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ENVIRONMENTAL GUIDELINES FOR THE DIRECT REDUCTION ROUTE TO STEEL MAKING

UNITED NATIONS ENVIRONMENT PROGRAMME

Environmental Guidelines for the Direct Reduction

Route to Steel Making

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PREFACE

The environmental aspects of the iron and steel industry were reviewed at a UNEP workshop, held in Geneva, 17 - 20 October 1978, the proceedings of which have been published (1), and priorities for action defined by a balanced group of experts from Governments, industry and international organizations. The direct reduction route to steel making was one of the areas identified at the workshop where further review and guidance as to the environmental aspects was considered necessary. In order to provide this review and guidance, a meeting of experts (2), held in Puerto Ordaz, Venezuela, 24 - 30 April 1982, at the invitation of the Venezuelan authorities and Siderurgica del Orinoco, was organized in co-operation with the United Nations Industrial Development Organization (UNIDO). Experts at this meeting represented all the major commercialized industrial direct reduction processes. As for each industrial sector environmental review, UNEP established a consultative process among the main interested parties, namely : Governments, industry and international institutions concerned. Through this process a wide range of information on the environmental aspects of the direct reduction route to steel making was collected and synthesized by the Secretariat, with the help of consultants, in the form of a first draft Secretariat report on the subject. This report gave an overview of the environmental aspects and highlighted the main environmentally related issues involved in the process of producing liquid steel from iron ore by the direct reduction route. It was examined at the meeting of experts who also drafted environmental management guidelines for direct reduction and electric arc furnace steel making using direct reduced iron. A period of time was allowed for participants to submit additional material for inclusion in a revised draft of the report, which was amended in accordance with the comments and discussions of the meeting. The revised draft report and the environmental guidelines were finalized through a procedure of correspondence, which included also experts not able to participate in the meeting itself. The report has been published as the UNEP technical review (3) on the subject. The present guidelines are meant to provide guidance to Governments and industry in the development and implementation of environmental protection policies for the direct reduction route to steel making. For details concerning processes and pollution control techniques reference should be made to the technical review (3). Supplementary information will be found in the UNEP overview and technical review on the environmental aspects of the iron and steel industry, currently under preparation.

ACKNOWLEDGEMENTS

These environmental guidelines were drafted at the UNEP/UNIDO meeting of experts, held in Puerto Ordaz, Venezuela, 24 - 30 April 1981, by two working groups : one, under the chairmanship of Mr. John B. Trescot (USA), dealing with direct reduction ; the other, under the chairmanship of Dr. Leon Hütten-Czapski (Canada), dealing with electric arc furnace steel making using direct reduced iron. The section dealing with mining and ore processing was drafted by the Secretariat. As referred to in the Preface, the draft guidelines were subsequently given wider distribution for comment, along with the draft technical review, and edited in this form for publication. The inputs and valuable comments provided by the following are gratefully acknowledged :

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Mr. Ernesto Gonzalez, FIOR de Venezuela C.A., Ciudad Guyana, Venezuela ;

Mr. W. T. Hogan, Industrial Economics Research Institute, Fordham University, New York, USA ;

Dr. Leon Hütten-Czapski, SIDBEC-DOSCO, Quebec, Canada ;

Mr. Dominique Larré, Director, UNEP Industry and Environment Office, Paris, France ;

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I. INTRODUCTION

The electric arc furnace and the development of the mini-steel mill, along with direct reduction, has enabled countries to install for themselves steel making capacities for 60 to 70% of the capital cost required for an integrated steel works. Unlike the classical process which needs an annual production capacity of several million tons to be economically viable and competitive, a mini-steel mill can operate efficiently with a small scale as low as 5 t/hour, enabling flexibility. Furthermore, a direct reduction (DR) plant has a much larger turn down ratio (i.e. the lowest proportion of the installed capacity at which an installation may continue to function in practice) than a blast furnace, although the specific energy consumption may rise. The turn down ratio can be 40% for DR units and a direct reduction plant running at 50% capacity would have a supplementary specific energy consumption of 10%. The modular aspect of the DR route also provides another favourable aspect of flexibility.

