Report on Best Available Techniques (BAT)
in the German
Ferrous Metals Processing Industry

FINAL DRAFT

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Glossary

AbWV	Ordinance on Waste Water (Abwasserverordnung)
AbWAG	Water Pollution Control Levy Law (Abwasserabgabengesetz)
AG	Public Limited Company, plc
Art.	Article
BAT	Best Available Techniques
BImschG	Federal Immission Control Act (Bundes-Immissionsschutzgesetz)
BF	Blast Furnace
BOF	Basic Oxygen Furnace
BREF	BAT Reference Document
Cap.	Capacity
CBAT	Candidate Best Available Techniques
CC	Continuous casting
ChemG	Chemicals Law (Chemikaliengesetz)
cf.	Confer
COG	Coke Oven Gas
CPR	Casting Pressing Rolling
CSP	Compact Strip Production
CVC	Continuous Variable Crown
i.a.	inter alia
i.e.	id est
EAF	Electric Arc Furnace
EC	European Community
e.g.	For example
Esp.	Especially
etc.	Et cetera
EU	European Union
EWC	European Waste Catalogue
FMP	Ferrous Metals Processing
GmbH	Limited Liability Company
HDG	Hot Dip Galvanising
IISI	International Iron and Steel Institute
IPPC	Integrated Pollution Prevention and Control
IPPC-D	Directive on Integrated Pollution Prevention and Control
ISP	In-line Strip Production
KrW-/AbfG	Federal Recycling and Waste Management Act (Kreislaufwirtschafts- und Abfallgesetz)
LAGA	Committee of the Federal States for Waste Control
LAI	Committee of the Federal States for Immission Control
LPG	Liquid Petroleum Gas
max	Maximum
MPS	Multi-Purpose-Section
n.a. / n.d.	Not available / Not detectable
NG	Natural Gas
STP	Standard Pressure Temperature
TA	Technical Instructions (Technische Anleitung)
TSP	Tippins Samsung Process
TWG	Technical Working Group
UBA	German Federal Agency for the Environment (Umweltbundesamt)
WHG	Federal Water Act (Wasserhaushaltsgesetz)
VE-water	Deionised water

Chemical symbols

AOX	Organic Halogen Compounds
C	Carbon
Cd	Cadmium
Cl	Chlorine
C_nH_m	Hydrocarbon
CO	Carbon monoxide
CO_2	Carbon dioxide
CO_x	Carbon (x) oxide
COD	Chemical Oxygen Demand
Cr	Chromium
Cu	Copper
Fe	Iron
FeO	Iron oxide
Fe_2O_3	
$FeSO_4$	
H_2	Hydrogen
HC	Hydrocarbon
Hg	Mercury
H_2O	Water
H_2SO_4	Sulphuric acid
HCl	Hydrogen chlorine
HF	Hydrofluoric acid
HNO_3	Nitric acid
Hg	Mercury
N_2	Nitrogen
Ni	Nickel
NO_x	Nitrogen (x) oxide
O_2	Oxygen
P	Phosphorus
Pb	Lead
SO_2	Sulphur dioxide
SO_x	Sulphur oxide
VOC	Volatile Organic Compouns
Zn	Zinc
ZnO	Zinc oxid

Units

a	year
μg	micro gram
μm	micro metre
°C	Degree Celsius
dB(A)	decibel acoustic
g	gram
GJ	gigajoule
h	hour
K	Kelvin
kg	kilogram
kWh	kilowatt hour (3.6 MJ)
l	liter
m	metre
min	minute
mm	millimeter
m^2	square metre
m^3	cubic metre
mg	milligram
MW	megawatt
min	minutes
MJ	megajoule
N	Newton
ng	nanogram
s	second
t	ton
Tons	thousand tons

Preface

Remark 1:

The goal of this study is to provide background information on (candidate) best available techniques for environmental protection within the German ferrous metals processing industry (hot and cold rolling mills, continuous galvanising lines). It gives information on the energy and materials input and output levels of German rolling mill plants and identifies the impact of certain particular environmental protection techniques, but also of production techniques on these levels. It also includes information on continuous galvanising plants with respect to integrated pollution prevention and control. The paper is based on the study of literature, on technical discussions with experts and on information collected at plant visits. Its intention is to support the TWG Ferrous Metals Processing.

Remark 2:

In this technical study the term ***waste****, as used within the chapters A.4.2, A.4.3 and A.4.4, includes a variety of materials arising within hot and cold rolling mill plants, which are not produced on purpose by the investigated production processes. The authors are aware of the fact that in particular cases for certain materials other terms might be also suitable in order to characterise the recirculation or recycling properties of these materials.*

On September 24th, 1996 the Council of the European Communities issued Directive 96/61/EC on Integrated Pollution Prevention and Control (IPPC-D) [33]. This Directive aims to achieve a high level of protection of the environment taken as a whole. It was enacted especially considering the common environmental goals of the EC, laid down in article 130r, EC-treaty (conservation and protection of the environment and improvement of environmental quality (i), protection of human health (ii), sustainable use of resources (iii), promotion of measures on an international level to handle regional or global environmental problems (iv)), and being aware of the fact that the implementation of an integrated concept of pollution prevention needs to be addressed by measures on a community level.

Annex I of Directive 96/61/EC contains an extensive list of industrial activities, which the Directive applies to. According to this list, also industrial activities related to the production and processing of metals are subject to the measures within the IPPC-D (N° 2). The Directive provides a general framework with principles for integrated pollution prevention and control. Pollution is defined to be "*the direct or indirect introduction as a result of human activity of substances, vibrations, heat or noise into the air, water or land which may be harmful to human health or the quality of the environment, result in damage to material property, or impair or interfere with amenities and other legitimate uses of the environment*". The goal of this integrated concept is to protect the environment taken as a whole against pollution, mainly by the prevention and control of emissions related to the mentioned industrial activities into all environmental media (air, water, and land) and the efficient use of resources and energy.

The necessity for drawing up notes on best available techniques (BAT) for certain industrial activities is constituted by measures laid down within the Directive:

- First of all, Article 16.2 demands explicitly an exchange of information on best available techniques: "*The commission shall organize an exchange of information between member states and the industries concerned on best available techniques* ..." [33]. In particular this Article 16.2, demanding an exchange of information on BAT, is the motive for this document.
- Furthermore, the IPPC-D obliges the member states to provide the EC-commission with representative data and possibly information on BAT for the categories of industrial activities listed in Annex I (art 16.1). The member states also have to ensure that the competent authorities follow or are informed of developments in best available techniques (art 11).

Within the IPPC-D the concept of BAT is defined the following way:

BAT "*shall mean the most effective and advanced stage in the development of activities and their methods of operation which indicate the practical suitability of particular techniques for providing in principle the basis for emission limit values designed to prevent and, where that is not practicable, generally to reduce emissions and the impact on the environment as a whole* ..." (art 2.11).

Annex IV names a list of considerations to be taken into account generally or in specific cases when determining BAT. Inter alia,

– the use of low-waste technology,
– the use of less hazardous substances,
– the furthering of recovery and recycling of substances generated and used in the process, where appropriate,
– the nature and volume of the emissions concerned,
– the consumption and nature of raw materials (including water) and energy used in the process and their energy efficiency and
– the need to prevent or reduce to a minimum the overall impact of the emissions on the environment and the risks to it

should be considered, always having in mind the likely costs and benefits of measures and the principles of precaution and prevention.

Further important contents of the IPPC-D are the basic obligations of the operators, defined in Article 3. Installations must be operated in such a way that:

"*(a) all the appropriate preventive measures are taken against pollution, in particular through application of the best available techniques; (b) no significant pollution is caused; (c) waste production is avoided [...] ; where waste is produced, it is recovered, or, where that is technically and economically impossible, it is disposed of* *while avoiding or reducing any impact on the environment; (d) energy is used efficiently; (e) the necessary measures are taken to prevent accidents and limit their consequences; (f) the necessary measures are taken upon definitive cessation of activities to avoid any pollution risk and return the site of operation to a satisfactory state.*"

The concept of BAT is used in several places within the IPPC-D. It is employed to specify dynamic requirements with respect to integrated pollution prevention and control. Requirements, applying the notion of BAT, include the following provisions:

- The definition of a permit procedure for the operation of industrial plants, according to which permits shall be granted only if operators fulfil several requirements, that are further specified in the Directive (cf. art 3, 6, 7, 8).
- In particular the definition of the aforementioned basic obligations, with which operators of industrial activities have to comply in order to receive a permit (art 3, esp. 3 a).
- The reminder to the competent authorities, that a permit has to include emission limit values for at least a minimum number of substances explicitly named in Annex III. These emission limit values, or possibly equivalent parameters or technical measures, shall be based on reference values derived from the *Best Available Techniques* (art 9 4.). The operators are obliged to use BAT or alternative techniques which show BAT-performance. The latter may differ from the BAT described within the BAT Reference documents (BREF). Nevertheless, they have to achieve at least the same level of prevention and control as the techniques mentioned within the BREF.

As a consequence of the information exchange specified in Article 16, according to Article 18 the Council of the European Union will set emission limit values for sectors and polluting substances for which a need for Community action has been identified. As an instrument of control, the implementation of the Directive and its effectiveness in comparison with other Community environmental instruments shall be documented in reports according to Article 16.3.

As already mentioned above, the purpose of this document is to support the identification of BAT for the ferrous metals processing industry and so to support the information exchange on BAT. To perform this task, the basic intentions of the IPPC-document have to be considered, i.e. the integrated approach in environmental protection has to be taken account of. Thus, summarising the provisions of the IPPC-D it can be concluded, that the identification of BAT for the ferrous metals processing industry requires an investigation of the underlying production system with particular respect to the emission of substances, heat, and noise caused by the system into the environmental media air, water, and land as well as measures to prevent and control these emissions. Also the considerations of Annex IV, IPPC-D, have to be taken into account, in particular the requirements of point 9 of Annex IV (consumption and nature of raw materials and energy efficiency of the processes). The IPPC-D also takes account of the fact, that minimisation of releases into one medium may result in only a shift of pollution from one medium to another. Therefore, an integrated approach means to take into consideration all environmental media at the same time, including the consideration of cross-media aspects, in order to protect the environment as a whole.

The structure of the document is as follows:
It is divided into five main parts (A to E). Part A deals with information on hot and cold rolling mills. Chapter A.1 gives general information about the German rolling industry. Chapter A.2 provides basic information about products, applied processes and techniques of hot and cold rolling mills. Chapter A.3 investigates related typical material and energy input / output levels. Chapter A.4 contains a list of candidate best available techniques, i.e. techniques that are possible BAT. In chapter A.5 best available techniques are determined with respect to integrated pollution prevention and control. A selection of so-called *emerging techniques*, i.e. promising novel pollution prevention and control techniques, is presented in chapter A.6. Part B deals with information, that is relevant for the determination of BAT for continuous galvanising lines. Chapter B.1 gives general information on the German continuous galvanising industry. Chapter B.2 describes applied processes and techniques of that industry sector. Then chapter B.3 states information on mass streams and selected measures for pollution prevention and control in continuous galvanising lines. Part C contains conclusions and recommendations. More detailed information on selected topics is provided in the Annex (Part D), including an overview of selected relevant legislation for ferrous metals processing activities in Germany and on an EU-level. The last part E gives an extensive list of references.

A Hot and Cold Rolling Mills

A.1 General information on the German rolling industry

This chapter provides basic information on the German rolling industry, mainly with respect to production figures, employment figures and the geographical distribution of selected plants. Also a first indication of main environmental issues for the sector is given.

A.1.1 Economic aspects

In 1995, Germany contributed 42.051 million tons (39.8 million t in 1996) to a world steel production of 756 million tons (1995, 1996: 752 million tons). Of that output, altogether 41.732 million tons of blooms were cast. The major share of these, 40.131 million tons (96.2%, 1996: 95.8%), was continuously cast, which confirms the extreme growth of importance of this technology since its introduction in the sixties. Subsequently, the production of finished products in rolling mills was 10.698 million tons of section steel, 21.846 million tons of flat rolled steel and 1.256 million tons of seamless tubes in 1995 [185]. The temporal development in the production of rolled products is naturally related to the produced quantity of crude steel, so roughly the same development in total production can be observed. The number of workers employed in German rolling mills was 16,052 in hot rolling mills and 9,235 in cold rolling mills in 1995 [152]. Table A.1-1 shows the development in output of rolled products starting in 1995 and going back to 1985.

Table A.1-1: Output of rolled products in Germany in 1,000 t

Year	1995	1994	1993	1992	1990	1985
Section products (total)	10,698	10,277	9,702	10,219	8,433	8,549
Wire	5,436	5,424	4,933	4,908	3,765	3,438
Rod, bars	3,008	2,670	2,505	3,129	2,689	3,161
Sheet piling products	235	239	197	223	202	189
Wide-flanged beam	917	827	904	776	813	476
Structural steel	830	867	897	848	740	888
Superstructure products	272	250	266	335	224	397
Flat steel (total)	21,846	21,790	20,016	21,172	21,295	20,370
Hot wide strip (final products)	4,789	4,834	4,818	4,441	5,522	4,874
Strip including tube strip	1,748	1,774	1,502	2,051	2,310	2,085
Sheets	11,552	11,422	10,207	10,693	9,823	8,549
Heavy plates	3,619	3,637	3,395	3,837	3,009	4,139
Wide flat steel (merchant bar)	138	123	95	150	224	290
Seamless tubes	1,256	1,145	972	1,047	1,362	1,962
Sum rolled products	33,800	33,212	30,690	32,438	31,090	30,881
Crude steel production	42,051	40,837	37,625	39,711	38,434	40,497

Source: [185]

In Germany, the locations of rolling mill plants are spread out all over the Federal States and are often directly connected to steelworks.

Figure A.1-1, to Figure A.1-3 give an overview of the spread of locations in Germany selected by the size and the type of rolling mills.

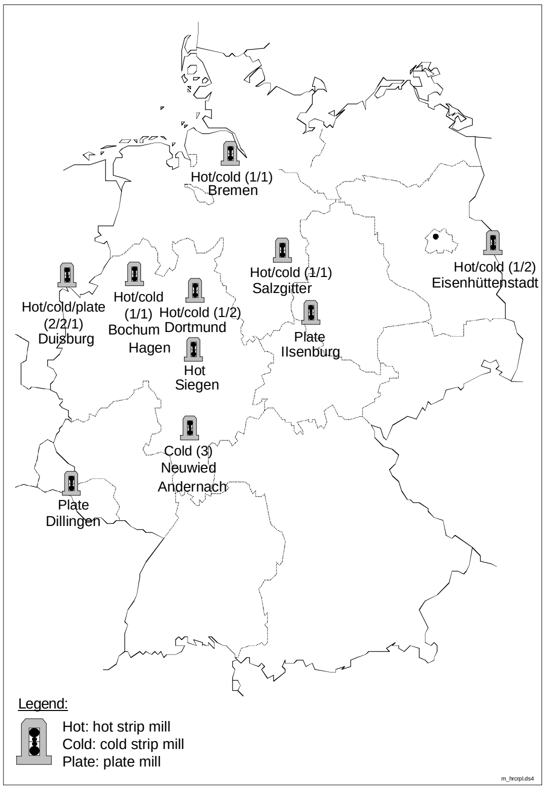

Figure A.1-1: Locations of hot strip, plate and cold strip mills in Germany (examples)

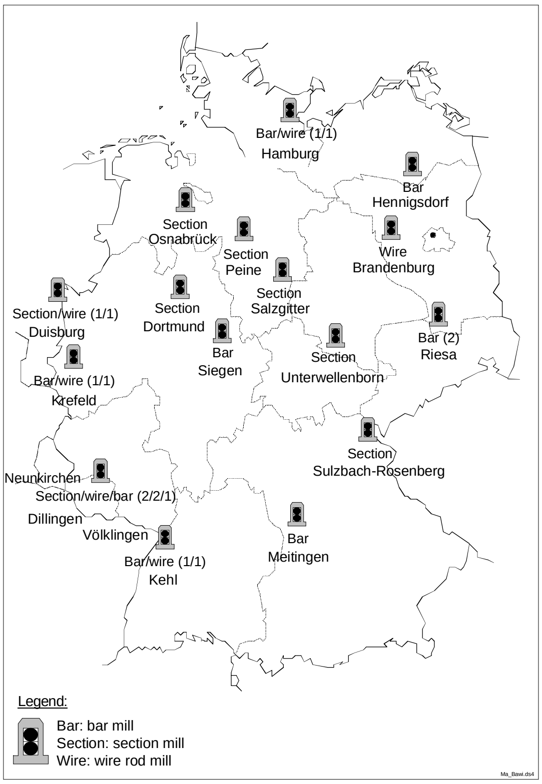

Figure A.1-2: Locations of bar, section and wire rod mills in Germany (examples)

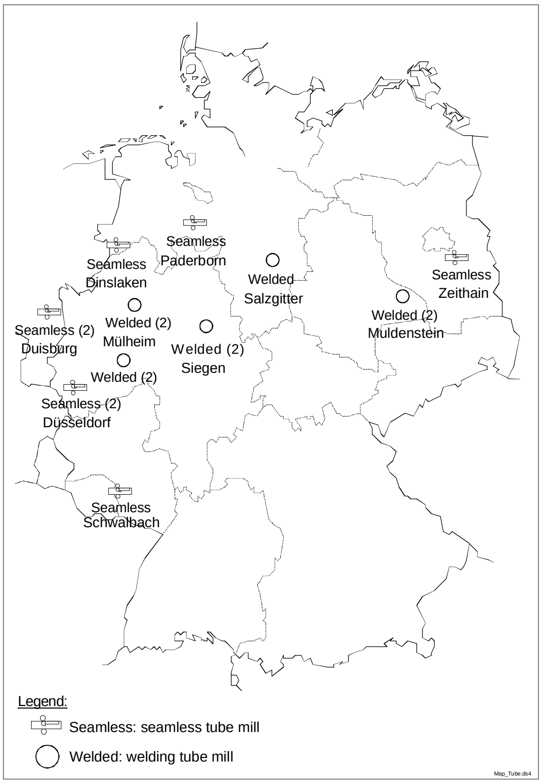

Figure A.1-3: Locations of tube mills in Germany (examples)

Sources Figures 1-1 to 1-3: [Firm data, own compilation]

Rolling mills, in particular hot wide strip mills, are capital intensive investments and are usually subject to continuous maintenance and improvement measures. Many rolling mills were built several decades ago, but are still in use, thanks to continuous modernisation. But also new plant concepts have been developed resulting in the construction of new mills, i.a. near net shape casters. However, no thin-slab caster is being implemented in Germany at the moment[1]. Near net shape production allows a reduction of process steps, in particular if it directly connects casting and rolling processes and making time and money consuming storage and reheating processes at least partly obsolete. The development and implementation of new concepts put a significant economic pressure on plants using conventional technology, as the new technologies have significant advantages in cost related to the investment [72]. However, there are also reasons stated in recent literature to maintain and revamp existing conventional plants for further use besides their high residual book value [135].

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1 One project has been started in order to erect a plant for the commercial production of hot strip by thin slab casting in Germany. It is planned to complete this project in 1999.

A.1.2 First indication of environmental concerns

Within this section a first overview of required inputs and arising outputs of rolling mills is given, so that the main points of focus for the determination of BAT can be identified.

A main environmental concern within hot rolling mills is the absolute quantity of energy needed to reheat the slabs, billets and blooms. Related to this energy consumption are emissions that arise because of combustion processes in order to supply the required thermal energy. These gases may contain NO_x, SO_2, CO, dust and further components, depending on the type of fuel used for the energy supply. Water is used extensively in hot rolling mills for cooling (direct and indirect), descaling and transporting purposes. It is often used many times or in closed loops within the mills. Water losses may occur inter alia because of direct cooling. Due to the scaling processes within the reheating furnaces and the following rolling, the process water used in hot rolling mills is loaded with reheat furnace scale and mill scale, as water serves as a media for descaling. Because of leakage from the rolling stands it is also loaded with oil. In particular the oil loads of the water and the oil content of the precipitated scale are of environmental concern. Collected oil-free scale can be directly recycled to metallurgical processes. Oil containing scale or sludge resulting from process water treatment possibly has to be treated further and requires special attention, if the oil content is too high to allow immediate recycling to metallurgical processes. Another output, which can be recycled to metallurgical processes, is the scale arising by surface cleaning (scarfing) of continuously cast slabs before entering the reheating furnaces. Electrical energy is used in hot and cold rolling mills for the driving motors of the rolls as well as for the operation of auxiliary installations (e.g. fans).

Within cold rolling mills, with respect to the different media emissions into the atmosphere from annealing furnaces (NO_x, SO_2), the pickling section (H_2SO_4, HCl, NO_x, HF) and the cold rolling section (oil emission / mist), discharges into the water by the rolling and pickling sections, as well as different types of outputs arising at various spots (oil recovery sludge, acid regeneration sludge, neutralisation sludge, water treatment installation sludge, dry dust, oil / emulsions / greases and dismantled refractories) are of environmental concern [43].

A.2 Applied processes and techniques

This section gives a brief overview of products, technologies and modes of operations employed within hot and cold rolling mills. It also includes some remarks on the necessity to take account of developments in near-net-shape casting and directly connected hot rolling mills. First of all, the scope of the study is set out in the following sub-section.

A.2.1 Scope of the study

As pointed out in Chapter 1, over 96% of liquid steel were cast continuously in Germany in 1995. For this reason, this study only deals with the processing of liquid steel that is cast the continuous way. Figure A.2-1 shows different process lines for handling liquid steel from continuous casting to final products. The scope of the study comprises the two routes, which take the continuously cast material as an input. Extruding and surface treatment are not covered, because these processes are not points of focus for this study.

