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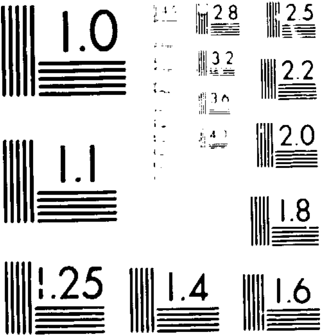

MICROCOPY RESOLUTION TEST CHART

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WATER USE AND TREATMENT PRACTICES AND OTHER ENVIRONMENTAL CONSIDERATIONS IN THE IRON AND STEEL INDUSTRY*

Prepared by the
Division for Industrial Studies

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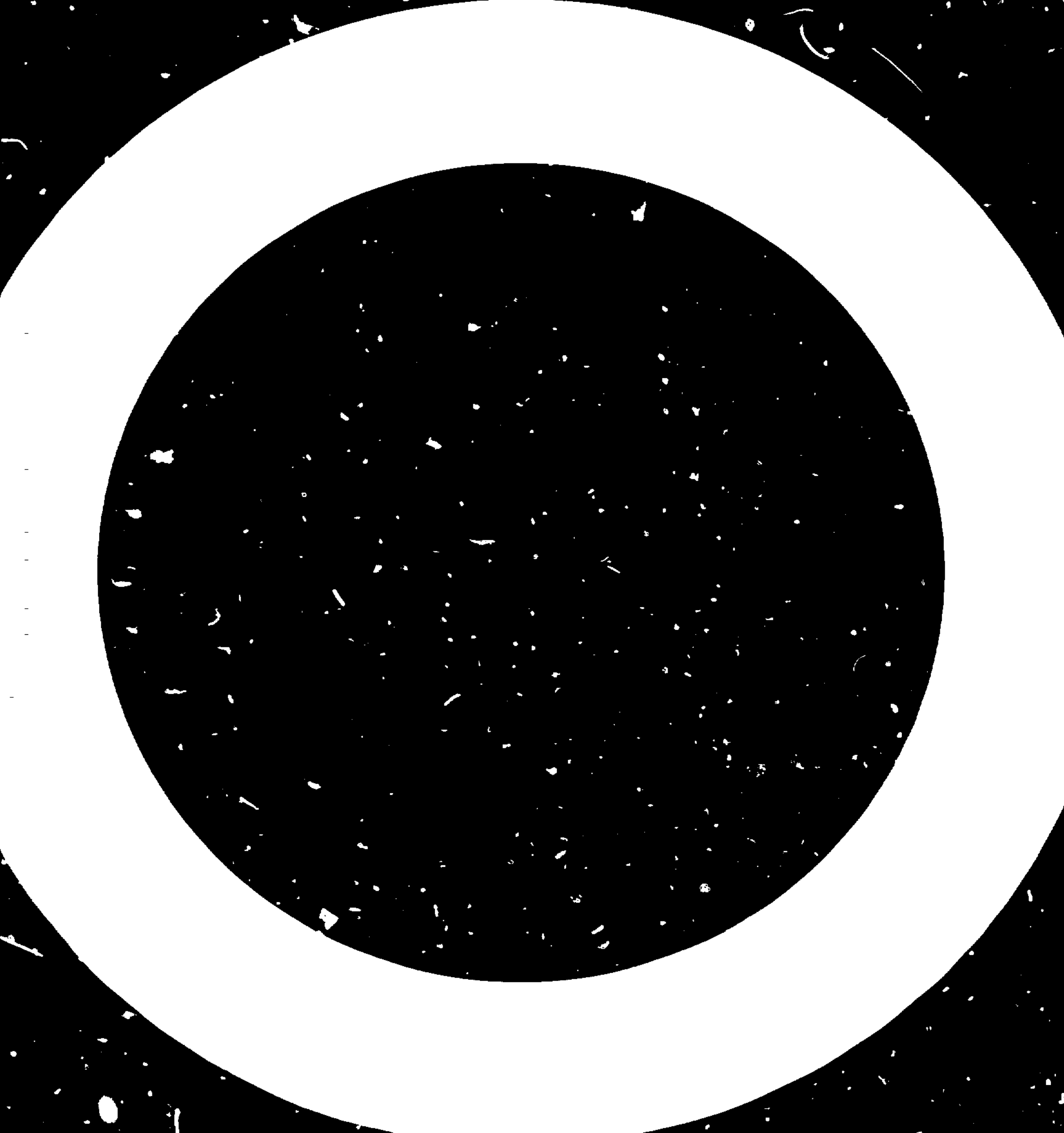

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BOD (shorthand notation for BOD_5)

The 5-day, 20°C, biochemical oxygen demand (BOD_5) test is widely used to determine the pollutional strength of waste water in terms of the oxygen required to oxidize or convert the organic matter to a nonputrescible end product. The BOD_5 is a bioassay procedure that measures the oxygen consumed by living organisms while utilizing the organic matter present in the waste water under conditions as similar as possible to those that occur in nature. To make results comparable, the test has been standardized. The BOD_5 test is one of the most important in stream pollution control.

COD

The chemical oxygen demand (COD) is an alternative to the biochemical oxygen demand (BOD_5). It is widely used and measures the quantity of oxygen required to oxidize the materials in waste water under severe chemical and physical conditions. The major advantage of the COD test is that only a short period (3 hours) is required to conduct the test. The major disadvantage is that the test does not indicate how rapidly the biologically active material would be stabilized in a natural condition.

Acidity

Acidity is a term used to express the corrosive properties of a waste water. Although not an exact measure of acidity, the pH value is frequently used to measure the effect that a discharge may produce. Effluents from waste water treatment plants are usually controlled near neutrality, or a pH value of 7. Wide fluctuations or prolonged changes in the pH value of a receiving stream can be devastating to an aquatic environment.

Suspended solids (SS)

Suspended solids are the suspended material that can be removed from waste waters by laboratory filtration excluding coarse or floating solids that can be screened or settled out readily. Suspended solids are a vital and easily determined measure of pollution and also a measure of the material that may settle out in slow moving streams. Both organic and inorganic materials are measured by the suspended solids test.

Oils and grease

Oils and grease are determined by multiple solvent extractions of the filterable portion of a sample of waste water; therefore, floating oils and greases which are easily removed by skimming are not included in the analysis. Several solvents are commonly used and each gives a different result with the same sample. Standardized tests are recommended but there is much disagreement as to what constitutes the best method. Solvents such as hexane, ether, freon, and carbon tetrachloride are used, and it is important that the solvent be specified. Grease and oil exert an oxygen demand, cause unsightly conditions, and can interfere with anaerobic treatment systems.

INTRODUCTION

At the 1981 meeting of the UNIDO Industrial Development Board, the Secretariat indicated that it would begin a programme of collecting and disseminating information on technological developments in water use and treatment practices in certain key industries. The Board noted the growing importance of techniques of conservation, re-use and recycling of water, linked with effluent treatment methods. The interest of the Board followed in pursuance of certain recommendations of the Mar del Plata Action Plan adopted by the United Nations Water Conference in 1977. In the follow-up to that conference ECOSOC adopted a resolution in August 1979 in which the Industrial Development Board was asked to examine detailed proposals on industrial water use and treatment practices made by UNIDO.

The audience of engineers, managers, planners and economists for whom this paper is intended is considered to be interested in the entire scope of environmental effects of the plant and their economic implications. For that reason the subject of water is not isolated from other environmental considerations.

However, the problems of air and water pollution from the iron and steel industry become inter-linked once effective solutions for control are considered. The dust which was formerly an air pollution problem becomes part of a water pollution problem when removed from the air by means of a high energy scrubber. The ammonia and phenol contaminants of the coke plant effluent become potential air pollutants when this effluent is redirected to the sinter plant to moisten and bind the mix.

United Nations efforts to disseminate information and promote good environmental practice in the iron and steel industry have been manifold. In 1970 the Economic Commission for Europe published a review of the sources of pollution in the iron and steel industry as well as air and water pollution control devices and associated costs.[1/] In 1973 UNIDO sponsored an international meeting on the iron and steel industry at which several presentations were devoted to environmental problems.[2/] In 1978 the United Nations Environment Programme organized a workshop on the environmental aspects of the iron and steel industry.[3] In 1981 the Economic Commission for Europe published a study on low-waste and non-waste technology in the iron and steel industry.[4]

WATER USE PRACTICES IN THE IRON AND STEEL INDUSTRY

According to average data obtained from Eastern and Western European countries and the USA, about 200 m^3 of water are utilized per tonne of steel. In the case of a steel mill in France, if the steel mill uses 200 m^3 water per tonne of steel at FF0.15 per m^3 this represents a water cost of FF30 per tonne of steel (without amortization).[5]

Total water utilization at a large steelworks carrying out all steel-making operations exceeds 2,000 million m^3 per year. This usage is divided as follows among the various branches of production:[4]

Table 1. Water usage in various steelmaking processes

Branch	Per cent of water use
Sintering	3
Coke by-product manufacturing	7
Blast furnace production	24
Steelmaking	23
Rolling mill production	42

Only about three tonnes of this water is permanently lost, due mostly to evaporation. Reduction and re-use techniques reduce the demand for intake water far below the gross amount. Davis[6] has cited an example of a water intake demand of 77 tonnes of water per tonne of steel for an integrated works situated near the coast. At the other extreme Davis refers to a works at a water short inland site which uses only three tonnes of water intake per tonne of steel. The British Steel Corporation used a water intake of 30 tonnes of water per tonne of steel produced in 1976.