Initially mini-steel mills limited their production to ordinary products not requiring high quality steel ; but developments in electric arc furnace technology now enable highly sophisticated steels to be produced. In the past the mini-steel mill was dependent on the availability of scrap at economic prices. The advent of direct reduction and availability of direct reduced iron (DRI) has provided the mini-steel mill with greater flexibility and independence, as well as with a high quality source of iron enabling attainment of more stringent quality requirements for steels.

Currently, direct reduction technology favours countries with readily available supplies of natural gas and electricity, the potential being particularly favourable at present in a number of developing countries of Latin America, Africa, West Asia and South-East Asia. With the development of coal based processes and subsequently possibly of the use of biomass, the potential for a greater number of countries to meet their own steel making needs will improve. Furthermore, many developing countries have untapped hydroelectric resources. This new situation will now permit new regional development of the steel industry using different approaches as may be appropriate to the local regional market conditions and supply of raw materials and energy.

Whilst the potential environmental impacts of this new route to steel making are less serious than those of the classical routes based on the coke oven and blast furnace or on scrap melting, strict measures must be applied to protect efficiently both the working environment and the environment around plants. Industrial operational experience of the direct reduction approach is available in all regions of the world, but environmental criteria are less well known in areas of the world other than the temperate zones. Attention is called to the problems of long range transport of pollutants and their effects, particularly of sulphur oxides and acidity, such as had been observed in Europe and North America, which could also later affect other parts of the world and have environmental consequences, particularly on sensitive ecosystems.

Whilst emphasizing the need to avoid the negative aspects, the benefits of industrialization are considered very important. Accelerated economic growth and social betterment are inextricably linked to the pursuit of environmentally sound and sustainable industrial development. Although industrial development inevitably brings about changes, it need not be ecologically destructive and should be environmentally sustaining. There are patterns of development which can be achieved without environmental destruction, provided wise resource management is ensured.

The undesirable negative social impact may be mitigated if recognized early and appropriate protection measures taken into consideration from the beginning. The benefits from these measures may significantly outweigh the costs.

Working environmental conditions are often different in developing countries from those in industrialized countries due to both the external physical conditions of climate and the social conditions. As yet there has been little systematic study of these conditions.

Environmental training and education of management and the work force in an industry is an essential element in ensuring effective environmental protection. Sound environmental and resource management begins with the senior staff in a plant and it is important for them to be convinced of the overall benefits of environmental protection and the economic soundness of wise resource management. Implementation of appropriate environmental, including health, protection measures calls for the training of the whole work force in proper operation and maintenance of plant and pollution control equipment, in following health and safety procedures, including wearing of protective clothing and equipment, and in ensuring plant cleanliness by good housekeeping practices. In developing countries there is often a shortage of experienced and trained manpower which gives particular emphasis to the exigence of education and training at all levels in a plant.

II. MINING AND IRON ORE PROCESSING

A. Process Description

There are two methods of mining iron ore : open-pit and underground mining. In the former the non-ore overburden is removed from the surface, leaving the bare ore body exposed for exploitation. In the latter a relatively more complex and expensive installation is required to remove the ore and bring it to the surface as well as to ensure the health and safety of the working population. Raw ore generally has undesirable characteristics of size and shape for further use as well as usually containing gangue materials such as lime, silica, alumina, magnesia etc. and also other elements such as sulphur, phosphorus, arsenic, copper, tin and manganese may be found in it. Consequently ores are usually beneficiated, a process involving crushing, screening, blending, grinding, concentrating, classifying and agglomerating. Differences in physical properties, such as density and magnetism, between iron ore and gangue materials are used to concentrate the ore. The fine concentrated ore is agglomerated into larger sized material by pelletizing and induration.

B. Environmental Impacts

Many of the environmental impacts of a mine and the infrastructure associated with the mining operation (including transportation network and bulk loading facilities) are site specific but the extent of operations invariably means disturbance of the land, changes in land use, destruction of natural ecosystems and of communities and changes in life-styles. Proximity to habitation is an important aspect. Impacts may include : dust, water pollution, noise, visual disamenity, ecological disturbance with loss of flora and fauna, increased soil erosion and changes in the water table, as well as socio-economic aspects, for example associated with relocation of populations, competitive use of the land etc. Beneficiation and tailings disposal are potential sources of water pollution. Noise and dust may arise from ore grinding. Dust is often a problem in handling and transport of fine ores. The firing process in pelletization may also produce dust, as well as gaseous emissions of sulphur and nitrogen oxides. Gaseous fluorine compounds can arise when using fluorine containing ores.