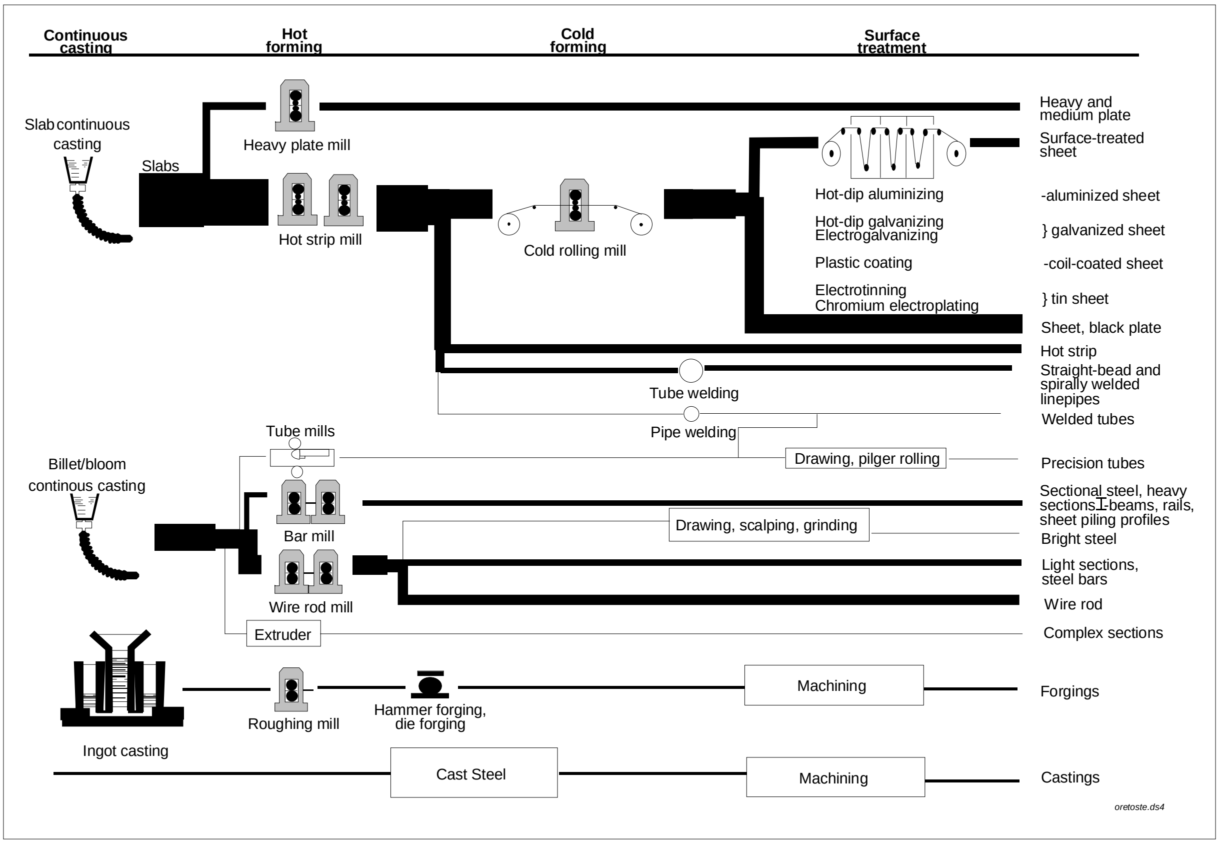

Figure A.2-1: Flow of liquid steel from continuous casting via rolling mills to final products

Source: [150]

Additionally, Figure A.2-2 shows the basic steps within hot and cold strip mills.

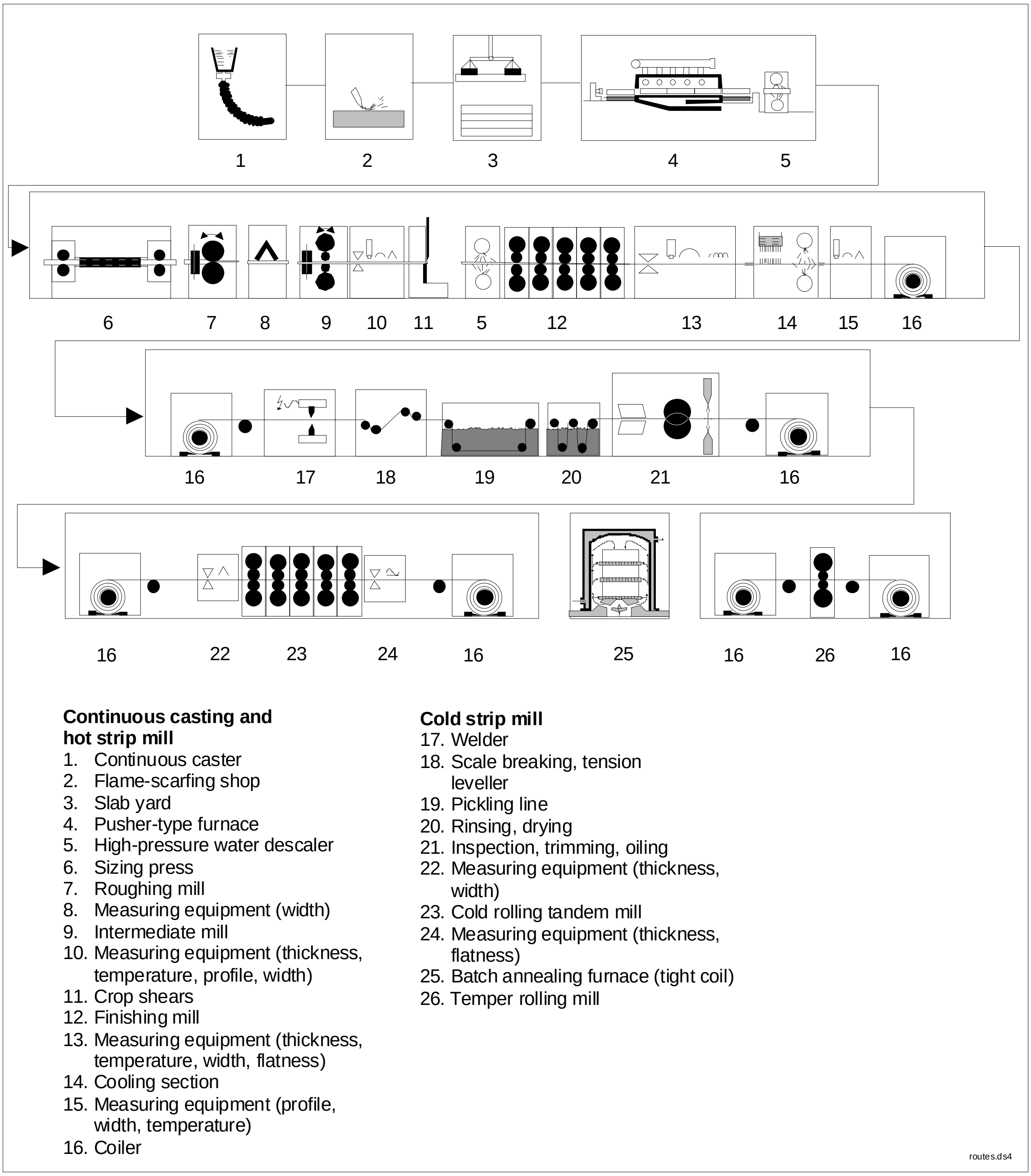

Figure A.2-2: Overview of processes from continuous casting to cold strip mill

Source: [162]

Within the steel industry, a subdivision into main production lines is made principally by the shape of final products and corresponding continuously cast products. Generally, slabs are used for the production of *flat products* and blooms / billets are used for the production of *long (section) products*. Within these two groups a further differentiation according to the final shape of products and the mode of production is common. With respect to the distinction into flat and long (section) products about 31.7% of the total rolled finished products were long (section) steel, about 64.6% were flat steel, and about 3.7% belonged to the special category of seamless tubes (cf. Table A.1-1) in Germany in 1995.

The different shapes of rolled products require different types of rolling mills. For this reason, the next sections briefly present products and technologies of rolling mills in order to form a basis for explaining the differences in their effects on emissions, if any exist. Generally, forming processes can be carried out either at an ambient temperature or at elevated temperatures. This study focuses on rolling as a special forming process; the terms forming and rolling are used interchangeably in this document[2]. However, this use is only correct in the limited scope of this study. According to this distinction, this document comprises the processes:

- Hot forming and
- Cold forming

Hot forming in rolling mills, as considered in this study, comprises the sub-processes surface preparation (scarfing, descaling, shot blasting), (re-) heating, hot rolling and finishing operations, if there are any. Possibly, related downstream activities, like the processing or treatment of recyclable material, are also considered, if it seems appropriate. **Cold forming** includes the sub-processes surface cleaning (mostly pickling), cold rolling, heat treatment (annealing) and finishing operations.

The term hot forming always relates within this study to the processes mentioned including hot rolling, while cold forming implies cold rolling. The study also includes remarks on the direct linking together of continuous (near-net-shape) casting and hot rolling, where it seems appropriate. However, if it is not explicitly mentioned differently, the study covers the processes taking the continuously cast material as an input.

A.2.2 Main products of rolling mills

As mentioned above, products of rolling mills are usually classified into flat products and long products (sections). Furthermore, tubes may be considered as a separate category. According to Stahlhandel [24] **flat products** comprise *plates*, including heavy and medium plates (thickness about 3-150mm), sheets (thickness about 0.5-3mm) and black sheets (thickness <0.5mm), and *other flat products*, eg. hot rolled strip (width <600mm, thickness 0.8-15mm), wide hot strip (width ≥600mm, thickness 0.8-15mm), wide flat steel (four sides rolled, width 150-1250mm, thickness 5-80mm), cold rolled strip (width 4-599mm, thickness 0.03-6mm), and flat steel. **Long products (sections)** include sectional steel (height >80mm) and bars (with profile section, < 80mm height, or complete section, thickness ≥5mm, width ≤150mm), also wire rod is usually classed with this category. **Tubes** may be considered as long products if they are produced directly by special tube mills, or they are produced by welding from flat

2 Drawing, which is also a forming process that can be carried out cold or hot, is not considered in this study, however, it will be addressed within the scope of the TWG Ferrous Metals Processing.

products (strip, plate); they are also often listed separately. The different categories of products sometimes also overlap each other, due to the historically developed terminology.

A.2.3 Hot forming

At increased temperatures, the strength values (yield stress, proof stress, tensile strength) of metals decrease and they become "softer". Also, the possible plasticity at higher temperatures is greater, as a rule, and the metal becomes more ductile [96]. This change of properties with rising temperatures is used for the hot forming of steel. In general, the temperature for hot forming is higher than the recrystallisation temperature of the steel. However, if the applied temperature is too high, a course-grained structure can be formed, which is undesirable. The resulting advantages of hot forming include [40]:

- Improved formability of the workpiece
- Less force required
- Large degree of possible deformation in one step, resulting in a reduction of processing time
- Beneficial effect on the structure and the properties of the workpiece
- Little or no work hardening (if not desired)

Some disadvantages of hot forming are [40]:

- High resource input and related costs for heating the steel in comparison to the energy required for forming
- Inevitable formation of hard and brittle scale on the surface of the workpiece and related tool wear
- Reduced standing time of tools due to the thermal load and increased wear

In Germany a total of 34.316 millions tons of hot rolled products were produced in 1995, both as intermediate and as finished products [152]. The hot forming of steel usually comprises the following main steps:

- Surface preparation
- Reheating
- Descaling
- Hot rolling
- Finishing

A.2.3.1 Reheating of billets / blooms / slabs

Hot forming takes place at rolling temperatures of about 1,070-1,260°C, depending on the type of steel processed [75]. In order to feed the billets / blooms / slabs with this temperature to the rolling mills, they have to be reheated in furnaces. Nowadays, continuous furnaces, in particular,

- pusher-type furnaces (e.g. for blooms, billets, slabs),
- walking-beam furnaces (e.g. for blooms, billets, tubes, slabs),
- rotary-hearth furnaces (e.g. for round bars) or
- inductive furnaces (e.g. for soaking of near-net-shape products)

are usually used for this task [85]. The continuously cast material is usually charged cold (at about 20°C) or warm or hot (600°C-800°C) into the furnaces and is heated up to the required entrance temperature of the rolling mill. The furnaces usually consist of the three zones preheating, heating and homogenisation in order to supply the metal with the right temperature, both on the surface and internally (soaking).

A.2.3.2 Near-net-shape casting and connected hot rolling

The scope of the TWG Ferrous Metal Processing does not explicitly include continuous casting. However, as a direct linking together of continuous casting and hot rolling saves a significant amount of energy input, it would seem appropriate to discuss this topic briefly[3]. Modern near-net-shape casters with direct charging at about 1,100°C avoid the costly reheating of slabs or beams and only need about 25-55 kWh/t energy for soaking, which can be supplied by different types of gases (e.g. natural, BF, Coke oven or Corex gas) [134]. On the other hand, cold charging of slabs at about 20°C requires an energy input of about 1.4-2.2 GJ/t (about 375-640 kWh/t) or more [18, 75]. Figure A.2-3 shows in principle 4 different concepts of hot strip production. Whereas the first two concepts can be considered as conventional technology (slab casting and processing to strip) and improvements to it, the latter two aim to produce strip directly by casting. However, these technologies are still under development and have not been applied on an industrial scale yet [18]. It should be mentioned, that warm or hot charging of continuously cast blooms within conventional plants also saves a considerable amount of energy.

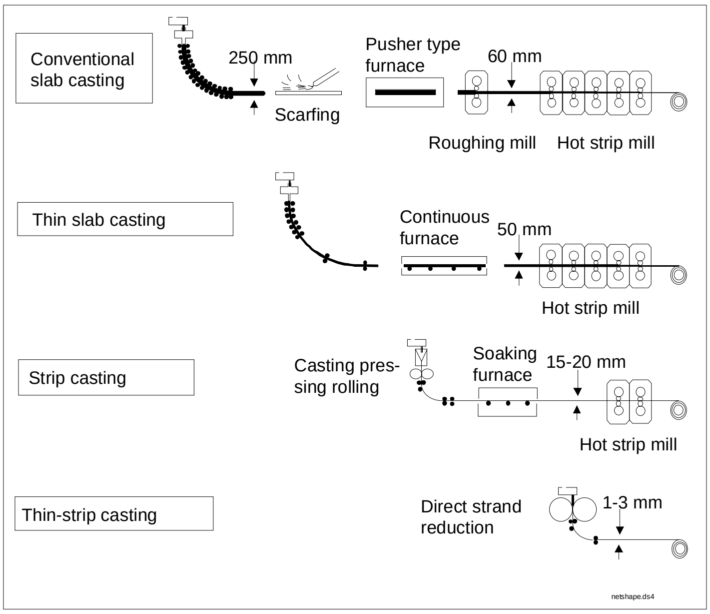

Figure A.2-3: Selected development stages of strip production

Source: [108]

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3 The TWG Iron/Steel also deals with this topic, cf. for example Dutch Notes on BAT for Production of Primary Iron and Steel, The Hague, 1997.

The actual technical implementation of the depicted production facilities may differ from Figure A.2-3, depending on the plant manufacturer. Although near-net-shape production has significant advantages especially with respect to energy efficiency, it can not be applied in all cases [168], for example the technology is still not suited for the processing of stainless steels [26]. In Chapter 6 more details are given on recent developments of these technologies.

A.2.3.3 Production of flat products

Flat products have a rectangular cross section, where the width is significantly greater than the thickness. Their surface is generally even and smooth, though sometimes a regular pattern of raised or depressed areas may be produced, e.g. grooves or tears, for checker plate, button plate or bulb plate [24]. Main flat products of hot rolling mills are plate and hot-rolled strip. Also wide flat steel plate belongs to this category, but this product is usually produced by cutting from plate or hot strip, nowadays, and not obtained by using an extra universal roll stand [40]. The next section briefly characterises the production of (wide) hot strip and plate.

A.2.3.3.1 (Wide) Hot strip

In Germany, almost 50% of the crude steel produced is processed to wide hot strip [99]. In 1995, 42,051 million tons of crude steel resulted in 34,316 million tons of hot rolled products, of which 19,806 million tons were wide hot strip [152].

The raw material for hot strip rolling consists of continuously cast slabs, in most cases. These are usually about 160-300mm thick, 600-2200mm wide and 5-16m long, depending on the shape of the hot strip [75]. Generally, hot (wide) strip mills contain most or all of the following installations or sub-processes:

- Inspection and possibly scarfing
- Furnace (usually pusher type furnace or walking beam furnace)
- Descaling plant
- Roughing mill (e.g. 4-high-stand reversing mill, possibly more 4-high-stands in tandem, vertical rolls or press)
- Roller table
- Coil box
- Crop shears and descaling plant
- Finishing mill (5-7 stands)
- Water cooling
- Reeling plant

Figure A.2-4 shows a schematic view of a hot wide strip mill with a capacity of about 5 million t/a wide hot strip. This mill shows all the above mentioned features, except the coil box before the crop shears.

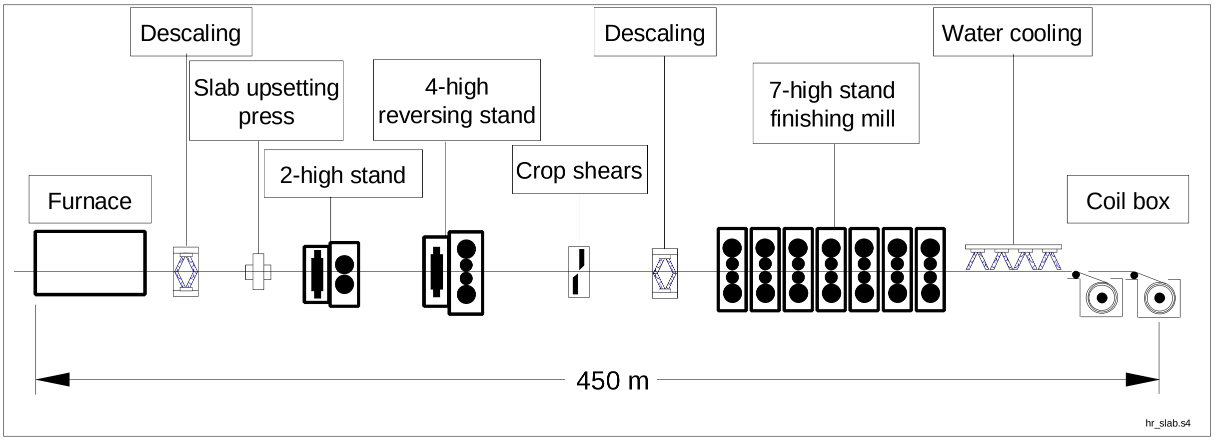

Figure A.2-4: Diagrammatic view of a wide hot strip mill

Source: [127]

In hot strip mills the slabs are charged cold (20°C), warm or hot (600-800°C) into the furnaces (pusher type or walking beam type) and heated to 1,080-1,260°C, depending on the type of steel processed. Usually, the slabs are inspected (hot) and possibly flame scarfed before entering the furnace. This can be done manually or automatically by torches. If near-net-shape concepts are applied and slabs are directly charged (at 1,050-1,150°C), only (inductive) warming of the edges of the slabs is necessary (cf. Figure A.2-3). However, this requires a high surface quality of the continuously cast material. Before entering the roughing mill, the slabs are descaled by high pressure water washers (usually at about 150-170bar, but also above). In the roughing mill section the thickness of the slabs is reduced to 20-60mm. A coil box can be installed between the roughing mill and the crop shears, inter alia in order to homogenise the temperature profile of the strip and to shorten the roller table. The crop shears cut the beginning and the end of the slabs, then they are descaled again by high pressure water washers (at about 130-160bar). In the finishing mill, which usually consists of four to seven 4-high-stands, the thickness of the slabs is reduced to about 1.5-20mm. Subsequently, the strip is cooled down specifically, usually by laminar cooling, to reach a reeling temperature of about 500-780°C. Finally, the strip is reeled with a reeling machine. It is important to maintain a specified rolling temperature over the length of the strip to get constant mechanical properties. Sometimes reversing stands are used to produce hot strip (so-called Steckel mills).

Conventional hot strip mills produce about 1-5 million t/a of rolled products, near-net-shape caster and connected finishing mills up to 1 million t/a per line, and Steckel mills about 0.4-0.7 million t/a [40, 73]. Table A.2-1 gives a list of German (wide) hot strip mills with selected data.

Table A.2-1: Wide hot strip mills in Germany (examples, cap.>250,000 t/a)

Operator at the moment	Location	Type	Length [m]	Capacity[4] [Tton/a]	Barrel length [mm]
EKO Stahl AG	Eisenhüttenstadt	Hot strip	312	1,500	~1,800
Preussag Stahl AG	Salzgitter	Hot strip	474	2,900	2,080
Stahlwerke GmbH	Bremen	Hot strip	661	3,000	2,300
Thyssen Krupp Stahl AG	Beeckerwerth	Hot strip	611	5,150	2,250
Thyssen Krupp Stahl AG	Dortmund	Hot strip	476	4,000	1,700
Thyssen Krupp Stahl AG	Bochum	Hot strip	497	4,000	1,800
Thyssen Krupp Stahl AG	Bruckhausen	Hot strip	463	3,350	1,500

Source: [Firm data, own compilation, 138]

A.2.3.3.2 Plates

3.619 million tons of plates (medium and heavy plate) were produced in Germany in 1995. The input material usually consists of slabs, sometimes also slab ingots for the production of heavy plates (thickness>100mm), because of their large mass. Figure A.2-5 shows the technological course for the production of heavy plates [75]. For production generally 4-high-stands are used nowadays, possibly complemented by a cogging stand. The rolls of heavy plate mills can show a maximum width of about 5m. Heavy plates have a geometrical spectrum of 3-160mm thickness, 1,000-3,500mm width (sometimes up to 5,000mm), and a length between 8-30m, with a maximum of 40m. Heavy plate mills usually produce outputs between 0.4-1 million t/a [40, 75]. Table A.2-2 supplies a list with selected German plate mills.

[4] Stated capacities and other technical data for this and all following tables are approximate figures in thousand tons per year and are subject to change. The capacities are stated in steps of 25 thousand tons. They do not necessarily correspond to actual production figures.