The amount of water required by the British Steel Corporation is contrasted in Table 2 with quantities of other raw material consumed in 1976.

Table 2. BSC raw material consumption 1976[6]

	Million tonnes per annum
Iron ore	23.5
Coal	12.6
Iron and steel scrap	10.1
Water intake	570.0
(Crude steel production - 19.1 million tonnes)	

The most important volume use of water at an iron and steel works is the removal and dissipation of heat. Since temperatures in the blast furnace can reach 1500°C and even higher in steelmaking vessels, the importance of water cooling can be easily appreciated.

The iron and steel industry can operate satisfactorily for most requirements from water which is not prime quality. Minimum quality water requirements for processes at an integrated iron and steelworks are shown in Table 3.

Table 3. Qualities of water required in an integrated steelworks

Type	Important quality parameters	Main use
Potable	Physically, chemically and biologically wholesome	Drinking, amenity, air conditioning
High-grade industrial	Low total dissolved solids, low organic matter	Steam raising
General industrial	Low suspended solids, non corrosive, non scale-forming	Cooling condensers, furnaces, rolling mills, gases
Low-grade industrial	Absence of gross pollution	Coke and slag quenching

Treated sewage effluent provides a satisfactory water source at some works. Saline water (from estuaries or the sea) is used for certain cooling applications at some works. Le Laboratoire d'étude et de cont· ɔle de l'environnement sidérurgique recommends the design of a steel mill with three independent water systems. System 1 consists of collection and discharge of all rain waters and other surface run-off. System 2 consists of potable and all sanitary water which are collected and sent for treatment to a biological waste water treatment plant. System 3 consists of all process waters. These are recycled after appropriate treatment (e.g. separation of sludge after gas scrubbing and treatment of waste waters from rolling mills).[5]

The British Steel Corporation uses only 7 per cent of potable water within its water intake of 11 million m^3 per week for all UK operations. Nearly 40 per cent of water intake is met from tidal sources, although these may be estuaries on the ebb tide or docks fed by fresh water streams. The relevant amount of different water sources is shown in ·e 4.

Table 4. BSC water intake 1976 for all works[6]

	Water intake [1000 m^3 per week]	
Source	Potable quality	Industrial quality
Public water supply	760 (7 per cent)	350 (3 per cent)
Boreholes and wells	30 (-)	140 (1 per cent)
Rivers and streams	-	4110 (38 per cent)
Canals	-	600 (6 per cent)
Tidal sources	-	4300 (39 per cent)
Other sources	-	680 (6 per cent)
Total	790 (7 per cent)	10180 (93 per cent)
GRAND TOTAL	10,970 (100 per cent)	

Overall about 10-12 per cent of the water intake is lost by evaporation. The remainder is discharged as effluents.

The quantities of water in circulation for an integrated steel works of 4 million tonnes per year production are shown in Table 5. The figures are typical, except that the amount of cooling water required for power generation will depend on the extent of power generated by

Table 5. Quantities of water in circulation at a typical integrated steelworks producing 4 million tonnes per annum (British Steel Corporation) 6/

Plant	Main purpose	Quantity $m^3 min^{-1}$	Percentage of grand total
Main indirect cooling water system			
Coke ovens	Gas primary coolers	75	7.9
Sinter plant	Cooling ignition hoods and fans	10	1.0
Blast furnaces	Furnace cooling	170	17.8
	Furnace blowing (condenser cooling)	180	18.9
Steel furnaces	Furnace and equipment cooling	70	7.3
Continuous casting	Mould and machine cooling	35	3.7
Hot rolling mills	Cooling electrics and hydraulics	30	3.1
Power generation	Condenser cooling e.g. 20 MW	85	8.9
Miscellaneous	e.g. Air compressors, exhaust fans	20	2.1
TOTAL indirect cooling		675	70.7
Main direct cooling water systems			
Coke ovens	Gas cooling and purification	15	1.6
Blast furnaces	Gas cooling and cleaning	75	7.9
Steel furnaces	Fume cooling and cleaning	35	3.7
Continuous casting	Quenching hot steel	10	1.0
Rolling mills	Roll cooling, product quenching, scale washdown	130	13.6
TOTAL direct cooling		265	27.8
Other water uses			
Process water	Coke quenching, sinter mix, miscellaneous	7.7	0.8
Boiler feed	Steam raising	4.8	0.5
Domestic and amenity		1.5	0.2
TOTAL other uses		14.0	1.5
GRAND TOTAL		954.0	100.0

the works on site. All the figures in the first half of the table are for indirect cooling (70 per cent). This water does not become contaminated, except by heat. About 30 per cent of the water is used in direct cooling where contamination is likely. Appropriate treatment must be incorporated to remove the pollutants and the heat. Factors influencing the choice of treatment systems include relative costs, water availability, and constraints on effluents which are discharged.

According to the experience of the British Steel Corporation, the cost of water services (including operation and maintenance costs and capital depreciation [15 years straight line]) represents about 1 per cent of the price of general products such as cold reduced sheet, beams and plates. This cost is a much smaller percentage of the price of special products such as special alloys and stainless steels. Specifically, these costs include cost of abstraction or changes for external water supply, water treatment, distribution, recirculation, effluent treatment and disposal. For a specific works using extensive recirculation and re-use of water, 80 per cent of the cost was due to recirculation and in-circuit effluent treatment. However, if once-through cooling were adopted, the total amount of water in circulation would have to be pumped from the sources thus incurring much higher abstraction, pre-treatment and distribution changes.[6/]

Constraints on effluents are becoming an increasingly important factor in developing as well as in industrialized countries. Pergelly and Rees present an extensive table of water quality standards applied to industrial effluents discharged to water courses in eight countries. Also tabulated are standards for surface waters used as sources of drinking water for six countries.[7/] Now, and more so in the future, it is not acceptable to discharge indiscriminately large volumes of effluent with relatively low concentration of pollutants because of the overall large pollution load this represents. Water recirculating systems result in much smaller quantities of effluent streams with relatively high pollutant concentration. Treatment works can be engineered to treat these effluents effectively. The most modern design for the process water supply for a steel mill is a closed circuit which consists of complete recovery of waste water and re-use after an adequate treatment process. The ideal system is a hermetically sealed recirculating system with a cooling loop. This will eliminate discharge of effluents except through accidents.

The British Steel Corporation estimates that about 6 per cent of the capital costs of a new integrated iron and steel works would be attributable to water supply, water use and effluent disposal.[6] Capital costs for water use and treatment are necessary for the operation of the plant. Water treatment to prevent pollution discharge is only a portion of this charge.

POLLUTANTS PRODUCED IN THE IRON AND STEEL INDUSTRY[8]

The main air pollutants from the iron and steel industry are smoke, dust and sulphur dioxide. These arise principally from coke plants, sinter plants and steelmaking furnaces. As one example, oxygen-blowing process furnaces emit large quantities of iron oxide fumes.

Large quantities of cooling and process waters are required by the iron and steel industry The major water pollutants are oil, phenols, tars and acids.

Solid wastes produced by the iron and steel industry include blast furnace and steelmaking slags, coking plant residues, iron-containing dust and slag, and general rubbish. In blast furnace operations up to 500 kg slag are produced per tonne of iron.[4] In France up to 1,000 kg slag may be produced using low grade Lorraine ores.

There are three ways in which measures can be taken to eliminate and prevent the harmful consequences of iron and steel plant pollutants.

(a) Through the design and utilization of recycling systems in which all components of the raw materials, fuel and energy can be utilized and the amounts of harmful pollutants produced are minimal.

(b) Introduction of waste treatment facilities to neutralize and remove those pollutants which are produced and establishment of buffer zones around those emission sources which are unavoidable.

(c) Through environmental monitoring systems to measure levels of pollutants and ensure that standards are not violated.

In this section the data presented on pollutants resulting from various processes represent raw waste loads. The values are those reported by the OECD. At the end of the section the OECD values reported for particulates are compared with data reported by the ECE.