C. Recommendations for Mining and Processing of Iron Ores

These recommendations highlight areas requiring special attention in relation to iron ore mining and processing and are not meant to be comprehensive guidelines in relation to mining itself. They do not include coal mining, where coal is used as the solid reductant in the direct reduction process.

(a) Mine Sites, Siting of Ore Processing Facilities and Associated Infrastructure

As a tool to facilitate the incorporation of the appropriate environmental protection measures from the planning stage an assessment should be made of the environmental aspects relating to the mine site, the ore processing facilities and the associated infrastructure (4). Attention should be given to both the physical and social aspects.

Mining may involve relocation of populations at the mine site or changing of the current land-uses. Furthermore, mining attracts people either for direct employment or in servicing of the mining community. It is important before mining starts to develop relocation plans ensuring that members of the community are not deprived of benefits which they previously enjoyed and that there is little disruption in cultural and traditional lifestyles. Furthermore, opportunities should be taken to provide additional benefits, such as improved housing, recreational, educational and other infrastructural facilities. There may be wider socio-economic aspects of mining activities in the region, for example through impacts on agriculture and tourism, which should also be considered from the conceptual stage of the mining operation.

As a general rule, mining sites should be restored to an equal or more useful state than before mining operations were undertaken. Mine planning should include the options for land use after mining and a clear recognition of the requirements for reclamation, so that reclamation costs and implementation plans can be incorporated into mining costs and operation. Plans should also be made concerning reclamation of tailings dams and waste-disposal areas, including the necessary environmental monitoring during and after mine and ore processing operations have ceased.

(b) Air Pollution Control

Particularly when located near habitations, surface operations such as rock breaking and excavating, crushing, grinding and transportation of ore can be a source of wind blown dust. In these circumstances dust should be contained by spraying during specific operations and by covering transfer points. Binding agents may be added to unpaved road surfaces and roads sprayed with water. Specific care, particularly for mine workers, must be taken in limiting exposure to dust containing crystalline silica.

Dust from stockyards can be minimized by maintaining a sufficiently high surface moisture content. Use of water sprays in cold climates may not be practicable.

Grinding operations in preparation for pelletizing, as well as the kiln firing and fines screening operations need to be fitted with dust extraction equipment (cyclones, electrostatic precipitators or fabric filters). If control of sulphur oxides from pelletizing is required it is usual to use low sulphur fuels for drying and firing. A wet scrubber may be used to control fluoride emissions, if necessary. Appropriate burner design can minimize nitrogen oxides formation.

(c) <u>Water Pollution Control</u>

Mining can have an impact on water quality as well as the water table itself. It is essential to foresee effects on water resources of mining operations in terms of other water uses in the area, e.g. irrigation, domestic consumption and recreation. Acid mine draining should be treated before discharge.

Provision should be made for tailings disposal from ore beneficiation and for treatment of run-off water to remove suspended solids, undesirable dissolved impurities, e.g. toxic chemicals from the beneficiation process, surface activating agents and flotation dispersants, and to adjust the pH as necessary. Provision should be made for storm water overflow. Regular monitoring of surface and underground waters should be started before mining and ore processing begin, to be able to evaluate possible subsequent degradation of water resources. Contingency plans should be made in case of accidental spillage, especially of toxic reagents.

(d) <u>Noise and Vibration Control</u>

Noise and vibration from heavy machinery and explosives which constitute a nuisance to surrounding inhabitants can be mitigated by providing an adequate buffer zone as well as landscaping and screening in the initial plan. Plants housing crushing and grinding equipment can be acoustically insulated. Intense noise constituting an occupational health hazard requires workers to wear appropriate ear protection devices. Noise levels should be regularly monitored and workers periodically examined for occupational deafness.

(e) <u>Solid Waste Disposal</u>

Overburden is normally used in reclamation of open cast mining sites. Gangue may be used for backfilling, but provision for initial stocking should be made. Tailings should be disposed of in properly designed tailings dams, kept moist to avoid wind blown dust and revegetated when filled. Exceptionally tailings may be deposited in water, but it is essential to undertake beforehand a comprehensive physical and ecological pre-audit to assess possible effects in the aquatic system, particularly to avoid toxic effects.