Table A.2-2: Plate mills in Germany (examples, cap.>250,000 t/a)

Operator at the moment	Location	Type	Capacity [Tton/a]
AG der Dillinger Hüttenwerke	Dillingen	Plate	1,550
Preussag Stahl AG	Ilsenburg	Plate	700
Thyssen Krupp Stahl AG	Duisburg-Hüttenheim	Plate	900

Source: [Firm data, own compilation, 138], cf. footnote 4

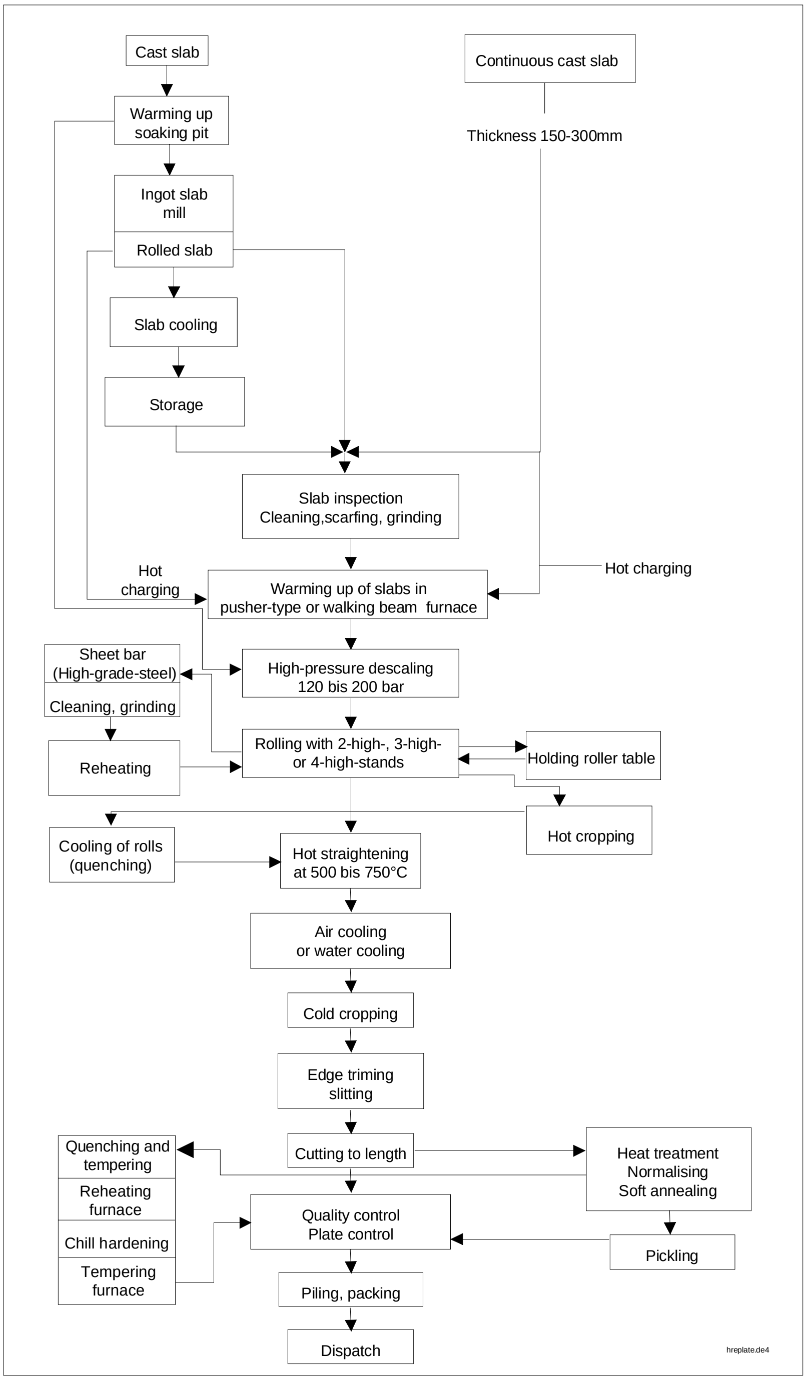

Figure A.2-5: Technological course for the production of heavy plates

Source: [75]

A.2.3.4 Production of long products (sections)

Long products (sections) show a constant cross-sectional area throughout their length, but are usually of variable thickness over the cross-section [40]. Long products include bars and wire rod, sectional steel, and special steel sections [24]. 10,698 million tons of section products were produced in Germany in 1995. The most important categories are (rolled) wire rod (5,436 million tons) as well as bars (3,008 million tons) with a share of 79% together. Wide flanged beams (0.917 millions tons) and structural steel (0.830 million tons) account for about 16% of long products. Sheet piling products and superstructure products (e.g. rails) are quantitatively of minor importance (together about 5%). However, these are qualitatively superior products, in particular rails.

Most long products are formed between grooved rolls in two-high or three-high stands. Parallel flanged beams are produced in universal stands, which can also be used for rolling rails [40]. The wide range of shapes and sizes of long products requires a large number of roll pass designs, and a wide range of rolling mill layouts. Depending on the production program, a comprehensive stock of rolls is required, which can include several thousand sets. The term "rolling mill" includes in this case all equipment required for rolling the material, and also the equipment for feeding, descaling, edging, guiding, hot cutting, and coiling. Mills for long products can be classified according to [40]:

- The arrangement of the stands and the route taken by the material being rolled (e.g., open or continuous mills)
- The roll diameter and / or the product (e.g., a 550mm mill for medium sized products)

In the following, technologies for the production of wire rod, light bars, and heavy- and medium-sections are presented briefly.

A.2.3.4.1 Wire rod, light sections (bars)

The development of the technology of steel wire production is characterised by [40, 75]:

- High final rolling speeds of about 60-120m/s for commercial steels and 30-60m/s for high-grade steels
- Tight tolerances for the workpiece (about ± 0.12mm for 1-strand, ± 0.15mm for 2-strand and 0.2mm for 4-strand rolling mills, with respect to a 5.5∅mm final rolling diameter)
- Modern cooling lines for accelerated, retarded or slow cooling of the workpiece
- New rolling train concepts, including twist free roll blocks, intensive forming, and continuous rolling mills for high-grade steels

For the increased rolling speeds, larger cross sections of the continuously cast material can be used for the initial pass, without leading to a too low rolling speed at the first stand. High performance wire mills have led to an increase of the coil mass to up to 1,200-2,000kg or more. Modern plants need to satisfy high requirements with respect to surface quality, dimensional accuracy, mechanical properties of the workpieces, variability of production programs and input [67]. Steel wire rolling mills usually comprise the following parts [75]:

- Rod mill rougher (instead of cogging mills also high reduction machines can be used)
- Intermediate wire mill
- Wire rolling train
- Water cooling
- Layer and transporting facilities
- Shears at several places

Modern multi-strand wire rod mills show production capacities of 700,000 t/a [40] up to over 1,000,000 t/a [10].

The production process for light section steel (light bars) is similar to the process for production of wire, so combined wire rod / bar mills are often operated [40]. Table A.2-3 and Table A.2-4 show examples for wire rod and bar mills in Germany.

Table A.2-3: Wire rod mills in Germany (examples, cap.>250,000 t/a)

Operator at the moment	Location	Type	Capacity [Tton/a]
Badische Stahlwerke GmbH	Kehl	wire rod	1,100
Brandenburger Elektrostahlwerke GmbH	Brandenburg	wire rod	300
ISPAT Hamburger Stahlwerke	Hamburg	wire rod	350
Krupp Thyssen Nirosta GmbH	Krefeld	wire rod	325
Saarstahl AG	Burbach	wire rod	1,000
Saarstahl AG	Neunkirchen	wire rod	375
n.a.	Duisburg-Hochfeld	wire rod	950

Source: [Firm data, own compilation, 138], cf. footnote 4

Table A.2-4: Bar mills in Germany (examples, cap.>250,000 t/a)

Operator at the moment	Location	Type	Capacity [Tton/a]
Badische Stahlwerke GmbH	Kehl	bar	500
Elbe Stahlwerk-Feralpi GmbH	Riesa	bar	450
Elbe Stahlwerk-Feralpi GmbH	Riesa	bar	300
Hennigsdorfer Elektrostahlwerke GmbH	Hennigsdorf	bar	800
Hennigsdorfer Elektrostahlwerke GmbH	Hennigsdorf	bar	800
ISPAT Hamburger Stahlwerke GmbH	Hamburg	bar	500
Krupp Edelstahlprofile GmbH	Siegen-Geisweid	bar	450
Krupp Thyssen Nirosta GmbH	Krefeld	bar	375
Lech-Stahlwerke GmbH	Meitingen	bar, hi.-gr. steel	350
Saarstahl AG	Neunkirchen	bar	575

Source: [Firm data, own compilation, 138], cf. footnote 4

A.2.3.4.2 Heavy-, medium-sections

Heavy-, and medium-section mills usually consist of a cogging mill, an intermediate mill and a finishing train [75]. Also cooling beds for a controlled cooling of the bars are part of these rolling mills. There is a multitude of possible different plant types on the one hand, but no significant different effects on emissions and by-products on the other, thus no further description of plants is necessary. For a more detailed technological coverage of this topic cf. [75]. Table A.2-5 gives examples for section mills in Germany.

Table A.2-5: Section mills in Germany (examples, cap.>250,000 t/a)

Operator at the moment	Location	Type	Capacity [Tton/a]
Georgsmarienhütte GmbH	Osnabrück	sections	400
NMH Stahlwerke GmbH	Sulzbach-Rosenberg	sections	425
Preussag Stahl AG	Peine	section	550
Saarstahl AG	Völklingen	sections	475
Saarstahl AG	Völklingen	sections	450
Stahlwerk Thüringen GmbH	Unterwellenborn	sections	600
Thyssen Krupp Stahl AG	Dortmund	heavy sections	325
Thyssen Krupp Stahl AG	Bruckhausen	sections	350

Source: [Firm data, own compilation, 138], cf. footnote 4

A.2.4 Cold forming

For many applications, the products of hot forming are not satisfactory [40]. In particular, cold forming is used for the production of thin strip. Additionally, cold rolling is sometimes applied for the production of wires and tubes. However, by far the most important application is the production of cold rolled strip, for this reason this study only deals with that case. The advantages of cold rolling are [75]:

- Production of thinner strip than by hot rolling
- Production of blank surface with little depth of roughness
- Production of strip with narrow gauge tolerance and even surface over width and length
- Good control of strengthening
- Control of physical characteristics

In cold rolling, usually no heat is applied to the workpiece before forming. Only some special steels like spring steel, tool steel, tempering steel or alloyed steels may be subject to heat treatment before pickling and rolling [75]. However, frictional energy at the contact surfaces of the workpiece is also converted to heat. This heat may increase temperatures in rapid adiabatic processes over 100°C [40]. Figure A.2-6 shows the principle steps within the production of cold strip. The processing of steel in cold rolling mills differs considerably from the production in hot rolling mills. The raw material is first descaled (usually pickled, sometimes shot blasted and pickled), then cold rolled and heat treated. Further treatment steps include slitting, skin-pass rolling, coiling and packing [40, 75].

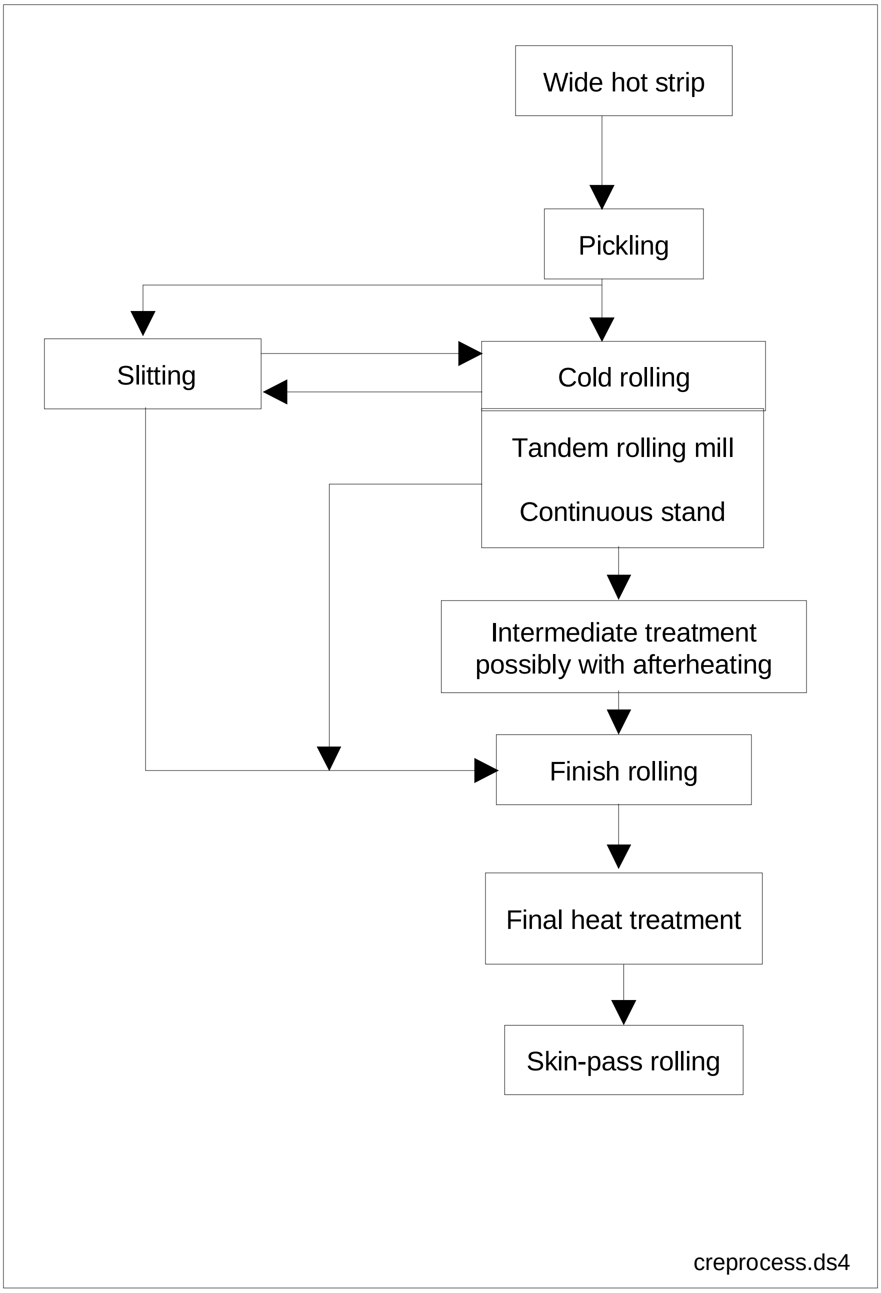

Figure A.2-6: Technological course of cold strip production

Source: [75], adapted

Cold rolled strip or plate production amounted to about 11.51 million tons in Germany in 1995. Furthermore, about 0.57 million tons of electric quality sheet were produced [152].

A.2.4.1 Surface preparation

Hot rolled steel always has a layer of scale of variable structure on its surface, depending on the conditions of hot rolling. In order to achieve good surface quality and better frictional behaviour, the strip has to be descaled before cold rolling. Descaling is usually done chemically (continuously by pickling) only or in combination with mechanical means (stretching, levelling abrasive blasting, rolling). Pickling removes oxides and mill-scale from the surface of steel. Unalloyed steel is usually pickled by the action of an inorganic acid, generally sulphuric or muriatic acid, diluted with water [81]. For stainless steels there is no single acid that is able to remove all types of scale layers. However, most commonly for the pickling of stainless steels nitric acid / fluoric acid mixtures are used. Furthermore, electrolytical pickling enhances the descaling of alloyed steels, that are otherwise hard to pickle [131]. Pickling can be carried out by push pickling or by continuous pickling installations. Figure A.2-7 shows a scheme of a modern continuous pickling plant. Carbon and low alloyed steels are usually pickled in 20-30% sulphuric acid at 95-105°C or in 15-20% muriatic acid at 60-70°C in fully enclosed pickling baths [40, 75, 131]. Large continuous pickling lines have capacities of up to 2.4 million t/a of steel [148].

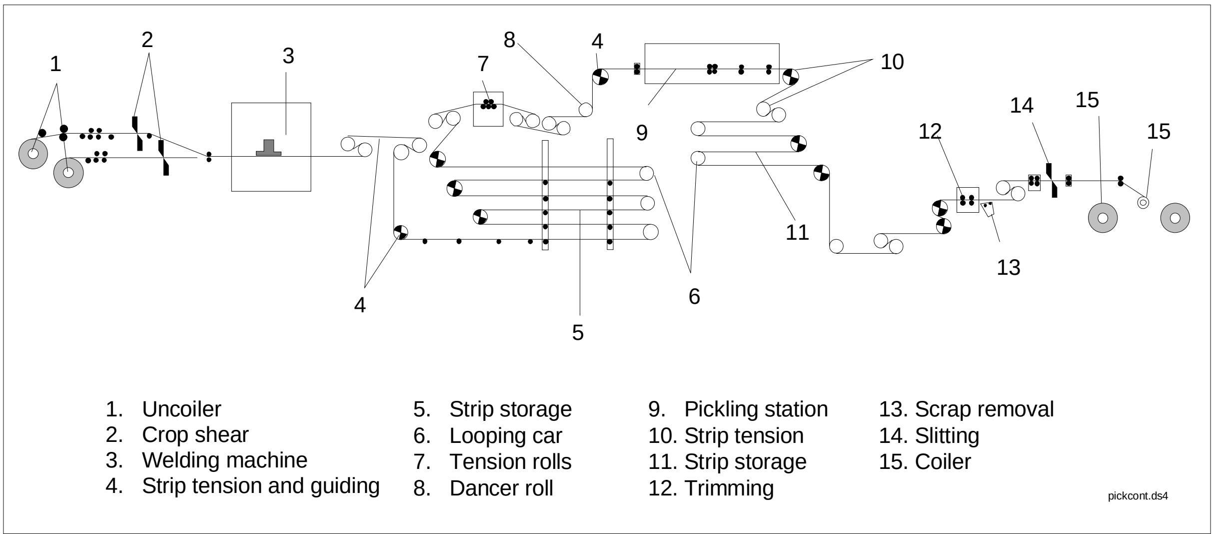

Figure A.2-7: Diagrammatic view of a continuous pickling plant

Source: [148], adapted

A.2.4.2 Cold rolling

Cold rolling of the pickled hot strip reduces its thickness from about 1.5-5mm down to about 0.02-4mm, depending on the type of steel and on the desired product [75]. Rolling is usually carried out either with so-called tandem mills, which are two to six 4-high-stands in a row, or with cluster mills, having 6 to 20 rolls, also 2-high-mills are sometimes used. Rolling can be done continuously or reversing. Cluster mills have two small working rolls and many supporting rolls. This configuration allows the exertion of high pressure on the strip and the rolling of very thin sheets. However, the capacity of continuous tandem cold rolling mills is a lot larger. They are used for big lot sizes and annual capacities over 500,000 tons. Tandem mills with 4-5 stands have capacities of up to 1.5 millions t/a, or even 2.3 million t/a in particular cases [75, 148]. Figure A.2-8 shows a diagram of a continuous cold rolling mill and Table A.2-6 selected examples of cold rolling mills in Germany.

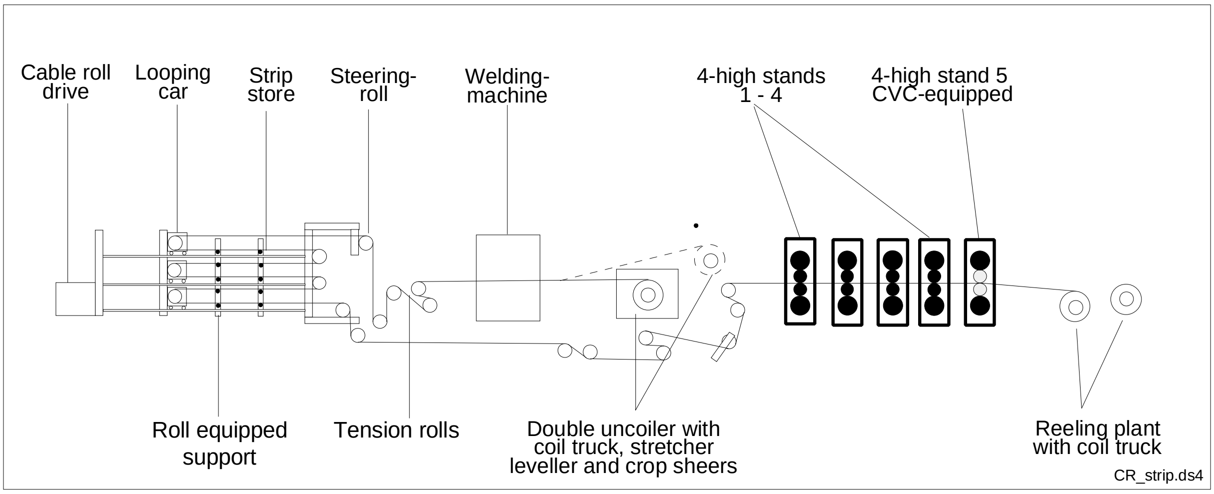

Figure A.2-8: Diagrammatic view of a continuous cold rolling mill

Source: [148], adapted

Table A.2-6: Cold rolling mills in Germany (examples, cap.>250,000 t/a)

Operator at the moment	Location	Type	Capacity [Tton/a]
EKO Stahl GmbH	Eisenhüttenstadt	CR coil	400
EKO Stahl GmbH	Eisenhüttenstadt	CR coil	1,025
Preussag Stahl AG	Salzgitter	CR coil	1,300
Rasselstein Hoesch GmbH	Andernach	CR coil	1,300
Rasselstein Hoesch GmbH	Andernach	CR coil	775
Rasselstein Hoesch GmbH	Neuwied	CR coil	425
Stahlwerke Bremen GmbH	Bremen	CR coil	1,500
Thyssen Krupp Stahl AG	Dortmund	CR coil	1,800
Thyssen Krupp Stahl AG	Dortmund	CR coil	575
Thyssen Krupp Stahl AG	Bochum	CR coil	1,250
Thyssen Krupp Stahl AG	Beeckerwerth	CR coil	1,700
Thyssen Krupp Stahl AG	Bruckhausen	CR coil	1,375

Source: [Firm data, own compilation, 138], cf. footnote 4

A.2.4.3 Annealing

During the annealing process the steel is directly heated to a determined temperature, usually with a longer holding period to attain soaking, and then slow cooling [38]. The process aims to influence the microstructure and internal stress of steel towards a uniform and stable state. According to the task and temperature-time combination, stress relieving-, softening-, recrystallisation-, normalising-, and diffusion-annealing are distinguished. Annealing can be carried out batch-wise or continuously. The lower temperature limit of annealing processes for steel is at about 600°C [173]. Figure A.2-9 shows a continuous annealing furnace. Batch-wise annealing by means of hood-type furnaces is depicted in Figure A.2-10. In these furnaces the coils are heated by convection in an inert gas atmosphere. The heat is usually produced by a combustion process between the protection hood and the heating hood, for example. A disadvantage of this technology is that the annealing temperature should not exceed about 700°C, as otherwise the coils may suffer damage [85].