For convenience, the pollution problems in the iron and steel industry are categorized from five sequential production processes. These are:

(1) Preparation of raw materials
(2) Cokemaking
(3) Raw iron manufacturing
(4) Raw steel manufacturing (where the alternative technologies of the open hearth furnace, the basic oxygen furnace, and the electric arc furnace are considered)
(5) Finishing of steel products

(1) Preparation of raw materials

During the sintering process the main pollutants produced are particulates and sulphur dioxide. The range of concentration of particulates produced is 15-25 kg per tonne of product. The amount of sulphur dioxide may range from 1-12 kg per tonne depending upon the amount of sulphur in the iron ore concentrate, the coke dust, and the fuel.

Chemical analysis of sinter dust in the Federal Republic of Germany shows an iron content of 35 to 56 per cent. The dust particles can be collected in cyclones, eletrostatic precipitators, or, to a lesser extent in gravel bed filters.

Some steel producers have installed desulphurization units to treat the gas stream rich in SO_2 from the sintering process.[4/]

Water is required in the sintering plant for admixture with the sinter, as well as for miscellaneous cooling purposes.

(2) Cokemaking

Most of the air pollutants from cokemaking result from the charging of the ovens. The OECD reports that the ranges of amounts of particulates are 0.5 to 3.5 kg per tonne, of sulphur dioxide from 0.2 to 5.0 kg per tonne, and of hydrocarbons from 0.2 to 2.0 kg per tonne.

One member country of the ECE has listed the following quantities of coke and coke dust collected during coke production:

Charging ovens with coal:	0.15 kg/t coke
Coke discharge:	0.40 kg/t coke
Coke quenching:	0.35 kg/t coke
Coke preparation:	1.40 kg/t coke

The USSR estimated that up to 5 kg of dust per tonne of coke is generated during oven filling and coke discharging.[4/]

Lesser amounts of hydrogen sulphide and hydrogen cyanide are also produced.

In the cokemaking process water is used for direct and indirect cooling of coke oven gas, for quenching of hot coke and in some of the distillation processes at the by-product plant. The coke plant effluent is one of the most difficult to treat. It contains phenols, thiocyanate, thiosulphate and ammonia, and therefore has a high BOD and COD. The phenol can be recovered, or the effluent can be treated biologically after sufficient dilution. In this process a large measure of the phenol, thiocyanate and thiosulphate is removed, but the ammonia remains.[6/] The amounts of suspended solids in the effluent can range from 0.1 to 15 kg per tonne, phenols from 0.3 to 5 kg per tonne, ammonia from 0.3 to 2 kg per tonne, sulphide from 0.3 to 2.5 kg per tonne, cyanide from 0.2 to 5 kg per tonne, and BOD_5 from 1 to 6 kg per tonne.

Biochemical waste water treatment has proven very effective for treating coke plant effluents. This is preceeded by sedimentation to remove all settleable matter. About 1/4 to 1/2 kg sludge (dry weight) is produced from an activated sludge plant per kilo of phenol degraded.

(3) Raw iron manufacturing - the blast furnace

Around the period of 1960, about 100 kg of dust per tonne of hot metal was produced[4/] but this has been reduced in the present days to 20 to 30 kg per tonne. This residual load is normally trapped using dry cyclones as a first step of the blast furnace gas cleaning process.[8/] A downstream high pressure scrubber can then be employed to reduce the dust content of the gas even further. Thus the air pollutants from raw iron manufacturing are primarily particulates in the range of 0.2 to 1.6 kg per tonne from the tapping operations.

In the blast furnace process large quantities of water are required to cool the furnace structure and for cleaning and cooling the CO-rich furnace gas. Some water is required to cool the condensors of the air-supplying turbo blowers. The furnace and condensor cooling circuit are indirect, so heat is absorbed but there are no contaminants. However, the water used for gas cooling and cleaning is contaminated with suspended solids, dissolved alkaline salts, cyanide, thiocyanate, zinc, lead and fluoride. When recirculation water systems are used the suspended solids are removed, often with the aid of flocculation. Zinc, lead and fluoride must be removed by precipitation, whereas cyanide and thiocyanate can be removed by oxidation.[6/]

Solid wastes resulting from iron manufacture in a blast furnace are blast furnace slag, dusts and slurries from top gas cleaning, dusts from secondary fume collection, spent refractory materials and ladle skulls. In the Federal Republic of Germany the amount of blast furnace slag is now 345 kg per tonne of hot metal. In France, where local ores are charged in conjunction with other ores, an average amount of 650 kg slag per tonne of hot metal was produced in 1974. In general, the amounts of blast furnace slag produced have decreased by about 50 per cent over the past twenty years and world wide figures generally vary from 200 to 400 kg slag per tonne of hot metal.[4/]

Water pollutants result from gas cleaning and slag granulation; a total of 2 to 7 kg per tonne of suspended solids and lesser amounts of sulphide, ammonia, fluoride, cyanide, phenol, chloride, sulphate and hydrogen sulphide are produced.

(4) Raw steel manufacturing

Operation of the open hearth furnace results in particulates ranging from 2 to 5 kg per tonne of steel without oxygen and from 5 to 20 kg per tonne with oxygen. A small amount of sulphur dioxide is generated from the fuel oil.

During the basic oxygen furnace process, large amounts of air pollutants are generated from the process of blowing pure oxygen into the furnace. About 30 to 33 kg of particulates per tonne result from the process.[8/]

In the case of the electric arc furnace the particulate load ranges from 3-8 kg per tonne of steel without oxygen lancing to 5-20 kg per tonne with oxygen lancing.

The adjustment of raw steel by degassing can also produce particulate loadings ranging from 0.1 to 16 kg per tonne of steel depending upon the technology used.8/

In order to meet present pollution control laws, European steel manufacturers control fumes from steelmaking using two-stage heavy duty scrubbers and at least double-field electrostatic precipitators. Between 12 and 20 kg of dust are collected per tonne of steel. The dust can be recycled into the blast furnace process unless the percentage of zinc is too high.4/

Once primary emission control is achieved, attention should be centred upon secondary emission control. Main pollution sources are points of transfer, mixers, charging and pouring. The dusts thus collected are mainly iron dioxide, which can be recycled.

Water is required in indirect cooling systems to cool various items of equipment, such as the oxygen lances. Water is also used to clean and cool waste gases to prevent air pollution. This effluent is treated to remove the large amount of suspended solids, mostly finely divided iron oxide, and recirculated. The water may also take up fluorides and other chemicals. When the recycled water is purged it requires chemical treatment.6/

(5) Finishing of steel products

The finishing step is important because more than 90 per cent of all steel production goes through a rolling mill. Wastes from a rolling mill operation are mill scale, scarfing slag, soaking pit slag, spent refractory lining and spent oil and grease. Studies in the FRG showed that an average 4.4 per cent of the rolled steel production was obtained as mill scale in the mechanical cleaning of waste water from the hot shaping of steel.

Water pollution with hot mills result from iron oxide scale and oil and grease leaked from the mills. Pergelly and Rees report that typically 2 per cent of product weight is coarse scale which can be readily collected in scale pits. Another one per cent of product weight is fine scale which is taken up in the effluent water. Oil and grease contamination can range from 0.2 to 1.0 kg per ton product and is discharged with the effluent water unless measures are taken to remove it.7/

The secondary cooling water from continuous casting machines contains lesser amounts of scale. The effluents from continuous casting and rolling mills can be jointly treated.

Indirect cooling requirements for hot rolling mills include cooling air for the electric motors and cooling lubricating oils and hydraulic fluids.

Continuous casting does not produce nearly the same level of air pollutants as mould casting and primary rolling, where the range of particulates is 10 to 35 kg per tonne of ingot and sulphur dioxide ranges from 0.5 to 7.0 kg per tonne. The water pollutants from both processes are oil (about 1 kg per tonne) and suspended solids (0.3 to 2.8 kg per tonne).

Forging can produce particulates in the range of 0.5 to 3.5 kg per tonne and water pollutants in similar amounts to casting.

Mechanical finishing operations can produce amounts of particulates ranging from 2 to 16 kg per tonne.

When acid pickling is carried out, water is required for make-up of solutions and product rinsing. Other finishing processes which require water for solution make-up and product rinsing include tin-plating, galvanising and product rinsing. Sometimes it is possible to mix waste streams to achieve some degree of self-treatment, for example, acidic waste can be used to separate oil-water emulsions. Pickling operations produce suspended solids (0.1 to 0.4 kg per tonne), dissolved iron and iron salts (2 to 22 kg per tonne), and acids (1 to 27 kg per tonne).

Table 6 compares the amount of particulates from the five production processes as reported by the OECD and the ECE.

The major sources of pollution in the iron and steel industry are summarized in Figure 1.