(f) <u>Protection of Local Ecology</u>

Primary ecological impacts arise from clearing of vegetation and certain loss of flora and fauna are inevitable. A comprehensive ecological pre-audit survey before mining begins should be undertaken. In most cases flora can be replaced. Development of implementation plans for conservation of rare indigenous species should be considered. Changes in weather conditions may accompany removal of vegetation, particularly in highly forested areas, which may have numerous concomitant direct and indirect consequences, such as changes in the water regime. Special techniques to prevent soil erosion may be necessary, depending on local conditions. Soil erosion gives rise to increased turbidity of water which can affect aquatic fauna and flora as well as supplies of domestic, industrial and agricultural water and even give rise to accelerated silting of dams, each with its multiplicity of adverse secondary effects.

(g) Worker Health and Safety

Of particular concern to worker health are dust and the possible problems of toxic dusts from certain ores ; noise and vibration from equipment maintenance shops and use of explosives ; air pollution from diesel motors and ancillary equipment ; handling of toxic reagents and accidents. Attention is called to the guidance developed through the International Labour Office (ILO) in this field (5).

III. DIRECT REDUCTION

A. Description of Process and Environmental Impacts

Iron ore in the form of pellets, lump, briquettes or fines is reduced by a gaseous or solid reductant in a shaft furnace, fixed bed, fluidized bed or rotary kiln to produce a solid metallized product. In undertaking this operation, special consideration must be given to the following possible environmental impacts :

(a) air pollution ;
(b) water pollution ;
(c) solid waste ;
(d) noise ;
(e) social conditions and working environment.

With few exceptions, all pollutants associated with a direct reduction plant arise from the raw materials, iron ore and reductant used. Consequently, if there are changes in the raw materials which differ from the range of design characteristics for a specific process, the resultant effects on pollution, as well as process operation, must be studied. For example, a change in iron ore composition, such as the additional presence of heavy metals which could not be adequately controlled, or the presence of sulphur or other impurities in the reductant, could cause serious environmental problems in processes not designed to deal with these additional materials. Similarly, changes in the physical characteristics of the ore could give rise to excessive dust production which would over-load the installed dust control equipment.

(a) Air Pollution

Air pollution from a direct reduction facility may arise in two forms, solid and gaseous. Solid emissions can come from : (i) fines and dust generation in raw material and product handling ; (ii) particulate matter generated as products of combustion ; (iii) coal fines generated through the use of solid reductants ; (iv) iron ore fines and dust which may occur as a by-product of the reduction process. As gaseous emissions, there may be : (1) sulphur oxides arising as a product of combustion ; (2) nitrogen oxides arising as a product of combustion ; (3) accidental discharges of process gases, where special consideration needs to be given to the possible discharge of carbon monoxide and hydrogen sulphide. Fluorides could possibly be a problem for processes using ores containing fluorine compounds. It should be borne in mind that up to 0.5% loss may occur in material handling at each transfer point, a loss which from both an economic and environmental viewpoint is important to minimize. Particular care is needed in the handling of direct reduced iron due also to its potential for reoxidation and consequently fire and explosion risk.

Gaseous emissions and discharge of dust, if uncontrolled, can affect the surrounding countryside. For example, vegetation, soil, and animal life can be harmed and secondary effects such as erosion and changes in the aquatic system may occur. In most cases, however, discharges may be controlled to or below standard industrial emission levels (see section III B (a) below).

(b) Water Pollution

Water pollution from direct reduction processes may arise in four forms : (i) chemical ; (ii) dissolved solids : (iii) suspended solids and (iv) thermal. These pollutants may be discharged to the water system by : (1) blowdown from cooling towers ; (2) overflow from clarifiers ; (3) dewatering of sludge ; (4) blowdown from boilers ; (5) spillage from equipment ; (6) run-off from the plant site and (7) heat exchange equipment for plant cooling.

The chemical pollutants that may be discharged and should be considered are : (i) chemicals used to treat the plant water system ; (ii) chemicals entering the plant water system from gas and ore treatment processes ; (iv) possible generation of toxic hydrocarbons during abnormal operation in the solid reductant processes.

