

GUIDELINES FOR ENVIRONMENTAL MANAGEMENT OF IRON AND STEEL WORKS



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OF IRON AND STEEL WORKS



Industry & Environment Office
UNITED NATIONS ENVIRONMENT PROGRAMME

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FOREWORD

Environmental effects of operations in the Iron and Steel Industry were studied by UNEP in 1978 in a workshop held in Geneva 1/, organized with assistance from the International Iron and Steel Institute and with the participation of many national and international bodies.

Following publication of the conclusions of the workshop, two documents, an Overview 2/ and Technical Review 3/ of Environmental Aspects of Iron and Steel Production were prepared. A Technical Review document on Environmental Aspects of the Direct Reduction Route to Steel Making 4/ and Environmental Guidelines for the Direct Reduction Route to Steel Making 5/ were also published following the experts' meeting in Venezuela in 1982. These studies provide background material essential to any evaluation of interactions between the Iron and Steel Industry and the environment.

One of UNEP's goals is to provide guidelines on ways of reducing the impact of Industry. These are intended to assist policy makers and those involved in decisions on environmental issues. In them major points requiring attention and significant actions required to minimize damage are summarized. The guidelines do not set out statutory or mandatory rules, but rather indicate generally accepted good environmental practice.

The integrated Iron and Steel Industry is large and complex. To meet the above objectives these guidelines provide, in sections 1 and 2, an evaluation of the major environmental issues involved. This is followed by a check listing (table 2), setting out points requiring attention, where effects can be significant.

Finally each sector of the Industry normally associated directly with a steel plant is considered in sufficient depth to suggest actions which could be taken in developing policy and in adapting practices to local conditions.

Generality is maintained, with the intention that the information should retain, for some time, its relevance to the user.

1/ Environmental Aspects of the Iron and Steel Industry, Workshop Proceedings, Geneva 17-20 October 1978 Part I and Part II

2/ Environmental Aspects of Iron and Steel Production - An Overview (UNEP 1984)

3/ Environmental Aspects of Iron and Steel Production - A Technical Review (UNEP 1986)

4/ Environmental Aspects of the Direct Reduction Route to Steel Making - A Technical Review (UNEP 1983)

5/ Environmental Guidelines for the Direct Reduction Route to Steel Making (UNEP 1983)

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- . all members of the UNEP Environmental Consultative Committee on the Iron and Steel Industry (27 experts).
- . most of those experts who took part in the UNEP Workshop on Environmental Aspects of the Iron and Steel Industry, Geneva 17 - 20 October 1978 (42 experts).
- . some experts who took part in the UNEP/UNIDO Meeting of Experts on the Environmental and Resource Aspects of the Direct Reduction Route to Steel Making, Puerto Ordaz, Venezuela, April 1982 (7 experts).
- . other partners in the UNEP consultative process on this industry (18 experts).

Their assistance is gratefully acknowledged. A list of contributors of specific comments is annexed.

The UNEP officer responsible for this activity was Mr. Takao Hamada, Senior Industry Liaison Officer.

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1. INTRODUCTION

1.1 The Size of the Iron and Steel Industry

Throughout the world more than 700 000 000 tonnes of steel are produced annually. In developed societies the primary energy spent in making the steel consumed represents 7 to 10 per cent of the national energy usage. The pervasive nature of the steel industry is readily appreciated.

1.2 The Structure of the Iron and Steel Industry

The iron and steel industry is not a single entity, but involves a number of different industrial complexes and successive manufacturing stages, for example:

1.2.1 Mining

Major mining operations for iron ore and coal; mining activities of some importance for silica, manganese, nickel and chromium ores, and other components for alloys; and the winning of limestone and industrial minerals for the manufacture of fluxes and refractories.

1.2.2 Preparation of raw materials

The operations of transportation; stockpiling; blending; coal washing; ore beneficiation; screening; coke-making; the manufacture of pellets and sinter; the burning of limestone and the fabrication and firing of refractories; and the recovery of scrap.

1.2.3 Ironmaking and alloy manufacture

The production of liquid or solid iron and alloys, i.e. the manufacture of direct reduced iron by fluid bed, shaft or kilning processes; the use of the blast furnace to make pig iron (for foundry use) and liquid hot metal (for steelmaking); and the use of electric furnaces to smelt ferro-alloys.

1.2.4 Steelmaking

The manufacture of steel, usually in basic oxygen vessels (BOS) or in electric furnaces (EAF). In some countries flame combustion processes (e.g. the open hearth) are used.

1.2.5 Making of semis

The transformation via solidification, rolling or forging of steel to make "semis" (semi-finished or intermediate products, for example, ingots, slabs, blooms or billets), which pass on to other manufacturing stages or are sold to other processing companies.

1.2.6 Hot rolling

The inspection of semis for internal and surface quality; their preparation, reheating and hot rolling or shaping to make different sections (e.g. refer figure 1, plates, structurals, rails, sheet, strip and bar). Much steel is sold at this stage to final customers.

1.2.7 Cold forming and rolling

Fabrication of hot rolled products to make light angles or sections; cold drawing or twisting to make wire products; cutting or machining for engineering use; or cold rolling to bright sheet. Products largely are sold at this stage.

1.2.8 Coating

Covering with metallic or plastic materials certain hot or cold formed products for direct sale.

1.2.9 Manufacture of steel-based products

The forming, assembling, painting, enamelling or coating of cold rolled, drawn or shaped products to make goods which are sold.

1.2.10 Waste handling

The recycling, preparation for sale or disposal of residues.

1.3 Nature of its Environmental Impact

As indicated in the Foreword, prior publications of UNEP [1]-[4], set out in considerable detail the environmental problems raised by the industry, outline the processes involved and discuss methods used to control pollution.

Other useful general references, prepared by the International Iron and Steel Institute, are cited in the bibliography [6] - [9] together with a number of studies by other bodies [10] - [17].

There are several major pollution problems faced by the steel industry. These are not confined to any one processing stage. Due to the size of the industry, control is costly and has to be applied to many points within any one steel plant. Figures 1 and 2 illustrate the flow of materials and stages of processing in steelmaking. Figure 3 indicates the sources of pollutants associated with these operations, and table 1 provides a semi-quantitative (since the levels of emission and control differ from plant to plant) guide to the amounts involved.

Fig. 1 Flow Sheet of principal operations in an integrated Steel plant
Intermediate products, by-products and final products
are shown

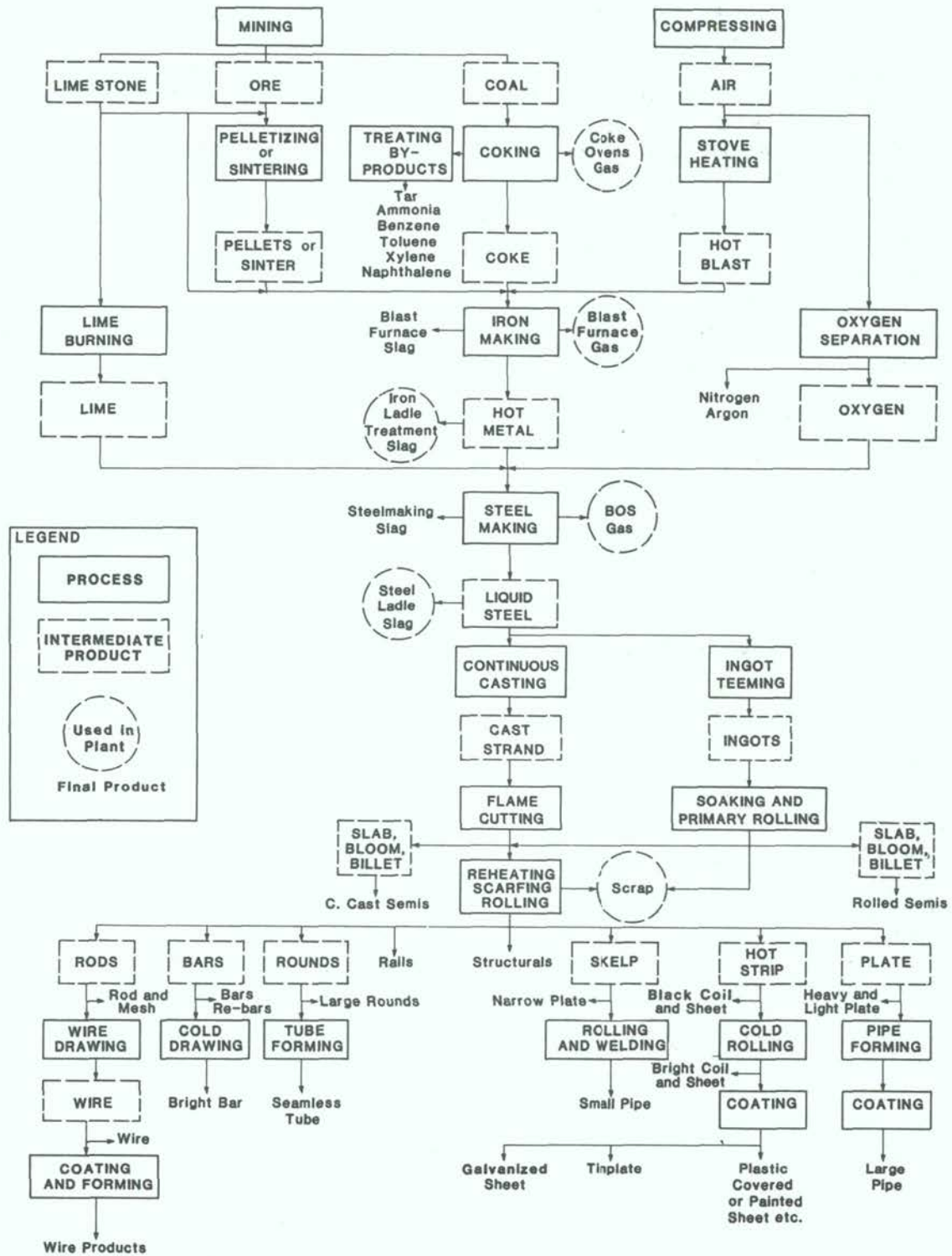


Fig. 2 Flow Sheet indicating equipment used and material flows to produce 1 tonne of rolled steel in an integrated steel plant. For simplicity sintering and continuous casting only are shown and quantities are rounded

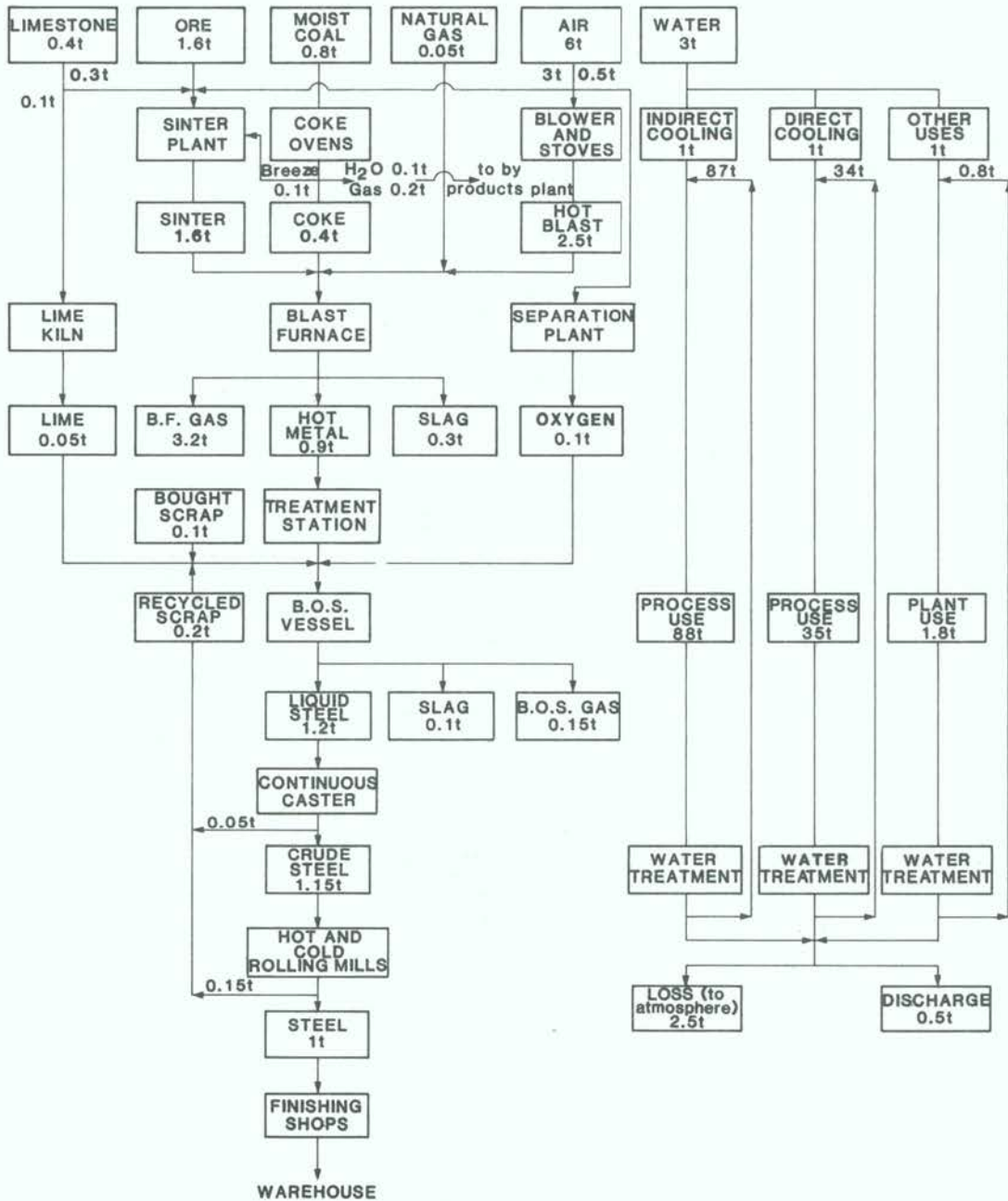


Fig. 3 Flow Chart linking pollutants and principal operations in an integrated steel plant