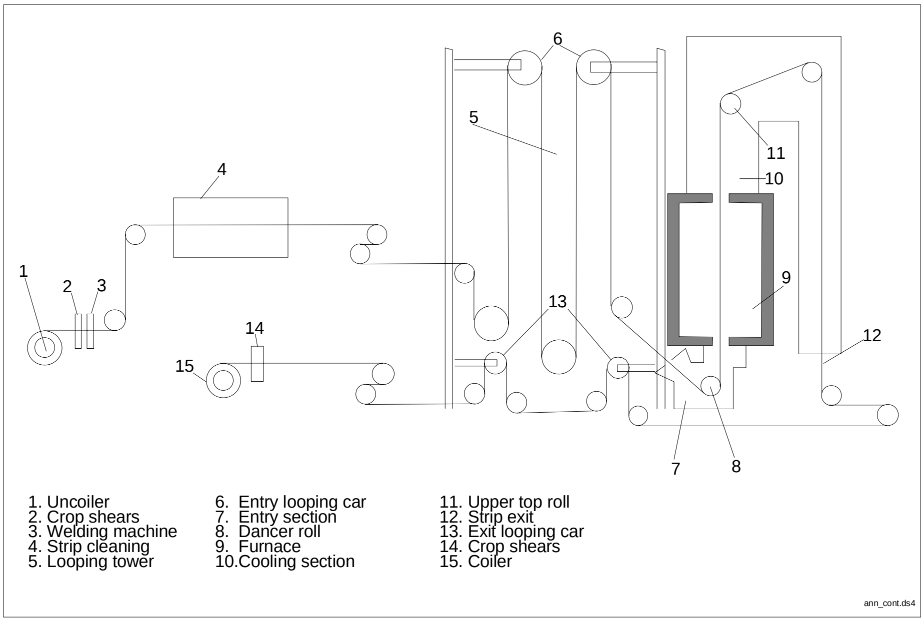

Figure A.2-9: Diagrammatic view of a continuous annealing furnace

Source: [148]

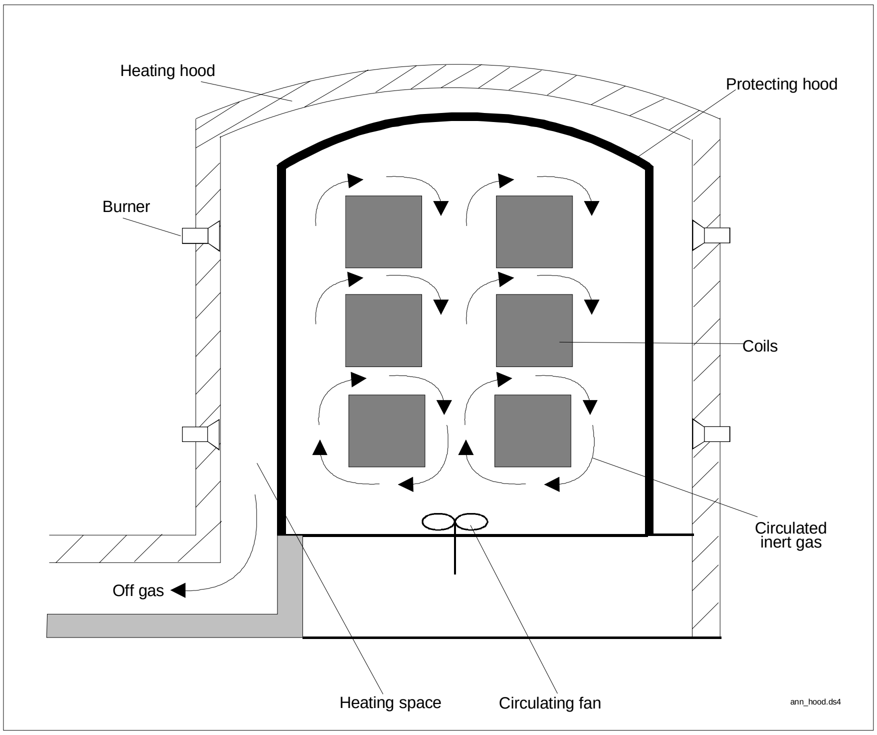

Figure A.2-10: Diagrammatic view of a hood-type annealing furnace

Source: [85]

A.2.4.4 Skin pass rolling

An annealed strip is cold re-rolled with a thickness reduction of about 0.5-3% in order to level or roughen and compress the strip surface, to improve the stracking factor of electro-plate, and to decrease the tendency of sheets to form crease lines and flow lines.

A.2.5 Production of tubes

Tubes are usually distinguished by their way of production. They can be produced either *seamless* from (continuously cast) round bars or sometimes also from square bars by

- piercing, elongating, final rolling

or with *seam (welded)* by

- longitudinal welding or
- spiral welding

from cold- or hot-rolled strip, hot-rolled wide strip, or thick plate. A detailed description of the processes for tube production can be found inter alia in [75]. The following sections just briefly point out main features of the processes. In 1995, about 1.25 million tons of seamless tubes, 1.46 million welded tubes, 0.19 million tons precision tubes (seamless) and 0.6 million tons precision tubes (welded) were produced in Germany [152].

A.2.5.1 Seamless tubes

The production of seamless tubes is roughly characterised by the above mentioned steps. Furthermore, production includes the heating of the billets, which is usually done in a rotary hearth furnace before the piercing step [40]. For high quality requirements, heat treatment is carried out after final rolling. Table A.2-7 presents a selection of German tube mills for seamless production.

Table A.2-7: Seamless tube mills in Germany (examples, cap.≥100,000 t/a)

Operator at the moment	Location	Type	Capacity [Tton/a]
Benteler AG	Paderborn	tube, seamless	225
Benteler AG	Dinslaken	tube, seamless	110
Mannesmannröhren-Werke AG	Düsseldorf	tube, seamless	100
Mannesmannröhren-Werke AG	Düsseldorf	tube, seamless	100
Mannesmannröhren-Werke AG	Mülheim	tube, seamless	100
Mannesmannröhren-Werke AG	Mülheim	tube, seamless	100
Mannesmannröhren-Werke Sachsen GmbH	Zeithain	tube, seamless	175
n.a.	Schwalbach / Bous	tube, seamless	125

Source: [Firm data, own compilation, 138], cf. footnote 4

A.2.5.2 Welded tubes

The share of welded tube production is still higher than that of seamless tube production, despite the fact that the input material, usually cold rolled strip, involves considerable costs. This is mainly for 3 reasons [75]:

- Very big tubes (∅>660mm) are usually produced by welding only
- Improvement of welding processes to get good quality
- Production of strip at reasonable costs

There are mostly two types of welding processes employed [40]:

- Pressure welding
- Fusion welding

Tube production by either process involves at first forming of the strip. Then the welding takes place. The finished tubes can be either hot or cold hardened, if necessary [40]. Table A.2-8 shows selected German tube mills employing welding processes.

Table A.2-8: Welded tube mills in Germany (examples, cap.≥100,000 t/a)

Operator at the moment	Location	Type	Capacity [Tton/a]
Bergrohr GmbH	Siegen	tube, welded	100
Eisenbau Krämer mbH	Siegen	tube, welded	125
Europipe GmbH	Mülheim	tube, welded	150
Europipe GmbH	Mülheim	tube, welded	150
Rohrwerke Muldenstein GmbH	Muldenstein	tube, welded	100
Mannesmann Hoesch Präzisrohr GmbH	Hamm	tube, welded	175
Mannesmann Hoesch Präzisrohr GmbH	Hamm	tube, welded	175
Preussag Stahl AG	Salzgitter	tube, welded	150
Röhrenwerk Gebr. Fuchs GmbH	Siegen	tube, welded	125
Rudolf Flender GmbH & Co. KG	Siegen	tube, welded	150

Source: [Firm data, own compilation, 138], cf. footnote 4

A.3 Present consumption / emission levels in the rolling industry

This section contains information on currently observed levels of energy input, raw material input and water input, as well as information on quantities of solid outputs, waste water and effluents, and emissions arising within rolling mills, and the related sub-processes.

A.3.1 Inputs and outputs caused by hot forming

Hot forming, as considered in this study, includes the sub-processes surface preparation (mainly descaling and shot blasting), reheating, hot rolling and finishing of the workpieces. Figure A.3-1 gives an overview of selected relevant input and output streams in a hot strip mill with respect to environmental concerns. The identified relevant input / output streams are to a large extent representative for all types and sizes of rolling mills mentioned before, if the corresponding sub-processes exist. However, this is only true with respect to the existence of the streams, but not necessarily with respect to their quantity and composition. The arising releases generally depend on factors like product shape, mill type, mode of operation, steel grade, etc.

A major concern on the *input* side is the energy source supplying the energy needed to reheat the workpiece to the required rolling temperature, because it mainly determines the arising emissions. Energy sources are usually gas (natural, coke oven, BOF, BF, mixed, etc.) or oil.

Important outputs (*outputs* besides main products) related to the hot forming process are [82, 83, 168]:

- Emissions into the air by reheating furnaces (e.g. NO_x, SO_x, CO_x, particulate), depending on the type of fuel
- Scale by surface preparation (reheating-, mill-scale), crops, cobbles, scrap and samples, trimming and cutting scrap, scrapped coil as well as downgrades (by metallurgical, geometrical defects)
- Water used for cleaning, transport and cooling, possibly contaminated by scale and oil

In the following sub-sections, inputs and outputs of the sub-processes surface preparation, reheating, cooling and descaling, as well as hot rolling and finishing are presented.

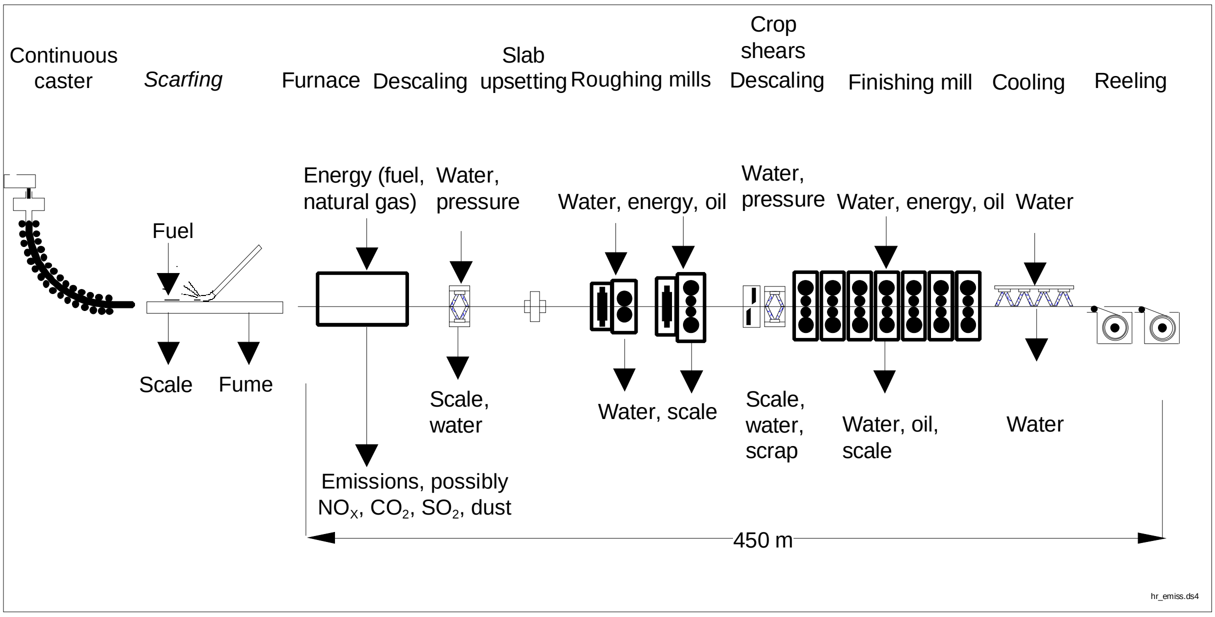

Figure A.3-1: Selected inputs / outputs of a hot strip mill

A.3.1.1 Surface preparation

In order to ensure the desired quality of the finished products it is usually necessary to clean at least a share of the slabs / blooms from surface defects resulting from earlier production stages (usually continuous casting, but also annealing). Depending on the method of cleaning (automatic or manual flame scarfing with oxygen or oxy-acetylene torches, grinding, shot blasting) and the quality of steel differences arise in the amount of the resulting *scale*.

With plate production a share of *0.3 to 1%* losses during cleaning (scarfing) can be expected, for example [75]. Figures reported by the European Commission [43] range from *0.2kg/t to 35kg/t* solid by-products (scale) arising when scarfing / grinding / shot-blasting with an average of 3.5kg/t.

Correspondingly, according to [43], about *1.5-3.25kg/t* dust (oxide fume) from scarfing is collected at selected plants, if the gas is cleaned. The same source states *250-1,000g/t* of dust collected from grinding and shot blasting sections to be fairly representative for the total dust emissions (collected in the filter and emitted) from large sized plants.

There are no figures available for the required fuel input.

A.3.1.2 Inputs / outputs related to reheating

Reheating furnaces usually use *gases* (e.g. natural, coke oven, BOF, BF, mixed) or *oil* as fuel inputs [26]. The furnaces are lined with *refractory material*. The direct heating processes within the furnaces possibly give rise to emissions of:

- NO_x

- *SO_x*
- *CO, CO_2*
- *Particulates*

The existence and quantity of these emissions depend mainly on the type of fuel used. NO_x is generated by all types of fuel due to the high combustion temperatures in reheating furnaces. However, its formation can be at least partly influenced by the factors temperature of the combustion process, excess air, excess of oxygen, burner design, and air preheat temperature [46, 168].

Next to the emissions into the air *scale* arises on the surface of the slabs from oxidation processes. The rate of oxide formation depends on the temperature, composition and physical characteristics of the steel and is also influenced by the temperature and flow conditions in the atmosphere surrounding the hot metal. Furthermore, the degree to which scale forms is a function of the length of the time that the steel is exposed to oxidising conditions, the types of steel product being manufactured (i.e. surface area), and whether direct or hot charging (i.e. rolling of steel immediately after it is cast) is carried out [82]. Material losses due to oxidation are about 1-3% [108]. The reheating scale is usually removed before the slabs / blooms enter the rolling stands, in order to avoid rolling it in the workpiece. Table A.3-1 gives an overview of approximate numbers of input and outputs streams of reheating furnaces. However, it should be noted, that the stated numbers may vary significantly with respect to a change in parameters like furnace size and type or fuel employed.

Water is required in this section for cooling purposes on the furnace [168].

Table A.3-1: Input / output levels of reheating furnaces

Input		**Output**	
Slabs, blooms, billets	1,010-1,030 kg/t	Slabs, blooms, billets	1,000kg/t at about 1,150°C
Energy (varies with charging temperature, 20-1,100°C)	0.1-1.5 GJ/t	Emissions to air:	(depending on fuel input)
Possible fuel types:	Gas (e.g. Natural, BF, Corex)	NO_x	25-500g/t
	Oil	CO_x	n.a.
	Fuel-mix	SO_x	0.02-900g/t
Cooling water	closed loop	Dust	0.2-30g/t
Refractories	n.a.	Scale (charging at 20°C)	5-28 kg/t
		Refractory breaks	n.a.

Source: [several sources, i.a. 18, 85, 43, 75]

A.3.1.3 Water use for cooling and descaling

Water is used within hot rolling mills for the main purposes direct and indirect cooling as well as for descaling and scale transport. It is employed within all sub-processes of hot forming (e.g. reheating furnace: furnace cooling, descaling: abrasive medium, rolling section: cooling, rinsing, scale channel: transport, roller table: directed cooling, rinsing). Direct and directed cooling is necessary in order to obtain the desired metallurgical properties of the workpiece and to cool the rolls. The water used after the reheating furnaces serves primarily for descaling, then within the rolling train it is used both for descaling of the workpiece as well as for cooling the rolls and the workpiece. After the last stand (laminar) water cooling serves for directed cooling in order to obtain specific metallurgical properties.

Descaling is required in order to prevent quality defects of the workpiece. As already mentioned, the scale arising within the reheating furnaces has to be removed before entering the rolling trains. Descaling is also done after cogging and within the finishing train, as scale forms also during the rolling process due to the elevated temperatures above 1,000°C and the resulting temperature rise for the deformation work. Within hot rolling mills descaling is usually performed by high pressure water jets, by scale breaking roughing mills or by a combination of both. In modern plants it is common to use high pressure water jets, but also the cogging trains help to break scale. For example, the jet pressure is about 160bar for hot strip production and for plate production 180-400bar [75]. The components of the descaling process with water jets are breaking of the scale layer through the high kinetic energy of an impinging water jet, the detachment of the scale layer through shrinkage of the parent metal and scale caused by shock quenching, the blasting-off of the scale through explosive type vaporization of the water drops underneath the scale layer, and the flushing away of the detached scale through an inclination of spray jets to the surface [21]. The amount of water used for descaling can be generally estimated at 0.1-0.12m^3/s within the cogging train, 0.05-0.06m^3/s in front of the finishing train and 0.03-0.04m^3/s within the finishing train [75]. The scale arising at reheating furnaces depends on the type of product and ranges within the following amounts at selected plants [43]:

- Plates (reversing 4-high stands) 0.5-18kg/t, average 4.5kg/t
- Hot strip 0.1-3.3kg/t, average 0.85kg/t, extreme figure 11kg/t
- Sections (blooming, billet mills, heavy sections) 0.5-47kg/t, average 24kg/t
- Sections (light and medium bar and section) 1-10kg/t, average 4.9kg/t, three extreme figures 25-30kg/t
- Wire 0.3-12kg/t, average 4kg/t, three extreme figures 18-20kg/t

An investigation by IISI [83] states the following reference yields[5] for the scale losses arising:

- Hot rolled coil: 0.7%, range of supplied data 0.5-2.0%
- Section mills (angles, medium sections, rails): 1.0%, range of supplied data 0.5-3.9%
- Heavy sections: 1.4% (best), range of supplied data 1.4-2.0%
- Rod and bar mills: 0.6%, range of supplied data 0.2-2.0%

[5] Reference yield as considered in [83] means that "the reference can be considered as representative of achievable, not necessarily the very best, yield". The study is based on an investigation basically carried out between 1990 and 1992. 95 works or shops participated in this study and supplied data.

Normal mill scale is relatively coarse, with 85 to 90% of the constituent particles >0.15mm. The iron content is about 70% (on an oil and moisture free basis) with less than 4% silica, alumina, lime and magnesia [82].

The process water used for descaling directly after the furnace is usually oil-free. The process water used for descaling within the hot rolling section mostly contains oil because of bleeding. As the two waste water streams are usually mixed in the sinter channel, the result is one oil containing scale loaded waste water stream. A share of the scale load can be easily separated from the waste water. As the oil content of this share is usually sufficiently low, it can be easily recycled to metallurgical processes via the sintering strand.

A.3.1.4 Hot rolling section

As shown in Chapter 2, the production routes for long and flat products differ considerably. For this reason also the material flows of the rolling sections differ to some extent. For the hot rolling of flat products the mills are considered to comprise cogging (usually 2-high stands) and intermediate (usually 4-high stands) trains and the finishing train (4-high stands) as well as crop shears for strip production and one or two reversing 4-high stands and shears for plate production.

For the production of long products the mills usually consist of a series of reversible 2- or 3-high stands, that make the blooms pass gradually through the different grooves shaping its cross-section until the product is finished.

The main inputs in the hot rolling section are:

- *Reheated* slabs and blooms / billets
- *Water* (for descaling, cooling, cf. A.3.1.3)
- *Energy* for the drives
- *Oil* and *lubricants*

The main outputs related to the hot rolling section include:

- *Crops*, *cobbles*, *scrap ends* and *samples, metallurgical* and *rolling rejections*
- *Waste water* (loaded with scale and oil) yielding
- *Mill-scale* (oil-free and oily, cf. A.3.1.3)

Table A.3-2 shows streams of inputs and outputs for the rolling section of section products. Table A.3-3 shows the same for hot strip. The quantity of inputs / outputs depends strongly on the type of product being produced.