Both suspended and dissolved solids will be products of water contact with iron ore, dust reduced product, or with solid reductants.

Concerning thermal pollution, direct reduction processes are similar to many other industrial processes and there are no unusual problems which need to be considered.

(c) Solid Waste

Solid wastes arise from fume and water treatment systems as well as from operation of the process itself. The former consist of dust, sludges, sulphates if the plant comprizes a desulphurization unit, and mixtures of carbon and dolomite for solid rotary kiln direct reduction processes. The latter consist of iron ore dust, metallized pellets dust, molecular screens, catalyst, broken refractories etc. Most solid wastes can be reutilized (see section III B (c) below). Proper storage and disposal must be planned for sludges produced as by-products of direct reduction processes.

(d) Noise

Acoustical pollution takes the form of noise generated by process equipment, signalling equipment, and the voluntary and involuntary discharge of high pressure gases. Fans, valves, compressors and burners can be sources of noise. Charging and extraction of solid products can also be noisy operations.

(e) Social and Working Environment

The social impact of a direct reduction plant should be considered from two points of view : those occurring inside the plant battery limits and those occurring outside the plant battery limits. Inside refers to the working environment and worker health and safety : outside refers to the impact of an industrial facility on the surrounding community.

B. Recommendations for Direct Reduction Plants

The recommendations will follow the same general outline as used above, those areas requiring special attention being highlighted. For examples of pollution control techniques and other environmental protection measures, reference should be made to the relevant parts of the technical review (3).

(a) Air Pollution Control

An adequate dust collection system must be installed at all material transfer points, including those transfer points which may be outside the plant battery limits, such that emissions of dust meet applicable government standards. Particular care should be taken in the design of these systems to reflect changes in climatic conditions and variations in the raw materials and products. For oxidized dust of iron ore and mineral products, conventional cleaning systems such as cyclones, wet venturi scrubbers and, preferably, bag filters, may be used. For metallized dust it is better to use wet filter systems, which take into consideration the pyrophorosity of the dust. The excessive formation and build-up of superfines and fines present also very serious ambient working conditions in closed areas and where constant daily cleaning may be required and cannot be performed. The fine dust can penetrate into moving machinery parts and electrical controls and be responsible for premature mechanical and electrical failures. Vacuum systems for dust collection in a plant are available. Furthermore, safety precautions must be built into systems that may come into contact with explosive process gases. All systems should be kept properly maintained according to the manufacturers specifications and good housekeeping measures operated. Since sulphur and nitrogen oxides are usually below most industrial emission standards, there is normally no need for excessive concern with these contaminants. Where these substances need to be controlled, appropriate measures are available. Under specific circumstances where fluorides need to be controlled scrubbing techniques are available.

(b) Water Pollution Control

The treatment of waste water from direct reduction processes is similar to that from industrial operations in general and there are no special problems. Provided waste water treatment systems are properly designed, maintained and operated there should be no environmental problems.

A closed water supply system should normally be installed at direct reduction plants. Insoluble suspended matter, including tars and oils, should be removed and the pH adjusted. It may also be necessary to reduce levels of hazardous substances, e.g. heavy metals and certain organic micro-pollutants after standard effluent treatment before discharge. Furthermore, it may be necessary to install evaporative heat interchangers so as to reduce thermal discharge. Any effluents discharged should be monitored.

(c) Solid Waste Disposal

With proper planning, wastes generated as by-products of direct reduction processes can be recycled by ore sintering iron oxide pellet production, briquetting or can be reused industrially in ways such as cement making and pigment manufacture. Techniques exist also for injecting DRI fines into the electric arc furnace. There may be difficulties in residue use where a direct reduction plant is not integrated with other processes. Wastes can also be used as landfill material under controlled, monitored conditions, provided the groundwater is adequately protected from leaching of harmful products.

(d) Noise Control

Noise at direct reduction plants can be a serious problem both for the work force and the surrounding population, but there are existing measures which can attenuate noise to acceptable levels. These measures consist of standard, readily applied, technological solutions, such as modified equipment design and noise insulation, as well as personal protection for the work force. The technological solutions, however, may be expensive. Where it is necessary to supplement these with personal protection devices, the work force must be trained in their use. Furthermore, these devices should be properly designed for comfortable wearing under the local climatic conditions.