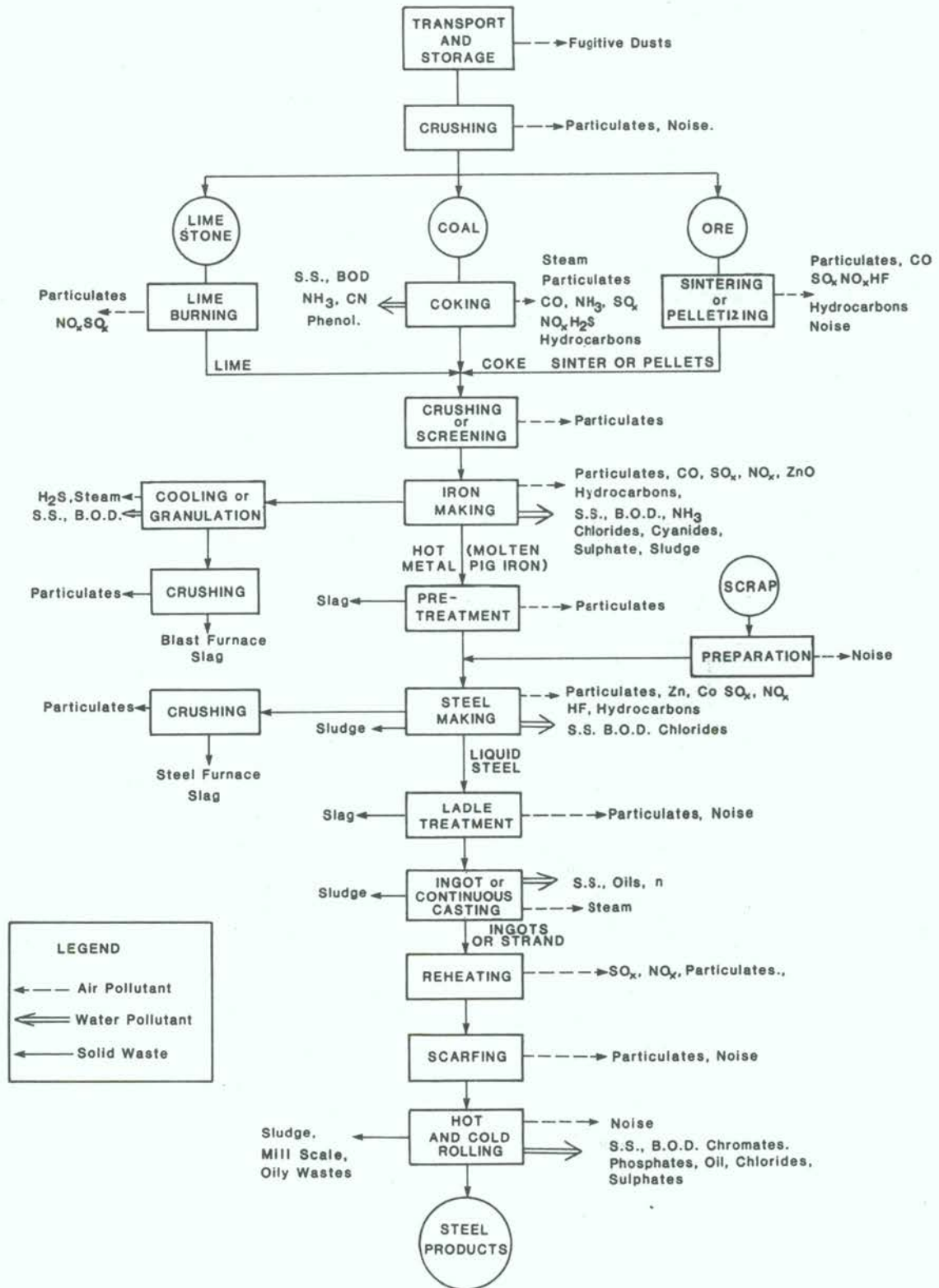


Table 1 - Steel Plant Pollutants, Kg/t Rolled Products

SOURCE	FACTOR	SINTERING	COKING	IRONMAKING	STEELMAKING	CASTING & ROLLING	GENERAL	APPROX TOTAL
Fugitive	Dust Fume & Grit	3	1	2	0.5	0.6	-	7
Stack gases	SO _x	4	0.3	0.2	0.2	2.0	-	7
	NO _x	1	0.2	0.2	0.1	0.5	-	2
	CO	40	0.3	5	15.0	0.3	-	60
	HF	0.04	trace	trace	0.01	variable	-	0.05
	Hydro- carbons	0.1	0.2	0.05	0.05	0.2	-	0.5
Waters	Suspended solids	0.28	0.06	0.24	0.07	0.20	-	1
	Oxygen demand	0.05	0.08	0.16	0.20	0.14	-	0.5
	Ammonia	-	0.03	0.08	-	-	-	0.1
	Phenol	-	0.005	-	-	-	-	0.005
	Cyanides	-	0.02	0.03	-	-	-	0.05
	Chlorides	na.	-	0.05	0.05	0.20	-	0.50
	Sulphates	0.004	na.	0.003	-	0.40	-	0.50
Solids	Dust	Recy-	(12	30	-)	70
	Sludge	clcd	(12	15	10)	
	Slag	-	-	300	100	-	-	400
	Mill- scale	-	-	-	-	30	-	30
	Oily wastes	-	-	-	-	10	-	10
	General	Refrac- tories	-	-	-	-	-	20
Debris		-	-	-	-	-	40	40
Human wastes		-	-	-	-	-	10	10

- Note 1. Many slags are now recycled or sold.
 2. These figures assume environmental controls.
 3. Levels shown are indicative only and are rounded from Ref. 19 (which provides typical ranges) and other information. Individual plants vary widely depending on raw materials used. The distribution between solids and emissions to water or air depends on the environmental protection technology employed, e.g. under best available practice, emissions would be lower than the figures cited.

1.3.1 Emissions to the atmosphere

(i) dust, fume and steam

Granular particulates are generated in mining, crushing and screening operations. They are spread during transportation, are released at points of belt transfer or are blown by winds from storage heaps and blending beds.

The high temperatures generated, for instance in high-intensity oxygen steel refining processes or in electric arc discharges in electric steelmaking, create very large quantities of fume which can only be controlled effectively by well-engineered facilities.

The wet quenching of coke leads to high emissions of steam to the atmosphere. Unless efficient grit arrestors are placed in the quench tower the operation is also accompanied by dispersal of relatively coarse dusts.

Oil in scrap in electric furnaces and in scale returned from rolling operations in sinter plants can result in visible emissions. Dust loadings in gases passing to the sinter plant exhaust stacks can also be appreciable, if not effectively controlled.

These dusts and fumes differ in size depending on the source of emission. Costs of control, visibility, and effects on health vary accordingly.

(ii) acid emissions

Substances such as oxides of nitrogen and sulphur (NO_x , SO_x), and (to a much lower extent) fluorides and chlorides (F^- , Cl^-) may be emitted, since they are present in materials being heated or burnt, or may be formed from air in high temperature combustion.

Given the concern in certain countries that acid rain may contribute to damage to inland water systems in cold climates and to forests these emissions are of current interest and the extent of control required is a matter of controversy.

(iii) fugitive emissions

While primary collection systems handle about 99 per cent or more of the total fume and dust generated in steelmaking small proportions escape as fugitive emissions particularly during intermittent operations such as charging and tapping, and these have to be controlled. Pouring and alloying operations for molten iron, steel and slags also lead to releases of fume, mainly iron oxide but graphite (kish), soot and silica may also appear.

Another major source is the coke oven. In charging, dusts can escape, and on pushing coke, coarse grit can be emitted to the atmosphere. If the charge is not fully coked high quantities of dense smoke may be generated.

Emissions from ovens being coked and certain emissions from coke ovens by-product plants have been alleged to cause health problems. In particular, benzo-alpha-pyrene (BaP) is a polynuclear aromatic hydrocarbon representative of a group known to be carcinogenic. Analyses of these materials in the neighbourhood of coke ovens and monitoring of benzol emissions are advisable and should be a continuing concern of plant managements.

(iv) toxic gases

Large quantities of toxic carbon monoxide are produced in the processes of combusting carbon with oxygen to refine pig iron into steel. Carbon monoxide is also generated in the blast furnace, and can sometimes, in low (0.5 to 1.0 per cent) concentration, be found in gases from sinter plants. CO is recovered for its energy value (except from sintering) or is burnt to CO₂.

By-product coke ovens gas contains CO and H₂. Care must be taken in its distribution and use.

Products of combustion can asphyxiate and must be vented. Similarly care is required in ventilation when N₂, Ar or natural gas are used.

1.3.2 Water discharge

For many operations within the steelmaking complex, high quantities of waters are used in direct contact with process materials, e.g. cooling and purification of coke oven gas can lead to pollutants such as tar oils, ammonia, phenols, cyanides, thiocyanates and thiosulphates entering the water system. The water requires extensive purification before it can be recycled or discharged to the environment or to local sewage treatment stations.

Cooling and cleaning waters in contact with gases from the blast furnace can pick up traces of cyanides, fluorides, lead and zinc compounds in addition to heavy loadings of dust particles. Waters from fume cooling and cleaning in steelmaking furnaces may carry particulates, fluorides and zinc compounds.

In continuous casting, scale and lubricating oil and hydraulic fluids can contaminate the water. Similar materials are problems in the effluents from rolling mills coating operations and from scarfing.

Indirect cooling waters require treatment to prevent fungal or bacterial growths, scaling and corrosion in water circuits. Certain chemicals may need to be removed before the waters are released to the environment.

1.3.3 Solid wastes

These include materials rejected as waste from coal washeries, slag, dusts recovered from the cleaning of gaseous effluents, sludges from chemical treatment circuits, roll-scale, used refractories, oil and grease residues, waste by-products from coking, domestic wastes and discarded tools and equipment.

Where these cannot be sold or recycled they must be dumped. Considerable quantities of material are involved and the establishment and maintenance of land disposal areas can create problems. If not properly designed there are also possible dangers of the dump leaching at a later stage to release effluents containing hydrocarbon residues, soluble salts, sulphur compounds and toxic heavy metals.

1.3.4 Noise and vibration

Noise from steel plants is not generally as high as from many other mechanical working operations. As an occupational environment the steel industry is however noisy. There are some sources of noise pollution, for instance, sinter plant fans, the snort valve in the blast furnace, ultra high power (UHP) electric arc furnaces, certain burners and scarfing and cutting equipment. The noises of metal rubbing against metal in mills and on processing lines can be disturbing. Truck and rail movements can be quite loud.

1.3.5 Occupational health

Most environmental problems interlink with concerns for the health of the workforce. For example, noise in the workplace implies that personnel should undergo testing for hearing quality before commencing work in such areas, should be issued with protective equipment and should regularly be tested for the effects of exposure so that damage, should it occur, can be limited. Means of reducing noise intensity should actively be sought. Similar provisions apply to hazards such as toxic gases, lead, asbestos, solvents, heat stress and equipment associated with repetitive strain injury.

1.4 Control

Most of the above problems can be solved. In certain cases, however, the complexity, size and the long depreciation time expected of steel plant make it difficult to achieve economic answers. As in other industries technological changes frequently lead to improvements in environmental control.

The following guidelines describe, for each of the several stages of steelmaking, resolutions to the environmental problems which are believed to be acceptable currently. The statutory regulations affecting industry differ in detail from country to country and slightly from one industry to another. These have been summarized by the Aluminium Industry, which has similar emission problems [15]. Governments which have not yet established emission standards could use the guidelines and the statutory data in determining basic controls required.

The guidelines do not discuss problems associated with mining operations (these are common to the winning of many metals); nor do they consider the environmental problems raised by the production of ferro-alloys, or by services not necessarily controlled by steelmakers. Such services would include, for example, the manufacture of tonnage oxygen, the operation of boilers to raise steam, the generation of electricity from gases and residues, the handling of coal tar chemicals and the manufacture of products from slags, wastes and steel after these leave the steelworks.

Throughout it is assumed that a greenfield site is available, so optimum choices of technology to control pollution can be made, consistent with economic reality.

The more usual "brownfield" situation (new plant to be added in older works) will frequently require similar criteria to be explored, but detailed studies may then have to cover other special considerations, e.g. use of nearby equipment or facilities and costs of specific adaptations of equipment to site limitations.

Table 2 summarizes the environmental problems outlined above and indicates those sectors of the Industry in which they are of importance. The remainder of this report considers steelmaking sector by sector in greater detail and indicates the techniques used for control.

Table 2 - Typical Emission from an Integrated Steel Plant

	WATERS	STACK EMISSION	FUGITIVE OR SECONDARY	SOLIDS
Transport	Suspended solids. Run-off water.		Dusts : iron oxide, coal, limestone.	Spillage, muds.
Blending and Bedding	Suspended solids. Run-off water.		Iron oxides, coals, recycled dusts.	Dusts from baghouses, cyclones etc
Sinter and Pellet Plants	Scrubber waters. Suspended solids. Lime, acids.	SO _x , NO _x , F ⁻ , CO, particulates.	Dusts from sinter plant coolers, transfer points. Noise.	Baghouse (etc) dusts with alkalis, filter cake.
Coke Ovens	Phenols, cyanides, tars, ammonia, thiocyanates, sulphides, chlorides	Smoke, SO _x , NO _x , steam, gas flare.	Coal or coke dusts, sulphurous or carcinogenic emissions, smoke, benzene, BaP, steam.	Carbonaceous solids from baghouses, pitch, tar, refractories.
Blast Furnaces	Suspended solids, phenols, cyanides, fluorides, lead and zinc compounds. Chlorides, heat.	H ₂ S, SO ₂ . Steam from slag cooling beds.	Iron oxides, H ₂ S, cast-house fume, CO coke dust, noise.	Baghouse (etc) dusts, blast furnace slags, refractories, filter cakes.
Hot Metal Treatment	Alkalies. Suspended solids.	Particulates, alkalies, fluorides.	Na ₂ O, K ₂ O, lime dust, kish, iron oxide fume.	Baghouse dusts with high lime, corrosive slags.
Steel-making	Scrubber waters. Suspended solids. Zinc compounds.	CO flare, CO ₂ , SiF ₄ , fluorides, iron oxides.	Fine iron oxides, alloy fume, noise.	Skimmer, EAF, BOS & ladle slags; refractories, baghouse dusts.
Casting	Oil, fluorides. Suspended solids, Heat.		Fume, lead, SO _x , fluorides.	Slag from exothermic compounds, refractories filter cake.
Rolling	Oils. Suspended solids. Chromates, acids, alkalies.	SO _x , NO _x , CO ₂ , smoke.	Scarfig fume and . noise	Mill scale, oily mill scale, filter cake, ferrous sulphate.
Coating	Chromates, phosphates, alkalies, acids, oils, Suspended solids.		Chlorinated hydrocarbons, solvents, acid mist.	Neutral sludges, filter cakes, carbon.

2. ENVIRONMENTAL MANAGEMENT POLICY

2.1 Siting

Management should be concerned from the moment of initiation of a steel plant project to minimize its environmental impact and in working towards preventing pollution damage. The impact may involve regions and communities far beyond its immediate location.

Plant siting is controlled by economic and political factors, raw material availability, port or railway access, market considerations and the acceptance by society in the form of governments or local governments of the need for the plant.

Alert entrepreneurs will be aware that in every case the establishment of an industry in an area will lead to some impact on the environment. Change as it occurs must be made compatible with the forward aspirations of the region. The evaluation of impacts (social, environmental, financial...) should be based as far as possible on sound scientific evidence.

Quite simple considerations - such as the desirability to separate public transport systems from those required for the plant; to site the plant away from residential and commercial areas and with due regard to meteorological data, such as predominant wind directions; to screen it from its surroundings; and to maintain grassed and tree-covered areas in the works with trees around the perimeter - can lead to a lowering in the degree of environmental impact, in the dissemination of dust and grits and in the tension between the community and the plant.

Obvious concern to apply anti-pollution measures is only one of the many steps needed to create a harmonious interaction between the plant and its surrounding community.

2.2 Need for Assessing Environmental Impact

Within the economic and political factors outlined above there must be room for choice and with proper forethought many future problems can be avoided, e.g. topographical and meteorological considerations may well limit the presence or the location of other types of plants in the area.

The assessment of environmental impact during the development stages of a project is almost essential to managers and to environmental protection agencies (even if preparation of a formal Environmental Impact Statement is not enforced) in order to understand these problems, determine economical solutions and minimize community objections. Early establishment of an environmental control organization within the structure of the company is desirable.

2.3 Scope of Environmental Impact Assessment

Such a statement should include analyses both positive and negative of economic, aesthetic and social impacts on the region; consideration of the present land use and the way in which land use is expected to move in future; the demands that the plant and its potential expansion can make on the infrastructure of the area; effects on the atmosphere and meteorology of the region; on water supply and use; on fauna and flora; and, very importantly, on the problems of solid waste disposal, since this will be a continuing requirement.

Disaster precautions should be considered and risk analysis of major hazards should also be carried out. Accident controls, for example, should spills or flooding occur, need to be provided.

2.4 Monitoring Pollution and Equipment Maintenance

Before the commencement of operations, management should be concerned to ensure that targets are set for the levels of environmental protection against each of the emissions and impacts of the plant. Also, it should see that these targets are understood and agreed by whatever local and national authorities will later be involved in the activities of the plants.

Well in advance of the plant's construction, monitoring should be established to collect data on levels of noise, contaminants, airborne particulates and wind direction and variability so that at a later time accurate comparisons can be drawn and assessments made of the actual impact of the industry in the area. Measurements need to be made of all the parameters which will later be assessed, e.g. dust, SO₂, NO_x, CO, fluorides, noise, water analysis and temperature, etc.

In any newly established plant it should be the objective both of the plant management and of the environmental protection agency responsible for the area to ensure, within the limits of available methods, that the level of pollution control technology is fully in line with the latest economically acceptable developments throughout the world, will meet the targets required by emission standards within the nation and will be installed and operated as an integral part of the production facility.

If these criteria are met, since retrofitting is very expensive, then the agency should be prepared to make consent agreements that no changes in emission levels will be requested (except those which involve a health risk) until new construction is required, should emission standards change after the plant is established.

Under such circumstances the "bubble" approach in which within a defined site a total emission, rather than the emission from specific sources, is considered can provide useful guidance on suitable control strategies and on the monitoring that will be required.

Careful control will also alert management to failure of pollution control equipment. Procedures for regular maintenance and preventive maintenance should be instituted when plant is installed and practices should be checked by pollution control agencies.

2.5 Education and Training

Managements will need to make provision for the training of personnel in the correct operation of pollution control equipment. Education on the desirability and necessity of minimizing environmental interactions is also needed and will require reinforcement from time to time. Goals for continuing improvement in pollution control performance (economic and absolute levels) should be incorporated in the objectives for the performance of operational management; these can be based on the monitoring equipment installed, visual checks, or on records of operational availability of equipment.

2.6 In-plant Hygiene

Matters concerning the protection of workers, discussed in section 10 - Occupational Hygiene, must be respected in establishing the standards for environmental control (see sub-section 1.3.5) and should be closely considered in determining the security that must be achieved [14].

3. RAW MATERIAL PREPARATION

3.1 Transportation and Handling

3.1.1 Processes involved

Ore, coal, limestone and other raw materials are brought to the steel plant by road truck, rail or water transport; are unloaded; placed on storage areas; recovered and then usually placed on belt transport systems for transfer within the plant. In a limited number of plants coal washing is carried out - usually this is done at the pithead and will not be discussed in these guidelines.