Table 6. Summary of particulate loadings produced during various stages of iron and steel manufacturing

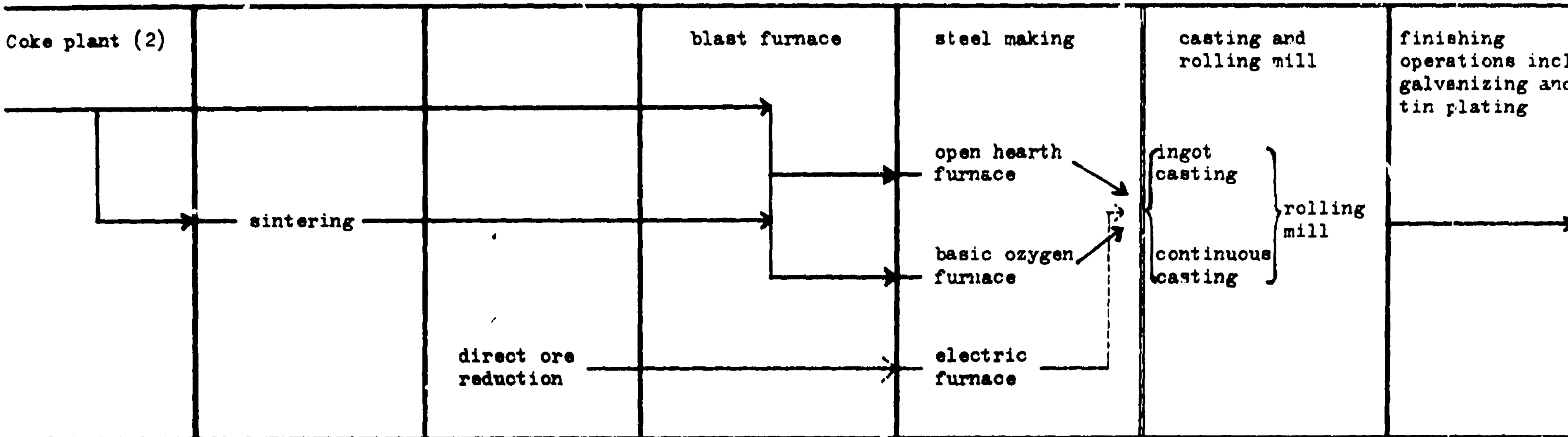
(data in kg particulates produced per ton of intermediate material produced at each stage)

Operation		OECD 8/	ECE 4/
Coke production		0.5 - 3.5	2.3 (Europe) 5.0 (USSR)
Sintering plant		15.0 - 25.0	14.0 (FRG)
Blast furnace:	tapping	0.2 - 1.6	-
	gas cleaning	20.0 - 30.0	20.0 - 30.0
Steelmaking;	open hearth	5.0 - 20.0 w/oxygen	-
		2.0 - 5.0 w/o oxygen	-
	BOF	30.0 - 33.0	12.0 - 20.0*
	Electric arc	5.0 - 20.0 w/oxygen	2.0 - 10.0**
	Furnace	3.0 - 8.0 w/o oxygen	
Rolling mills		15.0 - 35.0 scale 0.02- 4.5 susp. solids	20.0 - 70.0 scale plus suspended solids

* Average range for all oxygen steelmaking plants.

** Reference does not specify whether oxygen lancing is included or not.

Figure 1. Major pollution sources and types in the iron and steel industry (1) 4/, 7/, 10/



WASTES PRODUCED

Coke plant		Sintering		Direct ore reduction		Blast furnace			Steel making			Casting and rolling mill		Finishing operations	
Air	Water	Air	Water	Air	Water	Air	Water	Solids	Air	Water	Solids	Water	Solids	Water	Solids
Dust (3) NH_3 Steam H_2S NO_x CO	NH_3 BOD Phenol Cyanide Acidity	Dust SO_x NO_x Fluorides	Susp. Solids (SS) BOD Phenols Cyanide Sulfides	Dust SO_x (4) NO_x	SS	NH_3 CO (5) SO_x	SS NH_3 Phenol Cyanide	Slag Spent refractories	Dust NO_x	SS	Sludge Slag	SS Oil + grease Chloride Sulfate Iron Acidity	Scale Sludge Spent refract-ories Spent oil + grease	SS BOD Cyanide Oil + grease Chromium Iron Tin	Scale

(1) Other sources of relatively minor contamination include the yards (ore, coal and scrap), power generation, lime kiln and cooling towers.
(2) By-product plants associated with coke plants produce benzol, tars, sulfuric acid and phenol, which are used by the chemical industry.
(3) Note: whenever dust is removed by means of a wet process, such as a scrubber, a water pollution problem in the form of suspended solids results. When removed by a dry process a solid waste results.
(4) Amount depends on sulfur content of fuel used.
(5) Waste gas containing CO is frequently collected and cleaned for use as a fuel.

RE-USE AND BY-PRODUCT RECOVERY

Most of the contaminants of an iron and steel mill end up as solid matter. It is frequently important to the economy of the industry to recover and re-use much of these unless cheap dumping is available. In particular the re-use of solids found in mill scale, blast furnace dust, sinter plant dust, slag, lime dust, scrap and scarfing powder, is recommended as much from an economy standpoint as from a pollution abatement point of view.

For example, two Japanese manufacturers have jointly developed a process for recovering valuable metals from dusts collected from steelmaking, scale from hot rolling and annealing and sludge from waste acid treatment in pickling.[9] The combined wastes amount to about 60 kg per tonne flat product. These combined wastes contain substantial quantities of valuable metals such as Ni, Cr and Fe. However, the presence of undesirable elements such as Zn and S means the waste cannot be directly used in the melting process for stainless steel. Therefore a recovery process was developed consisting of dehydration and drying, briquetting and smelting. Coke is used as a reducing agent in the smelting process. The plant recovers Ni, Cr and Fe with purities of 98.5 per cent, 95 per cent and 97 per cent respectively. During the first three years of operation, 44,000 tonnes of pure metals were recovered.

In general, the particulate solids recovered from various processes - except slag - can be incorporated into the sinter mix, pellet making, coke making, or in powder metallurgicals. The blast furnace slag can be re-used in the production of cement, insulation, building materials industry, and in making aggregates for road building. Slag from the basic oxygen furnace is also valuable for its iron content as well as its relatively high phosphorus. The iron can be reclaimed and re-used. If there was phosphorus in the original ore the remainder can be used as a fertilizer because of the phosphorus content.

POLLUTION CONTROL TECHNOLOGY

1. Air pollution

Particulates can be removed by cyclones, wet scrubbers, fabric filters, and electrostatic precipitators. Cyclones ordinarily have low efficiencies and are used ahead of more efficient devices or when particle sizes are large.

The principal methods of controlling sulphur dioxide emissions are elimination of sulphur from the fuel or replacement of a high sulphur fuel by a low sulphur one.

Ammonia emissions can be controlled through gaseous absorption. The ammonia can be recovered.

2. Water pollution

Many processes are available for treatment of waterborne residuals. The Arthur D. Little Company [11/] has prepared a summary of waste water treatment technologies applicable to treating iron and steel wastes. This is shown in Table 7.

3. Pollution control and cost effectiveness

To obtain a basic measure of the cost-effectiveness of pollution control measures, the OECD followed the procedure of the Arthur D. Little Company in defining emission control requirements according to "Base Level", "Stage I", and "Stage II" nomenclature. The waste water treatment schemes are shown in Table 7. The air pollution treatment procedures are too lengthy to duplicate here for each unit operation and the reader is referred to the OECD report [8/] for details. Stage I technology includes the technology of the Base Level while Stage II technology includes both that of the Base Level and Stage I.

As an example of Base Level, Stage I and Stage II levels of pollution control the treatment operations which must be employed for a cokemaking plant are shown in Table 8.

The discharge reduction implied by different treatment levels for coke manufacturing operations are shown in Table 9.

