alluvial deposits. These are purified by roasting or leaching operations and subsequently processed in two or three stage smelting operations. In recent years an increasing proportion of lode tin has been mined as alluvial deposits have become exhausted and these require a different approach.

Lode tin usually has a lower tin content and contains higher levels of sulphide impurities, particularly lead, bismuth, arsenic and antimony. The trend has been to adopt fuming processes to produce medium grade concentrates since normal mineral processing methods lead to unacceptable levels of tin loss.

In an effort to recover more tin from the finer grinding of low grade ore to liberate cassiterite, the tin oxide mineral required, flotation methods have been widely introduced. Flotation is a highly developed method of ore separation and concentration for non-ferrous sulphides but it was not previously used for tin ore beneficiation. The flotation of cassiterite has required the development of specific reagents for this purpose, using adaptations of those normally used for the removal of non-metallics or heavy metal oxides. In view of the considerable cassiterite losses made in the processing of alluvial deposits, the further development of tin flotation is highly desirable.

75% of all tin is still found in low grade placer deposits in Thailand, Malaysia, Indonesia and Central Africa where wet gravity methods can be used successfully for concentration. The extraction of tin by pyrometallurgical process involving fuming is only economic when tin prices are high. In the present day situation of very depressed prices, such processes remain in doubt.

II. Research and Development (R and D) Institutions in Developing Countries

In the field of non-ferrous raw material exploitation R and D has obvious importance. Non-ferrous ore sources are becoming increasingly dilute and complex in character at a time when the demand for high value technological materials is increasing. The ability to process complex ore bodies for all their potentially valuable by-products is financially attractive and strongly influences the economics of extracting base metals. The production of molybdenum from copper extraction and silver from lead are two obvious examples.

The exploitation of non-ferrous ores is often of a highly localised nature and requires techniques specific to the particular ore deposit. Consequently there is a need to develop scientific and technical expertise in all the developing countries with non-ferrous ore resources. In addition to specific local competence, there are also advantages in both regional and inter-regional co-operation. To an extent the need for this is already recognised in the existence of various International organisations created by the individual metals industries involved in the production of copper, zinc and tin. These R and D associations are very active in the collection and dissemination of information of specific interest to their metal producers and users. They also undertake research and provide a model for such activities in the developing world.

Non-ferrous research and development can co-exist with that in the ferrous field although they may have different objectives. Ferrous ore exploitation has a well developed technological base and research is focussed mainly on the end product, steel. In the non-ferrous case the primary production stage is still of great technical complexity and the financial rewards of success in this area are very high.

Both non-ferrous and ferrous research require similar equipment and staff of a similar scientific background. In a developing country or region it is unnecessary to separate the activities as is usually the case in most industrialised developed countries.

The areas of R and D which would be particularly valuable in the non-ferrous field are:

1. The extraction of all useful components from ores and the recovery of valuable by-products at all stages in the processing of base metals.
2. Improvements in flotation technology to increase metal recovery and improve separation efficiency.
3. Increased use of hydrometallurgy to achieve higher energy and capital savings by leaching and solvent extraction methods.

Non-ferrous research shares, with all other such activities, the aim of achieving lower energy consumption in all operations. It also produces similar beneficial spin-offs in the country as a whole in stimulating scientific and technical awareness and raising the level of technical education.

III. The Marketing and Distribution of Non-Ferrous Products

The non-ferrous metal industries based on aluminium, copper, lead, zinc and tin each have their own market structure and each should be considered separately.

1. Aluminium: The developing countries produce roughly half of market-economy bauxite production but have only 20% of metal production. The industry is dominated by six vertically integrated transnational companies in which the production of bauxite, alumina and aluminium are closely linked to consumption in all their main markets. As a consequence there is very little open trading of either bauxite or alumina as commodities.

The vertical integration of the major companies also extends into fabricating, since they have facilities to use all the aluminium they produce. This self-sufficiency extends also to independent and second-tier aluminium producers and very little aluminium is available to independent fabricators.

The market for aluminium is likely to grow at the same rate as that of economic activity in the major industrialised countries. Aluminium is the only non-ferrous metal used widely for structural purposes and its good strength/weight characteristics have always made it attractive in the field of transport. In more recent times it has made major inroads into the market of its main rival, steel. There is intense research effort within the major producers to develop higher value products such as aluminium-lithium alloys and aluminium-silicon carbide composites. Aluminium is also making advances in the electronics industry in super-pure form.