3.1.2 Matters requiring attention

Problems occur during unloading and at transfer points due to the release of fine material into the atmosphere. On storage areas dust may be carried away by the wind.

3.1.3 Guidelines for treatment

If the materials are normally received in a moist condition and are unlikely to cause a dust nuisance no precautions are necessary. On the other hand if the material is received dry in a highly comminuted condition the use of water curtains, or dedusting by evacuation to a bag filter while unloading, and extensive enclosure of the receiving hopper should be considered. Designs of equipment for unloading with a minimum height of fall should be specified, to avoid wind entrainment.

Storage of materials in heaps requiring removal by mobile equipment should, if possible, be avoided since tyred vehicles and front-end loaders give rise to dust emissions.

Checks should also be made whether there are other materials being received in nearby areas which are themselves sensitive to contamination, e.g. cement and salt in storage areas. If so the use of bucket conveyor unloaders, together with water sprays, may be required.

In storage areas, where materials are distributed in thin streams over the surface of the receiving heap, restrictions on the use of the equipment in periods of high wind may have to be imposed. Methods of spray control used should ensure the maintenance of adequate moisture levels in the surface of the bed, despite local rates of evaporation. Chemical sealing might be considered but its effectiveness is inconclusive, except perhaps for stockpiles which are left undisturbed for long periods.

Roads and areas around heaps should be paved, kept clean by road sweepers or by washing. Suitable sumps to receive run-off, and water recovery and treatment plant should be provided for both wash waters and rain.

3.2 Blending and Bedding

3.2.1 Process description

Materials are layered on to large beds to achieve a greater homogenisation of composition. The blend is then recovered from the bed, placed on a belt and transported to bins from which further blending on to belts occurs.

3.2.2 Matters needing attention

Problems which occur are similar to those which occur in storage, but in the actual transportation of material to bins (from which dust losses are relatively low) at each point of belt transfer dust losses occur if the material is not sufficiently moist.

3.2.3 Guidelines for treatment

Precautions outlined above for storage of materials also apply to material in large blending beds. If works dusts are to be recycled to such beds, measures should be taken to ensure that these will not blow around freely.

Consideration should be given whether a binding agent is required in the water spray or if, in order to ensure wetting, detergents are also needed. Clearly if these can be avoided costs are reduced, usually water alone suffices.

At transfer points of belts, enclosures could be provided and evacuated at sufficiently high rates to ensure that fine particulates are recovered. Cleaning of the gases can take place in bag filters.

Spray installations at transfer points, to keep dusts at a low level, are cheaper and sufficient in many cases, but care is required to avoid blockages and wastage of water. Recovery of the particulates-laden waters for later treatment is necessary.

Plantations in and around the raw material yard will reduce the spread of dust.

3.3 Sintering and Pelletizing

3.3.1 Description of processes

Fine ore must be made suitable for treatment in blast furnaces by agglomeration. In pelletizing it is mixed with a binder and rolled in drums or pans to form small balls or pellets and these are indurated at high temperature, either on moving grates or in rotary kilns, then cooled.

In sintering, a blend of fines with coarser granular ores and the necessary fluxes is mixed with coke breeze, partially pelletized through drums, then placed on a moving grate and ignited. Combustion of the breeze takes place using air drawn through the bed. The ores are fritted together and fused on the bed to form large thick cakes which are crushed and sized before feeding to the blast furnace. Fine materials are returned to the sinter mix.

3.3.2 Matters requiring attention

Fines are generated in crushing and sizing materials for sintering; in grinding materials for pelletizing; in cooling, crushing and screening sinter; and in cooling and screening pellets.

Within pellet plants, up to the point of moistening the mix following dry ore grinding, there are numerous transfer points where fugitive dusts can escape.

Where ores with high fluorine content are used, emissions of gaseous fluorine compounds can occur and wet washing of the emissions leads to problems in waters from the plant; they must be further treated.

When pellet plants use oil as a fuel, emissions of SO_2 and SO_3 can lead to visible plumes from the stacks of pellet plants. White fumes are due to K_2SO_4 and Na_2SO_4 formed by sodium and potassium salts in the ore. Coke ovens' gas, if the pellet plant is near an integrated steelworks, or natural gas, can be used to fire the kiln, with reduced SO_x emission.

In sintering, similar problems occur and stack emissions, which sometimes contain up to 1 per cent CO, are involved. It is impracticable to remove CO at such low levels by incineration. If the materials for sintering contain high quantities of lubricants and soluble oils, for instance from rolling mill wastes, stack emissions will be visible and hydrocarbons can carry over into precipitators with subsequent possible afterburning problems.

Large volumes of gases are involved (approx. $1\text{m}^3/\text{m}^2$ of strand area/second) in sinter plants. The volume per tonne of sinter depends on the depth and permeability of the bed and on air

in-leakage, but would lie in the range of 1 500 to 2 500 Nm³/t. Because normally sulphur is retained in the sinter and ultimately is removed as blast furnace slag, the level of exhaust gas SO₂ is comparable to that of desulphurized gases from power stations. Coke breeze combusted on sinter strands is only a small fraction of the total energy used in a nation, so installed plant is not a major contributor to SO₂ intensity. In those nations which need to reduce acid emissions, SO_x and sometimes NO_x control on new installations is carried out despite its high capital and running cost.

On sinter plants very large fans are needed and high pitched noise of a directional quality can be emitted. This problem can be minimized by correct engineering design and by efficient enclosure. It should be discussed with the manufacturer when equipment is being specified and monitored after operation commences.

3.3.3 Method of treatment

(i) fugitive dusts

Throughout the plant, in the areas of dry material preparation, fugitive dusts can be recovered by the installation of suction hoods and bag filters or electrostatic precipitators. When the sinter or pellet feed is sufficiently moistened such precautions may not be required. Dusts from coolers should be monitored and collected if necessary. Energy savings can be achieved by recycling the clean heated air to the ignition hood on the sinter strand.

(ii) treatment of stack gases

As suggested in sub-section 3.3.2 it is not normally necessary or economically desirable to treat sinter plant stack gas other than to remove dust. However, one parameter of interest is the basicity ratio (CaO/SiO₂) at which the sinter is to be produced. If this is very low, it will be necessary to calculate whether the SO_x emission will be sufficiently high to require de-sulphurization of the gases. On the other hand dust resistance grows with increased basicity, and the form and method of the lime addition (burnt, slaked or unburnt stone) has an influence. Above a basicity of the order of 2, the increased resistance could make it difficult to apply electrostatic precipitators to remove fume, or require higher capital investment in extra precipitator capacity.

When high levels of SO_x are present and must be removed, high energy wet scrubbing with alkaline scrubbing liquids (e.g. milk of lime) may be used to remove both particulates and SO_x. This is an expensive system. Its potential for fouling and the need to dispose of the waste waters can lead to other environmental problems.

After dry treatment of the sinter plant gases in an electrostatic precipitator, to remove SO_2 they can be passed through a column of limestone chips or attacked with milk of lime. The by-product gypsum is saleable.

If the ores contain high fluorine levels then again wet scrubbing may be required, although F emissions may be reduced by contact with alumina or lime and are related to the basicity of the sinter: high basicity leading to low emission.

Catalytic methods to remove NO_x have been installed, but these are costly to operate and involve considerable capital.

To remove particulates (as contrasted to SO_x , F^- , and NO_x) high energy scrubbers, using water, can be employed, but electrostatic precipitators are also used.

The strand area from the wind-boxes onward could be followed by cyclones to remove coarse grit, but it is satisfactory to pass directly to the electrostatic precipitators although this does lead to increased wear rates of equipment. The dust can contain alkalies. This causes problems with precipitator performance and tends to clog Redlers and other transport mechanisms.

Usually dusts recovered must be dumped. Analyses of the dusts will indicate whether recycle is possible.

The effect of oil on the wastes has been discussed earlier. Oily scale from rolling mills should be separately treated and not recycled to the sinter plant.

(iii) waters

Waters from plants are normally not difficult to treat, requiring removal of suspended solids before recirculation. If lime is used in scrubbing, clarification and the removal of lime sludges present more difficult problems.

If scrubbing is used to remove particulates, the waters require treatment to prevent oil, and lead and zinc compounds passing to the environment.

3.4 Coking

3.4.1 Brief description of process

The manufacture of coke requires the charging of blended coal, in a fine particulate form, into a large heated oven (refractory chamber). The materials fuse, devolatilize and form a cake of coke which is pushed from the oven, breaks and falls into a receiving

coke car. The coke is transferred either into dry cooling units for the recovery of heat or taken to a tower, quenched with water and allowed to dry on the coke wharf before screening and transport to the blast furnace.

In by-product coke ovens (those normally used), the volatile materials released during coking flow from the ovens to a plant where ammonia, benzol, xylene and toluene, tars, pitch and tar acids may be recovered.

These operations can be associated with fugitive emissions of organic substances.

The manufacture of coke in non-by-product recovery ovens has been advocated in recent years. Increasing costs of by-product recovery and the environmental problems in controlling emissions can make this an economic solution, but it wastes a valuable resource. Improvements to the security of the coking process and vigilance in maintaining good control practices would appear to be a more satisfactory solution.

3.4.2 Matters requiring attention

Basic problems include dusts in run-off waters from bedding and blending operations; dusts and organics emitted when cold moist coal blends are charged into the hot oven; the emission of sulphurous fumes and potentially carcinogenic materials from improperly sealed doors and lids during coking; emissions from stacks of products of combustion from the gases used in heating the ovens and leakage through the refractories into the combustion chamber; fugitive emissions of grit, smoke and combustion products during discharge of coke from the oven into the coke car; the emission of large quantities of steam containing grit during wet quenching, or problems associated with the generation of fine breeze and dusts during the handling of dry quenched material over belts and at transfer points.

Gas from coke ovens, when produced from high sulphur coals, contributes to the total SO_x emitted from a steel works. Commercial processes are available for removal of H_2S from coke oven gases and are being more widely used. These generally involve absorption of H_2S , HCN and CO_2 into a circulating alkaline solution, regeneration of the solution and treatment of the acid gases to recover sulphur, sulphates or sulphuric acid. There are problems of build-up of thiocyanates, thiosulphates and sulphates in the scrubbing solution, requiring incineration or other treatment.

The waters from the by-product operations of coke ovens contain high levels of phenols, cyanides, tarry residues and high levels of residual ammonia, despite ammonia recovery circuits. Their treatment before release to the environment is essential.

In general in steelmaking operations, from an environmental viewpoint the coke ovens and by-products recovery plants are the most difficult installations to control.

3.4.3 Guidelines for treatment

(i) charging

Gravity charging through three or more holes simultaneously can cause considerable emission of fume, dust, flame and toxic gases. Doubling the collecting mains allows greater suction to be applied to each oven by steam or high pressure liquor ejectors in the ascension pipes to control the problem, but working conditions on the battery top become hotter. Breech pipes which can be connected between the oven being filled and an adjacent empty oven can reduce emissions during charging.

Stage or sequential gravity charging of coal from hoppers offers a major advantage, allowing the gases to escape throughout the charging cycle. Whether staged charging (one hopper charged at a time) or sequential charging (two or more hoppers released at a time) is used depends on permissible charging time and the available suction at the ovens. Both practices avoid blockage and emissions through the lids and involve lower capital cost than other solutions.

Emphasis has to be placed on the provision of adequate capturing devices for the fugitive emissions that occur during levelling. Pollution control when the doors are opened is also required, but not always readily applied, particularly when only one door is used.

Linking simple extraction on the charging car by a connection to a fixed duct along the battery top and to a separate static ground-based gas cleaning system has given acceptable availability of equipment in some installations and has reduced problems with operating equipment on the charging car. Precautions have to be taken against explosions.

(ii) coke pushing

Many solutions have been proposed to the problems of the pollution created during coke pushing, but assuming adequate carbonization time, the provision for a link between the coke guide, the coke car and separate static equipment to allow the removal of material recovered by aspiration during discharge appears to be an optimum solution. Of these, the travelling hood with belt has low maintenance cost, but requires improved engineering to achieve higher suction. Problems still remain if ovens are pushed too soon and the coal is insufficiently coked.

Other more elaborate methods, such as enclosure of the coke side of the oven, while requiring lower maintenance, create their own environmental and health difficulties and need large fans and consume higher energy to ensure that the atmosphere within the enclosure remains clean and suitable for people working in it.

Solutions which require more complex equipment on the coke car have been unsatisfactory. In general, simplicity in engineering leads to low maintenance and to acceptable control by virtue of the continuous operation of the equipment. Environmental control for a high proportion of real time is to be preferred to high removal rates of contaminants, but only on an intermittent basis.

A recent trend has been to provide a common collection system incorporating charging fume, pushing fume and door leakage emissions, all passed to a bag filter through an intermediate spark arrest cyclone.

(iii) quenching

Modern methods of wet quenching involve rapid addition of limited quantities of water to the bed of hot coke to ensure that the coke surface temperature is quickly lowered but that sufficient heat remains in the coke after quenching to dry it. The systems lead to smaller releases of steam than the former practices of very heavy quenching. They also reduce the amount of quench water that has to be handled by the coke ovens water treatment plant. The product has low moisture levels and must be handled correctly (see below for dry quenched product) to avoid dusting or to recover dusts released.

Dry coke cooling offers the removal of visible release of steam, but it is capital intensive and can be expensive to run, if the price of electricity is high, there there may be a case for energy recovery by heat exchange to raise steam for electricity generation.

Fully dry quenched product is very friable and is likely to lead to problems in handling, due to the generation of dusts at transfer points. This will require the introduction or the installation of hoods and fans in transfer areas to reduce the emissions of dusts at these points.

(iv) doors and lids

Provision of effective seals on doors, lids and caps on ascension pipes must be verified in any installation for coke oven plant. The major problem lies in the seal on the door

where a long length of contact is subject to distortion by heat, and hand or mechanical cleaning is difficult. High pressure water jets have recently been introduced to clean this area.

In older installations hand luting (sealing by clay) of doors was employed (often ineffectively) to control emissions. In more modern practice provision of flexible knife-edged seals between the door and the oven is usual. In the best of these, being sufficiently well serviced with cranes to enable doors to be handled and remade and for seals to be repaired is critical to the long-term viability of emission control. Leaks must be corrected as soon as the oven is pushed, otherwise conditions deteriorate badly.

To ensure good door operations a disciplined approach is required. This will include keeping a record of leakage from the doors and continuing encouragement and instruction to operators towards meeting standards.

(v) stack emission

The gases used to heat the ovens chamber are themselves usually very clean, being based on either pre-cleaned blast furnace gas and natural gas or on coke ovens gas. There can be, however, contamination from gases evolved by the coals being carbonized, due to leakage through cracks in the refractory walls of the oven, which can increase with the age of the oven. Silica welding techniques are available to treat cracks in older batteries, improving heating performance and reducing emissions.

SO_x in the emitted gases should not exceed levels acceptable in the community. Consideration must, however, be given to maintaining correct control of combustion conditions, so as to minimize the generation of NO_x.

Reduction of NO_x by ammonia in the presence of a catalyst can possibly be used to control NO_x emissions from coke ovens stack gases. As discussed under Sintering this is expensive and demands high capital.

(vi) coke ovens waters

Coke ovens gases are cooled and scrubbed with recirculated water to recover ammonia and other water soluble constituents. The liquor is then steam distilled and this removes free ammonia. Fixed ammonia can be displaced by the addition of an alkali to the waters, either lime or caustic soda.

Problems occur in the preparation, handling and control of lime slurries, in fouling by the precipitation of insoluble calcium salts, and in the coating of particles with tar and

oils which make disposal of lime sludge very difficult, i.e. the use of lime is operationally expensive, whereas for caustic soda the raw material is dear.

The ammonia can be converted to its sulphate, its phosphate or to anhydrous ammonia, but in certain works the recovered ammonia is burnt because there is inadequate demand for nitrogenous fertilizers in the region. Incineration can lead to oxidation of ammonia to NO_x and in some cases there are limits on NO_x emissions. The temperature is kept to 1 000°C for this reason.

A concentration of 50-300 mg/l of ammonia may remain in the waters with phenols, thiocyanates and cyanides. This must be treated, before discharge to natural waters, commonly by some form of micro-biological oxidation. The activated sludge process is cost effective for phenols and thiocyanates, but there are problems in ensuring removal of ammonia. To achieve ammonia removal, processes involving successive stages of biological oxidation, nitrification and denitrification are being tested; pH control is needed since the nitrification process generates acids, so there is a further cost for alkalis.

A recent proposal put forward has been a single sludge biological process for nitrogen removal (not yet a fully fledged commercial practice) in which there is mixed liquor recirculation between aerated and anoxic regimes. The recirculation of high pH liquor from the anoxic to the aerated basin reduces the demand for neutralizing chemicals. Sludge disposal after filtration would have to be fully planned.