Table 7. Applicability of waste water treatment technologies to the iron and steel industry11/

Control Parameter	Base level Technology													Stage I Technology						Stage II Technology							
	Coagulation/Sedimentation	Dissolved Air Flotation	Mixed Media Filtration	Lime Precipitation	Neutralization	Distillation	Solvent Extraction	Biochemical Oxidation	Carbon Adsorption	Alkaline Chlorination	Chemical Reduction Precip.	Cooling Ponds and Towers	Ultra Filtration	Cloth Media Filtration	Centrifugation	Anaerobic Denitrification	Air Stripping	Ozonation	Activated Alumina Adsorp.	Sulfide Precipitation	Electrodialysis	Ion Exchange	Reverse Osmosis	Multi-Stage Flash Evapor.	Floc Adsorption	Ion Flotation	Freeze/Thaw
Suspended Solids	●	●	●										o	o	o												
Oil and Grease	●	●	●				o		o									o								o	
BOD_5	o	o	o					●	o			o	o					o			●	o	●	o	o	o	
Ammonia						●		o				o				o	●										
Nitrate																●					●	o	●	●			o
Phenols						●	●	o	●			o						●			o	o	o	o			o
Cyanides								o	o	●		o						●			o	o	o	●			o
Sulfides						o		o										●			o	o	o	o			o
Fluorides				●					o				o						●		o	o	●	●			o
Total Iron	o	o	o										o	o	o				o	o	●	o	●	●			●
Ferrous Iron				●																●	●	●	●	●			●
Soluble Iron				●																●	o	●	o	●	o	o	●
Manganese		o		●					o	o										●	o	●	●	●	o	o	●
Lead		o		●					o	o										●	●	●	●	●	o	o	●
Zinc		o		●					o	o										●	●	●	●	●	o	o	●
Tin				●					o	o										●	●	●	●	●	o	o	●
Total Chromium				o					o	o	o									o	o	●	●	●	o	o	●
Hexavalent Chromium									o	o	●										o	●	●	●	o	o	●
Total Dissolved Solids						●															●	●	●	●			●
pH					●																						
Temperature												o															

For explanation of terms, see "Glossary of Water and Wastewater Engineering", Water Pollution Control Federation, Washington, D.C.

Legend:

o - indicates some removal of pollutants may be achieved

● - indicates greatest effectiveness in removing pollutant

Table 8. Treatment operations implied by the different treatment levels for coke plant residuals[8]

Type of operation	Base level		Stage I		Stage II	
	Airborne	Waterborne	Airborne	Waterborne	Airborne	Waterborne
	Type of equipment	Type of equipment	Type of equipment	Type of equipment	Type of equipment	Type of equipment
Coal handling	Spr		H,DC		H*, BH	
Charging			PM (H, VS)	(CL)	PM	
Coke-oven operation			Me*		(Me*)	
Pushing	H, VS	Cl	H*, VS*	Cl	H*, BH	
Quenching	B				PM	
By-product recovery (Ph./Ch.)	RFC, CT, DP, Fr, Cl	RFC, CT, DP, Fr, Cl	DS	Fx, N	H*, BH	RBC, CT, AO, A, ACl_2, N, PF, BCl_2, Cl, VG
By-product recovery (Biol)		RFC, CT, Fr, Cl	DS	Fx, N, SS Bio, Cl, VF	H*, BH	RBC, CT, MS Bio, PF

Abbreviations:

Airborne residuals:

H = Hoods
DC = Dry cyclones
VS = Wet scrubbers
BH = Baghouse
PM = Process modifications
Me = Maintenance
Spr = Spraying
DS = Desulphurisation
* = Improvements
B = Baffles

Waterborne residuals:

RFC = Final cooler recycle
CT = Cooling tower
DP = Dephenolizer
Fr = Free ammonia stripper
Cl = Clarifier
Fx = Fixed ammonia stripper
N = Neutralisation
SS Bio = Single-stage biological treatment
VF = Vacuum filter

RBC = Barometric condenser recycle
AO = Air oxidation
ACl_2 = Alkaline chlorination
BCl_2 = Breakpoint chlorination
PF = Pressure filter
AC = Activated carbon
MS Bio = Multi-stage biological treatment

Table 9. Effectiveness of different levels of control technology in reducing air and water pollution from coke manufacturing

	Total Reduction (per cent)		
	Base Level	Stage I	Stage II
Air pollution:			
particulates	85.0	93.0	96.0
sulphur dioxide	15.0	93.0	96.0
hydrogen cyanide	86.0	93.0	96.0
Water pollution:			
ammonia	50.0	93.7	99.5
BOD_5	75.0	92.0	98.0
phenol	98.5	99.7	99.9

The OECD has estimated that the range of variation of the total costs of Base Level emission control ranges between US$3 and US$6 per tonne. This corresponded to between 2 and 4 per cent of the end-1972 average selling price for principal iron and steel products.

The estimated total costs of the Stage I level of emission control ranged between US$12 and US$18 per tonne, or between 8 and 12 per cent of the end-1972 average selling price for finished iron and steel products.

For the Stage II level of emission control the total costs of treatment were estimated between US$38 and US$52 per tonne which is equivalent to betwen 25 and 35 per cent of the end-1972 average selling price for the principal finished iron and steel products.

It is interesting to note that the costs of pollution control measures actually implemented in the six OECD countries studied in reference 8 ranged from 1.3 per cent (Finland) to 6.6 per cent (United States) of the end-1972 average product selling prices.

The British Steel Corporation has separated the cost of pollution control elements (6.66%) from overall plant capital costs for a major development at their Redcar works. The capital costs given in Table 10 include all main plant, building and civil works but exclude general works services and infrastructure.[1/]

Pergelly and Rees quote a value of 10 per cent of the capital cost of plant and building as that expected for pollution control in fully developed areas where the highest standards are required. They note, however, that a clear distinction can often not be drawn between that part of the

Table 10. British Steel Corporation - Redcar Development Pollution Control and Main Plant Costs (1979 basis)

Zone	Gross Plant Cost (US \$ x 10^6)	Pollution Control Plant (US \$ x 10^6)	% PCP of Gross
Committed Plant (Redcar)			
1. Ore Terminal	66.7		
Unloader and Stock Piles		10.1	15.2
2. Sinter Plant	78.24	14.4	18.4
3. Pellet Plant	113.02	10.5	9.3
4. Coke Ovens	231.3		
(a) Coke Side	-	6.5	
(b) Coal Side (Preheater)	-	0.5	
(c) Ammonia Incinerators	-	1.5	12.7
(d) CO Effluent (Bio. Treatment)	-	2.0	
(e) CO Gas - Desulphurisation	-	18.8	
5. Blast Furnace	269.5		
(a) Fume - Stockhouse	-	14.26	9.0
(b) Gas Cleaning - Recirculating Effluent Only	-	10.0	
Additional Plant*			
6. Basic Oxygen Steel-making Continuous Casting	400.0	23.0	6.0
7. Hot Strip Mill	800.0	18.9	2.4
TOTAL	1958.76	130.46	6.66

* For guidance to represent "Creenfield" range of plant. Figures estimated from recent budgets.

plant which is specifically for pollution control and that which is an essential component of the production plant. The contractor's tender price usually does not clearly distinguish between the two. These authors further give 8 per cent to 12 per cent of the initial investment in pollution control equipment as a rough measure of annual operating costs.[7/]

The steel industry in the industrialized countries is extremely concerned with the costs to carry out advanced pollution control. George Stinson, Chairman of National Steel Corporation, has claimed that, in meeting the 1982 and 1984 US standards, the steel industry will have removed over 95 per cent of the conventional pollutants from the steelmaking process.[12/] This suggests that the creative development of low and non-waste technologies must be stressed throughout the industry to reduce the pollution loads which must be treated. Stinson estimates that an additional US$6 billion investment by the US steel industry would be required during the 1980's to remove a further 2 or 3 per cent of pollutants. This is nearly 10 per cent of the total capital investment planned by industry in that period.

Richard Schubert, Vice Chairman of Bethlehem Steel Corporation, made similar observations at the annual meeting of the International Platform Association in 1980. He noted that by 1982 the US Steel Industry is scheduled to remove about 97 per cent of particulate emissions to the air and, by 1984, about 97 per cent of conventional water pollutants. He states that the cost of these control measures will have been US$10 billion.[13/]

UNIDO suggests that the emission control costs for the Base Level of pollution control as described in the OECD study are sufficiently low that this control level should be adopted in construction of all new plants in developing as well as developed countries.

CASE STUDIES OF WATER TREATMENT AND POLLUTION CONTROL COSTS

Case Study 1: Present and Future Water Use and Treatment Practices for Companhia Siderurgica Paultista (COSIPA - a 2.8 million tonne per year integrated works near Sao Paulo)

The water requirements for the hot rolling mills of COSIPA in Santos, Brazil, are 12,000 m^3 per hour for 2 million tonnes per annum of production.

The current water supply is inland water with a heavy BOD loading from Sao Paulo sewage. It is utilized in a once-through system. Furthermore, 22,000 tonnes per year of iron oxide and 2,600 tonnes of grease are discharged into the Santos estuary. The situation is summarised in Figure 2.[1]

A fully recirculating water system for the hot mills would cost about Cr$400 million (about US$15 million). This system would reduce water demand to 6 per cent of the once-through system as well as reduce pollution due to iron oxide and oil and grease discharges by more than 99 per cent. The system could be built in stages. Although Stage 1 (sedimentation and oil skimming) has no effect on water demand it reduces pollution by 75 per cent at 25 per cent of the capital cost and would be required eventually anyway as pretreatment for a water recirculation system. Therefore this is an extremely cost effective way of solving much of the pollution problem and lays the first stage for a water recycling programme that will eventually be required anyway due to water cost constraints and to improve product quality.[1]

The overall water pollution control budget for retrofitting the entire plant is shown below.