(e) Protection of the Working Environment and Social Conditions

Of special concern for a safe working environment at direct reduction facilities are the following considerations : air pollution and asphixiation ; safety and explosion and fire hazard ; noise (see section III B (d) above) ; heat stress (see section IV D (d) below) and ergonomics. At those points where process gases may escape, CO monitoring devices should be installed, and portable CO monitors should be available. Likewise gas masks and resuscitation equipment should also be available. Direct reduced iron dust can be a potential explosion and fire hazard. Therefore, in addition to an effective dust collection system, good housekeeping is very important in a direct reduction plant. Accumulations of dust should not be allowed to occur, and enclosed areas should receive special attention. The importance is emphasized of the training of the work force in proper process and pollution control equipment operation and maintenance, as well as in safety and good housekeeping measures.

Concerning conditions outside the plant battery limits, the effect of a direct reduction plant will be similar to any other type of industrial plant and will depend on local circumstances. A buffer zone should be established and maintained around a plant, with residences kept at some distance from the plant perimeter. This calls for not only a well prepared initial plan but also constant vigilance by authorities to ensure that there is no gradual erosion of the zoning provisions. Appropriate urban and transport infrastructure, as associated with any industrial development, should be provided. Care should be particularly taken to avoid the unintentional transport of metallized dust on vehicles leaving the plant.

IV. ELECTRIC ARC FURNACE STEEL MAKING USING DIRECT REDUCED IRON

A. Description of Process and Applicability of Guidelines

In the new route to steel production, sponge iron is melted into an electric arc furnace with or without addition of scrap. The following guidelines are applicable for electric arc furnace (EAF) melt-shops processing carbon or low alloy steels. For further technical details concerning measures, reference should be made to relevant sections of the technical review (3).

B. Sources of Environmental Impact

The melt-shop is principally a source of air pollution by emission of fume and dust from the furnace (charging, melting, refining, de-slagging and tapping) and from some auxiliary operations (handling of direct reduced iron, fluxes or scrap).

Some water pollution may occur in casting and from air pollution wet scrubbing processes. In addition to fume and dust, there are also : noise from the arc of the EAF ; heat released into the melt-shop from the EAF and the handling of liquid steel or hot slag ; other possible problems for worker hygiene. It is also important to bear in mind the environmental impacts of transportation from the direct reduction process and storage of sponge iron, mainly air pollution ; and noise involved in scrap handling.

C. Dust and Fume Control Systems

The degree of fume and dust control required for EAF melt shops may be different in various countries and even in various locations within a particular country. It may depend on several conditions and requirements, some of which are : concern for environmental impact of a projected development on the surrounding area, particularly human health and welfare, and effects on animals and vegetation ; the compliance with government regulations and standards ; cost of investment, operation and maintenance of pollution control equipment. The quality of the sponge iron has little influence on the design capacity for the air pollution emission control system, the quality of the scrap being a more important factor. However, the gangue content of the sponge iron influences the quantity of slag produced and possibly the dust subsequently arising from slag handling. It is important to ensure that in the design of an electric arc furnace with continuous charging of sponge iron, the air pollution direct evacuation hole is located either amongst the three electrodes or on the opposite side of the furnace from the charging hole.

D. Recommendations for Electric Arc Furnace Melt-Shops

(a) Air Pollution

For a new EAF shop the most efficient dust control system which can be recommended is a total enclosure of the electric arc furnace and ladle. This system, combined with direct evacuation from the EAF, is capable of controlling up to 98% of total emissions generated during an operating cycle of an EAF. The highest filtering efficiency can be obtained by use of the baghouse. The enclosure system also allows the natural ventilation through the roof of the melt-shop to be maintained.

For existing EAF melt-shops the total enclosure over the EAF and the ladle may not be possible due to space limitations. In this case a system consisting of direct evacuation from the EAF and an evacuation hood close to the ladle may be considered as a minimum requirement, enabling a dust collection efficiency of 94% to be obtained. This system controls most of the dust and fumes from the electric arc furnace.