Table A.3-2: Inputs / outputs of the hot rolling section (sections)

Input		Output	
Reheated blooms / billets		Sections	
Energy		Scrap, cobble, cutting	
Water		Waste water loaded with	
Oil		Mill-scale	
		Mill-scale (oily)	

Table A.3-4 gives examples for the required forming energy for hot wide strip finishing trains processing unalloyed low-carbon steels. However, it should be mentioned that these figures only represent rough reference values, as the energy requirement for forming depends on technical parameters like workpiece temperature, rolling speed, thickness reduction by pass, etc. [75]

Table A.3-3: Inputs / outputs of the hot rolling section (hot strip)

Input		Output	
Reheated slabs		Hot strip	
Energy		Scrap, crop loss, cobbles	
Water		Waste water loaded with	
Oil		Mill-scale	
		Mill-scale (oily)	

Table A.3-4: Examples for required forming energy of hot strip finishing trains

Finishing train	1	2	3	4	5
Number of stands	6	6	6	6	7
Dimension input	32x1,150mm	32x1,150mm	32x1,050mm	32x1,850mm	42.3x1,750mm
Dimension output	1.8x1,150mm	6x1,150mm	2.5x1,050mm	1.8x1,850mm	3x1,750mm
Forming energy	51kWh/t	16.1kWh/t	34.1kWh/t	46.7kWh/t	30.8kWh/t

Source: [75]

A.3.1.5 Finishing section

During finishing operations (e.g. trimming, cutting to a particular length, slitting, downgrading, etc.) usually certain amounts of scrap arise. According to [83] finishing losses from the production of hot rolled strip may be within the range of 0.0-1.6%, with a reference value of 0.4% (cf. footnote 5).

A.3.2 Inputs and outputs caused by cold forming

The sub-processes related to cold forming included in this study are surface preparation (pickling), trimming and oiling, cold rolling, degreasing and heating processes (annealing). Furthermore, the processes skin-pass rolling and finishing also belong to the cold forming section, as considered in this study.

The inputs of these processes include:

- Hot rolled strip
- *Pickling acids* (e.g. sulphuric, hydrochloric, nitric)
- *Steam* for the heating of acid bath and cleaning tank
- *Lubricants* (e.g. oil like palm oil, or oil-water emulsion)
- *Energy* for the mill drives, roll coolant pumps and fans
- *Fuel* used for heating processes (annealing)
- *Water* (for cooling and rinsing)

Important outputs within these processes are [168]:

- *Acid aerosols* generated within the pickling process, *VOCs* and *oil mists* derived from the rolling oils, and further *emissions* into the air from the *combustion processes* of the heat treatment
- *Off-cuts* when trimming, *pickle tank sludges*, *acid regeneration sludges*, and *effluent hydroxide treatment sludge*
- *Effluents* may contain *suspended solids* and *oil emulsions* from cold rolling and *acid wastes* from pickling. Acid regeneration itself may give rise to *acidic effluent*, that is treated for *waste acids*, and pure iron oxide or iron sulphate, depending on the type of acid and regeneration process.

It has to be mentioned, that the processing of stainless steel usually requires the input of special auxiliary materials, for example pickle or rolling oil. However, the data available on this is very limited, at the moment. If any information is available, it will be given in the following.

A.3.2.1 Pickling

Pickling is carried out in order to prepare (remove scale and oxides) the steel surface for the following cold rolling process. The thickness of the scale depends mainly on the processing parameters of the hot mill, the main factor being the recoiling temperature, although the rolling process itself also has a marked influence [86]. It may be a batch process or a continuous process, depending on the volume and nature of materials to be treated [81]. The type of acid used depends on the sort of steel and the desired cleaning effect. The use of sulphuric and hydrochloric acids is very common. To pickle corrosion resistant alloy or stainless steels, containing large proportions of chromium and nickel, strong acids must be used. Silicon steels also develop a passive film when highly alloyed and require different acids, for example mixtures of hydrofluoric acid / sulphuric acid or hydrofluoric acid / nitric acid [81].

It is very difficult to make a detailed analysis of the inputs and outputs of all process steps related to pickling (cf. [43] on this topic). For this reason, the data provided in this section mainly aggregates data of the pickling lines itself, but also of neutralisation and regeneration units. Figure A.3-2 depicts an overview of inputs and outputs of the pickling process.

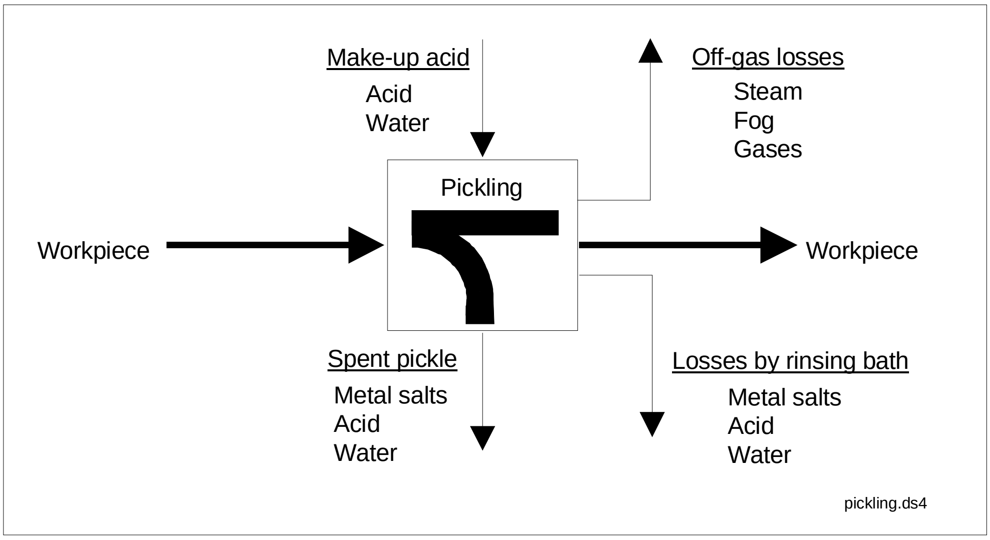

Figure A.3-2: Selected inputs and outputs of the pickling process

Source: [131]

Inputs for the pickling process depend inter alia on the steel-grade being pickled. The pickling agents for low alloyed and carbon steels are mainly *hydrochloric* (muriatic) or *sulphuric acid*. For the pickling of stainless steel usually *acid mixtures* (e.g. acid / sulphuric or hydrofluoric / nitric) are used. Pickling processes can be carried out more effectively at temperatures higher than the ambient temperature [131]. Depending on the acid, different amounts of energy input are required, as these are used at different temperatures. Sulphuric acid is heated up to about 95-105°C, muriatic acid up to 60-90°C and mixed acids up to about 70°C by indirect heating with *steam* or *hot water* [131]. These heating methods are usually advantageous as steam or hot water are mostly present within the battery limits of an integrated steelworks. *Water* is used for *rinsing* and *waste gas cleaning*.

As mentioned before, the common pickling processes are operated at temperatures that usually give rise to *acid aerosols* and *fumes* at the surface of the bath [131]. The amount of emissions depends on the temperature and the bath agitation. *Waste water* arising in the pickling process from rinsing also contains *acid wastes*. Solid outputs caused by pickling and acid regeneration include *pickle tank sludges*, *acid regeneration sludges* and *effluent treatment hydroxide sludge*. The mentioned regeneration of used pickle may cause *effluents*, that are *acidic* themselves and these are treated as for waste acids. Regeneration may also give rise to pure *iron oxide* and *iron sulphate*, depending on the process [168]. Table A.3-5 gives the relevant input / output streams related to pickling.

Table A.3-5: Main inputs / outputs related to pickling

Input		Output	
Hot strip		Pickled hot strip	
Acid (depending on steel grade)		Acid aerosols and fumes	
Muriatic acid		Used pickle	
Sulphuric acid		Rinsing water	
Acid mixture (e.g. hydrofluoric / nitric)		Water from gas cleaning	
Water (rinsing, gas cleaning)		Acid regeneration by-products (e.g. iron hydroxide)	
Steam, hot water			

A.3.2.2 Oiling and trimming

Directly after the pickling process, the strip can be oiled and trimmed before entering the cold rolling section. Within this step oil is put on the strip in order to prepare it for following cold rolling. Also the edges of the strip may be trimmed in order to ensure good rolling results. This results in off-cuts.

A.3.2.3 Cold rolling section

Cold rolling reduces the thickness of the strip by compression within the rollers. On the input side, the drives of the rolls need a corresponding *energy* supply. Because of the high applied roll forces applied, the strip is heated by the forming heat to up to 50-240°C [75]. In order to cool the rolls and also the workpiece, they are lubricated and cooled by *oil*, *water* or *emulsions*. Examples for rolling oils are fat oil, mineral oil or palm oil; water-free rolling oils need to have flash points of over 300°C [75]. The main reasons for lubricating are also, in particular, the reduction of roll forces and roll moments, the reduction of tool wear and the enhancement of the strip surface.

Because of the temperature increase mentioned before, the oil partly evaporates and forms an *oil mist*, which is exhausted by suction plants. Rolls and strip are usually also cooled by water, giving rise to an *oil-water emulsion loaded waste water*. Furthermore, *off-cuts* from trimming arise within the cold rolling section. Table A.3-6 summarises main input / output streams related to cold rolling.

Table A.3-6: Inputs / outputs related to cold rolling

Input		Output	
Pickled hot strip		Cold strip	
Energy		Oil mist	
Lubricant (e.g. palm oil, synthetic emulsion)		Waste water (scale and oil loaded)	
Water		Scrap (e.g. cobble)	

A.3.2.4 Degreasing

Before the annealing process, the cold rolled strip may be degreased in order to prevent undesired burning of the rolling oils in the furnace. For this purpose, an electrolytic degreasing process can be applied. During the course of the degreasing process, the strip is uncoiled, passes a degreasing bath, is brushed, rinsed, dried and coiled again [125].

No further information on the inputs and outputs of this process is available, at the moment.

A.3.2.5 Annealing

Because of high strain, cold rolled strip shows often strength values of up to 1,600 N/mm^2, which are too high [85]. In order to guarantee sufficient material properties of the final products, after cold rolling thermal treatment is usually applied, i.e. annealing [29]. Recrystallising annealing is carried out at about 600-700°C and allows the required strength values to be set. Annealing is either done batch-wise in hood-type furnaces or continuously in continuous furnaces with the use of inert gases. Some steel grades cannot be annealed by means of hood-type furnaces (e.g. austenitic steel), because they have to be annealed above 950°C, which is not possible in these furnaces [85].

The required input and output levels depend on the type of furnace and the type of fuel used. Usually, if natural gas supplies the *energy* for heating, low SO_2 and *particulate* emission figures can be expected. As within reheating furnaces, the formation of NO_x cannot be totally omitted. Annealing is carried out by means of an *inert gas* (N_2 or preferably hydrogen[6]) to support a better convection from the protecting hood to the coils in batch-type furnaces or to the strip within the furnace space of continuous furnaces. Scrap may arise for example, if different layers of the coils bake together because the heating temperatures are too high.

Table A.3-7 shows corresponding input / output streams of the annealing process.

6 Investigations showed, that hydrogen reduces the required heating times considerably (cf. chapter 4).

Table A.3-7: Inputs / outputs of annealing

Input		Output	
Cold strip		Annealed cold strip	
Energy (fuel, electric)		Air emissions:	
Inert gases		NO_x	
		CO	
		SO_2	
		Dust	
		Scrap	

A.3.2.6 Skin-pass rolling

Skin-pass rolling enhances the strip flatness, allows the setting of particular surface qualities and suppresses the yield point extension for subsequent forming free of flow lines [75, 162]. It is mainly carried out on 2-high, 4-high or 20-high stands and reduces the strip thickness by only about 1-3%. It is carried out either dry or with lubrication, depending on the type of steel.

No more data is available for this process, at the moment.

A.3.2.7 Finishing

Depending on the further use or processing of the strip, it is trimmed, slitted, oiled or prepared in another manner for subsequent steps. Trimming actions may result in off-cuts.

A.4 Candidate best available techniques for integrated pollution prevention and control within the German rolling industry

This chapter presents a list of candidate best available techniques for IPPC in German rolling mill plants, taking the definition of BAT in Art 2.11 IPPC-D as a basis.

A.4.1 The definition of BAT

"The term ‘best available techniques’ signifies the most effective and advanced stage in the development of activities and their methods of operation which indicate the practical suitability of particular techniques for providing in principle the basis for emission limit values designed to prevent and, where that is not practicable, generally to reduce emissions and the impact on the environment as a whole.

‘Techniques’ include both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned.

‘Available’ techniques means those developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced inside the Member State in question, as long as they are reasonably accessible to the operator.

‘Best’ means most effective in achieving a high general level of protection of the environment as a whole.

In determining the best available techniques special consideration should be given to the items listed in Annex IV." (Art. 2.11, IPPC-D).

"Taking the Article 2.11 IPPC definition of 'available techniques' as a point of departure, all relevant techniques currently commercially available for prevention or reduction of emissions / waste and reducing consumption of energy and raw materials, both for new and existing installations should be mentioned. [...] From these, a certain number may be obsolete, theoretical or highly unlikely to meet the BAT criteria. In order to limit the assessment in the document to the really relevant techniques, a first scrutiny will be required to obtain 'Candidate BAT' " (General outline of IPPC BREF documents, 4.1).

A.4.2 Candidate BAT for hot rolling mills

This section presents Candidate Best Available Techniques (CBAT) for the prevention and control of emissions into the air and releases into water, for the efficient use of energy and resources as well as for the prevention, recovery and use of outputs besides steel within hot rolling mills.

Bold numbers in brackets indicate techniques, that are considered to be CBAT after a first screening (CBAT X would be marked by **(X)**, for example). These numbers refer to Figure A.4-9, which gives an overview of CBAT for hot rolling mills.

A.4.2.1 Air pollution prevention and control within hot rolling mills

Air pollution prevention and control within hot rolling mills is mainly related to the process reheating but also to surface preparation. Important factors with respect to the prevention of emissions (in particular NO_x, SO_2, CO) within reheating furnaces are the type of fuel employed and measures to prevent unnecessary heat losses.

A.4.2.1.1 Air pollution prevention and control in the scarfing shop

Prior to hot rolling, cast steel may be scarfed in order to modify the surface and to remove surface defects. Although scarfing shops for organisational reasons are often included within the continuous casting section, they are also covered by this study. The process, especially automatic scarfing of complete slabs, gives rise to significant quantities of oxide fumes and combustion products. The prevention of emissions by scarfing and the related arising collected dusts, which mainly consist of iron oxide, is at least partly possible using several measures. Emissions may be prevented by delivering a good input material quality from the continuous casters **(1)**, which does not need to be scarfed, by a good process quality control, helping to select the material to be scarfed **(2)**, and by selective scarfing, i.e. scarfing only parts of a slab **(3)**. The introduction of a computer aided automatic quality control system **(cf. 2)** for improved hot charging of slabs brought about a reduction of about 2/3 of scarfing losses together with an enhancement of product quality in one particular integrated steelworks [45]. The system mentioned takes into account the required properties of the final product and helps to avoid unnecessary scarfing of qualitatively non critical material. Fumes from scarfers can be extracted by means of suction hoods and recovered by precipitators (bag filters, electrostatic precipitators) **(4)** [168].

A.4.2.1.2 Air pollution prevention and control at reheating furnaces

The relevant emissions from combustion processes of reheating furnaces comprise NO_x, CO, CO_2, particulates and possibly SO_x. The prevention and control of these emissions can be achieved by several measures.

Particulate and CO emissions from reheating furnaces depend mainly on the fuel type. Next to the choice of fuel **(5)** measures to minimise these emissions include a careful control of combustion conditions, such as excess oxygen levels, aided by computer control systems **(6)** [168]. The high process temperatures of 1,100-1,400°C within the reheating furnaces require an adequate burner design in order to control these emissions. CO_2 emissions are generated inevitably during the combustion of hydrocarbons and CO. These emissions can be minimised only by furnaces with a high thermal efficiency **(5)** [22]. However, emission levels of <100 mg CO/m^3(STP) can be achieved by well maintained plants.

The major parameters for NO_x generation in general are the air preheating temperature, burner design, furnace temperature, excess air, fuel type, burner capacity, furnace configuration and oxygen in combustion air [46]. NO_x emissions during the burning processes within reheating furnaces of hot rolling mills can be controlled by a reduction of the generation of fuel NO_x and thermal NO_x[7] [22, 46, 69]. The generation of fuel NO_x can be reduced by using fuels with a low NO_x content, e.g. natural gas or BOF gas **(5)**. A technological option for NO_x reduction is the use of low-NO_x burners **(8)**. Low-NO_x burners can be installed both within new and existing installations. They can distinguished according to the principle employed for NO_x limitation: staged burning and waste gas circulation [22]. Generally, air-staged, fuel-staged and flue gas recirculation low-NOx burners are used [167]. In a case study of two reheating furnaces using COG and heavy oil as fuels the use of low-NO_x burners made it possible to give guaranteed levels of 330mg NO_2/m^3 (STP) in a dry waste gas with 5%O_2 [22].

Emissions of SO_x from reheating furnaces are a function of the sulphur content of the fuel only [168]. For this reason, they can be reduced by switching to low sulphur content fuels **(5)** like BF gas, natural gas or desulphurised coke oven gas (COG) and oil, and by general energy saving measures, reducing the required fuel input [128]. Emission levels below 100mg SO_2/m^3 (STP) are achievable by well maintained plants with corresponding fuels.

A reduction of the total emissions is possible by decreasing the fuel input by energy saving measures. An important energy saving measure within reheating furnaces is waste gas heat recuperation through air preheating **(9)**. However, it has to be taken into account that an increased air preheating temperature also increases NO_x formation [128]. Overall emissions can also be reduced by using the hot charging practice **(10)** and hot direct rolling (with a soaking furnace) **(E1)**, because these techniques reduce the required energy input for reheating as the delivered material contains more heat (cf. A.4.2.2.2). However, for existing plants, the possibility of using these methods depends on the specific plant conditions. For new plants it should be incorporated in the planning of the site. Specific emissions rates can also be reduced by optimising productivity (fostered by improved maintenance, scheduling and operating as well as engineering practises (cf. 15)) [168].

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[7] Fuel NO_x is generated from nitrogen that is chemically bound within the fuel. It reacts with oxygen during the combustion process. Fuel NO_x creation is hardly dependent on the temperature but rather on the partial oxygen pressure within the furnace [22]. Thermal NO_x is created by the combustion products outside the flame front and is mainly dependent on temperature and oxygen concentration [22, 69].

A.4.2.1.3 Air pollution prevention and control in the hot rolling section

Dusts arising at the rolling stands within the hot rolling section can possibly be controlled by directed water spraying within the stands, avoiding a dissemination of dust **(11)** [firm information]. Treatment of the process water has to be provided subsequently.

A.4.2.2 Efficient energy use within hot rolling mills

Investigations into the structure of energy consumption within hot rolling mills showed that about 76-84% of the total energy input within hot rolling mills is required as thermal energy and about 16-24% for forming, idle running and auxiliary processes [74]. Consequently, the main energy consumers within a hot rolling mill are the reheating furnaces and the drives of the rolls. The overall energy requirement of a forming plant is mainly dependent on the factors mass throughput, technical level and rate of utilisation of the plant and the type of energy transfer process [74]. Measures to save energy can be carried out within all process units of a hot mill. However, one has to take into account cross-media effects by these measures, in particular possibly increased NO_x formation because of combustion air preheating in the reheating furnaces.

A.4.2.2.1 Efficient energy use related to reheat furnace operation

As an advance summary, the following rough estimations can be made for energy consumption for reheating. Thermically optimised walking beam furnaces achieve a fuel consumption of about 1.2GJ/t reheated workpiece (from ambient temperature), nowadays [85]. Hot charging at about 650°C saves about 0.4 GJ/t reheated workpiece in comparison to the former case and finally direct charging at about 1,150°C one GJ/t reheated workpiece (cf. section 6) [18].

In general terms, measures to reduce energy consumption at reheating furnaces are measures that maximise heat transfer to the cast material, minimise unnecessary losses and recover energy. In particular these measures are [8, 20, 84, 85, 168]:

- Use of computer combustion control models, to optimise furnace firing based on cast material temperature, mill status, off gas analysis, excess air level, etc. **(6)**
- Proper installation and continued maintenance of furnace insulation (i.a. lining) to ensure an on-going high thermal efficiency and a minimisation of radiation losses **(7)**
- Minimisation of heat losses by hot cooled skid rails **(7)**
- Improved burner design to maximise heating efficiency and to minimise emissions into the air (e.g. NO_x) **(8)**
- Waste gas heat loss minimisation and heat recovery, e.g. by combustion air preheating (**(9)**, however, the increase in NO_x emissions must be taken into account) or heat recovery by workpiece preheating (cf. next point) or heat exchanger to recover energy from waste gas or hot furnace cooling **(12)**
- Construction of reheating furnaces with different zones. In particular the incorporation of a long unfired preheating zone, to allow the preheating of cast material by waste gases with maximum heat transfer, can lower the additionally required energy input **(13)**

- The incorporation of isolated firing zones within the furnace, which allow flexibility for firing individual zones, according to the actual heating requirements and an enhancement of the temperature distribution within the furnace **(13)**

Figure A.4-1 shows a pusher-type furnace with three zones, bottom- and top-burners as well as a waste gas heat recuperator.

The waste gas temperature is an important parameter for the fuel consumption of reheating furnaces (e.g. by **(9)**, **(12)**, **(13)**). A lowering of this temperature permits a reduction of unnecessary losses. It is mostly advantageous with respect to this criterion to build new furnaces as walking beam furnaces **(13)**, as these furnaces can be constructed in an almost unlimited length. In comparison with pusher type furnaces, which are limited to about 35-40m, the longer walking beam furnaces allow a better heat transfer from the waste gas to the workpiece. This permits a reduction of the specific output of hearth furnace and a lower waste gas temperature [85].