Where demand on water quality is very high, for discharge final absorption on to activated carbon can be considered together with treatment with an oxidizing agent, e.g. ozone or chlorine, to ensure the destruction of all organics.

Given the costs of these stages of treatment, serious consideration should be given to the operation of stills at maximum efficiency forcing a greater proportion of cyanides and ammonia into the gas phase, followed by dilution with nutrient-bearing wastes, such as treated sewage, to produce a final acceptable effluent, after indirect cooling.

3.5 Lime Burning

3.5.1 Description of process

The lime used in steelmaking operations must be of a special soft burnt quality, so it is quite usual to find lime burning equipment in steel plants (either kilns or shafts) in which the material is taken to a temperature high enough to remove the carbon dioxide and where the time at this temperature can be controlled to give a reactive lime which produces a satisfactory slag in the steelmaking furnace.

Another advantage of close proximity between the lime burning equipment and the steel plant is that the material does not recarbonize or slake during transport or handling.

Further quantities of lime are likely to be required in the future for improving the permeability of sinter mixes.

3.5.2 Matters requiring attention

Environmental control of the lime-burning kiln should not be overlooked in establishing the engineering specification for steel plants. The major problem is that the material must be handled dry. At all transfer points, because it is fine, wind-blown dust can arise. The material is caustic, unpleasant to encounter, and if blown on to paintwork can cause damage.

3.5.3 Guidelines for treatment

Provision of hoods over transfer points with adequate aspiration to ensure capture of the dry dust is essential. Transport to and from the lime plant should be arranged so as to minimize the release of dust, either through the use of covered conveyors, or by arrangements to seal trucks and transfer cars. Stack gases should be treated to minimize release of combustion products and fine dust, e.g. by wet scrubbing or bag filters.

If finely powdered lime can be injected into the furnace, for instance in electrical steelmaking and in bottom or top blown oxygen convertors, then pneumatic transfer into and out of sealed transport vessels is to be preferred.

3.6 Scrap Handling

3.6.1 Brief description of process

For an integrated steel works there are usually three sources of scrap; scrap recovered from local users of the steel plants products; material recycled from the steel plant itself; and scrap supplied by merchants.

Merchants normally carry out the majority of the bundling and compression required to prepare the scrap in suitably dense form for charging. The plant scrap yard must be responsible for some of the preparation required for recycled material, e.g. torch cutting, shearing, breakage of ingot moulds with large ball and chain and the loading of scrap pans.

3.6.2 Matters requiring attention

These operations can lead to generation of noise and some fume. The peak noise level is as high as 105 dB(A), on an intermittent basis, at 25 m distance from a scrap loading pan. Breakage operations are likely to lead to low frequency noise. Noises of scraping and falling scrap in loading can be annoying.

Pollutants from oil, paint or galvanized and tin coatings do introduce problems in cutting scrap. Baled or fine contaminated scrap will give rise to fume on charging. Closed vessels, for example gas cylinders, represent high risks of explosion.

3.6.3 Guidelines for treatment

If the plant is sufficiently screened from local inhabited areas there is little problem, but in smaller scrap based plants, frequently close to residential areas, every effort should be made to handle scrap at a point well within the plant (if possible within buildings) rather than on its periphery. Minimization of drop height, good maintenance of magnet cranes and operator training can reduce the nuisance considerably. If required noise barriers can be erected.

4. REDUCTION

4.1 Direct Reduction

4.1.1 Brief description of process

Direct reduction is normally followed by electric arc steelmaking. However, a number of plants throughout the world produce direct reduced ore as a preliminary to smelting the material to iron in submerged arc furnaces or adding it to blast furnaces. It can also be used as a very low metalloïd coolant, substituting for scrap in the BOS process.

Direct reduction may be defined as the removal of oxygen from iron in the solid state by gaseous or combustible reductants. It is usually carried out on pelletized ore, but a proportion of lump is normally included today. Fines can be reduced in fluidized beds.

The processes used are :

- shaft kilns, using desulphurized, reformed natural gas for reduction;
- rotary kilns with coal or oil as the heating and reducing medium; and
- there are a few installations using fluid beds and gaseous reductants.

4.1.2 Matters requiring attention

In DR rotary kilns, problems similar to those seen in grate-kiln pelletizing plants and in lime-burning kilns exist, i.e. the potential for release of dusts and the emission of gases possibly containing sulphur through stacks.

In shaft DR processes, if reformation of natural gas is carried out by steam, control problems are related to combustion emissions and to the boiler blow down liquids. SO_x and NO_x depend upon the analyses of materials burnt and the flame temperature and flame stoichiometry. In plants where process gas is used to heat the reformer, the flue gas contains low levels of NO_x since ammonia in the process gas reduces oxides of nitrogen. Compatibility with plant water systems must be considered in determining the final water control practices to be employed.

Fine fume may also be prepared for reduction by cold bond briquetting or by pelletizing with lime. This can be a method of disposal of iron oxide wastes provided these have a moisture content and sizing handleable in the plant and are of sufficient purity for the purpose.

The use of ore and pellets causes problems associated with handling prior to direct reduction. In plants which reduce fine ores, these may have to be screened, crushed and blended.

Hoods should be installed to minimize dust emission to the air during the handling of solids.

Waters in general are not a problem except that verification should be made that the waste waters associated with scrubbing of gases are correctly handled.

The exit gases contain CO and unreacted reductant, such as carbon monoxide, hydrogen and methane, with reaction products and dusts. They are treated in wet scrubbers and the cleaned gas is recycled to the gas reforming unit and heated before passing back to the reactor.

Particulate solids in the scrubber waters must be handled correctly.

4.1.3 Guidelines for treatment

One of the potential by-products from such plants is direct reduced iron (DRI) fines which in certain cases are saleable. The DRI product is not considered to be particularly difficult to handle, but fines can arise from pellets and hot briquetted materials, due to their friability. Storage cannot take place in too large a heap otherwise overheating may occur.

In shafts, before natural gas can be used in the catalytic gas reforming units, the sulphur-containing compounds, e.g. H₂S and mercaptans, must be removed on activated carbon, zinc oxide or molecular sieve beds. For materials from the absorption towers, nitrogenous compounds are removed in a regeneration stream which is released into the atmosphere. Zinc oxide is discarded as solid waste. The SO_x emissions are extremely low in the flue gases and since the temperature of operation is relatively low, NO_x emissions are also within acceptable levels.

Sulphur from the ores is converted to H₂S in the reactor reduction zone. It is eliminated in part in the quench tower and to a greater extent in the CO₂ removal unit, if CO₂ absorption is practised.

Coal reduction processes give stack gases which contain carbon monoxide, carbon dioxide, hydrogen, steam, SO_x and NO_x plus hydrocarbons. Heavy metals can be present depending on coal analysis and similarly fluorides may be released depending on the ore analysis. Plants using limestone to hold sulphur, discharge calcium sulphide in the char and the stack gases are relatively low in S. The shaft type processes, with high recirculation of natural gas based reductant, are relatively clean.

In some kilns the exit gases are combusted in an after-burner to reduce the concentration of reduction gases and hydrocarbons. This can be followed by wet scrubbing or by electrostatic precipitation.

Where briquetting and pelletizing equipment is available the collected scrubber products can be recycled to the kiln, but usually they have to be simply dumped in solid waste areas. Materials recovered from the separation of the reduced ore from char (ash and other solid wastes) can contain calcium sulphate and slaglike materials. Large char particles are recycled. The smaller char particles and the other solids pass to waste storage areas.

Effluent from the scrubbing in the after burner also contains sulphur compounds and has pH 2.3 to 4.5 which has to be neutralized. This results in about 600 kg of sludge per tonne of DRI, while the dust in the gas stack is about 150 mg/Nm³.

4.2 Blast Furnace Smelting

4.2.1 Brief description of process

The blast furnace consists of a refractory lined shaft. In a stockhouse solid materials are prepared and weighed and sent by belt or car to the blast furnace top where ore, sinter or pellets and fines are charged together with layers of coke. In the bottom of the furnace, air, pre-heated in associated stoves, is injected under a few bars pressure. Passing into the furnace it burns the coke, creating reducing gases and sufficient heat to melt iron and slag which are produced by reduction and by fusion as the solids pass down the furnace through the rising hot reducing gases.

At the base of the furnace the molten iron is intermittently tapped and passes to receiving ladles or "torpedo" cars for transport to the steel plant.

Slag is separated from the iron and may be treated in the vicinity of the blast furnace or taken in ladles to another area for treatment.

Major facilities receive the gases generated during the operation of the furnace, and treat and clean the gas.

4.2.2 Matters requiring attention

Blast furnace gas is a valuable resource to the steel plant, but must be very clean before it can be used as a fuel.

Gas is frequently taken from the top of the blast furnace at the pressure of operation of the furnace and, laden with dusts, expanded through a turbine in order to recover electrical energy.

Stages of cleaning include: collection in a dust catcher, and occasionally cyclones, followed by high energy scrubbing and/or electrostatic precipitation. The use of dry electrostatic precipitator or bag filters followed by a back pressure recovery turbine is a recent development.

The intense cleaning of the gas uses a large volume of water and this requires treatment. The water contains suspended and dissolved solids, phenols, cyanides and ammonia.

Owing to recycling of materials from steelmaking to the blast furnace via the sinter plant, the dusts recovered from the furnace may have quite high levels of zinc. Measures to remove zinc are often uneconomic (although a coarse separation based on size classification is practicable). With precaution, disposal as landfill is usual for the zinc-rich fractions.

Surges of pressure when the burden in the blast furnace suddenly drops can lead to occasional release of dust and of highly toxic carbon monoxide in the upper levels of the furnace and this is of concern near the furnace, although there is no serious air pollution from this source.

On the blast furnace casthouse floor the exposure in troughs or runners of hot metal to air can lead to emissions of particulates and fume including alkali oxides (from slag), zinc oxides and smoke from the combustion of tars or resins in refractory clays. When hot metal pours into ladles considerable quantities of fume are evolved, due to oxidation of iron.

Several processes exist for handling slag at the blast furnace. It may be granulated by running it into water as it is produced; it can be run out into a slag handling yard near the furnace to cool more slowly for later crushing to make coarse aggregate; and in certain cases foamed or pelletized slag can be produced by the reaction of the melt with small quantities of water under conditions where the slag is broken up before contact with the water.

When water and molten slag are in contact, since sulphur is partially recovered in the slag, H_2S forms.

In slag preparation effective dust control measures are required on crushing and screening equipment.

It should be noted that other processes producing a molten iron (e.g. electric furnace smelting) engender pollution which differs only slightly from that described for the blast furnace. The general principles outlined below will cover the majority of the problems created.

4.2.3 Guidelines for treatment

(i) charging

In material handling in stockhouse areas fugitive emissions can be controlled through the use of closed conveyors and evacuation through hoods at transfer points to bag filters.

(ii) tapping

In the casthouse the use of side extraction equipment adjacent to the tap hole, troughs and pour points is now common. Covered runners are used and hoods are placed over transfer points. The aspirated gases pass to baghouses to capture particulates. It is an effective method of maintaining clean operating conditions and freeing the floor of the casthouse for relatively unencumbered movement. Where the floor is enclosed, casthouse evacuation and air cleaning roof monitors etc. are used. Recently combustion of gas or other methods of producing a non-oxidizing atmosphere have been introduced to control this problem.

Whether runner side or roof extraction is employed, the most important principle is to provide very high extraction volumes to ensure good working conditions for staff.

(iii) water treatment

Waters from the top gas scrubber require cleaning and there are problems in terms of fouling of the circuitry when waters are recirculated to the blast furnace. Carbon dioxide from blast furnace gas dissolves in the scrubbing water and lowers its pH. Lime treatment in thickeners converts the dissolved CO_2 initially to calcium bicarbonate and then to calcium carbonate. Unfortunately competing reactions with zinc and ammonium salts can leave calcium in solution; also below pH 8.3 the bicarbonate reaction may not be complete and such waters in cooling towers liberate CO_2 . As the pH rises - or if it is set incorrectly - carbonates of calcium and zinc precipitate as a scale, fouling pipework and the cooling tower. Fungal growth is also a problem in recirculation system pipework.

In general the controls include settling tanks, filters, chemical treatment for coagulation, clarifiers, chlorination and carbon absorption. The low concentration of organics makes biological treatment of these waters difficult and chlorination, to achieve low levels of pollutants, makes carbon absorption necessary.

Recirculated water systems require strict control of their chemistry. Once-through systems, if salt water is available, using thickeners and chemical treatment, have been found to be easier to operate, but chemical control of the discharge is still difficult.

While coke oven and blast furnace waters might be considered for treatment together it appears advisable to treat blast furnace water separately from others. Very high variations can occur in the level of pollutants, e.g. of cyanides, in the material passing from the blast furnace because of sudden changes in operating conditions within the furnace.

Biological treatment plants recover only slowly from such challenges. Sinter plant scrubber waters, however, can be compatible with blast furnace waters.

(iv) noise

A nuisance on smaller blast furnaces is the continuous noise from the septum valve. With modern large furnaces, damping via the turbine and generator, which recover energy, eliminates the problem. Tuyere noise needs control by careful design, for example the use of flexible (bellows type) tuyere stock to minimize air leakage. Silencing of the snort blow-off valve is frequently practised.

(v) slag treatment

It may be necessary to arrange for the steam above the beds to be collected. Where a continuous granulation operation takes place a condensing chimney is usually employed. On larger beds an oxidant in the water can also be used to try to control the odour of H_2S , but in practice the amount of oxidant required may make the cost of this treatment prohibitive. Control of pH in the water minimizes odour.

4.3 Hot Metal Pre-Treatment

4.3.1 Brief description of process

In integrated steel plants part removal of undesirable elements takes place during steelmaking, part is carried out through pre-treatment of hot metal.

De-siliconization takes place by the injection of iron oxides or other oxidants into the hot metal on the casthouse floor, in the ladle or in a separate treatment station.

De-sulphurization is carried out through the injection of magnesium or calcium compounds and fluxing agents in separate stations as the material is being transferred from the blast furnace to the steelmaking shop. Such installations are normally fully set

up with lances which pneumatically transfer the agent (Mg), (Mg-Al₂O₃), (CaO-Al₂O₃), (Al-CaO) or (CaC₂ or CaSi-CaF₂) into the metal. The operation can lead to considerable generation of fume.

De-phosphorization is only possible under conditions where silicon has previously been removed and involves the injection of agents, such as sodium carbonate, which can generate very large quantities of highly corrosive fume.

4.3.2 Matters requiring attention

Where desiliconization is carried out at the blast furnace floor the quantities of fume evolved may exceed the capacity of the side extraction units above the runners. It may be necessary to increase the extraction fan capacity in planning for such conditions.

The operations of de-sulphurization are not difficult to handle in terms of fume generation, but for de-phosphorization in most plants problems have been found in handling the very large quantities of fume associated with the use of sodium carbonate. Sodium, produced by reduction, and sodium compounds are volatile at high temperatures.

Handling of the slags generated can be difficult. Calcium carbide used for desulphurization has led to explosions when the slag and water have come into contact. Slags based on sodium carbonate (soda ash) are corrosive. They must be removed from ladles to minimize refractory attack. Such slags should be quarantined in land disposal sites on impermeable bases. Processes have been developed for their retreatment but these are expensive.

4.3.3 Guidelines for treatment

The action required is to provide high extraction capacity. Use of bag filters can lead to problems with blinding when lime is used.

Care has to be taken in recovering waters from the washing of gases from sodium carbonate extraction facilities. These are alkaline and should be segregated for use in the neutralization of acid solutions in other parts of the plants, if possible. The slag remaining in the treatment ladles must be removed and, at a cost, can be treated to recover and regenerate the sodium carbonate.

Risks of explosion exist with calcium carbide and with slags from calcium carbide treatment (or with (Mg-Al₂O₃) systems), so care must be taken.

5. STEELMAKING

5.1 Oxygen Furnaces

5.1.1 Brief description of the process

The basic oxygen steelmaking process (of which there are a number of variants) essentially consists of a refractory lined vessel within which hot metal from the blast furnace and scrap are placed and contacted with oxygen. The oxygen may be lanced from above, bubbled into the metal from tuyeres below the bath, or both in combination. Steel reaches very high temperatures and at points of contact between the oxygen and the metal large quantities of iron oxides are evolved. The oxygen reacts with the hot metal to release carbon monoxide and small amounts of CO₂, which leave the mouth of the vessel laden with the iron oxide fume.

To increase the quantity of scrap melted, secondary oxygen jets in the vessel may be used to combust some of the CO to CO₂; carbon (as coal) might also be injected. Gases from the vessel may be burnt either at the mouth of the vessel or after collection, or can be recovered for use as a fuel in the steel plant.