To obtain greater value from their bauxite resources, the developing countries would benefit from greater regional and inter-regional co-operation. Since they possess all the necessary raw materials and have cheap sources of power, the developing countries collectively have the means to create self-sufficiency. The technology for producing aluminium for consumer and industrial products is readily available but the lack of experience in its operation is a problem which requires time and patience to overcome.

2. Copper: In contrast to the situation in aluminium, the developing countries have established national ownership and control over most of their copper industries. The major developing country state enterprises in Latin America and Africa have displaced the former transnational corporations as the leading force in world copper production. Copper is a relatively expensive base metal on a price/volume basis and, as such, its uses are confined to those areas where it has attractive physical and chemical properties such as conductivity and corrosion resistance. Electrical applications account for 70% of new copper production although the market for telecommunications material is declining with the advance of glass fibre optic technology. A well-developed scrap industry supplies much of the copper used in construction and transport and, overall, provides 40% of Western needs.

3. Lead and Zinc: The production of lead is largely determined by the demand for other metals, principally zinc and silver, with which it is usually associated in ore deposits. The principal market for lead is in acid storage batteries and demand for these stems from the activity of the car industry. Lead is another metal, like copper, where up to 40% of supply is derived from scrap, with used car batteries the principal source.

There are a number of technological developments in the battery field which will lead to increased lead consumption and will help to balance the decline associated with the expansion in the use of lead-free gasoline. Small batteries for use in permanent memory storage in computers are under development and an American electrical utility has installed the first large scale lead-acid battery for off-peak electricity storage. This battery uses 2300 tons of lead and has a 10 megawatt power output capacity.

Zinc is produced quite widely, in association with lead, and enjoys a stable market based on its use in a variety of forms and end-products. Galvanising, die castings and brass (a copper-zinc alloy) are its principal markets. The large number of producers of zinc and lead means that these metals can be freely traded through the commodity exchanges.

4. Tin: Tin is an expensive metal with the highest percentage level of production of any base metal in the developing countries. Its consumption has been dominated for many years by its artificially high price which has also allowed the development of ore resources of low concentration.

Due to this high price, research has been mainly directed at reducing its use rather than expanding it and it has lost much of its traditional market in the canning industry. Solder has now taken over as its principal end-use. It is likely that new uses and increased consumption will develop if the present low price situation persists since tin has unique physical and chemical properties.

IV. Mineral Processing in the Developing Countries

The fact that much of the non-ferrous ore production of the developing countries is exported directly and that they have a much smaller involvement in mineral processing or metal production, raises the question of their increased participation in such activities. Many indirect benefits have been claimed for such a strategy in the past, relating to accelerated industrialisation, improvement in infrastructure and increases in national technological capacity. The expected direct benefits of the strategy are the retention of a greater share of the value of mineral production and the creation of independence from the control or influence of the transnational corporations.

Experience has shown that the expected benefits of export-based development are difficult to attain and slow to accrue. The greatest problems have been financial, in that mineral processing development requires large capital investment and the creation of large scale plants. These costs and the associated indebtedness can easily negate any added value in the products.

The marketing of higher value added mineral products requires an extensive organisation, the creation of which involves costs. Apart from aluminium, where markets are highly concentrated, the trading of non-ferrous commodities is not significantly restricted and the metal exchanges provide a last resort. Tariff barriers and other artificial trade constraints also appear to have little influence in the specific case of non-ferrous minerals.

The linkage from the mining of ore through smelting and refining to the fabrication of metal products and finally capital goods production, is one of the basic patterns of successful industrialisation. The basic metals are among the highest ranking industrial sectors in terms of the ability to generate economic linkages and promote growth.

These arguments have less force in very small economies and the development of a totally rounded industrial economy may be impossible. A national strategy based on the export of crude ore in order to generate foreign exchange is perfectly valid where a developing country has an abundance of non-ferrous ore and requires essential imports for other sectors of the economy. The development of agriculture and the supply of pharmaceuticals are obvious examples of priority areas.

For the long term, however, a strategy of greater inward-oriented development can offer advantages, particularly if pursued on a regional basis. Collectively most regions of the developing world have the required combination of raw material resources, cheap energy, space and freedom from environmental constraints, and some access to foreign capital. Whether a particular developing country pursues a strategy of vertical or horizontal integration, and whether it aims for export or inward orientation, will vary with its particular needs and stage of development. The advantages of co-operative planning and integration on a regional basis are, however, very apparent and offer a means of avoiding the difficulties of the past.