The next largest source of secondary fume and dust in the melt-shop is the handling of slag. At the present time in most EAF shops the slag from the furnace is poured on the floor of the shop. This operation creates relatively little dust. However, removal of the slag from the floor of the shop creates a major emission, often bigger than the quantity of fumes generated during tapping and in ladle refining. A partial solution can be provided by pouring of the slag from the EAF into slag pots and their transfer from the melt-shop by slag pot carrier or overhead crane. The additional cost of slag handling in slag pots is approximately US $ 3 per ton of molten steel.

If a higher degree of dust control of EAF emissions is required, then in addition to direct evacuation, canopy hoods may be installed in the roof over the cranes. There are two locations for such canopy hoods :

- over the furnace - this hood may collect dust and fumes generated during fettling and charging which are about 2% of the total EAF emissions.

- over the ladle - this hood may capture dust and fumes generated during tapping and addition of alloys.

Such a solution cannot be always recommended due to its possible inefficiency caused by an excessive dilution of the hot gas column by the ambient air or by the deflection of the hot gas plume by crossdrafts in the EAF shop.

In order to reduce the amount of suspended dust in the EAF melt-shop atmosphere, as well as the ambient air temperature, a natural draft or forced draft ventilation system is necessary. This is important in ensuring an acceptable working atmosphere in the plant. A recommended minimum rate of EAF shop ventilation is 0.1 cubic meters per minute per ton of the shop annual production capacity. According to recent Japanese experience the roof wet electrostatic precipitator which works by natural extraction without fan can accommodate the different constraints of environment quality and work place hygiene. The results appear environmentally interesting and energetically cheap.

Concerning control of air pollution from the handling of sponge iron and the transport from the direct reduction process, attention is drawn to the recommendations given in section III B (a) above.

One important problem with electric arc furnace dusts is their tramp metal content, which makes them difficult to recycle and calls for careful disposal, if discharged, due to the content of toxic materials such as lead and cadmium. Care must be taken to avoid pollution of groundwater by leaching of various heavy metals.

(b) Water Pollution

The main water requirement in electric arc furnace steel making is for cooling purposes and there are adequate techniques for avoiding thermal pollution. Considerable amounts of water are used in casting, usually in closed recirculating systems with chemical treatment. A small proportion (less than 10%) may have to be discharged after treatment for : pH adjustment, removal of solids and toxic substances such as cyanides and organo-phosphorus compounds, oils, greases, and various metals.

(c) Noise

Most of the noise in an electric arc furnace melt-shop is generated by the operation of the furnace during the melt period. The intensity of noise may reach 125 dB(A) at the beginning of melting of the scrap. During a period in which the reduced pellets are added the noise level drops to approximately 90-100 dB(A). The low frequency noise generated by the EAF is difficult to control by acoustic attenuation. The use of doghouse type total enclosures enables very satisfactory noise protection both within the plant and of the surroundings. Technological solutions need to be found to reduce noise at existing plants.

In order to protect workers against hearing damage, three mutually supportive methods should be employed : (i) the use of ear muffs and/or plugs ; (ii) acoustically and thermally insulated enclosure for operators of the EAF ; (iii) limitation of time of exposure to the noise. It must be borne in mind that ear muffs and plugs are not regarded as the most satisfactory solution since they may not be comfortable to wear and are considered by some people to be unhygienic. The work force must be trained adequately to use protective equipment.

(d) Heat Stress, Ionizing Radiation and Vibration

The operation of EAFs involves a release of substantial amount of thermal energy, mostly due to radiation from the furnace, ladle and exposed molten metal and slag. The present practice of thermal stress prevention consists of the following measures : increased ventilation to lower the temperature of air ; radiation reflective clothing for workers exposed to heat ; local fans blowing ambient air towards operators ; rotation of personnel allowing sufficient time for cooling of the body ; provision of beverages, with a small amount of salt, according to individual medical guidance ; radiation insulating screens ; insulated booths.

Ionizing radiation arises from electric arc furnace operation and appropriate protective measures are required. Vibration is another possible problem calling for careful design of observation platforms, seats and operation of vibrating equipment as well as for controlled duration of exposure.

(e) Worker Hygiene

It is customary to provide to the workers employed in EAF melt-shops with showers and provisional protective equipment such as : helmets, ear muffs or ear plugs, dust and radiation protective glasses, heat insulation and reflective clothing, face masks, insulating gloves, metatarsal protecting shoes. The need for training of the whole work force, including management, in the wearing of protective equipment is re-emphasized.

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