The vessel is tapped after the hot metal is refined to steel and slag and steel are separated. The process is called basic, because the slag contains high quantities of lime in order to hold phosphorus and sulphur to remove them from iron. Similarly the refractory lining of the vessel is made of basic material, normally magnesia or calcined dolomite with additions of carbon, tar or pitch.

After tapping, the steel may be further treated in the ladle, to lower the levels of phosphorus or to alter the nature or decrease the quantity of oxide inclusions contained within it. Special treatments, for instance vacuum degassing and alloying additions, can also be made in the ladle.

From all these operations waste slags are produced. The slag from the main steelmaking activity is usually high in iron oxide and lime.

5.1.2 Matters requiring attention

Hot metal is carried from the blast furnace in torpedo ladles then passes through transfer ladles for pouring into the oxygen furnace. The cooling metal tends to release carbon in the form of fine flat platelets of graphite, called kish. The escape of fugitive materials also occurs during charging and tapping the steelmaking vessel. Solids and liquids, e.g. slags and refractories must also be handled on the tapping side of the steelmaking furnace.

Gases from the converter may be burnt in open combustion and the oxide dust recovered. More commonly today the combustion of the gas is suppressed or eliminated by hoods which descend around the mouth of the vessel during the blowing period.

If either in open or closed combustion the waste gases are washed through high intensity scrubbers, then the raw waste waters from the scrubbers must be treated. High efficiency electrostatic precipitators can be used, and allow greater energy economy and improved dust recycling.

5.1.3 Guidelines to treatment

De-sulphurizer slags have to be skimmed prior to charging hot metal into the converter and an evacuation hood over the slag removal station for the transfer ladle is desirable. Hooding and provision of extraction equipment near the pouring station is needed to capture kish emission. Such loads require high flows of air to achieve extraction and care has to be taken to minimize noise from extraction fans.

Open combustion dusts are recovered by electrostatic precipitation or high intensity scrubbing. Baghouses could be employed, although they are expensive given the quantity of gas to be contacted.

The collection of secondary fume (fugitive emissions) may be by local hoods, by roof monitors or by surrounding the furnace with an enclosure ("dog-house"). Emissions during vessel charging can be reduced by practices such as slow pouring and by controlling the angle of pour. Tapping fumes can be controlled by providing a blanket of flame or inert gas around the stream.

Fugitive dusts can come from fluxing agents and provisions for their capture and cleaning in baghouses are needed.

Closed combustion practices are to be recommended for primary fume for large converters and have the advantage of reducing the total amount of gas to be treated and therefore allowing the use of more compact pollution control equipment, usually high intensity scrubbers or, more recently, horizontal electrostatic precipitators. An energy saving can be made from the recovery of the off-gases and their use for combustion purposes through the plant.

Wastes from scrubbers should be passed through a thickener, using polymers to assist settling. The thickener under-flow would pass to vacuum treatment and the majority of the over-flow could be recycled. However, in order to maintain suitable conditions in the recycled water a bleed of approximately 10 per cent is needed and this has to be treated under conditions such that the final waters have adequate pH control. Any suspended solids can be precipitated and vacuum filtered. The basic problem with these dusts is the relatively high level of zinc that may be associated with them.

Slags from the transfer ladle and from steelmaking are collected as liquids and taken to treatment stations for the recovery of scrap (see 8.2.3). The crushing and handling of this slag can lead to fugitive emissions which must be controlled.

5.2 Electrical Furnaces

5.2.1 Brief description of the process

In electric arc furnaces scrap or direct reduced iron is charged from the top into a refractory and water panel lined chamber. A refractory and water panel lined roof is moved over the chamber. Through the roof three graphite electrodes, connected to a powerful A.C. transformer descend and melt the steel using high power arc discharges.

After several baskets of scrap are charged and melted the steel in the furnace is refined then the furnace is tapped, either by tilting or through a hole in the bottom of the furnace. Slag and steel are separated.

The gases emitted during the process are combusted, cleaned and ejected to the atmosphere.

Furnaces using D.C. electrodes or plasma guns to melt scrap are under development but, other than noise - which should decrease - will involve similar problems in environmental control.

Induction furnaces are generally of lower capacity and are more used in foundries than in steelmaking plants (other than as ladle furnaces to maintain the temperature of molten steel).

5.2.2 Matters requiring attention

The slag and metal, as they leave the electric arc furnace, cause emission of fugitive dusts and fume. Provisions need to be made to control this and other emissions which occur during the process. Dust can escape either through the tap hole or various observation ports, or through the holes in the roof of the furnace.

Normally the main body of fume is evacuated through a fourth hole in the roof of the furnace - three holes being required for the electrodes - or by a hole cut into the side of the furnace. Air is aspirated into the duct to combust CO.

A basic problem is that at the various stages of the operation of the furnace different atmospheres are required. During melt-down mildly oxidizing atmosphere can be tolerated and there is no problem associated with establishing sufficient suction above the furnace to recover gases, despite some small air inleakage.

During the stage of reducing slag operation little air can be permitted so it is not possible to use the full suction available from the stack (or fan responsible for evacuating the vessel) hence fugitive emissions from the furnace increase.

In the final stages of carbon removal in the furnace, when oxygen is injected, then the difficulty is to match the possible flow rate of fume-laden gases from the vessel with the available suction. The process is, therefore, characterized by a number of possible points and times of emission.

The cooling applied to the walls and hood of the modern furnace requires an appreciable flow of water and these waters must be treated if corrosion and fouling are to be avoided - once-through cooling being very expensive. Deposits and sludges from the cooling circuits have to be handled.

The other major problem in the electric furnace is noise, particularly during the melt-down phase. Variations of power as the arc strikes on to the scrap lead to very high acoustic emissions, to 105 dB(A) at 6 m in the early phases of the operation. Obviously, noises of this level lead to concern for the furnace operators and can create considerable nuisance in nearby areas.

5.2.3 Guidelines for treatment

(i) gas and fume

Primary and fugitive emissions, associated with the furnace, must be controlled. Consideration has to be given to optimizing the costs of control and there is considerable inducement towards minimizing the cost of treating noise and fume by isolating both together (see later).

Emissions escaping from the furnace body are collected either by point source hoods, in large roof monitors or in both. This involves capturing large volumes of dust-laden air; and the capital and operating costs are correspondingly high.

Another technique which may be considered in treatment of gases in the roof of the furnace hall is the installation of an electrostatic precipitator roof monitor. This relies on the hot plume of air from the furnace to provide the motion of dusts through it.

In most electric arc steel works, because of the need to collect both primary and fugitive emissions, the volume of gas which must be treated is so high that high intensity scrubbers are no longer advocated, and (since the colder roof monitor gases can be used to cool the hotter furnace gases) bag filters are generally used. Other approaches include heat exchange (difficult to justify due to the intermittent nature of the process) or admixture with fresh air. Care has to be taken with bag filters, to understand the variations of flow

from the furnace. These can lead under improper operation to the dangers of explosion.

A spark box may need to be fitted between the furnace and the precipitator or baghouse.

It may be necessary to eliminate the control of combustion by the movement of the aspiration gap, and instead use a combustion chamber so that air and gas flows can be better matched by a controller. The introduction of effective pre-heating for scrap will demand control of the temperature and flow condition of the gas.

Partial enclosure of the entire furnace appears to be a simpler system for handling the problems of both fume and noise from arc furnaces. The advantage is that a much smaller total volume of material needs to be extracted. There are disadvantages in an unpleasant dusty work environment when actions have to be carried out in such enclosures.

(ii) pre-heating

Some of the simpler pre-heaters have failed, because the presence of oily waste in the scrap has led to excessive pollution. Better techniques are now available.

(iii) noise

Noise is an acknowledged problem in AC-arc furnace operation. It appears essential to provide acoustically insulated rooms for the operative staff. Double-walled enclosures are common to minimize external noise. Noise is somewhat reduced in the developing DC-arc or plasma-arc furnaces.

(iv) waters

Treatment of the waters, where high intensity scrubbing is used, is very similar to the treatment of BOS plant waters.

Cooling water treatment does not differ from the usual methods of control of indirect cooling waters.

(v) wastes

Owing to the use of active slags in the electric arc furnace in which sulphur and fluorine compounds may be present there are problems of fume within the steel plant and of entry of fluorides into waters when wastes are dumped.

Solid wastes containing zinc, lead, cadmium, chromium and alkalis, are very difficult to recycle. In special circumstances it has been possible to use such materials as feed to direct reduction kilns.

If the furnace is being used for stainless steel or special steel manufacture, precautions have to be taken in the treatment of particulates recovered from the furnace to ensure, if these are not recycled, that they are dumped under conditions where leaching of heavy metals - nickel and chromium contained within the residues - is not possible.

The hexavalent chromium is particularly dangerous, since it is toxic and soluble and the dusts should be deposited only on sites which have been treated to be impervious to the percolation of groundwaters. Outflows of waters from the dump should be collected and treated before discharge. Reduction of Cr^{6+} and precipitation of chromium compounds in dilute waters are discussed in sub-section 7.4.3.

5.3 Open Hearth and Other Furnaces

5.3.1 Description of process

The open hearth furnace consists of a shallow bath of refractory materials on which hot metal and scrap may be charged, together with fluxes, such as limestone and dolomite.

A high intensity flame uses air at high temperature with tar or oil as a fuel. The air is pre-heated by regenerators which have previously been brought to temperature using the gases which leave the furnace.

In modern open hearth practice, when materials have melted but the carbon level in the bath is still high, injection with oxygen brings the composition of the bath rapidly to a relatively low carbon state. The operation is then completed using normal open hearth practice.

Gases from the furnace flow through the regenerators and then to a waste heat boiler and dust collecting system. In earlier installations, since the rate of evolution of fume and the intensity of steelmaking were very low, it was not necessary to introduce elaborate cleaning systems. However, as the intensity of the process has risen, the need for gas cleaning systems has become quite apparent. For example, tap-to-tap times have been in the past of the order 8 to 12 hours, but with the injection of oxygen the tap-to-tap time is reduced to 5 to 8 hours.

It is unlikely that new open hearth installations will be made since the UHP electric furnace appears to be a more economical melter of scrap.

5.3.2 Matters requiring attention

The emission of dust in handling and charging raw materials and on the tapping and teeming side of the furnace resemble in many ways the emissions which have been discussed under "Oxygen Steelmaking" and the points of attention discussed earlier apply also to this process.

One problem is that stack gases, if the fuel contains a high level of sulphur, are major emitters of SO_x . Also, since a high intensity flame is required to melt the material on the open hearth, the production of NO_x is high and increases when oxygen is injected into the bath.

5.3.3 Guidelines for control

Since no new open hearth furnaces have been constructed in recent years, an advanced pollution control technology appropriate to the specific process has not developed and control is tending to follow the patterns established for oxygen steelmaking. It is suggested that the use of electrostatic precipitators and roof monitors are all that could reasonably be expected of older plant.

When wet precipitation is used, the waste water is contaminated with suspended solids, fluorides, nitrates and zinc (if galvanized scrap is used). Again treatment of the waters resembles that recommended for the "Basic Oxygen Furnace".

The tandem process is a later development of the open hearth which is characterized by greater efficiency in the use of heat and by higher production rates. Its emission rate is lower than that of the open hearth process, but control is still required, particularly of dust and NO_x .

Electro-slag steel melting is used for making high quality and special steels or for cladding rolls and this process employs slags which contain high levels of calcium fluoride to control their viscosity, so emissions of dust, SO_x , NO_x and F^- could be anticipated.

New furnace designs are being developed which link back to the open hearth furnace, in particular the "energy optimizing furnace" which uses the gases from the hearth (which is oxygen-blown) to pre-heat scrap and iron prior to melting them in the furnace.

The problems of environmental control around such furnaces are similar to those already described. Submerged oxygen injection has reduced tap-to-tap times and smaller quantities of oil are required, so SO_x and NO_x emissions have decreased.

Considerable amounts of cooling water are used in these practices and the normal problems associated with the control of agents used to ensure continuing flow are met.

6. CASTING

6.1 Ingot Practice

6.1.1 Brief description of the process

Liquid steel in ladles is brought into the teeming bay and poured into individual iron moulds, in which it solidifies. The moulds are transported to soaking pits where the solidified steel is taken from the mould and reheated to temperatures suitable for rolling.

The ingot moulds are made of pig iron and are prepared in a separate foundry.

Moulds, when unsuitable for re-use, are broken up and added to the scrap to be returned to the steelmaking vessels.

6.1.2 Matters requiring attention

The passage of the liquid steel into the mould, either directly or through a funnel and runners, involves exposure to the atmosphere and there can be considerable generation of fume. In addition, moulds are often coated with tarry compounds to improve the surface quality of the ingot, and fumes are given off and passed into the steel shop.

Where special conditions are required in the top of the mould, the steel may come into contact with exothermic compounds to maintain a liquid structure near the top of the ingot, or low melting point compounds may be thrown on to the top of the steel in the mould in order to provide fluxing or a stimulus to degassing in the steel.

All these operations are accompanied by fugitive emissions which sometimes, particularly if fluorides are present, are potentially harmful.

The use of "bottle top" moulds lowers the risk of explosion and improves working conditions.

In the manufacture of free-cutting steels, lead and sulphur are added to the ladle or thrown into the mould during teeming. It should be recognized that these materials are potentially toxic and that control of emissions is essential.

Hoods with high levels of suction over the mould area enable a clean operation to take place. The problem is access to the teeming stage, since the ladle is required to pass over the top of the moulds. Side extraction with movable hoods is usually employed.

The extracted gases must be cleaned, normally in a bag filter, or washed and the suspended solids recovered. Storage of the solids is difficult and if possible these should be sold, to recycle the heavy metals. Regular checks of workers in these areas are advisable and may be required by health authorities. Such checks are mandatory when lead is used.

6.2 Continuous Casting

6.2.1 Brief description of process

Liquid steel in ladles is brought into position above an open bath of refractory (the tundish) and tapped to a defined height of liquid in the tundish.

Stoppers are then opened in the tundish and the liquid steel flows into moulds made of copper, cooled intensively by water, within which it partly solidifies to the point where it can be withdrawn from the mould and carried down through a series of guiding rollers where it encounters water sprays which further cool the steel until it solidifies.

The steel is then cut into lengths, either - in the smaller sections - with shears, or - for larger sections - using flame cutting techniques. The solidified steel passes to reheating furnaces (direct charging) or may be cooled and inspected prior to rolling.

6.2.2 Matters requiring attention

In the continuous casting process the ladle is in only one spot; the tundish nozzles are operated only infrequently; refractory tubes protect the steel against oxidation between the ladle and tundish, and the tundish and mould. These conditions make the continuous casting process one of the least polluting in current use. The addition of powder to the tundish is one point of worker exposure. Oils used in mould lubrication on billet casters can give rise to fumes requiring extraction and cleaning.

The main area of concern is in the flame cutting operation, where relatively minor quantities of fume are generated, but, due to the difficulty of enclosing the oxygen cutting heads and associated equipment, large air flows are needed and it is difficult to install efficient equipment. In cutting stainless steel, iron powder is used and a baghouse should be installed. If leaded steels are cast, provisions for control in ladle addition, tundish and mould fume and during cutting should be made.

Ladle and tundish slags and used refractories have to be handled.

Waters used in continuous casting must also be treated. The direct contact between water and the skin of the solidifying strand means the waters receive large quantities of scale and carry considerable proportions of suspended solids. As well, since they are in contact with the rollers that support the strand, which have to be heavily lubricated to ensure their long-term operation in arduous conditions, the waters become contaminated with soluble and lubricating oils.

Since the water must be extremely clean in order to pass through spray nozzles, separate water treatment plants are usually installed.

Steam from sprays, if exhausted to the atmosphere, is a visual pollutant.

6.2.3 Guidelines for treatment

In general the continuous casting machine waters cascade from the mould cooling circuit (highest quality water) through other circuits to strand quenching (lowest quality water) and in so doing pass to settling tanks or clarifiers, from the surface of which oil is skimmed and from which solids are removed at the base.

In order to ensure relatively high levels of clarification, the waters may be passed through a pressure filter and special techniques, such as dissolved air flotation, pressure ultra-filtration or vacuum flotation may be used.

The recycled waters pass to cooling towers, since consistency in water temperature is very important in the control of heat extraction in the continuous casting process.

A bleed from the treatment circuit is required in order to avoid a build-up of fouling materials.

As in other machine cooling applications, care has to be taken to ensure the control of additions made to prevent biological growth or precipitation and corrosion in the circuits, before release of waters to the environment.

7. ROLLING

7.1 Inspection and Scarfing

7.1.1 Brief description of process

After equalization of temperature in soaking pits, ingots are rolled to semi products and at this stage can be cooled down to room temperature to allow their surfaces to be inspected for defects which may have originated either in making the ingot or in rolling. Surface flaws must be removed before the product is rolled to its final form. Similarly steel which has been continuously cast to semis is also inspected, to determine whether there are any surface cracks or other mould-induced defects which might lead to problems in the later rolling of the product.