Table 11. Water pollution control budget (Cr.$ millions) for the hot rolling mills of COSIPA in Brazil

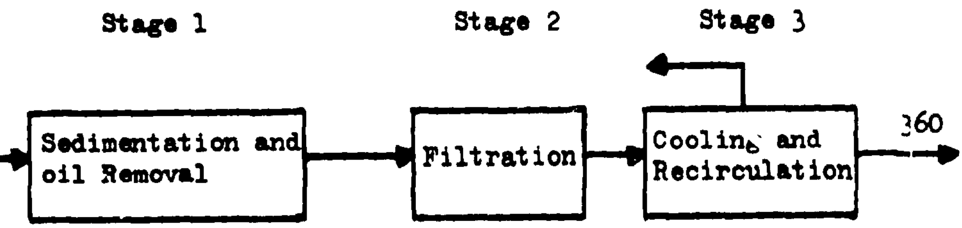
Source	Phase 1 (under way)	Partial Recirculation Phase 2	Full+ Recirculation Phase 3	Totals
Sewage	10	5	26	41
Blast Furnaces	8	-	(35)*	43
Steelmaking 1	35*	-	-	35
Mill Acids	-	5	47	52
Mill Waste	5	-	-	5
Mill Solids & Oils	104*	(131)	(132)	367
Scarfer Dust	-	17	-	17
Storm Water, Drain Oil	-	-	40	40
Blast Furnace Cyanides	-	-	25	25
TOTALS	162	158	305	625
Pollution Control	162	27	138	327
(Water Saving)	(0)	(131)	(167)	(298)

+ Includes plant sewage treatment and an acid recovery plant.

* An asterisk indicates water saving (or pollution control) associated with plant basically for the purpose.

Figure 2. Staged Hot Mill Water Treatment

	Existing
Water Vol. to Estuary	12,000 m^3/h
Make-Up Required	12,000 m^3/h
Solids to Estuary	22,000 tpa
Oil to Estuary	2,640 tpa
% Reduction of Solids	0%
% Reduction of Oils	0%
Capital Cost	



Stage 1	Stage 2	Stage 3
12,000 m^3/h	12,000 m^3/h	360 m^3/h
12,000 m^3/h	12,000 m^3/h	720 m^3/h
6,600 tpa	870 tpa	26 tpa
750 tpa	345 tpa	9 tpa
70%	96%	99.8%
72%	87%	99.7%
Cr.$ 104 million	Cr.$ 130 million	Cr.$ 132 million

The table distinguishes between those components which are specifically effective in pollution control and those which might be installed for that purpose but which are really more associated with improved operations, such as water saving or treatment. Of the Cr.$600 million budget for pollution control it can be seen that nearly half is associated with a recirculation system for water re-use.

Case Study 2: An Integrated Iron and Steel Plant in Volta Redonda, Brazil 14/

During May 1974, a team of two UNIDO experts studied the environmental impact of an integrated iron and steel plant (coke oven, blast furnace, open hearths and rolling mills). The study was carried out in Volta Redonda, Brazil (population 180,000) at a plant operated by Companhia Siderurgica Nacional. The study was updated in 1981 through correspondence with the company.

The plant had a rated annual capacity in 1974 of 1.5 million tonnes but produced 1.7 million tonnes. About 18,000 people were employed in the plant.

The plant is located in a valley and the township of Volta Redonda is spread over this valley and on the hillsides. The plant did not utilize any air pollution control equipment. Also there was overfiring at the boilers in the thermal power plants. Heavy smoke and brown fumes were emitted during smelting and from the power plant. The iron oxide fumes produced during the oxygen injection caused about 90 per cent of particulate emissions. About 8 to 12 tonnes of SO_2 per day were emitted into the atmosphere. Furthermore, the coke ovens were charged using cars of old design. As coal entered the hot ovens, copious brown fumes belched out of the charging holes into the atmosphere.

Prevailing winds are from the south-east and caused the bulk of the air pollution to drift over a zone to the north-west of the plant. About 3,500 people of low income lived in the zone; these people complained about the bad smell of the gases and soiling of clothes and buildings from soot and brown dust. When the direction of the wind changes, as happens frequently during the six-month rainy season, air pollutants are distributed over the entire city and cause a general nuisance. No air pollution monitoring data were available.

Another major air pollution problem occurred in the working environment inside the steel plant. The arc furnaces and cupola had no air pollution control facilities; for example, the most serious internal air pollution occurred in the production of castings during a process of shake-out in which the sand is shaken loose from the castings. This was done in an open space and the dust collector was inadequate to collect the fine, very dry SiO_2 particles. As a result, an average of seven workers working at the shake-out were absent each year from 3 to 12 months because of the lung disease silicosis.

There were almost no facilities for treatment of waste water at the plant. The discharges into the River Paraiba (average flow of 300 m^3/sec) reportedly killed all fish life at distances up to 50 km downstream from the plant. The water pollutants were produced at the blast furnace, coke ovens, and rolling and finishing mills. Toxic effluents included ammonia spent liquor, sulphuric and hydrochloric acid containing effluents from galvanizing and pickling, water containing oils from the rolling mills and waste waters from blast-furnace gas cleaning. The most toxic effluent was the ammonia spent liquor which included about 1,000 ppm of phenols, 50 ppm of cyanide and 2,000 ppm of free ammonia. An estimated 400-500 m^3 per day were discharged without treatment into the river. The blast-furnace gas cleaning resulted in a discharge into the river of about 60 tonnes of suspended solids plus cyanide.

The major pollution abatement process at the plant was the recovery of 340 tonnes of $FeSO_4$ per month from depleted pickling solution.

The plant produced about 12,000 tonnes per month of solid wastes. Much of this was either stock-piled for future resource recovery or used as fill for levelling low-lying areas around the plant. However, the plant granulated blast-furnace slag for sale to a nearby cement plant and recovered iron scrap from blast-furnace scrap and slag.

An expansion of plant capacity from 2.5 million to 4.6 million tonnes per year is under way.[15/] Investments in pollution control equipment total US$61.5 million which represent about 4 per cent of the total capital investment of the expansion. US$19 million will be spent on air pollution control, US$11.4 million will be spent on water pollution control, and US$4.2 million will be spent on noise control. The pollution control equipment will also be used to reduce pollution from the existing plant.

The charging cars to the coke oven are now equipped with gas collection and burning equipment. This was previously one of the biggest sources of air pollution. In the existing plant, cyclones, scrubbers and filters have also been installed in various operations to reduce air pollution. For example, the efficiency of multicyclones in the sintering plant is 95 per cent.

A number of water re-use practices have been incorporated in various plant processes. Waste water from the coke plant is treated in settling basins. A biological treatment plant is planned for the plant expansion. There is an ammonia still for the waste waters from the blast furnace. The sludge resulting from treatment in a scrubber of the off-gas from the blast furnace is removed. Scarfing from the hot rolling mills is also separated in a settling basin and the water is recirculated. Detergents, sulfuric acids and oils are recovered from waste water from cold rolling mills. The water is then recirculated.

Once the plant expansion is completed, a total of 31.04 m^3/sec of water will be in circulation whereas the withdrawal from the river for plant operations will be only 11.1 m^3/sec. The total consumption of water will thus total 42.14 m^3/sec. The percentage of recirculation will be 73.7. After the expansion the plant will require 285 m^3 water per tonne of finished steel, whereas the net consumption will be 75 m^3 per tonne. Previously the net water consumption was 154 m^3 per tonne.

Although a complete analysis of the situation in 1981 compared to 1974 is not available, it is obvious that the Companhia Siderurgica Nacional has incorporated a number of environmental measures into the operations of the works during the seven year period and plans to include even more air, water and noise control measures into the planned facilities.

The planned extent of water recycling of about 74 per cent can be compared with similar percentages of 60 per cent,[16/] 80 per cent[17/] and slightly less than 100 per cent[18/] at three integrated iron and steel works in the USA.