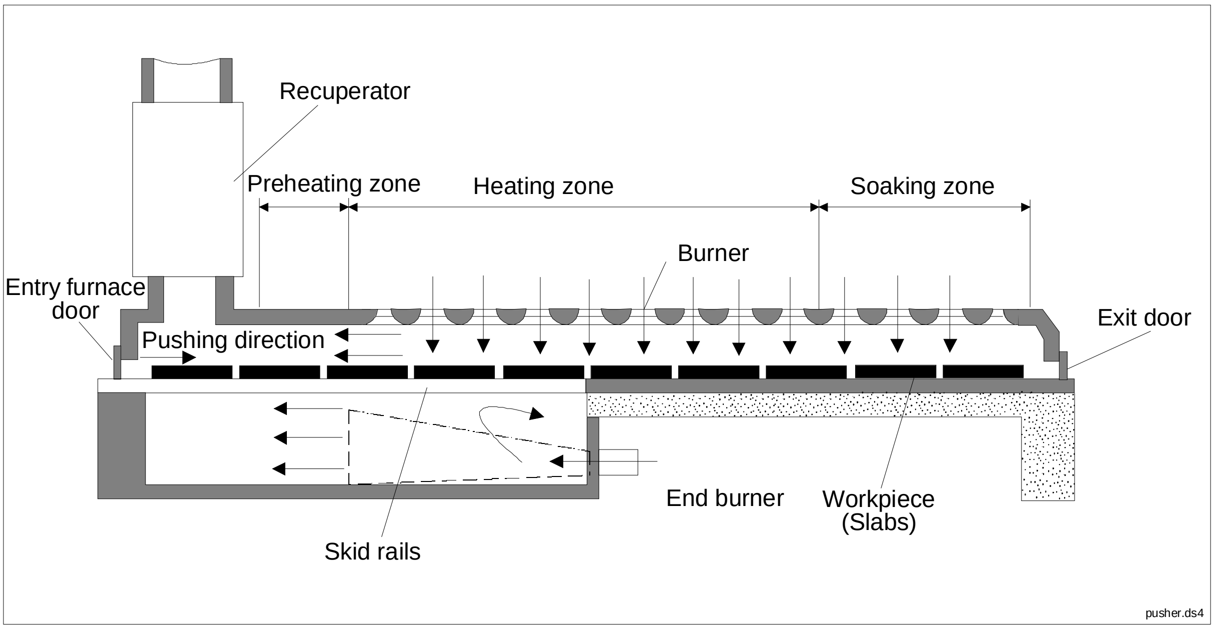

Figure A.4-1: Diagrammatic view of a pusher-type furnace

Source: [85]

Investigations into the options to increase the productivity of reheating furnaces and to save heat consumption identified the main factors for an improvement of these two aims. In particular, the factors production per hour, entering temperature of slabs, realised excess air, recuperator efficiency, and heat losses via cooling water, lining, and radiation losses were shown to be relevant [116]. Measures to improve these parameters in a case study included the installation of a new furnace entrance door (enhancing waste gas heat recuperation **(12)**, led to energy savings of about 0.05 GJ/t) and the increase of furnace charging temperature using several measures (reducing slab storage time and introduction of a protecting hood for slab storage **(14)**, cf. A.4.2.2.2, resulted in an energy saving of about 0.43 GJ/t) [116].

Furthermore, the improvement of lining technology **(7)** and an optimisation of the excess air level **(6)** by a new control strategy reduced the energy consumption and the productivity of the reheating furnace [115, 116]. Also the introduction of hot inspection of slabs and the related reduction of cool down periods as well as the use of automated quality control strategies reducing the need to scarf the slabs before charging may lead to an increased furnace charging temperature **(10)** and to reduce energy consumption [45, 116].

An external option to use the heat of reheating furnaces is heat recovery of the waste gas and its use for district heating **(12)**. This has been done in one case study using the waste heat of a steelworks producing constructional steel. The plant operates a pusher type furnace and plans to recover about 490MWh heat per month on average when operating [76]. However, the external use of waste gas heat is subject to several restrictions, e.g. a heat / steam consumer with a pattern as similarly demanding as the suppliers' supply scheme. It has to be checked in each specific case, whether this option is advantageous.

A.4.2.2.2 Efficient energy use by retaining heat of cast material

Taking advantage of the useful heat of the cast material bears a significant potential to reduce the energy consumption within the hot rolling mill [168]. The use of thermal covers **(10)** during the transportation of the workpiece between different process steps, in particular when transport over longer distances is required, helps in general to retain the useful heat of the material and provides for lower temperatures losses. These thermal covers may also allow a lower furnace drop out temperature leading to savings in fuel consumption and yield loss (i.e. scale loss) [168, 176]. Investigations into the use of thermal covers for the transport of slabs between a continuous caster and a walking beam furnace made it possible to decrease the heat consumption of about 0.33GJ/t in one particular case [176].

As pointed out in section A.2.3.2, warm or hot charging **(10)** at about 300-600°C into the furnace and direct charging at about 900-1,000°C into an (inductive) soaking furnace in front of the rolling mill can save a considerable amount of energy input of up to over 1 GJ/t reheated steel. As direct strand reduction is not yet applied in German rolling mills, at the moment (cf. footnote 1, however), it is covered in the section Emerging Techniques (cf. chapter 6). For other countries, direct strand reduction may already be a technique available on a commercial scale.

The possibility of applying these practices depends on the particular conditions of the site, in particular at existing plants. Important technological parameters are mill type and configuration, proximity of the caster to furnace and rolling mill as well as steel specifications. The implementation of hot charging or direct rolling depends furthermore on the installation of equipment to allow a higher furnace throughput, temperature normalisation (e.g. edge heaters), schedule free rolling, schedule matching between caster and rolling mill, high quality slabs, etc. [168, 176].

Figure A.4-2 presents possible material flows in a plant allowing both cold charging and warm or hot charging to the reheating furnace. Hot charging at about 650°C saves about 0.6 GJ/t in comparison to cold charging at 10°C, for example [18].

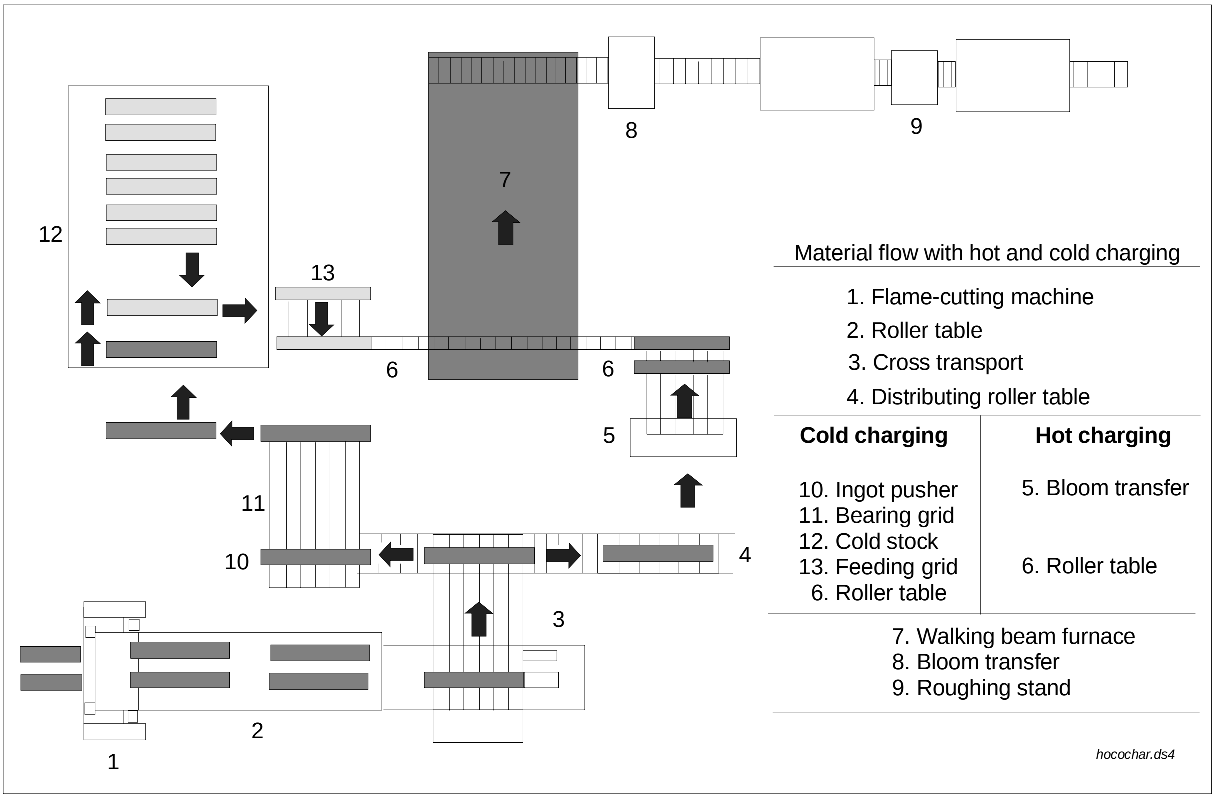

Figure A.4-2: Material flow: cold versus hot charging

Source: [28]

An optimised production planning and control system made it possible in one case study to synchronise the production schedules of a steelworks and a rolling mill. As a result, a hot charging share of over 60% at about 800°C could be achieved [141].

A.4.2.2.3 Efficient energy use in the hot rolling section

The main energy source in the rolling section is electrical energy. The electrical energy requirement of the hot strip mill may be reduced by installing a coil box **(14)**, which reverses the strip beginning and the strip end between the roughing and finishing mills, ensuring greater temperature uniformity throughout the rolling process. This measure may reduce the amount of additional power required to roll the strip as the temperature drops during rolling and allows for a greater control over the final steel properties. [168]. The potential to reduce the energy consumption depends however on the specific plant layout and also on the grades of steel processed.

In general, the main factors for an increased energy requirement within hot rolling mills are a low throughput, high energy requirements for auxiliary installations, high degrees of deformation and low forming temperatures [74]. Taking into account the technologically fixed framework, e.g. required product quality, etc., the aim should be to optimise the mentioned factors in order to minimise the energy input **(15)**. For example, during periods of low productivity the overall specific energy consumption is high, and vice versa. As a consequence, productivity should be maximised and the length of unscheduled delays minimised. A continued dialogue between maintenance and mill personnel as well as the use of computer control equipment can help to achieve these goals [168]. For the production of section products, near-net-shape casting also lowers the required energy input, as a lower degree of deformation and fewer forming steps are required **(15)**.

A.4.2.3 Waste prevention within hot rolling mills

Material losses within the hot forming process occur through the processes scarfing and grinding (surface preparation), descaling, cropping and cutting, cobble and finishing examination, revealing for example rolling defects, metallurgical defects or geometrical defects [168]. Waste arises for example within the scarfing shop (iron oxide), the reheating furnace (chipping off scale), the cutting and cropping stations and the inspection shops. This section discusses measures to prevent material losses or waste. Measures to process waste, both problematic and less problematic with respect to an easy use, will be covered in section A.4.2.5.

A.4.2.3.1 Waste prevention at surface preparation

Scarfing and grinding is carried out in order to ensure the final quality of the rolled product and is related to the surface quality of the material entering the mill. The surface quality is in turn dependent on the operating method during continuous casting [168].

A measure to prevent material losses when cleaning as well as the related emissions is to produce qualitatively good input material for the rolling section **(1)**, with little need for surface cleaning. However, due to process restrictions, it is usually not always possible to deliver cast material without defects (cf. also section A.4.2.1.1). Another option is to apply selective (manual) scarfing **(3)** in order to scarf only the damaged spots, instead of automatically scarfing the total slab. This practice may not be economically or technically feasible [26]. Citepa states dust emission factors of about 3 g/t product for selective / manual scarfing and about 30-60 g/t product for automatic scarfing [26].

A.4.2.3.2 Waste prevention in the reheating furnace

The scale forming by oxidation on the surface of the workpiece within the reheating furnaces is time and temperature dependent [168]. Yield losses when descaling can be reduced by controlling the oxygen level in the furnace **(6)**, by careful scheduling **(15)** and improved mill availability (to avoid over-soaking). Refractory breaks from the furnace may be treated for subsequent reuse by external companies **(16)**.

A.4.2.3.3 Waste prevention in the hot rolling section

Outputs besides steel arising within the rolling section include crop and cutting losses as well as cobble losses. Plant operators try to minimise these outputs in order to get a high yield. Crop and cutting losses might be reduced by optimising the rolling procedure **(15)** to improve the geometric or, in the case of plate, mechanical properties of the rolled product. The rolling procedure can be enhanced by introducing improved or automated control of the cropping process for an increased accuracy **(17)**, and the use of edging facilities (e.g. slab upsizing press) for dimensional control. Cobble losses can be reduced by ensuring a more uniformly heated semi, resulting from good maintenance practices and furnace control, improved cropping, mill availability and scheduling **(15, 17)** [168]. Also the use of a coil furnace **(14)** maintaining the coil temperature before it enters the finishing stands can help to prevent scrap, if the finishing train has an unexpected downtime. Used oil within the rolling stands can be treated and possibly reused **(18)**. Another reuse option is to inject used oil into the blast furnace [company information].

A.4.2.3.4 Prevention of finished steel losses

Finished steel losses like metallurgical, geometrical or rolling defects can partly be prevented by controlling the steel's metallurgical quality in the steel plant, improving the rolling procedure to minimise the quantity of out of specification products, and improved scheduling within the mill to ensure compatibility between the rolled product and the ordered lengths. Costly rejections of material can arise in significant amounts, particularly for demanding applications, and these can only be reduced by paying attention to detail in every aspect of the rolling process **(15)** [168].

A.4.2.4 Water management within hot rolling mills

Water management within hot rolling mills is a particular task concerning most sub-processes. Important aspects of candidate BAT are presented in the following sub-sections.

A.4.2.4.1 Introduction

Water is used within hot rolling mills mainly for the purposes the indirect cooling, direct cooling and the transport of scale (channel rinsing). Indirectly cooled are for example electric motors, the reheating furnace, control rooms and power systems, instruments and process control. Directly cooled are usually the workpiece, rolls, saws, cropped ends, downcoilers and hot runout tables. For scale breaking, flushing scale as well as for scale transport water is used as process water [168]. Waste water from hot rolling mills is mainly loaded with ferrous contents like scale and also with some oil-bleeds and grease from the rolling stands [4, 142]. Water management can take place by preventing waste water (loops, **(19)**) supported by efficient water cleaning **(20)**. The use of process and cooling water in (closed) loops in order to prevent effluents is well recommended and also state of the art in the German steel industry, in particular within (hot) rolling mills because of the large quantities of water needed. Possible problems within closed loops, because of contaminant build up, clogging and excessive temperature build up with the related need of cooling towers, have to be met by adequate technology [168]. In the following, options for modern water management within hot rolling mills are presented.

A.4.2.4.2 Options for water cleaning and the use of loops in hot rolling mills

Using water in loops **(19)** or in multiple stages is the basic measure in order to prevent waste water. As water within hot rolling mills is used for several purposes requiring different water qualities, this fact can be taken account of by maintaining different loops. The respective loops can be equipped with corresponding installations providing the water quality necessary, as a use in loops or multiple stages requires particular care. Main loops within hot rolling mills can be established for the cooling of machines (closed indirect cooling water loop), for descaling and the direct cooling of the rolls (open process water loop) and for the cooling of the workpiece (open direct cooling water loop). Figure A.4-3 and Figure A.4-4 show diagrams of modern cooling systems of hot wide strip mills with the implementation of several cooling loops.

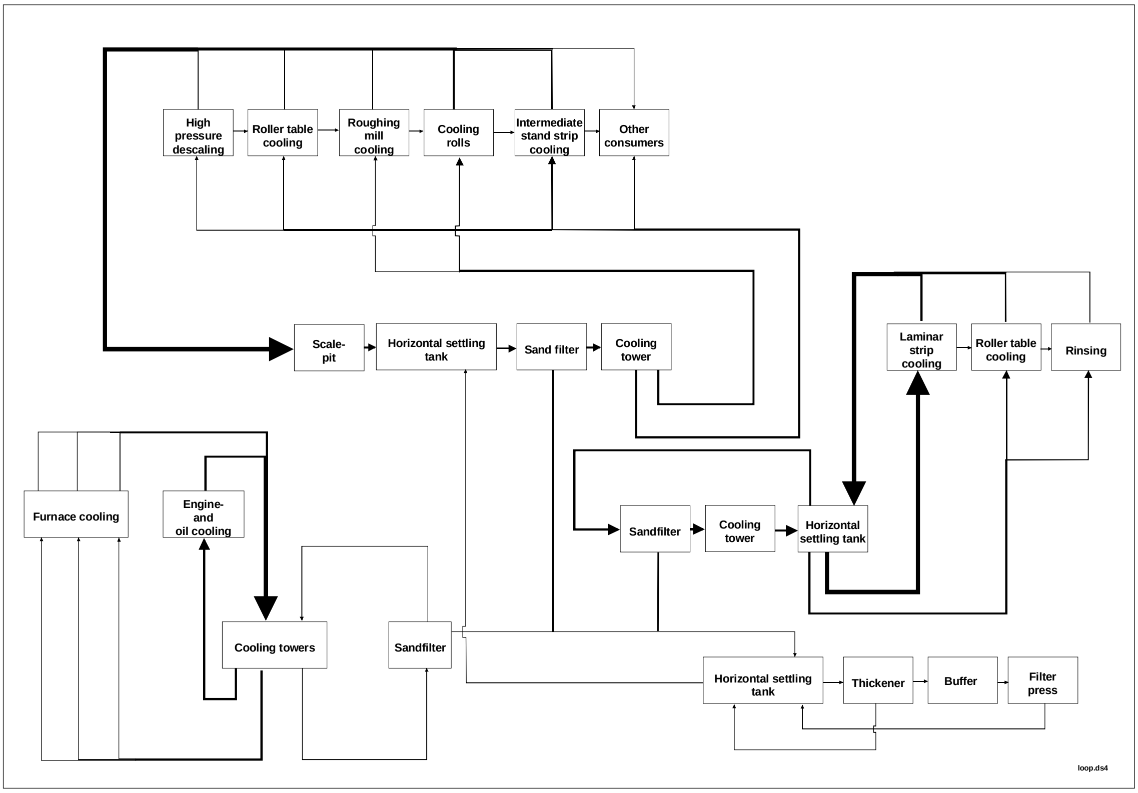

Figure A.4-3: Use of water loops in a hot rolling mill

Source: [148]

Another installation requiring cooling within the battery limits of hot rolling mills is the reheating furnace, where the skid rails can be cooled by a closed cooling system. The different cooling loops have to be equipped with corresponding filtering and precipitation systems, the loops may also have interfaces.

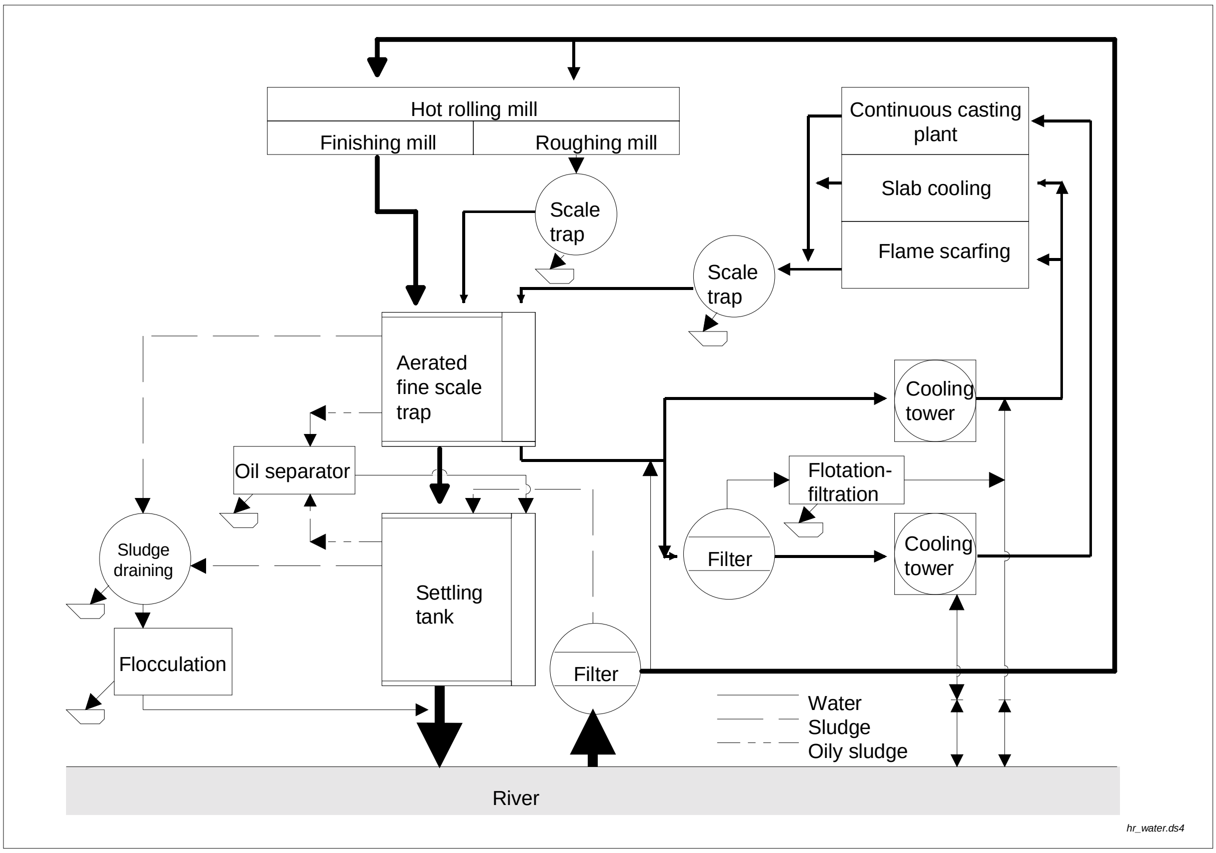

Figure A.4-4: Diagrammatic view of water loops in a hot strip mill

Source: [31]

A.4.2.4.3 Water treatment

Cooling and process water loops have to be suited to each individual case. With respect to water treatment the process water used for descaling and direct cooling is of particular interest. This topic is dealt with in more detail below. Concerning the cooling systems of the furnace and the machine cooling the following aspects should be considered. The reheating furnace cooling system can be an evaporation cooling system to recover heat or steam from the thermally loaded cooling water [company information]. The water from the indirect furnace cooling system might also be downgraded to the scale breaking system, if necessary [168], however this has to be checked for each individual case. Closed cooling systems for machine cooling nevertheless need some make-up water (deionized water) and periodical measures in order to ensure proper functioning of the cooling loop (addition of anticorrosive chemicals, desalinisation).