Material, after inspection, is scarfed (i.e. any defective area is removed) by washing an oxy-acetylene flame over the flawed region.

Currently, with direct charging, it is common practice to accept materials hot from rolling or continuous casting, to feed them directly to reheating or temperature equalization furnaces and then to carry out on the product after reheating an in-line automatic scarfing operation. This removes all the surface but avoids the loss of energy associated with cooling the product down for inspection and then reheating for rolling. If sufficient control of surface quality can be obtained, scarfing can be reduced to an occasional off-line corrective action on diverted slabs.

7.1.2 Matters requiring attention

During hand scarfing relatively minor quantities of fume, combustion products and oxides are emitted. These can be tolerated, since there is very little fine dust, within the confines of the inspection yard.

Automatic scarfers, however, remove more than 0.5 per cent of the steel, in the form of melted droplets, iron oxide, fuel and combustion products. Under these circumstances scarfing units must be controlled for their effect on the environment.

In terms of exposure of workers to fume and oxide dusts, automatic scarfing operations are to be preferred to hand scarfing. Noise is however a problem.

7.1.3 Guidelines for treatment

In hand scarfing operations it is essential that workers be supplied with individual protection against the inhalation of materials released during scarfing. Provision of an air conditioned environment and remotely operated devices so that the worker is not immediately exposed should be considered.

The fume from automatic hot scarfing operations can be collected by suction hoods and passed to wet electrostatic precipitation or high intensity scrubbing. Ear muffs should be worn to prevent noise damage to hearing.

With the advent of hot charging, considerable research is in progress towards methods of automatic detection of defects on semi products. If these methods can be perfected it is anticipated hand scarfing may no longer be required and it should be possible to carry out selective scarfing operations in-line to improve yield and reduce both the total quantity of dust emitted and the exposure of workers to the fumes and noise generated by scarfing.

7.2 Hot Rolling

7.2.1 Brief description of process

Ingots produced in the steelmaking plant or semis produced by continuous casting have to be reheated prior to rolling.

For ingots soaking pits are employed. These are used to even out the distribution of temperature within the ingot and bring ingots to the correct rolling temperature. The heated ingots are rolled to semis of similar shape to those produced by continuous casting.

Ingot semis and semis from continuous casting are brought to rolling temperature in reheating furnaces. (Where hot charging - or direct rolling - is applied, the amount of energy required to bring the cast product to the correct temperature is lowered and the impact on the environment is correspondingly decreased.)

During rolling the product is reduced in thickness and sometimes in width by passage through reversing mills or mill trains which elongate the material considerably.

The hot rolled product after shearing, cutting or sawing to final length is normally sold in this state, but some plate mills, for example, are equipped with surface preparation and heat treatment facilities.

7.2.2 Matters requiring attention

Furnaces require considerable energy when reheating cold material, and emit pollutants depending upon the fuel used. For example, oil firing can lead to emissions of SO_x and, if the temperature of combustion is not carefully limited, NO_x generation can be appreciable. Low NO_x burners are being developed. Employment of cleaner fuels, natural gas for example, and a reduction in the amount of heating required, based on hot charging, should considerably lower any impact that these particular processes might produce on the ambient environment. Recently induction heating has been used to provide, for a very low energy input, corrections to temperature profiles in products intended for direct rolling.

Owing to oxidation of the product in reheating furnaces, scale forms on its surface. The action of rolling breaks the scale and it flows away with the waters used to cool rolls or remove scale from the surface. There may be emission of flakes of fine iron oxide dust, particularly in the last strands, which might require capture.

At the end of the hot rolling mills, where colder material is being straightened, treated and moved around on rollers and on skid conveyors, noise generation from metallic contact and from impact should be anticipated and provisions made to minimize its effect.

7.2.3 Guidelines for treatment

Mill scale is very nearly pure magnetite and from the primary mills the material generally is relatively low in oil and can be recycled to the sinter plant.

The waters used in rolling contain small quantities of oil. In the later stands fine scale is entrained in the water and when separated from the water contains appreciable quantities of oil. As noted earlier this material can create difficulties on sinter strands, because of its potential to give rise to visible emissions, and the problems which it can cause in electrostatic precipitators. If possible it should be sold.

In certain installations for direct reduction mill scale can be mixed with other wastes or ores; it provides a fuel or reductant in kilning operations.

Chemical methods or physical methods of separating the oil from mill scale, e.g. solvent extraction, extraction in a critical fluid (carbon dioxide) and other techniques, have been attempted, but the costs rarely justify such treatment.

If the material is dumped this must be carried out in an area where interaction between the material dumped and the groundwaters has been eliminated, otherwise pollution of the water by oil will occur.

The rolling mills are the largest consumers of water in the steel plant but are also characterized by a high level of water recycle. There should be at least two distinct water lines:

a) one treating indirect cooling waters, e.g. those from the motor room, reheating furnaces, control rooms and instruments etc., and waters which require no more than normal care and treatment,

b) one handling direct cooling waters from the scale breakers, scale flushing, roll cooling, crop pit, scarfing machine, hot run table, down coiler, and hot and cold saws.

These waters can proceed to a clarifier and filters; any solids should be vacuum-filtered.

It is sometimes more economical, particularly when rolling mills are far apart, to treat the waters from each type of mill separately. On a greenfield site, however, (particularly when further expansion on the site is not expected) to save labour costs in the future it is generally sensible to bring all the water to a larger central treatment point.

7.3 Cold Rolling and Forming

7.3.1 Brief description of process

Flat products produced on hot strip mills are further processed by cold rolling after treatment in acid (pickling) to remove the thin scale formed during cooling from hot rolling. The cold mill may be of reversing or tandem-train design.

The product from cold rolling may require further processing to obtain desired properties, for instance it may need to be annealed; it may also require shape control, slitting, shearing and forming for final sale.

7.3.2 Matters requiring attention

In pickling, baths of sulphuric acid or hydrochloric acid at temperatures approaching boiling point are normally used. The coil passes through the tanks of acid and scale is removed. The pickled strip is rinsed and coated with oil to avoid staining due to rusting. During pickling an acid mist can be generated and this is either contained within an enclosed system (continuous coil lines) or collected using hoods over the tanks (batch lines). In both cases air drawn through the system extracts the acid mist. The acid-laden air should be water-washed before being released to the outside environment.

Rinsing waters discharged during the transfer of materials from the high acid tanks into washing areas; any spills, overflows, or other discharges from the pickling tanks, and the fume stack effluent also need treatment.

Waste pickling liquids are also discharged and lead to disposal problems.

Noise at the entry to pickling lines and neutralization plants can exceed 90 dB(A). Ear muffs should be worn.

The pickled and surface-coated product passes to the cold mills where, sometimes, oil is applied directly or mixtures of oil and water are used to cool the rolls and to lubricate the strip as it is rolled. This emulsion is recycled and leads to a number of pollution problems, particularly high BOD and contamination of waste waters by suspended solids and free oil. Biological growths in oils can lead to unpleasant odours.

After processing, the cold strip is treated to remove the soluble oils and clean its surface. This is usually done in an electrolytic cleaning line which could involve rinsing, electrolytic treatment in an alkaline solution, and washing to remove the alkaline solution. The gases generated need to be kept separate, otherwise there is risk of explosion, hydrogen and oxygen being released during the electrolytic treatment.

If annealing is required, combustion gases (and protective gases from bright annealing furnaces) have to be controlled.

In the manufacture of special steels, such as stainless grades, due to the highly acid-resistant nature of the material, strong acids, e.g. mixtures of hydrofluoric and nitric acids, are required for pickling. Abrasives are used in some installations to remove refractory oxides from high grade steels; care has to be taken in their recovery.

7.3.3 Guidelines for treatment

The waters from cold rolling and forming operations require preliminary settling in a tank. Oil is skimmed from the surface.

The finely divided and emulsified solids and oils are prepared with additions of alum and acids. Then the liquors pass to lime and flocculant treatment tanks, major problems being to remove oil and to obtain the solids in a form that can be filtered.

Processes used are neutralization, rapid and slow agitation in tanks with the addition of flocculants and polymers; scum skimming and final adjustment. The scum after de-watering is incinerated.

The use of ultra-filtration is becoming more common and the possibility of recovery of oils for later purification and recycling should be considered.

There are three main methods of removal of oil: skimming (the retention time required is of the order of 15 minutes, depending on the waste water characteristics), filtration (which can assist to reduce the oil level, but the problem is that the beds blind very quickly and must be back-washed frequently), and flotation (either froth flotation or dispersed air flotation in gas bubbles produced by mechanical agitation). Air flotation and vacuum flotation have the advantages of achieving a high level of separation for relatively low energy requirements. Filtration enables oil to be separated, but is costly, both in respect of the filter materials and the process energy required to carry out the operation.

The possibility of neutralizing the acid waste from pickling with the alkaline wastes from electrolytic cleaning should always be considered in establishing the final treatment circuitry.

Also the use of acid effluents to split oil-water emulsions contained in effluents from cold rolling should be considered.

The pickling waste liquor neutralized with lime precipitates a sludge, which after dewatering is usually sent to disposal on land. If these sludges contain heavy metals (from passivation baths or other sources), particular care to avoid remobilization of these metals is needed.

The recovery or regeneration of pickle liquors introduces another set of problems. The recovery of sulphuric acid leads to the production of ferrous sulphate. If the material can be sold the heptahydrate ($\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$) is the most suitable product. It has been used, for example, as a weed killer and is used in water treatment for flocculation and de-phosphorization treatments. Excess ferrous sulphate, however, has to be dumped under conditions such that its solution will not contaminate the environment. It can contain free acid (this should not exceed 0.4 per cent), and to maintain low acid levels the operation of the centrifuge used to separate the sulphate crystals has to be carefully monitored.

The development for hydrochloric acid pickling of a series of efficient regeneration techniques which recover the iron as iron oxide is one of the more interesting trends. Such oxides are fine and of relatively high purity and can be recycled within the steel plant, sold to pigment users or grown with specific magnetic properties and sold for ferrites, for coating recording tapes and computer memories.

Hydrochloric (and sulphuric) waste pickle liquors can also be used for waste water treatment, both within the steel plant and in other industries, including sewage treatment (phosphate removal and flocculation).

7.4 Coating

7.4.1 Description of process

In modern mills continuous coating lines are used to apply protective and decorative coatings of zinc, tin, aluminium, plastics of various types and paint. In a limited number of plants, terne (lead), brass, and cadmium coatings are also applied.

In many recent installations zinc is deposited electrolytically and may be of varying analysis at different depths within the surface of the coat; the process is becoming much more sophisticated and is using a broader range of coating materials.

Galvanizing may be, as stated above, electrolytic or can be by hot dipping in liquid metal. The main process steps are: alkaline cleaning; pickling; bright annealing; cooling; coating; heating by induction to flow the surface; water quenching; coiling and shearing.

The main elements in a tinning line would be alkaline cleaning; rinsing; pickling, rinsing; plating with tin; rinsing; chemical treatment of the tin-plated surface; rinsing; drying; oiling and coiling.

Other potential coating processes include the preparation of tin free steels through coating with chromium; and more exotic coating methods usually limited to wire products, such as brass, cadmium and hard chromium coating.

Many lines apply paint, or glue organic finishes to the surface of continuous strip.

7.4.2 Matters requiring attention

Degreasing can lead to the emissions of chlorinated hydrocarbons into the atmosphere. Acids can enter the atmosphere. When plastic coatings are applied with glues and, when paint is used, solvents are likely to be emitted.

The bulk of the problem, however, lies in the treatment of the dilute rinsing waters which are generated between each stage of treatment in the several plants.

It should be noted that some of the materials involved from surface preparation solutions, such as chromating or phosphating solutions, are in themselves undesirable if allowed to pass to the environment without specific care in rendering them either non-toxic or insoluble. Hexavalent chromium is toxic. Action must be taken to bring it to the trivalent state before release.

From all coating process lines as indeed from pickling lines there are weak concentrations of water-borne residuals from the cleaning of the strip surface and the removal of oxides; as well as diluted alkaline, acid or organic solutions and chemicals from the chemical treatment plant; so the waters are contaminated with oil, iron oxide, suspended solids and contain diluted alkalies, acids, chemicals and coating materials.

7.4.3 Guidelines for treatment

The optimum treatment circuit in any particular plant will be a function of the coatings applied. As far as possible the solutions generated should be used to achieve neutralization and the correct oxidation state in materials entering the external environment. In particular the correct oxidation state for chromium is of importance, for example galvanizing plant will have a chromate passivation treatment at the end of the line. The chromate rinse waters should pass to a reduction tank where acid and sulphur dioxide or recycled pickle liquor could be used to ensure that Cr^{6+} is reduced. These waters would then join wastes from the fume scrubber and other rinse waters to give an approximate neutralization. Neutralization would be completed after oil skimming by the addition of lime and flocculants, with later separation of solids, possibly in a clarifier and vacuum filter.

The problem in tinning and chromium plating lines is more intensified, but the general principles noted above should be considered in setting up an appropriate treatment circuit. Sludges from some of these processes contain high levels of chromium or other valuable elements and can often be sold to other manufacturers.

The basic principle for the removal of toxic metal ions is that alkaline compounds, such as lime or sodium hydroxide, precipitate them as hydroxides. The hydroxides are sometimes difficult to settle and flocculants are added to assist.

Hydroxides can be converted into insoluble carbonates using CO_2 . Lime also may precipitate phosphates as insoluble calcium phosphate and fluorides as the fluoride.

Soluble sulphides, e.g. sodium sulphide, can be used to precipitate many heavy metal ions as insoluble metal sulphides; a final pH adjustment may be required.

Activated carbon can be used to scavenge waters, provided these have been pre-treated to remove excess suspended solids, oils and greases which would otherwise blind the carbon. Carbon is particularly suitable for the clean-up of waters which contain organics which may be undesirable.

In certain cases the carbon must be dumped after use as an absorbant, but mostly it can be regenerated by the use of heat and steam or solvents.

On plastic coating lines and painting lines suction hoods should be placed to recover volatile materials, coming from glues and plasticizers. These would generally be led off through a combustion facility to ensure that there would be no release of the material to the environment.

A very difficult problem is the disposal of waste tins or drums containing plasticizers, glues and paints and the disposal of solvents and other materials which are in excess of their use in the plant.

For these an incineration and scrap recovery unit would appear to be the best method of disposal, but such facilities on an approved basis whereby emissions of soot, NO_x and possible generation of more dangerous compounds are minimized and disposal is properly supervised and licensed, are difficult to find in many countries.

If need be the steel plant could establish its own facility but services from some licensed authority should first be sought.

8. SOLID WASTE TREATMENT

8.1 Recycling

8.1.1 General

Wastes which are accumulated in steel plants can include refuse from coal washery operations (but see 3.1.1), slag and dusts from blast furnace plant; slag and dusts from steelmaking plant; used refractories; waste from coke making and by-product operations; oil and greasy residues; sludges from the cleaning of gaseous effluents or liquid wastes; materials from cleaning operations; by-product waste from human activity; and residual paints, fuels etc. The quantities involved are indicated in table 1 and waste disposal is a major problem for the industry.

8.1.2 Dusts

Dust generated during ore crushing and recovered from transfer points within the plant, such as those from iron oxide and coke breeze can in general be returned to the process. The most usual point is in the sinter or pellet plant. The sinter plant dust itself is often recyclable. When, however, alkalies and zinc accumulate in the dust, either due to high levels in the ore or due to the recycling of BOS dust, then it must be disposed of in some other way; sometimes it can be sold but usually it is dumped.

Blast furnace dust is recovered in both dry and slurry form. The dry coarse dust can generally be returned directly to the sinter plant, but dust recovered in slurries from the precipitators, or from intense scrubbing plant, can have, depending on raw materials used and other conditions, levels of lead and zinc due to the recycling of BOS dust to the sinter plant that may make it unacceptable for return to the process. Equally, there are limitations to the use of blast furnace dusts in pelletizing plants.

The dusts can be separated by cycloning into coarser and finer fractions, and the coarser fractions can be returned to the sinter plant. The lead, zinc and alkali containing fine dusts must either be further treated or disposed of on prepared land sites (see later sub-section 8.3).

The dusts from primary fume cleaning on the BOS process are of an analysis which depends very much on the quantity and quality of scrap used in the steelmaking process. The levels of elements such as zinc and lead can be too high to allow useful recirculation. If the amount of scrap from the local plant and its nearby facilities

is sufficient and of high quality the amount of zinc in the dusts can be low. Also, if a very high hot metal steelmaking practice is used with low scrap, it may be possible to recirculate the dusts.

Similarly, dusts from electric arc steelmaking plant are occasionally suitable for recycling by pelletizing and recharging to the electric furnace.