Case Study 3: Capital and Operating Pollution Control Costs for an Integrated Iron and Steel Plant

The following costs are taken from relatively recent and reliable studies and are given in dollars per tonne of liquid steel extrapolated from the original year of reference to the year 1973. These costs are presented on a plant basis and include air, water and solid waste treatment. They are based on a 2,000,000 tonnes per year steel mill and include annual operating costs as well.[2c]

		Capital costs (US$ mill.)	Annual operating costs (US$ thousands)
Lime kiln	- extraction system on all dust areas exhausting to bag filters; kiln gas scrubbers plus pumps	0.4	35
Coke ovens	- extraction of dust of all areas; delivery to multicyclones and wet scrubbers; irrigated baffle tower for quench fume control. NH_3 striping and biological treatment for wet emission control and coke oven gas cleaning system	1.5	195
Sinter plant	- cyclone dust control on exhaust extractors on all materials handling cyclones plus low energy wet scrubbers for sinter windbox fume extraction	2.0	700
Blast furnace	- cyclone dust control on extractor system for all materials handling in charging areas. Venturi scrubbers, settling ponds, thickeners, plus wet electrostatic precipitator on gas cleaning system. Chemical dosage of bleed-off water prior to final discharge	4.7	450
Linz-Donawitz steel furnace	- wet electrostatic precipitator treating cooled burnt gas plus thickener, filtering equipment and pug mill	6.0	260
Electric arc furnace	- same as requirements for the Linz-Donawitz process	1.0	100
Casting, pickling and rolling mills	- (i) settling ponds, clarifiers, and filters for collecting mill scale from all direct water cooling circuits		
	(ii) oil and emulsion collection via skimming and cracking		

(... cont.)

(cont.)

	Capital costs (US$ mill.)	Annual operating costs US$ thousands)
(iii) oil mist extraction and elimination from air exhaust of cold rolling plant		
(iv) acid fume water spray elimination from exhaust of pickling line		
(v) disposal of iron salts from acid regeneration	6.8	500
Sub-total	22.4	2,240
Plus G.W.S. allocation (25 per cent)*	5.6	560
TOTAL estimated pollution control costs	28.0	2,800

This capital cost is 4.5 per cent of the total Plant Capital Cost Estimate. The operating cost (excluding capital depreciation and charges) is 1.7 per cent of the total plant operating cost. When those costs are put on the basis of a tonne of finished steel product, the following are obtained:

Output: 1.64×10^6 tonnes steel per year

Total capital cost estimate:	US$375.00 per tonne finished steel
Waste treatment operating costs:	US$1.54 per tonne " "
Waste treatment capital costs:	US$3.38 per tonne " "
Pollution control costs (total):	US$4.92 per tonne " "

PROCESS MODIFICATIONS

The major changes which can result in a lessened environmental pollution load are:

(a) Formed coke process
(b) Dry quenching of coke (instead of wet quenching)
(c) Sintering
(d) Renewable sources of energy

* General works service charge for engineering and contingencies

(e) Direct reduction of iron ore (instead of coking and blast furnace plants)

(f) Spray cooling

(g) Hydrochloric acid pickling (instead of sulphuric acid pickling)

(h) Electrolytic (dry) pickling (" " " ")

(i) The cascade method for washing metal after pickling

(a) The formed coke process is a continuous production technique in which carbonization and briquetting occurs within a closed system. This may eventually replace the conventional batch production and thus eliminate the inherent air pollution problems. Similar water pollution problems are common to both processes, however.[19/]

(b) Dry quenching uses air or another gas as a coolant. The dust collected by the circulating gas is burned in the steam plant to aid in power generation. This is an example of increasing energy efficiency and reducing an important air pollution source.

The Council on Mutual Economic Assistance has extensively promoted the development and application of new technology to control environmental pollution from the iron and steel industry.[20/] The CMEA reports that the capital expenditures for equipment to remove chemical contaminants such as carbon monoxide and oxides of nitrogen are roughly double those for dust collection facilities. According to the CMEA, emphasis should be placed on reducing process wastes when developing new or modifying existing process techniques. The CMEA notes, for example, that the dry quenching of coke makes it possible to eliminate almost completely water pollution due to phenols.

(c) Borisov et al[21/] report that effluents from the coke oven can be used to moisten and bind the mix in the sinter plant. These effluents have good binding properties due to the presence of phenols as well as free and combined ammonia. The strength of the sinter pellets in the green state was shown to be 15 per cent greater when moistened with coke plant effluent as compared with technical quality water. In summary, the entire output of coke plant effluent, which may exceed 100 m^3/h, may be utilized to fully cover the water requirements of the sintering plant. The authors report that it may be expedient to use dephenolated, bio-chemically purified coke-oven effluent if the level of phenols poses a health problem.

(d) The use of wood charcoal as a carbon source in blast furnaces and electric arc furnaces is now under way in a number of areas, most notably Brazil. Practiced properly, such a programme will include reforestation to ensure resource renewal.

Hydropower may also play a greater role in iron and steel making when it can be generated at low cost on a regular basis.[19/]

(e) Direct reduction of iron ore depends not only on an expensive (enriched) source of ore, but also upon a plentiful and inexpensive source of natural gas - or some other gaseous or solid combustible reducing agent. Where this has been feasible, the direct reduction process beneficiating the iron ore to 90-95 per cent iron has gone directly to the electric arc steelmaking furnace. Therefore, the coke and pig iron plants have been eliminated completely.

The Jijel complex in Algeria, scheduled to come on stream in 1986, is an example of a direct reduction steel plant planned for a developing country. Even though as of 1980, Algeria had no standards for industrial emission and pollution control, the plant is being designed in order to conform as closelyas possible to standards commonly applied in industrialized countries.

Water use in the steelworks will be kept low by operating with closed circuits whenever possible and avoiding evaporation losses by using air-tight circuits.

Sea water will be used as a coolant using a battery of heat exchangers with a flow of up to 60,000 m^3 per hour.[22/]

(f) Rolling mills use 30,000 to 40,000 m^3 of water per hour. This large amount is necessary due to the conventional technology of cooling using perforated pipes. This procedure is inefficient since the temperature drop is only 1 to 2^{o}C. A more efficient spray cooling method has been developed in the USSR which reduces water consumption by 25 per cent with greater cooling efficiency and also decreases the wearing of the rolls.[4/]

(g) When steel is pickled in HCl, the iron salts ($FeCl_3$) are recovered from the concentrated spent liquor by spray-roasting to yield Fe_2O_3 and HCl. The HCl is absorbed in water and recycled for re-use in pickling and the iron oxide is recycled and returned either to the sintering, pelletizing, or blast furnace plants. The normally higher cost of hydrochloric acid than sulphuric acid is countered by its regeneration and re-use potential. However, reduced volumes of pickling liquors are recommended even for HCl liquors.

If the metal is pickled in HCl and scale is removed from the surface by methods not requiring the use of acid, the pickling sections of rolling mills no longer produce effluents and product quality is high. Czechoslovakia, the GDR, the FRG, Poland, the USA and the USSR are principal countries which have introduced these changes.[4/]

(h) Pickling by electrolytic processes without using acid but simply by passing an electric current through the solution of the metal in water, deserves more consideration and use than is now the practice. Needless to say the elimination of acid pickling wastes would solve one of the major water pollution problems of the industry. If dry pickling is used, some system other than acid pickle liquors would be necessary for cracking oil emulsion wastes from the cold rolling mill. Solvent extraction and ultra high rate filtration have been suggested.

(i) The cascade method for washing metal after pickling can reduce the normal amount of wash water required by 80 per cent. In the cascade method, the washing channel is divided into three or four sections. Fresh or neutralized water is fed into the last section along the route of the metal. This used water is then pumped out to serve as a pre-wash for the advancing metal in the next section. The method was developed and is finding great utility in the USSR.[4/]

THE WORKING ENVIRONMENT

Occupational health and safety is a major concern in the iron and steel industry due to the hazardous aspects of many operations. An accident risk potential is presented by molten metals, high temperature as well as worker contact with heavy machinery. A variety of toxic and explosive gases as well as high levels of particulate matter are generated in many of the processes. Hazards are presented by significant quantities of toxic substances such as cyanides, chromium salts, and acids. Some processes are inherently noisy.[19/]

General problems of the working environment in the iron and steel industry are presented in detail in a recent ILO handbook.[23] Problems associated with working with molten materials, work in hot work places, hazardous gases, problems of oxygen under pressure, water pollution problems, noise and vibration are discussed and remedies to reduce worker risks are suggested.

The World Bank has also produced guidelines which cover recommendations on safety and health in order to prevent and reduce accidents and occupational diseases among employees. Threshold limit values for exposure of workers to various fumes and other pollutants are presented.[24]

ENERGY CONSIDERATIONS

Harrop and Smithson have carried out a detailed study of energy requirements for air and water pollution control for sub-processes of each process operation within a typical integrated iron and steelworks.[25] The authors surveyed energy requirements for pollution control from 93 examples for 50 processes at 18 plants.

For an electric arc plant with combined direct and indirect extraction, the current mean energy consumption is 59 kwh/tonne steel. This represents a consumption of 3,900 kwh/tonne dust.

For an integrated iron and steelworks, the consumption of electricity for pollution control is shown below for the main processes.