To ensure that the process water loops are well maintained requires particular effort as the process water collected in the sinter channel from descaling and the rolling stands contains scale (about 50-500mg/l, sometimes up to 1000mg/l) as well as oil and greases (about 10-30mg/l) and it is also thermally loaded [4]. So that it can be used in loops, the collected process water has to be treated in various steps, including coarse cleaning by gravity separators and subsequent fine cleaning by sand filters, two-layer filters or also pre-coated filters **(20)** [4, 142]. Figure A.4-5 and Figure A.4-6 depict examples of gravity separators. Coarse scale can be retained close to the spot where it arises to prevent installations from damage, e.g. if it is necessary to transport the scale loaded water by pumps. Usually the coarse scale is first arrested in scale pits, which are special types of vertically flown separators.

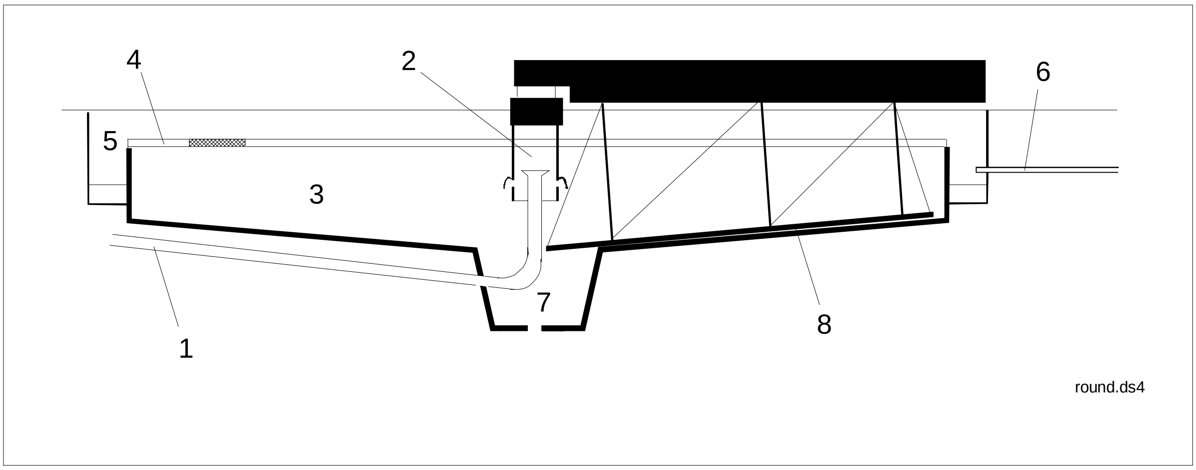

Figure A.4-5: Diagrammatic view of a circular settling tank

Legend: 1. Waste water inlet, 2. Distribution cylinder, 3. Sludge reservoir, 4. Clear water spill-over, 5. Clear water collecting pipe, 6. Clear water outlet, 7. Sludge reservoir, 8. Ground scrapper (suction pipes for sludge removal are not indicated)

Source: [4]

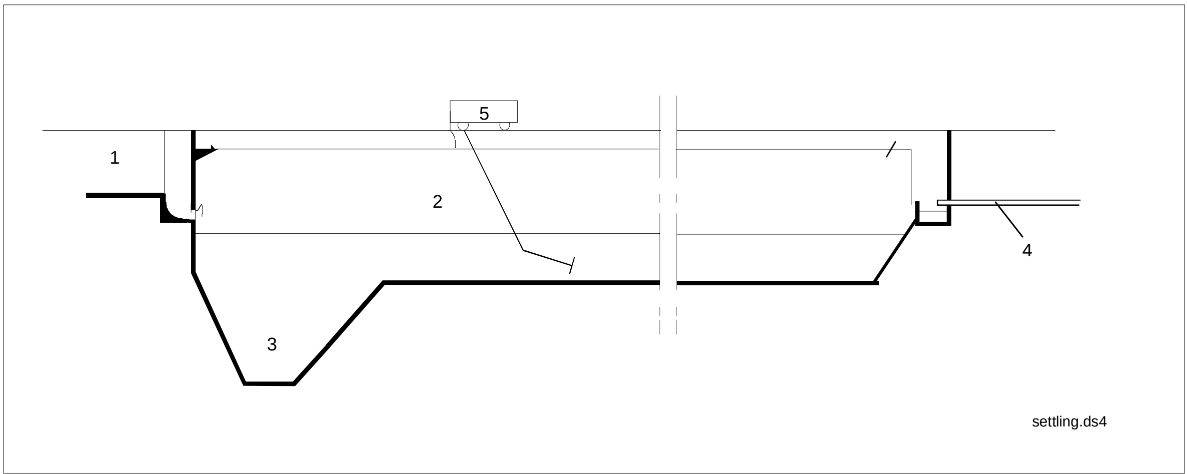

Figure A.4-6: Diagrammatic view of a horizontal flown settling tank

Legend: 1. Waste water inlet, 2. Useful space for sedimentation, 3. Sludge reservoir, 4. Clear water outlet, 5. Sludge scrapper

Source: [4]

Subsequently, as shown in Figure A.4-3, the water is usually treated in settling tanks for a second cleaning in order to separate coarse scale and hydrocarbons (also called intermediate cleaning). So-called aerated fine scale traps have been developed as a special type of separator for more efficient intermediate cleaning. These have the advantage that they separate the scale and the oil very efficiently [31]. Figure A.4-7 shows the scheme of an aerated fine scale trap.

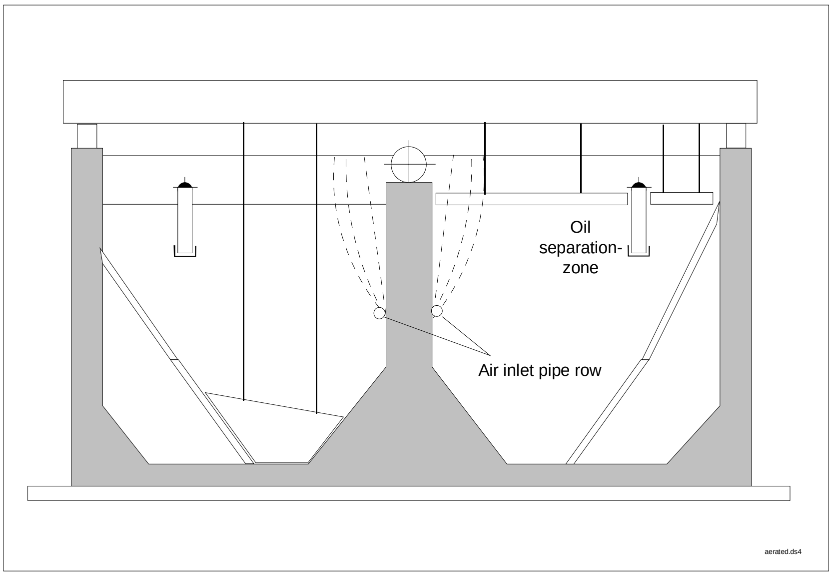

Figure A.4-7: Diagrammatic view of an aerated fine scale-trap

Source: [31]

Finally, fine cleaning is usually carried out in sand filters. Depending on the cleaning system all particles carried by the water can be removed down to a grain size of 1/1000mm by sand filters [142]. The cleaned, but still thermally loaded water then passes a cooling tower in order to adjust it to the right temperature for recirculation. The filters for fine cleaning need to be backwashed. The required amount of backwash water volume amounts to about 1-3% of the cleaned water [company information]. The arising rinsing water shows a high sludge concentration with up to 10,000mg/l. The backwash water is usually thickened in chamber filter presses. After thickening it shows an oil content of about 5%-20%.

Outputs from the different steps of water management in the hot rolling mill as described includes the following fractions: coarse mill scale by the first cleaning in scale pits, oily mill scale by gravity separation (oil content about 1-3% by intermediate cleaning), waste oil by skimming, and oily mill scale sludge (oil content >3%, after thickening) from fine cleaning and filter backwashing. The actual implementation of water treatment in hot rolling mills usually varies according to the conditions at the site.

A.4.2.5 Waste management within hot rolling mills

Among the solid outputs besides main product of hot rolling mills are the residues from water treatment as mentioned above. Furthermore, scrap arises at several spots due to handling and cutting processes. All the resulting clean ferrous residues like crop ends, coarse mill scale, cobble and downgrades can be recycled easily to metallurgical processes (**(21)**, e.g. BOF). However, the aim should be to minimise scrap by a good process control **(15)** [168]. Depending on the oil content of the scale, processing can be rather easy or it requires considerable effort. If oil content levels are sufficiently low (< about 0.5%), the scale can be directly recycled to metallurgical processes **(21)**, usually via the sinter plant. Otherwise it can be treated in order to permit subsequent recycling **(22)**. A process that may allow the direct use of high oil content scale in the sinter plant is the two layer sintering process that uses the high temperature flame front within the sinter bed to combust volatilised oils (cf. [155]). Scale is also sold for external use, e.g. to cement manufacturers, or it is supplied to an external company for processing, e.g. thermal treatment to burn the oil content (cf. [129] for a more detailed description of this process). Figure A.4-8 depicts a diagrammatic view of a plant yielding a product with a Fe-content of about 60-70%. If the plant is fed with oily mill-scale of about 4.5% no additional energy supply is required [129]. Another process developed to treat oily mill-scale is the gravity dressing principle[8] [89]. Furthermore, in one case study oily mill scale sludge with an oil content of about 5% is pelletized with other additives and directly recycled in-plant to the BOF [firm information].

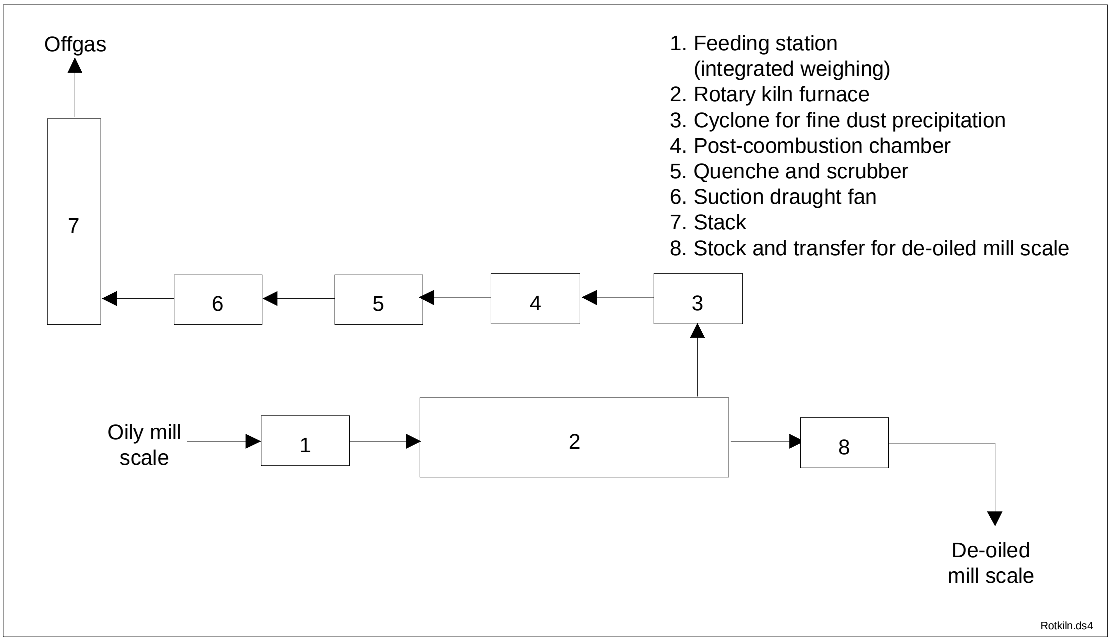

Figure A.4-8: Diagrammatic view of an oily mill scale treatment plant

Source: [129]

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[8] However, there is no information, as to whether this process is in operation at the moment.

A.4.2.6 Overview of candidate BAT for hot rolling mills

The following figure gives an overview of the presented Candidate Best Available Techniques presented in the previous chapters. The overview depicts a scheme for the production of hot strip. However, most techniques (except 2, 3, 4, and 14) can be also applied for section mills.

Legend:

N°	Sub-Process(es)	Technique(s)	Reference	Applies to
1	Scarfing / Total plant	Supply of good input quality of cast material	4.2.1.1. / 4.2.3.1.	Air / Waste
2	Scarfing	(Automated) Process quality control to minimise material to be scarfed	4.2.1.1. / 4.2.3.1.	Air / Waste
3	Scarfing	Selective scarfing to minimise scarfing losses	4.2.1.1.	Air / Waste
4	Scarfing	Cleaning of off-gas	4.2.1.1.	Air
5	Reheating	Choice of fuel	4.2.1.2.	Air
6	Reheating	(Automated) Optimisation of control of combustion conditions	4.2.1.2. / 4.2.2.1. / 4.2.3.2.	Air / Energy / Waste
7	Reheating	Furnace with high thermal efficiency, minimisation of heat losses	4.2.1.2. / 4.2.2.1.	Air / Energy
8	Reheating	Suitable burners (e.g. low-NO_x-burners)	4.2.1.2. / 4.2.2.1.	Air / Energy
9	Reheating	Preheating of combustion air	4.2.1.2. / 4.2.2.1.	Air / Energy
10	Reheating / Hot rolling	Retaining heat of cast material: hot charging, thermal covers	4.2.1.2. / 4.2.2.2.	Air / Energy
11	Hot rolling	Directed water spraying to arrest emitted dust	4.2.1.3.	Air
12	Reheating	Minimise waste gas heat losses, recovery of waste gas heat	4.2.2.1.	Energy
13	Reheating	Furnace concept to optimise heating	4.2.2.1.	Energy
14	Hot rolling	Installation of coil box and coil furnace	4.2.2.3. / 4.2.3.3.	Energy / Waste
15	Hot rolling / Total plant	Good scheduling, maintenance, operating and engineering practices, near-net-shape prod.	4.2.2.3. / 4.2.3.3. / 4.2.3.4.	Energy / Waste
16	Reheating	Treatment of refractory breaks	4.2.3.2.	Waste
17	Hot rolling	Automated, computer aided cropping	4.2.3.3.	Waste
18	Hot rolling	Treatment and / or use of spent oil	4.2.3.3.	Waste
19	Water management	Use of several loops corresponding to water quality requirements	4.2.4.1. / 4.2.4.2.	Water
20	Water management	Water treatment: coarse, intermediate, fine cleaning	4.2.4.1. / 4.2.4.3.	Water
21	Total plant	Recycling of clean ferrous material to metallurgical processes	4.2.5.	Waste
22	Total plant	Treatment processes for oily mill scale with high oil content	4.2.5.	Waste

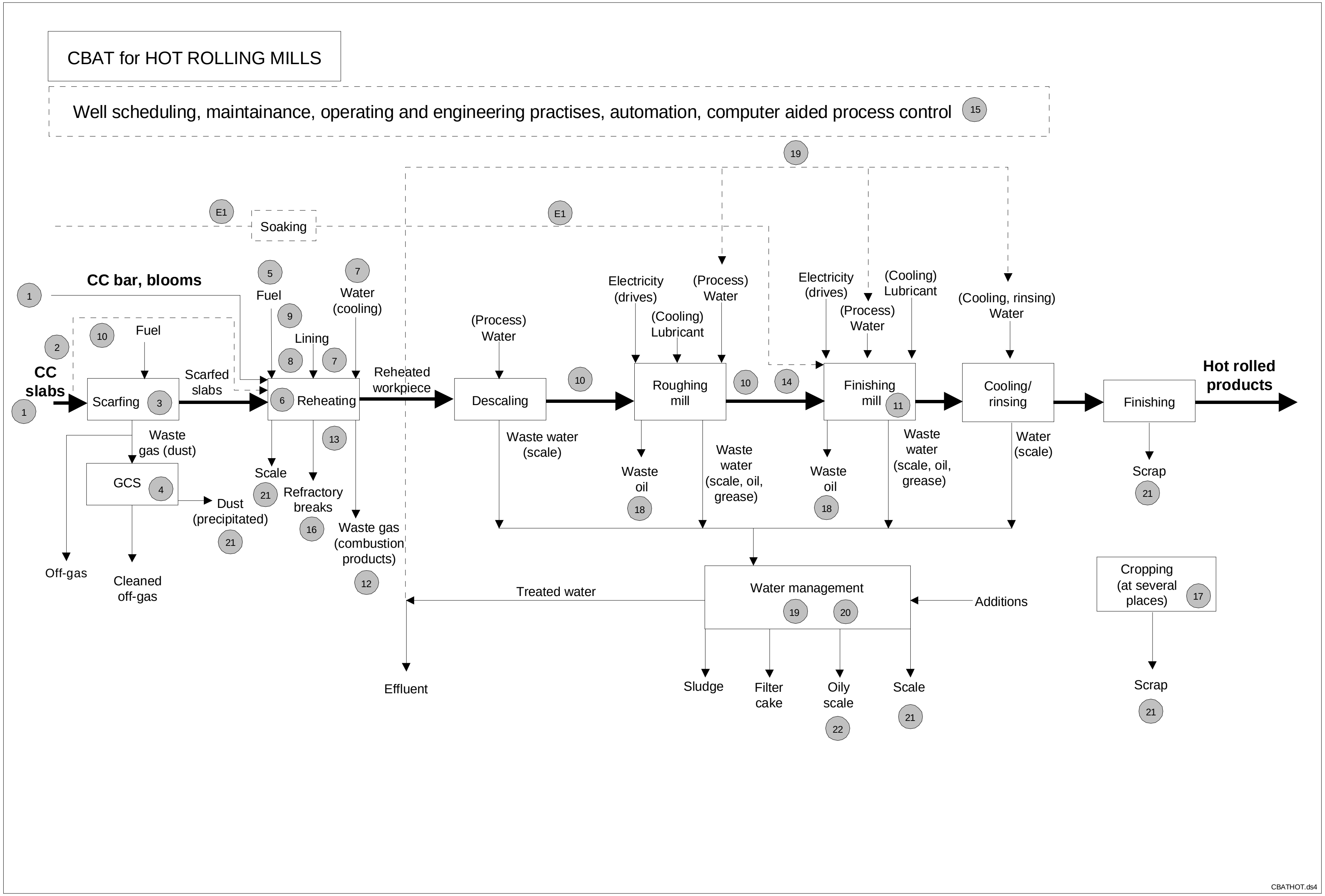


Figure A.4-9: Overview over candidate BAT for hot rolling mills

A.4.3 Candidate BAT for cold rolling mills

This section presents Candidate Best Available Techniques (CBAT) for the prevention and control of emissions into the air and releases into water, for the efficient use of energy and resources as well as for the prevention, recovery and use of outputs besides steel within cold rolling mills.

Bold numbers in brackets indicate techniques, that are considered to be CBAT after a first screening (CBAT X would be marked by **(X)**, for example). These numbers refer to Figure A.4-18, which gives an overview of CBAT for cold rolling mills.

A.4.3.1 Air pollution prevention and control within cold rolling mills

Air pollution prevention and control within cold rolling mills is usually related to heat treatment processes (annealing and tempering furnaces), to emissions from surface preparation (pickling bath and mechanical descaling), to emissions arising at the cold rolling and temper rolling section, and possibly to emissions by acid regeneration and neutralisation processes.

A.4.3.1.1 Air pollution prevention and control in the surface preparation section

Before the hot rolled strip enters the cold rolling section, the scale on its surface has to be removed in order to ensure that the surface quality is sufficient for cold rolling. This surface treatment is done both mechanically and chemically.

At first, the surface of the hot strip is usually mechanically pre-descaled in order to enhance the efficiency of chemical descaling [180]. The dust arising during mechanical surface cleaning (e.g. bending / tension levelling or shot blasting) can be evacuated and the dust cleaned by a precipitation system (e.g. bag filter) **(1)**. Dust concentrations in the off-gas of at least <50mg/m^3 are achievable by well operated precipitation systems.

Chemical surface preparation (i.e. pickling), which mostly follows mechanical descaling, gives rise to acidic aerosols and possibly gaseous emissions depending on the pickle in use. The pickle is chosen according the steel grade processed. Measures to prevent and control emissions from pickling stations i.a. depend on the type of pickling installation used for the processed workpieces. This study focuses on continuous type pickling stations where carbon steels or stainless steels are processed. Within these installations usually either sulphuric acid or hydrochloric acid are used to treat carbon and low-alloyed steels and mixed acids (often nitric / fluoric acid mixtures) for stainless steels.

For chemical surface preparation, the measures to prevent emissions include a reduction of the waste gas volume and the contaminant load of the waste gas, which is exhausted from the pickling tanks. The contaminant emissions i.a. depend on the equilibrium partial vapour pressure of the components of the pickling bath, but also on the operating conditions. This pressure is dependent on the substance, its concentration in the liquid phase and the temperature. Gaseous emissions might be reduced **(2)** in particular by a lowering of the bath temperature, by an optimisation of the composition of the solution and possibly by the use of surface active substances [131]. However, these parameters can only be changed within certain limits restricted by quality requirements.

Generally, for all types of pickling departments the following emission control measures can be taken **(3)** [154]:

- Covering of the baths with tight, well-maintained covers
- Location of exhaust ducts near openings in hoods and tanks
- Minimising of open area with local seals or closures, use of double covers
- Regular maintenance of fan, hoods and ducting and careful, well-balanced duct design

The cleaning process of the exhausted gas depends again on the acid in use. In the following, possible gas cleaning processes **(4)** for HCl, H_2SO_4 and HF / HNO_3 emissions are briefly[9] presented. While for H_2SO_4 pickling departments mist eliminators are usually sufficient, these precipitators serve at the most as pre-precipitators for the cleaning of exhaust gas from hydrochloric acid pickling departments [131]. The use of mist eliminators with intensive spraying zones for gas cleaning in pickling stations using H_2SO_4 allows easily clean gas concentrations of 5 to 10mg H_2SO_4/m^3 [131]. To clean exhausted gases and aerosols from pickling installations employing hydrochloric acids, packed scrubbers are most often used [131, 154]. Multistage absorption, operated in cascades, makes it possible to clean the exhaust gas to a clean gas concentration below 10mg HCl/m^3 and allows the recuperation of hydrochloric acid with a concentration ranging between 10 to 15 weight percent [131]. The cleaning of the nitrous fumes arising during pickling with nitric acid depends in particular on the workpiece being pickled and the resulting gas concentration as well as the NO / NO_2-ratio. In principal, absorption or catalytic processes are available, which have to be selected according the particular case. For the control of fluoric acid emissions absorption processes are suitable. However, if aerosols are present, the operation of an intensive spraying zone is required for an efficient aerosol precipitation [131]. Gas cleaning for nitric / fluoric acid mixtures can be done by a combination of the mentioned different gas cleaning processes. Figure A.4-10 shows a packed scrubber for absorbtive gas cleaning.