8.1.3 Slags

Concerning the treatment of BOS slags there are quite a number of different approaches. In general steelmaking slags have high lime and iron contents, but unfortunately also contain high levels of P_2O_5 .

One decision would be to recycle this to the blast furnace until the P_2O_5 level reaches a point where the ability to control phosphorus in the steel becomes difficult or the slag itself reaches a phosphorus level where it may be sold as a fertilizer. In order to limit the phosphorus problem a de-phosphorization step can be carried out on the blast furnace metal before it passes to steelmaking (see sub-section 4.3). It may be possible to take the slag produced from the de-P operation and grind it with a citric acid soluble phosphate, such as natural phosphate rock, in order to produce a blend suitable for use in agriculture. There are considerable associated economic benefits in prior dephosphorization, provided a low scrap BOS operation can be tolerated financially.

Usually, however, BOS slags are taken to an intermediate dump, poured out and allowed to solidify and crystallize. The slag is then broken up, iron is removed by magnetic separation for recycling and the crushed product is size graded if sale is possible (see 8.2.3).

8.1.4 Refractories

Waste refractory materials, for instance blast furnace linings and steelmaking converter linings, tundishes from continuous casting and ladle linings, normally have to be dumped. Some bricks can be reused and recycled; carbon bricks can be crushed and used as sinter plant feed, although this is not always done; the remaining bricks are dumped. Care must be taken that used blast furnace refractories, which can contain cyanides, are placed on land disposal areas with impermeable bases. The percolant liquid must be collected and tested (if necessary treated) before release. Soaking pit bricks, and reheating furnace brickwork are also disposed of on prepared land sites.

8.1.5 Scale

There is, as noted, a recycle of the coarser cleaner proportions of the rolling mill-scale to the sinter plant. The finer fractions are usually dumped or sold for the recovery of oil.

8.1.6 Miscellaneous materials

Arisings within the plant from excavation and other operations, such as earth, rubble from salvaged buildings and some of the discarded materials from operating equipment, can be returned into the construction of embankments or landscaping projects. Equally, BOS slag may be useful in such projects. Earthy materials can usefully be applied to the surfaces of dumps to assist the regeneration of vegetation.

8.2 Preparation for Sale

8.2.1 Valuable by-products

There are dusts, sludges, slurries and wastes, particularly from the treatment of waste waters in the finishing operations, which can be sold in the state in which they are produced in the steel plant. These include zinc-containing dusts, the iron oxides produced from HCl regeneration plant, which are relatively pure; gypsum produced in SO_x traps; residual dusts from electrostatic precipitators can be used in ceramics; lime fines are readily sold and some iron oxides are used in the paint industry.

8.2.2 Blast furnace slag

One of the most readily saleable materials, with quite a versatile range of properties, is blast furnace slag.

It can be allowed to solidify relatively slowly and crystallize to form stable material, very similar to an igneous rock. Slag is recovered then crushed and sized into grades suitable for use as aggregate in road building or concrete.

It can also be sold as a component in slagwool manufacture, but a problem in this application is that the variability of analysis makes the production of fine grades difficult to achieve.

In many cases the slag is also used for land reclamation from the sea, and as a fill for industrial landsites. In many cases the slags are marketable as such and are sold directly to firms which handle industrial minerals.

Further possible uses for the fine fractions of this slag include its uses as fertilizer, where long-term release of lime-based materials is required, for example in the growing of pineapples in tropical climates; and as an addition in glass making, for cheap clear glass.

A second way in which the slag can be prepared is to granulate it immediately it leaves the furnace, in water. This process yields a material capable of bonding under hydraulic conditions, which when fine ground can be sold as a cement. Due to the slower rate of reaction of this material it is a useful component for very large scale building and construction work since this type of cement in large blocks does not overheat. Blast furnace slag cement resists spallation in contact with reactive aggregates, which would cause Portland cement to expand.

In a third variant, blast furnace slag can be foamed by breaking it up and reacting it with a lesser quantity of water which produces a finely bloated material used in road construction, as light weight aggregate, as an insulating material, or in the ground state as a sand in cement.

8.2.3 BOF slag

The potential or the suitability of BOF slag for sale has been less developed by the industry, but there are quite a number of contexts in which it can be used.

The basic problem is free lime in the slag. This material is not stable under conditions of slaking and therefore, where BOF slag is used in civil engineering projects, swelling and changes in the configuration of the position where it had been placed can occur, e.g. distortions under roads or in dykes, etc.

Slag of larger size stabilized for more than six months in air, in relatively small heaps, has been found to be quite suitable for applications in road construction or as ballast for railway tracks.

Another use of the slag is as a dense aggregate added to cement, for instance projects such as the manufacture of large concrete blocks for the formation of protective quays in port areas.

The potential for use of slags for fertilizers is known. However, it should be recognized that BOF slags, while they do contain lime, are in general fairly sterile materials in which to attempt to establish growth over dumps, particularly when produced from low phosphorus raw materials. If the levels of heavy metals in the slag are high, growth of trees planted on slag dumps will cease once the slag is encountered.

Another use for BOF slag is as chipping material to be incorporated in road surfacing areas. This is a developing application, but is encountering problems of wider acceptance by Road Authorities.

8.2.4 Oils and wastes

In a number of plants it has been possible to find purchasers for reject oils and oily wastes, who take material from a number of sources to recover oil for refining and sale.

Downgraded oils and greases can be used for steam raising purposes.

Where oxidation of oil is minimal, as in rolling mills, then oil recovery and recycle are practicable. Vacuum distillation of recovered oil at relatively low temperatures to remove water can be employed (or other techniques can be used). Recycle will depend on the value of lubricating and solvent oils relative to the cost of recovery.

8.3 Land Disposal

This one of the more controversial aspects of steel plant operations, for which it is often difficult to achieve acceptance from local communities. It is essential in the initial planning of a steel plant that an adequate area be put aside, if possible within the plant site itself or in reasonably close proximity and with simple transport. Planning should assume provision for about 0.5 t of material to be dumped per annual tonne of steel. This will reduce as sales of wastes are achieved.

In dumping, if heavy metals are present, there should be no opportunity for groundwaters to penetrate the dump, or for rain to percolate through the dump and achieve contact with the groundwaters. This implies that the dumping area must have an impervious base and provision should be made for waters to be led off into drains or treatment areas. Such waters and groundwaters should be monitored regularly. Segregation of materials, when they are put into place, can assist recovery should technology change and the materials acquire value.

The smaller the quantities of heavy metal residues taken to dump, the better. Thought should be given, in establishing a new plant, to processes which recover heavy metals from wastes, such as blast furnace dust. Direct reduction which simultaneously volatilizes zinc and other volatile materials, such as lead, is one

approach but it has been difficult to justify economically. The most interesting recent development has been the use of selective reducing conditions along the kiln. Lead and zinc can be volatilized from iron oxides and recovered by condensation and oxidation outside the furnace. The iron remains in the kiln under a different oxidation potential and is recovered in the form of wüstite, instead of being reduced to metal. This decreases the energy required and may make such processes more viable.

In establishing a modern land disposal site, purchase of an area of surrounding ground which can be landscaped to create an outer embankment on which trees can be planted should seriously be considered. Care must be taken to ensure that access is secure against unauthorized personnel, because certain of the materials deposited will be caustic and some are thixotropic slurries. The latter can be mixed with dry inert materials to stabilize the dump. Chemically active wastes should be neutralized before dumping, whenever practicable.

Other wastes, such as debris from refractories and general iron and steel works residue are dumped, generally without problems; however care should be taken with blast furnace refractories which can carry high levels of cyanides.

9. WATER TREATMENT

9.1 Recycling

Water is extensively recirculated in a normal steel plant. It would be too expensive to purchase the requirements of the steel plant on a once-through basis. To ensure that recirculation can be carried out, it is necessary to check whether or not the incoming materials require filtration or clarification to reduce suspended solids, whether the waters are hard and would require lime and soda additions to reduce their tendency to scaling; whether the dissolved salt levels are high requiring ion exchange demineralization and whether the water should be potable (or not) in the circuits in which it would be delivered into the plants.

Saline waters can be used in certain circumstances to reduce the demand on fresh water supplies, for example for cooling condensers and in heat exchangers. Treated sewage effluent can be used as a general industrial water when required.

Much attention should be given to the use of waters from one circuit as the input to another, without extensive treatment when the second circuit does not require very pure water supply. For example, plant drainage containing bleed-off water from various water circuits, boiler blow-down and collected rainfall can be used for coke and slag quenching. This could reduce the amount and cost of waste water treatment.

Further action which can be taken to reduce the cost of treatment is to substitute indirect cooling systems for direct cooling systems. These are generally more capital intensive, but the reduction in the cost of later treatment and the improved quality of outflow may well justify the expenditure.

As previously mentioned, the available resources of low and high pH waters and slurries should be studied to ensure that as far as possible neutralization (required at various stages of water treatment) is carried out cheaply and with a minimum usage of additional chemicals before water is discharged to the environment.

A further consequence of high recirculation is that waters receive a high thermal load and for this reason care has to be taken in choosing an appropriate cooling system and ensuring that the waters are able to achieve a stable cooling cycle. Temperature limits at which waters may be discharged are often set by the authorities.

In selecting a cooling practice, while most systems use direct contact of air with the water, if the waters should be highly charged and contaminated it may be better to substitute indirect cooling, otherwise further treatment of the air may be required before it can be discharged to the environment.

Indirect cooling waters, where recirculation occurs, are treated to minimize corrosion and fouling, and precautions have to be taken to remove the agents used, before blow-down waters are released to the environment.

9.2 Release

As noted above, waters used for cooling purposes have a burden of thermal pollution, which in many circumstances is not acceptable when they are discharged into receiving streams or relatively small ecosystems. Discharge to the sea or to major lakes should probably be less unacceptable. The high use of recirculation which is typical of most steel plants means that the volume of water discharged may only be 3 per cent the total water in circulation, and the smaller volume is readily cooled.

Other problems such as suspended matter and contents of toxic pollutants should only be of marginal concern in a properly established plant with suitable installations at each stage of treatment. However, there can be problems concerning the biological oxygen demand, BOD, of waters released which can sometimes cause difficulties, particularly when oily wastes have been treated. Waters from the steel plant might be accepted by local sewage authorities. If so they would undergo a further stage of treatment before being released to the environment. Early discussions of this possibility should be sought in establishing parameters for a new plant.

In general, dilution by rainfall and site drainage waters is useful but can cause surge problems in water handling. Provision should be made for emergency storage and treatment for effluents, should for example damage occur to biological treatment stations due to a sudden surge of cyanide or other toxic material, then the plant should have sufficient storage space and emergency treatment or dilution facilities.

Consideration should also be given to accepting treated sewage effluent for recycling into the plant where this will not lead to too great a build-up of undesirable components in the recirculated waters.

10. OCCUPATIONAL HYGIENE

10.1 Problems Encountered

Occupational hygiene, safety and environmental protection are inter-related. Matters which are noxious outside the steelworks are equally undesirable inside.

Persons in the workplace can encounter hazards from:

- (i) physical agents (e.g. damage from falling objects, fire, excessive noise, vibration and unsafe equipment),
- (ii) chemicals. These may be used in steelmaking, but also may involve other sources, such as cleaning agents,
- (iii) electromagnetic radiation. Ionizing or non-ionizing radiation can cause damage, for example flashes from welding equipment and radiation from X-ray or neutron gauges.
- (iv) strain due to noise, heat or pressure. Faulty equipment design is responsible.
- (v) disease induced by poor sanitation or the contamination of food or of water.

Active prevention of damage through the provision of adequate lighting; good ventilation; isolation of the worker from noise and protection from other nuisances should be planned.

10.1.1 Sources of damage

In the processes of steel manufacture, typical chemical and physical agents which can affect the environment of the worker include:

- (i) coal, flux and ore handling and sintering
Coal dust, silica,, iron oxide, lime dust, ionizing radiation, noise and gases from mobile equipment, fluoride dust, sulphur dioxide, carbon monoxide and heat.
- (ii) coke ovens
Emissions from coal, carbon monoxide, hydrogen sulphide, hydrogen cyanide, sulphur dioxide; and from by-product plants ammonia, naphthalene, benzene, toluene, xylene, light oil, coal tar, diphenol, sodium phenolate, other polycyclic hydrocarbons and noise. Most of these arise from unexpected sources of leakage in sealed systems.

Heat stress from exposure to incandescent coke, humidity and heat radiated from the ovens are also of concern.

(iii) blast furnaces

Carbon monoxide (near furnace top), sulphur dioxide, iron oxide, free silica, coal tar pitch volatiles, metal fumes during tapping, heat, noise, ionizing radiation, micro-wave radiation.

(iv) bag filters

Dusts can contain iron oxide, lead, metal fumes such as zinc and zinc oxide, particulates of a very fine nature. Workers in baghouses can be exposed to toxic gases and heat.

(v) steelmaking

Exposures to iron oxide, lead, alloying additions, carbon monoxide, sulphur dioxide, fluorides, combustion products, heat, noise and solvents. Metal fume generation occurs during oxygen injection.

(vi) alloying

Nickel, bismuth, chromium, manganese, tungsten, molybdenum, selenium and other elements, many of which can be generated as dust or fumes.

(vii) casting and teeming

Noise, heat, exposure to liquid metal and exposure to lead during the making of leaded steels.

(viii) refractories

Free silica, asbestos, heat, noise and coal tar pitch.

(ix) re-heating furnaces

Carbon monoxide, heat, sulphur dioxide.

(x) hot rolling mills

Noise, heat, cobbles; in older plants physical contact with red hot steel in cross-country mills. In scarfing: iron oxide, metal fume and dust, heat and noise can be encountered, and nitrogen oxides are emitted.

(xi) pickling

Acid mists, hydrogen chloride, hydrogen fluoride, noise, cyanides, ionizing radiation, and ammonia during neutralization of acids.

(xii) cold mills

Noise, oil mist, organic solvents, nitrogen oxides, lasers, and ultra-violet light.

(xiii) coating

In galvanizing zinc oxide, zinc fluoride, ammonium chloride, lead oxide, hydrochloric acid mist, chromates, hydrogen chloride gas, noise and ionizing radiation. In tinning - fluorides, chromates, sulphuric acid, caustics, noise. In paint lines: organic solvents, chromates, lead and other pigments.

As well as within the steel plant, there are supporting services which can cause exposure:

(i) abrasive blasting: free silica and dust might be encountered. The surface being blasted could contain leaded paints.

(ii) cleaning: organic solvents, caustic agents (sodium hydroxide), and acids (hydrochloric).

(iii) plating: solvents, metal fumes, acids, polishing oxides.

(iv) welding and burning: iron oxide, lead, chromium, manganese, fluoride, ozone, nitrogen oxides, heat, noise and ultra-violet light. Torches on painted surfaces may increase exposure to metal fume, such as lead and chromium from paint.

(v) foundries: free silica, heat, aldehydes, noise, carbon monoxide, lead, metal fumes, chemicals, ionizing radiation, coal tar pitch volatiles. Vibration from use of pneumatic tools during fettling or mould cleaning.

(vi) laboratories: solvents, chemicals, ionizing radiation and lasers.

(vii) electrical departments: PCBs, solvents, ozone, cadmium and paint.

(viii) fire-fighting: carbon monoxide, carbon dioxide, combustion products and heat.

(ix) machine, blacksmith and boiler shops: cutting oils, solvents, noise.

(x) pipe fitting and laying: asbestos.

(xi) reticulated fluids: e.g. compressed air, steam, acetylene, oxygen, nitrogen, argon, coke ovens and blast furnace gases are potentially hazardous.

10.1.2 Possible effects on health

Excluding dangers from physical contact with solid objects, the major hazards are from inhalation of gases, dusts and mists; ingestion in food or drink of contaminants; swallowing of materials

which have entered the mouth or nose, so they reach the stomach; attack or absorption of liquids through the skin or via wounds; or penetration of radiation.

Many of the materials are irritants (e.g. ammonia) and are immediately noticed. The problem is that others are not detected by the body (for example carbon monoxide), and precautions have to be taken to create alarms against them; others are narcotics (for example H₂S dulls the sense of smell), or have subtle cumulative effects and are only tolerable in extremely low exposures due to their chronic effects on health. Included among these substances are the carcinogens, which may require 5 to 25 years for their effects to be detected.

Specific physiological effects of some of the materials are set out below (the data provided in this section and in 10.1.1 are largely based on material collated by Bethlehem Steel Co. Inc. [18]):

(i) Dusts and fume. In general dust is not a major problem though often a nuisance and normal cleanliness in the work environment will avoid any health risk. When levels in air are excessive, danger from reduced visibility; entry into eyes, ears and nose and mechanical damage to skin or mucus membranes can be encountered. A distinction should be drawn between respirable (fine) and non-respirable dusts. Physiological effects of the former are more noxious.