Table 12. Energy consumption for pollution control for an integrated steelworks [25]

	Current good practice		Advanced control systems	
	kwh/t steel	%	kwh/t steel	%
Ore stock yards and bedding	0.39	1	0.55	1
Sinter plant	9.10	20	17.00	15
Coke ovens	2.70	6	49.00	41
Blast furnace	2.90	6	12.00	10
Steelmaking	24.00	52	31.00	26
Rolling mills	6.20	14	8.70	7
Miscellaneous	0.24	1	0.24	<1
TOTAL	45.00	100	119.00	100

Harrop and Smithson estimate that the energy requirements for pollution control will rise from 45 to 119 kwh/tonne of steel as current techniques are replaced by advanced pollution control practice in a modern integrated iron and steelworks. Energy consumption in terms of pollutants removed will rise from 550 to 1,300 kwh/tonne of dust removed. This reflects the high expenditure of energy for collecting the relatively small quantities of dust from secondary emissions.

Under current conditions, steelmaking accounts for 52 per cent of the energy requirements. When more advanced control systems are introduced, cokemaking will become the most significant consumer of energy (41 per cent).

The cost of energy for pollution control is estimated at 90p per tonne of steel or £11 per tonne dust for current good practice, rising to £2.38 per tonne steel or £26 per tonne dust when advanced techniques are used.

In the Arthur D. Little study,[11/] the energy requirements for pollution control in the iron and steel industry were compared with production energy requirements. It was found that for integrated iron and steel mills, the Stage I level of pollution control would require about 4 per cent of production energy usage. For a Stage II level of control the energy requirement would be about 10 to 13 per cent of the total production energy usage.

The energy requirements for the Stage I level of pollution control in semi-integrated plants, mini-steel mills, and alloy steel plants were reported as 4.2, 5.3, and between 4.1 and 6.4 respectively as a percentage of total energy required.

These data offer an indication of the trends which will occur unless engineering advances are made which will allow savings in energy consumption for pollution control for the various processes. A prime example of energy savings as well as water savings is given by the USSR development of fully utilizing coke plant effluents in the sinter plant, as discussed earlier in this paper.

ENVIRONMENTAL IMPACT EVALUATION OF A PROPOSED IRON AND STEEL PLANT

The environmental consequences of a proposed iron and steel plant at a given site should be studied, reported and evaluated prior to approval of the project. The purpose of evaluating environmental impact are two-fold:

(1) to prevent the deterioration of natural resources, such as the river which is to receive plant waste waters, so that these resources can continue to provide a basis for further economic development; and

(2) to give ample warning of deleterious side-effects of the projects, which may result in economic or social costs not normally identified in the project review procedure.

Obata[22/] has estimated a productivity of 200-250 kg per man per year for a steelworks in a developing country. A steel plant with a capacity of 4 million t/y (one BOF shop with 3 x 180 t vessels) would therefore require a work force of 20,000. Given an average family size of four persons, the population directly attributable to the steelworks would be 80,000 inhabitants. If a by-products processing plant, steel structure fabrication plant, and pipe shop were also established, the population due just to the steel industry would swell to a total of 120,000 or more.

Obata recommends siting the plant 3 to 5 km from the town, a distance not too far for workers to travel by bicycle or on foot but far enough to remove workers from the psychological effect of always being in the working environment.

Environmental problems begin long before the operation of the plant. Site preparation, construction of a harbour, paving of roads, and the erection of the works will remove vegetative cover resulting in potential erosion, cause considerable noise from earth-moving equipment, cause temporary air pollution from dust, and may pollute the bay or other water course from suspended solids. Careful planning can reduce these impacts.

Plans to scrub gases, re-utilize process waters and solid wastes can minimize the environmental impact of the plant operation.[22/]

In addition, direct effects of an iron and steelworks on air and water quality, indirect consequences of pollution are:[4/]

(a) Deterioration of the quality of life - deterioration in the health of the population, loss of recreational value of land areas and water bodies, need for more frequent cleaning of clothes and living accommodation.

(b) Loss of working time due to higher incidence of illness in the working population.

(c) Reduced economic value of natural resources, such as lower agricultural productivity and fishing yields.

(d) Increased corrosion and equipment wear within the industrial areas.

In order to avoid direct and indirect pollution effects, the following series of steps should be followed when evaluating the environmental impact of a proposed iron and steel plant:

(1) Raw materials linkage: Environmental considerations beginning with extraction or arrival in country to project under evaluation.

(2) Site assimilative capacity: Present or baseline analysis of air, land and water carrying capacity to determine original conditions and effects of the project.

Site selection: An integrated iron and steel plant with a capacity of 4 million tonnes per year and surrounded by a green belt strip will require 5 million m^2 of flat land.

(3) Project design and construction: Analysis of alternative possibilities for unit operations and energy sources.

(4) Operations: Maintenance of project and monitoring (analysis of outputs, including by-products and wastes for treatment and re-use; monitoring waste discharges).

(5) Social and health aspects: Social implications of project; safety and welfare of population affected by plant.

(6) Place of ultimate deposit: Recycling, re-use or assimilation of product and future products.

(7) Long-term considerations: Plant expansions.

(8) Optimization: Cost analysis of alternatives.

Therefore the actual site of an iron and steel mill should be selected carefully so that there are ample receiving capacities of air and water to assimilate effluents and land to serve as a buffer zone and a receptacle of residual unusable solids. Some degradation of environment is almost inevitable from the production of iron and steel. However, UNIDO believes that the degree of degradation should be determined by the will of the citizens and the government. The policy of how much to pollute should not be left simply to the industrial plant to decide.

Furthermore, actions to mitigate environmental impact of a proposed iron and steel plant should be taken at the planning stage. The sources of impact or emission can then be clearly identified and means of effective control at least cost can be analyzed.[22/]

POLLUTION REGULATIONS

In recent years, more and more countries have expanded or adopted new environmental legislation. Governments have created official bodies which are responsible for the elaboration of new legislation and its application and enforcement. As a guide to present practice, a comprehensive listing of air quality* and pollutant emission** standards from a number of countries, including Japan, USSR, the USA and several European countries, are to be found in a recent World Bank publication[26/] which also refers to criteria for maximum concentrations of various water pollutants in public waterways.

A table is presented by Pergelly and Rees comparing ambient air quality standards for suspended particulates, sulphur dioxide, carbon monoxide

* An air quality standard requires that the concentration of a pollutant in the atmosphere at the point of measurement shall not exceed a specified amount.

** An emission standard requires that the amount of a pollutant emitted from a specific source shall not exceed a specified concentration.

and photochemical oxidants in twelve countries, mostly developed. A summary of the major effects of these pollutants is also given.[7]

A problem specific to the developing countries when endeavouring to protect the environment through regulations is a lack of experience. Never previously having had to face environmental problems due to industrial pollution, a large number of the developing countries have no specific regulations at hand. Such regulations are, however, indispensable to the contractor for the design of pollution control systems and should be in effect at the time the tender documents are sent out. It is recommended therefore that the ministries concerned, such as those of industry, health or development, should draw up the relevant regulations, referring as necessary to the experience of other countries cited in the previous paragraph.

However, having stringent air quality standards is a necessary but not sufficient condition to ensure a quality environment. These standards must also be enforced if the environment is to be clean. In a UNIDO study of an integrated iron and steel mill in Brazil, air quality standards were violated considerably.[14] As Pergelly and Rees note, "at one extreme, still to be seen in many parts of the world, pollution control regulations either do not exist, or are virtually completely ignored".[7]

RECOMMENDATIONS

1. In the case of the many developing countries without reserves of coking coal, UNIDO recommends the establishment of mini mills (from 200,000 to 1 million tonnes of finished steel product per year) using direct reduction and an electric arc furnace followed by continuous casting and finishing process. Less pollutants are generated by this type of works.

2. A site for a new plant should be chosen with a sufficient buffer zone to assimilate air pollutants and to serve as a receptacle of solid residuals. An adequate source of water is necessary as well as a transportation network for the flow of raw materials and finished products. Frequently a coastal site would be preferred.

3. Three separate water systems (rain water run-off, drinking and sanitary waters, process waters) should be established for a new plant. Domestic waste waters can be recycled after treatment to the process water system if the plant is in a water-scarce region.

4. For a new plant, the alternatives for water recycling should be examined. A cost study should examine the alternatives of using once-through water (raw water costs) compared with recycling (treatment and pumping costs) keeping in mind that environmental quality restrictions on effluent discharges may be more stringent in the future.

5. Oxygen blowing should be minimized to reduce air pollution from the plant.

6. When setting up integrated works on greenfield site, at least base level pollution control technology should be incorporated (text, pp. 17, 18) to reduce pollution.

7. Governments should make available low interest loans, subsidies and special tax benefits for pollution control measures taken at both new and existing plants.

8. Where a new or existing plant is located near a population centre, the government should insist on installation of efficient air pollution control equipment in order to meet strict air quality standards.

9. Governments should establish water quality standards for streams receiving waste water discharges from iron and steel mills and the manufacturers should be required to remove sufficient pollutants, especially toxic pollutants, in order to meet the water quality standards.

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