Some particular dusts are the cause of known illnesses, for instance coal workers' pneumoconiosis - characterized by cough, shortness of breath, reduced respiratory functions and eventually shortened life span, which can possibly be traced back to silica in the dust.

Exposure to freshly generated fine fumes, micron size inhalable dusts encountered in metal pouring and welding, should be minimized.

Iron oxide has no adverse health effects. An accumulation of particles in the lungs, called siderosis, may occur, but no impairment of function is associated with it. Certain iron ores can contain asbestos-like fibres, and checks should be made on new deliveries of ores to determine whether such fibres are present. If so, precautions should be taken. Iron oxide fume from welding, scrap burning or in certain areas of the steel plant may contribute to metal fume fever.

Lead is highly dangerous and a number of precautions must be taken, e.g. in foundries making bearings and in leaded steelmaking. The major effects of lead include anaemia, kidney damage, nervous system problems, and birth defects.

Manganese dusts have in susceptible persons led, on chronic exposure (e.g. in miners exposed to high levels of respirable dust) to damage of the central nervous system, impaired motor functions, and emotional disturbances.

Metal fumes lead to a condition, characterized by chills, fever, headache and aching muscles.

Nickel dust causes a form of dermatitis - "nickel itch" - and increases in nasal sinusitis, pulmonary and lung cancer have been observed in the nickel industry. Exposure in the steel industry is usually light.

Silica can lead after 10 to 25 years of exposure to cough, shortness of breath, chest pain, diminished ability to expand the chest, obstruction in the lung, emphysema and silicosis (a scarring of the lung).

Zinc oxide as fume or dust is related to irritation of the upper respiratory tract, vomiting and fever. It is more likely than iron oxide dust to be the cause of metal fume fever.

Asbestos causes very few short-term problems, but long-term exposure leads to fibrosis or scarring of lung tissue, cancer of the lungs, lining of the lungs and the abdominal cavity.

Fluoride can in short-term exposure lead to respiratory irritation and fever, but in chronic absorption the bones become brittle, there are changes in the teeth, and kidney damage can occur.

(ii) Noise in excess can lead to various degrees of hearing loss, damage to the inner ear and tinnitus (continuous buzzing in the ear), and to disturbances related to the stress experienced (excitability etc.).

(iii) Heat. Dehydration, salt depletion, cramps and muscle spasms in the legs, arms and stomach, exhaustion and stroke, coma and death. Long exposure to infra-red radiation has been related to higher incidence of cataract.

(iv) Acids and mists. Corrosion of exposed tissue, irritation, damage to the skin, eyes etc.; irritation of the respiratory tract and decay or destruction of teeth.

Hydrogen fluoride causes corrosion, attack and irritation in eyes and respiratory tract and damage to the subcutaneous skin layer, which can lead to gangrene.

Chronic effects of sulphuric acid mists include dermatitis, conjunctivitis and chronic bronchitis.

(v) Coal and coke emissions:

Benzene in high levels is a strong irritant to the skin, respiratory tract and eyes and can lead to nausea and death. In the chronic case it leads to anaemia, leucopenia (a deficiency of white blood cells) and to leukaemia. Light oil or coke oven distillate containing benzene has similar effects. Toluene and xylene are also unpleasant at higher concentrations, but toluene in the chronic case has been related to anaemia, and enlarged liver. Xylenes similarly lead to dermatitis and rarely to blood and liver damage.

Coal tar can be acutely irritating to the eyes, skin and respiratory tract; conjunctivitis, dermatitis and allergic skin reactions such as erythema (on exposure to ultra-violet light, reddening of the skin). In chronic exposure lung and other cancers have been attributed to it, but may be associated with other substances related to its production. 2-Napthylamine in tar aerosols is a known carcinogen, causing bladder cancer.

Coke oven emissions are related to lung and kidney cancer through BaP or other carcinogens. The polycyclic aromatics can be associated with irritation of the eyes, skin and respiratory tract, conjunctivitis, dermatitis and other allergic reactions; and in chronic cases lead to skin and other cancers.

Naphthalene in acute exposure cases can lead to headache, nausea, convulsions and death; anaemia, respiratory failure, optic neuritis (an inflammation of the optic nerve) and irritation of the eyes and skin. In chronic cases clouding of the eye lens, cataracts, liver and spleen damage have been related to excess exposure.

Phenols: sodium phenolate is extremely toxic by all routes of exposure - the high content of phenols and creosols can cause severe irritation, burns to eyes, skin and other tissues. Breathing difficulties, visual disturbances and damage to the kidney, liver and central nervous system may occur.

(vi) Cleaning agents:

Ammonia: can lead to irritation of the respiratory passages, cough and shortness of breath, pulmonary oedema, bronchitis, severe irritation of the eyes and conjunctivitis.

Caustics: can lead to nausea and vomiting. The caustic cleaners are very damaging to exposed tissue, they can cause irritation or burns to skin, eyes and mucus membrane.

Inhalation of dust, mist or spray can cause irritation of the respiratory tract, or pneumonitis (inflammation of the lungs). Dermatitis can also be associated with their use.

Organic solvents: can affect the central nervous system, causing headache, nausea, stupor, coma and finally death. Dry and irritated skin, dermatitis, irritation to the eyes and mucus membranes can occur after direct exposure, but long term contact can lead to damage to lungs, kidney, blood and liver, gastro-intestinal and other organs.

(vii) Gases:

Carbon dioxide can cause asphyxia, carbon monoxide can lead quickly to headache, dizziness, weakness, dimness of vision, ringing of the ears and death.

Hydrogen cyanide (vapour) is an asphixiant; over-exposure is rapidly fatal.

Hydrogen sulphide is an irritant to the skin, eyes and respiratory tract and eyes, leading to conjunctivitis, bronchitis, pulmonary oedema; dizziness, lack of muscular control and finally convulsions, nerve damage and death.

Nitrogen oxides again are irritants, leading to lung and respiratory tract problems, to permanent cough, headache, lack of appetite; corrosion of the teeth, emphysema and nose ulcers.

Ozone, generated where electrical equipment is in operation, is an irritant to the respiratory tract and eyes and can cause headaches, cough, congestion and pulmonary oedema.

Sulphur dioxide is an irritant to the mucus membranes, the respiratory passages; to the eyes; can lead to chest pain, shortness of breath, bronchitis and other lung diseases.

(viii) Other materials:

Asphalts and petrol emit fumes which may cause irritation to the eyes and respiratory tract. Asphalt in contact with the skin can lead to dermatitis, irritation, acne-like lesions and allergic reactions.

Cutting fluids similarly can lead to skin irritation and dermatitis, chemical pneumonia and possible cancer of the skin.

Chromates are irritating and corrosive, and ulceration can occur on the hands, forearms and mucus membranes of the nasal septum. Perforation of the nasal septum has been observed. Cancer of the lungs, nasal cavity and sinus has been linked with certain chromates.

Scrap. Explosives and hollow vessels can create damage. Breaking operations are dangerous. Charging of water with scrap into steelmaking vessels has led to very dangerous expulsion of liquid steel from the vessel.

Water. Care must be taken to ensure that the quality of potable water is strictly controlled in order to avoid infections, via micro-organisms or contamination by undesirable chemicals. In many steel plants non-potable and potable water systems exist. Continuous care has to be taken to ensure that cross-connections are not established by error between these systems.

Food. Improper handling, lack of sanitation and good housekeeping can lead to microbial infection; bacterial intoxication; animal parasitism or to the ingestion of toxic chemicals. Personal hygiene should be encouraged within the workforce, in particular to avoid the transfer of harmful materials to food.

(ix) Radiation:

Infra-red: A syndrome related to long-term heat exposure is increased frequency of cataract due to the infra-red absorbed by the lens of the eye. Short-term exposure to intense infra-red can cause burns, conjunctivitis and heat disorders.

Ionizing radiation: provided the exposure is contained below established limits, is not a serious problem, but high-level short-term exposure can cause erythema, nausea, vomiting or death; and chronic exposure over long periods can cause leukaemia and other forms of cancer.

Genetic effects are directly related to the exposure of the gonads.

Lasers: can lead to retinal and corneal eye damage if exposure occurs; to blindness, severe skin damage, etc.

Micro-wave radiation: can cause at certain specific frequencies heating of body organs without a warning sensation or pain.

Ultra-violet light: can produce effects on the eyes (such as conjunctivitis, cataract, photokeratitis and inflammation); and effects on the skin (such as erythema) particularly when exposed to coke oven tar and pitch. Other photo-allergic reactions can ultimately lead to skin cancer on long-term exposure.

(x) Vibration. The long-term use of equipment where arms and upper body may be continually exposed to excessive movement e.g. scarfing and fettling with pneumatic tools, should be guarded against and vibrations that affect the whole body, particularly at certain frequencies, can cause damage to major body functions. Alterations to the hands (Raynaud's phenomenon "dead hand" "white fingers") bone, muscles (tenosynovitis), and nerves have been recorded.

10.2 Methods of Protection

Basic requirements for protection of the worker are:

- information
- control of exposure to safe limits
- issue of personal protective equipment where generalized control is not practical.

Beyond these basic requirements effective monitoring, medical surveillance, the consistent use of warning signs and labels and proper record keeping allow continuing improvement.

A management structure to accommodate this requirement is also needed - for example, the appointment of occupational hygienists and environmental, health, fire and safety protection officers within steel plants to identify probable hazards and evaluate methods of control.

10.2.1 Legal

Below a description is given of practices as carried out within the United States, because these are reasonably well known on a world basis. However, it should be recognized that many nations have introduced legal protection for the work force. International bodies are now becoming accepted (not without controversy on specific rulings) as appropriate sources of advice, for instance the World Health Organization is re-examining exposure limits for a range of substances, and this work is to be published shortly [16]. The ILO has in its Encyclopaedia of Occupational Health and Safety [17] taken account of trends in industrial toxicology and cancer research. It contains recent epidemiological results. These references should be consulted for further information.

In the United States in 1936 the Walsh-Haley Public Contract Act made it mandatory for organizations with government contracts to maintain a healthful working environment. Health standards designated as "Threshold Limit Values (TLVs)" by the American Conference of Governmental Industrial Hygienists (ACGIH), a voluntary standards setting organization, were established.

These standards refer only to airborne concentrations of substances and represent conditions under which it is believed that the body can handle the substances by metabolism or excretion; alternatively, from a more modern viewpoint, that the risk of damage to the worker is so low that it is unlikely within the lifespan of the operator to lead to damage before other, normally acceptable, risks cause death.

In fact the Threshold Limit Values only provide guidance. Industrialists are recommended to seek the lowest practical exposure level, even if this is well below the TLV, since there is no absolute proof of the assumption that ingestion and metabolism by the body is effective; also, persons show differences in sensitivity to certain substances.

In 1970, the Occupational Safety and Health Act stated that it was necessary that men and women should have safe and healthy working conditions. This applied to all businesses affecting inter-state commerce. The Threshold Limit Values were referred to as Permissible Exposure Limits (PELs) within the terms of this Act.

The TLV or Time Weighted Average Permissible Exposure Limit (PEL-TWA) is the maximum average concentration of airborne contaminants, to which a person may be exposed over an eight-hour workday of five days per week. The average is time-weighted so that excursions above the limit can be tolerated.

The Short-Term Exposure Limit, or PEL-STEL, is the maximum concentration to which a worker can be exposed over a period of up to fifteen minutes without suffering irritation, irreversible or chronic tissue change, or impairment of sufficient degree to increase accident proneness or reduce work efficiency. No more than four times should this limit be exceeded in one day and there should be at least sixty minutes between times of exposure.

The Ceiling Limit, or PEL-C, is the concentration that should not be exceeded at any time.

These cannot be absolute and the effect of such concentrations on persons working within them should be continuously monitored. They are expressed as parts per million of the air, ppm; mg/m^3 of air, or millions of particles per cubic metre of the air, mpp/m^3 .

If absorption through the skin, as well as by inhalation, is possible the notation "SKIN" is introduced on the limit statement.

Mixtures are presumed to be additive, that is to say in the work environment $C_1/T_1 + C_2/T_2 + \dots$ etc. should not exceed 1 (C_i = the concentration of contaminant i , T_i = its TLV).

The limits themselves are not immutable and are subject to alteration and revision from time to time.

10.2.2 Physical

Beyond these specific limits there are many engineering controls on health hazards. These include the modification of processes to reduce noise or exposure; the development of heat shields, improved ventilation, local exhausts at points of generation of fume; and specific work practices to minimize occupational exposure (for example, it may be necessary to insist that particular workmen spend only limited times in specific work areas and retire regularly to air-conditioned or controlled atmosphere environments).

10.2.3 Personal

Protective equipment is issued as a last resort. There are problems with such devices in that they are not always comfortable to wear, and it is difficult to monitor their use.

Education and insistence on the provision of full information concerning the hazards involved is important.

Equipment under this category includes respirators, either those which actively purify air or those which supply an atmosphere directly to the individual worker. Diverse respirators are capable of removing dust and mists; metal fume; mercury vapour; specific chemicals; and pesticides etc. Care in the maintenance cleaning and restoration of such respirators is essential if full protection to the workforce is to be provided.

Hearing protection can comprise ear-muffs; or ear-plugs. The size of the ear should be checked when the initial inspection for hearing assessment takes place. Eye protection and face shields are also used where required.

Over and beyond these provisions comes the supply of relatively non-flammable clothes or clothes which do not melt under the action of heat; the provision of special suiting for conditions where temperature and exposure to heat stress is high; the complete enclosure and protection of people in dangerous environments etc.

10.2.4 Records

Also essential for the protection of the workforce is the keeping of good environmental health records. These enable the separate exposures of a particular person to be recorded and followed, allow the health hazards in any particular area to be identified, and permit the effects of changes in practices to be quantified.

10.3 Monitoring

When exposure to chemical agents in the environment is possible then the workplace should be sampled and the exposure to such physical agents evaluated. This is a prime objective of any environmental health programme and accurate assessment is essential.

The usual strategy is to sample the worker who is presumed to have the highest exposure risk, by being either in longest contact with or closest to the substance in question. In Breathing Zone (BZ) tests for personal sampling, the collection medium is placed close to the worker's mouth or nose, i.e. attached to his lapel, taped under his welding helmet, hand-held near his face. Since the efficiency with which a worker wears his respiratory equipment is uncertain, it is preferable to take measurements near his face, not actually measuring behind the mask.

Area sampling is carried out by mounting the collection device in a stationary location in the workplace. An average contaminant concentration is measured. Usually airborne concentrations vary depending on the siting of ducts, fans or exhaust systems. It is better if possible to sample within the breathing zone of the worker.

The degree and extent of sampling, numbers of samples required in an eight-hour shift and numbers of persons sampled may be determined by law, e.g. in certain cases, particularly in the handling of lead, measurements must be carried out on the blood to determine the exact degree of contamination experienced.

For noise, the sound level in decibels (dB) corresponds roughly to the sensation of loudness and the frequency, in cycles per second, expresses the pitch. For noises involving impact, an instantaneous sound-pressure level is measured and is referred to as the Peak Sound-Pressure Level (PKSPL).

Noise measurements are usually modified to an A weighting (dB(A)). A frequency filtering reduces the amplitude of the low frequency and very high frequency sounds in a manner which duplicates the sensitivity of the average human ear. Dosimeters can be worn by employees which detect the A weighted noise level experienced and compute the noise dose automatically.

Radiations, such as X-rays, gamma rays, U.V. and laser beams are measurable using appropriate equipment. For welding flashes and laser beams, detecting potential sources of danger and ensuring they cannot affect the worker is more important than quantitative measurement.

11. CONCLUSION

Coverage of each of the many individual processes which are involved in the complex of operations required for steelmaking has of necessity been brief. References providing further detail are available within the material cited in the bibliography and resort should be made to this information for guidance on specific queries.

While major gains have been made in improvements to the impact of the steel industry on the environment in past decades, the steel industry has by no means solved all the problems it faces. Environmental improvements in the future could prove relatively costly to implement. To find optimum means of control more research will be needed:

- seeking out synergistic possibilities within steel plants, whereby products from one section of the plant can be used to treat problems in another, for example, recovery of ammonia, which in itself is not a highly economically justifiable operation, may become of much greater interest in the future because of the ability of this gas to decrease SO_x and NO_x emissions by interacting with them to create solid recoverable, or gaseous innocuous, products.
- searching for the simultaneous use of several physical phenomena to improve the efficiency of capture and decrease the cost of capture of emissions.
- looking towards methods of recycling, detoxifying and using solid wastes in economically rational ways. Disposal of solid wastes is a very long-term problem in the operation of steel plants.

Training is also required. Education in methods of maintaining environmental control equipment; inculcation in the workforce of the desirability of the minimization of environmental impact; and the encouragement of interest in management at all levels in the achievement of continuing reductions in pollution, are major goals to be sought.

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