[9] Cf. i.a. Rituper 1993 [131] for a more detailed description of cleaning options for exhausted gases from pickling tanks.

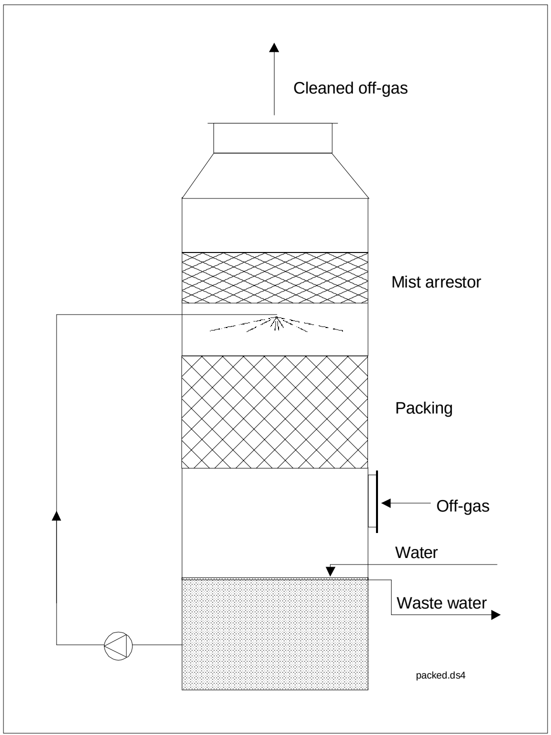


Figure A.4-10: Diagrammatic view of a packed scrubber for absorptive gas cleaning

Source: [131]

The process of acid regeneration (cf. A.4.3.3.2), that is related to chemical surface cleaning, may also give rise to emissions into the air, depending on the regeneration process. These emissions can also be arrested by a gas cleaning system **(5)**.

A.4.3.1.2 Air pollution prevention and control within the cold rolling section

Cold rolling gives rise to oil mist or fumes. These can be exhausted by a local exhaust ventilation system served by a mist eliminator **(6)**. Mist eliminators can be mechanical (e.g. using plastic media, filtering fibres, meshes) or electrostatic [168]. Citepa [26] states achievable residual emission levels of 8-50mg/m^3 (by a mechanical oil mist eliminator) and below 25mg/m^3 (by an electrostatic mist eliminator). A study of the European Union [133], including stainless steel plants, reversing C-steel mills and continuous mills states oil emission figures with concentrations ranging between 0.1mg/m^3 and 35mg/m^3 with a weighted average of about 4.9mg/m^3 from the cold rolling section for the reporting installations. However, it has to be noted, that both imprecision in the terminology and variations sampling / analysis methods led to difficulties in interpreting the data of the mentioned study [133].

A.4.3.1.3 Air pollution prevention at heat treatment furnaces

Combustion products arising within heat treatment furnaces can be minimised by the choice of fuel **(7)**, a good control of the combustion conditions **(8)** [168] and possibly the use of low

NO_x-burners[10] **(9)**, as in the case of reheating furnaces (cf. A.4.2.1.2) [26]. Off-gases have to be post-combusted, if necessary. Furthermore, the use of hydrogen instead of nitrogen as an annealing gas may reduce overall emissions within annealing furnaces **(10)**, because hydrogen fosters the heat transfer and reduces significantly heating times and energy input [168]. A comparison between conventional hood-type furnaces and high convection hood-type furnaces has shown savings of 15% of natural gas input (in kWh/t) at high convection hood-type furnaces operated with hydrogen (cf. A.4.3.2.3) [85].

A.4.3.1.4 Air pollution control within temper mills

Depending on the temper mill process (rolling dry / with lubricant), a suitable gas cleaning system has to be chosen to arrest the arising emissions (dusts) **(11)**.

At the moment, no data for achievable values is available for temper mills.

A.4.3.2 Efficient energy use within cold rolling mills

Within cold rolling mills, the necessary energy is mainly supplied in the form of steam to heat acid baths and cleaning tanks in the pickling section, in the form of fuel or steam for acid recovery, in the form of electricity to drive the rolls and various roll coolant pumps, fans etc. within the rolling train and in the form of fuel in order to heat the coils the annealing furnaces [168].

A.4.3.2.1 Efficient energy use in the pickling section including spent pickle recovery

Within the pickling process of strip, energy is required to heat the workpiece (i), to heat the acid bath (ii), to heat the pickling vat (iii), to compensate losses via the tank walls (iv) and to compensate losses by surface evaporation (v) [110]. Measures to reduce the energy input are in particular useful for the (i), (ii) and (v), as these are the main energy consumers in a pickling station [110].

To heat the acid bath the use of a steam / acid heat exchanger **(12)** instead of a steam sparging system can reduce the overall steam requirement and the amount of liquor requiring treatment in the acid recovery plant [168]. In order to obtain the maximum benefit from efficient energy use, the steam condensate from the heat exchanger should be used for strip preheating. In addition, shallow bath pickling, in which acid is sprayed onto the strip surface and continuously drained from the tank for reheating, permits a lower acid temperature while achieving the same productivity as the deep bath technology and it reduces evaporation losses and the amount of steam required **(13)** [168]. The heat contained in the spent acid may be partly recovered by means of heat exchangers and be used to preheat recovered cold acid (**14)**

[10] Citepa [26] states a possible reduction of 35% of NO_x emissions, achieved by the replacement of

[168]. Some regeneration processes for spent pickle supply regenerates with already elevated temperatures (e.g. about 82°C for hydrochloric acid regeneration). The recycling of the regenerate at this temperature to the pickling tank can save a considerable amount of energy **(14)** [110]. Another option to save energy is the minimisation of heat losses from the tanks **(15)**. Heat losses by tank walls can be minimised by a good insulation of the walls. Heat losses by surface evaporation should also be minimised by an optimised suction of off-gases, i.e. a minimisation of the volume to be evacuated [110].

The choice of acid can also affect the energy required for acid regeneration **(16)**. For example, for the pickling of carbon steels, hydrochloric acid gives rise to only about ¼ of the quantity compared to sulphuric acid (H_2SO_4), which is reported to be still more commonly used [168]. However, it has to be taken into account that first of all the pickled steel grade and quality requirements determine the type of acid being used. Also specific conditions of the site may affect the choice of pickling system.

A.4.3.2.2 Efficient energy use in the cold rolling section

The main energy source in the cold rolling section is electrical energy. The electricity consumption for the driving of the rolls in the cold rolling section is mainly determined by the initial and final gauge of the rolled steel. For this reason the possibilities for saving energy within this sub-process are limited. However, the use of control devices **(17)** in order to control auxiliary equipment, e.g. roll coolant pumps, in an optimal manner can minimise electricity consumption during delays [168].

The linking together of the pickling line and the cold rolling section **(18)** by welding consecutive strips may also increase the productivity of the mill and decrease the required energy input. For this technique savings of about 10% in energy use have been claimed [168]. According to the information available, this process is not operated in Germany, at the moment. However, one site plans to install a linked pickling-cold rolling line in Germany within the next two years [company information].

A.4.3.2.3 Efficient energy use in the annealing section

As mentioned above, annealing can be carried out batch-wise or continuously under an inert gas atmosphere. Continuous annealing allows for a faster heat transfer and greater control over annealing temperatures. This makes it possible to produce a wider range of steel qualities. However, a single stack batch annealing furnace operating with a hydrogen atmosphere (nitrogen has a lower capacity for heat transfer) can have a lower overall energy use because of reduced cycle times (compared to the nitrogen furnace), greater potential for

conventional burners with low NO_x-burners in a case study.

waste gas heat recovery and a lower gas requirement [168]. Combustion control systems **(8)** may also be installed on the single stack furnace to optimise gas firing rates and excess air levels throughout the annealing cycle, reducing losses associated with the waste gas [168]. Another option for an efficient energy use may be the recovery of thermal heat contained in the waste gas **(19)**. As already mentioned in section A.4.3.1.3, if hood-type annealing furnaces are used, furnaces operating with hydrogen as inert gas **(10)** may save up to 15% energy [85]. Figure A.4-11 shows a comparison of a conventional and a high convection hood-type furnace with respect to the course of power and time / temperature.

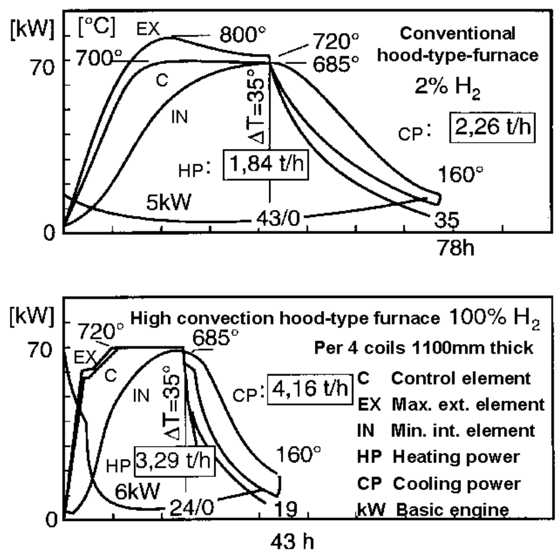


Figure A.4-11: Comparison of hood-type annealing furnaces (course of power and temperature / time)

Source: [44, 85]

A.4.3.3 Waste prevention and management within cold rolling mills

Waste products within cold rolling mills may arise during several processes. Scrap may arise due to processes like coil handling, related damage and ultimately rejection of coils, due to end and trimming losses as well as due to downgrades [168]. Spent pickle is also included in the term waste in this section. It can often be regenerated, depending on the type of acid in use. However, depending on the process regeneration usually also gives rise to outputs (emissions, solid by-products), which have to be taken care of. Furthermore, inevitable neutralisation processes for acidic liquids give furthermore rise to neutralisation sludge (cf. section A.4.3.4).

A.4.3.3.1 Waste prevention and management in the pickling section besides spent acid control

In order to reduce material losses due to handling procedures in the pickling section, but also in other sections, product handling procedures and equipment should be designed to reduce the occurrence of damage **(20)**. Furthermore, downgrading, end and side trimming losses are a function of hot rolled coil quality; also pickling losses depend on the surface quality of the hot rolled coil. By improving the quality of the processes in the hot strip mill and the resulting hot strip, losses in the cold rolling mill can be prevented [168]. Coils that can not be downgraded or sold can be recycled to metallurgical processes as an ultimate option.

A.4.3.3.2 Control of spent acid in the pickling section

The free acids of the pickling solution dissolve the layer of oxides on the surface of the strip. In this process, metal ions enter the process solutions in the form of soluted metal salts [131]. In the course of the pickling process, the concentration of metal salts in the bath increases and the amount of free acid decreases. In order to permit proper pickling, the bath must not exceed a certain concentration of soluted metal salts. It is possible to maintain a defined level of free acid by continuous regeneration or treatment processes of spent pickle, directly linked to the baths [131].

Depending on the type of acid used, several regeneration and treatment processes exist. Table 8-10 to Table 8-12 in the Annex show a comparison of different regeneration and treatment processes for sulphuric, hydrochloric and mixed acids. In general, it is desirable to achieve a total regeneration of the acid, i.e. a recovery of the free acid and a recovery of acid chemically bonded to metals **(21)**. Two very commonly used pyrohydrolytic processes for spent HCl pickle regeneration and the heptahydrate crystallisation process for spent H_2SO_4 pickle treatment (to recover the free acid) are described in the following.

<u>Hydrochloric acid regeneration by fluidisation</u>

Figure A.4-12 shows the main sub-processes of the fluidised bed acid regeneration process. The spent pickle is pumped into a separating vessel and then concentrated in a Venturi loop by hot gases from the reactor. A share of the concentrated pickle from this loop is continuously fed into the fluidised bed of the reactor. Within the fluidised bed, which consists of iron oxide granulate, acid carry-over and water are evaporated at a temperature of about 850°C and iron chloride is converted into iron oxide and hydrochloric gas. The setting of parameters in the reactor allows the iron oxide to be pulled off with a grain size of 1-2mm Ø and a piled weight of about 3.5t/m^3. This is pulled-off continuously in big installations in order to maintain a constant height of the fluidised bed. The resulting iron oxide is a qualitatively high output and can be used for several applications, e.g. as input for the production of ferromagnetic materials or for the production of iron powder.

The hot off-gas from the reactor contains hydrochloric gas, overheated steam, combustion products and small amounts of iron oxide dust, which is separated from the gas in the cyclone and recycled to the fluidised bed. The off-gas is then cooled down to a temperature of about 100°C in the Venturi scrubber. The thermal energy of the hot off gases is used to thicken the spent pickle, in order to feed it pre-condensed to the reactor. The cooled off-gas from the Venturi scrubber is ducted to an absorber. Within that, the hydrochloric gas is adiabatically absorbed by using rinsing and fresh water. The resulting hydrochloric acid (about 18%) can be directly recycled to the pickling plant or can be stored. The off-gas passes a scrubber in order to remove the remainder of hydrochloric acid and is then released practically free of hydrochloric acid into the atmosphere [131].

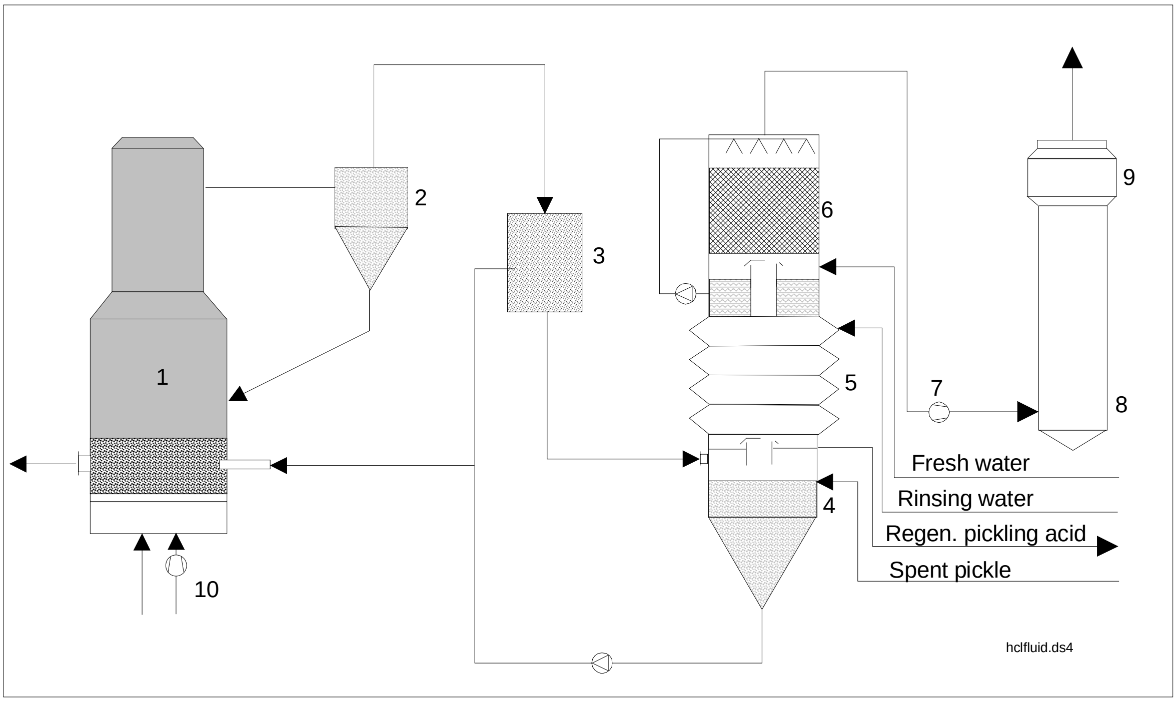


Figure A.4-12: Diagrammatic view of the fluidised bed acid regeneration process (HCl)

Legend: 1. Fluidised bed reactor, 2. Cyclone, 3. Venturi-scrubber, 4. Separating vessel, 5. Absorber, 6. Wet scrubber, 7. Off-gas ventilator, 8. Stack, 9. Mist eliminator, 10. Fan

Source: [131]

Hydrochloric acid regeneration by spray roasting

The spray roasting process is often employed for the recovery of metal oxides from metal chloride solutions. The Ruthner-spray roasting process recovers iron oxide and hydrochloric acid from iron chloride and water. The basic process steps are depicted in Figure A.4-13.

The pyrohydrolytic separation of iron chloride and water is carried out in the spray roasting reactor at a temperature of about 450°C. The spent pickle, containing iron chloride, is fed from the pickling station to a pre-vaporiser. There it comes into direct contact with the hot gases from the reactor and is partly evaporated. The concentrated iron chloride solution is injected from above into the reactor. Hot burn gases cause the fine droplets to evaporate as they descend. Iron chloride is separated into hydrochloric gas and iron oxide by means of steam and oxygen in the air. The resulting fine iron oxide is continuously pulled-off at the bottom of the reactor. The piled weight of the powder is about 0.3-0.4t/m^3.

The hydrochloric gas, steam and combustion gases are ducted via the pre-vaporiser to an absorber, there it is absorbed adiabatically by means of the rinsing water of the pickling plant. The arising hydrochloric acid (about 18%) can be returned to the pickling process. The resulting off-gas is cleaned in a subsequent alkaline washing and is released practically HCl-free via a stack into the atmosphere. The arising iron oxide can be used for different purposes according to its quality [131].

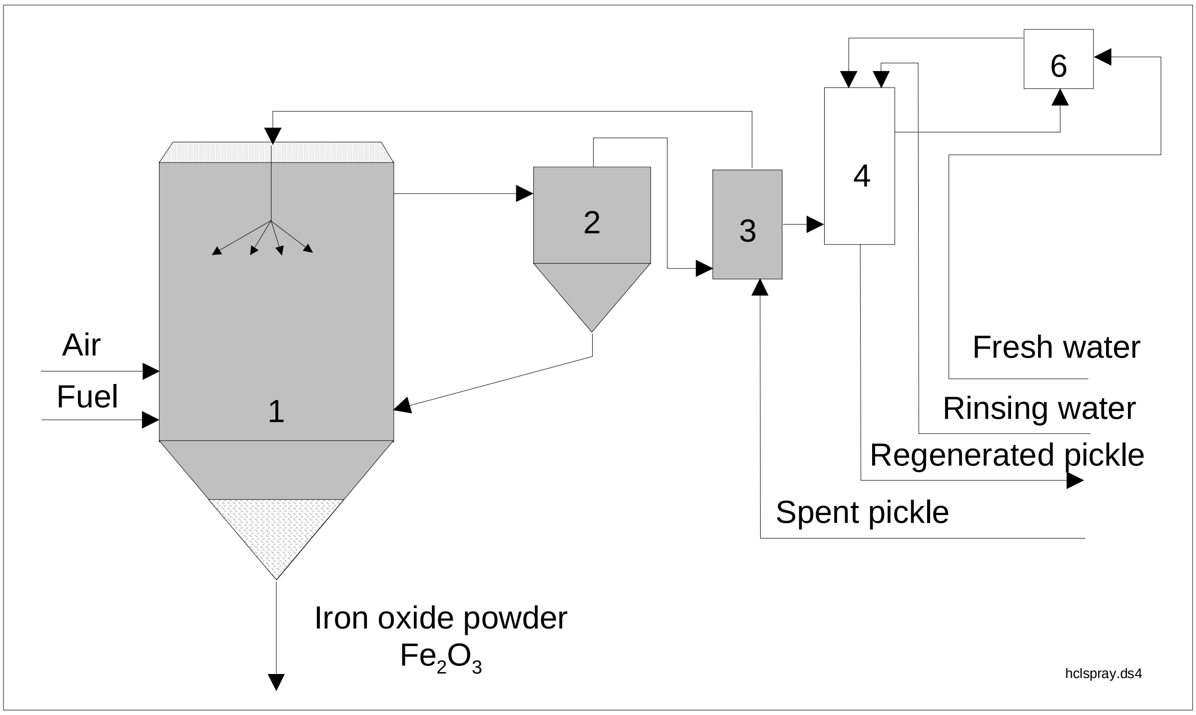


Figure A.4-13: Diagrammatic view of the spray roasting acid regeneration process (HCl)

Legend: 1. Spray roasting reactor, 2. Cyclone, 3. Venturi scrubber 4. Absorber, 5. Off-gas fan, 6. Wet scrubber

Source: [4]

By the use of the presented processes, pickling plants using hydrochloric acid can be operated virtually without waste water. A specific fresh acid consumption of 1-2kg HCl/t down to even 0.2kg HCl/t pickled workpiece has been reported using regeneration plants, while the use of acid without regeneration is stated at 18-30 kg HCl/t pickled workpiece [7, 132].

Sulphuric acid recovery by crystallisation

The sulphuric acid recovery process by crystallisation is based on the solubility relations of the substances water, sulphuric acid and iron sulphate. Iron sulphate is more soluble at increasing temperatures and crystallises out of saturated solutions when being cooled. For the recovery of free sulphuric acid of spent pickle from H_2SO_4 pickling lines, the heptahydrate crystallisation process, yielding $FeSO_4x7H_2O$, is usually applied in industry, nowadays. With respect to the type of cooling, the following heptahydrate crystallisation processes for regeneration are available: crystallisation with indirect cooling, cyclone crystallisation and vacuum cooling crystallisation. The treatment of spent pickle solution by crystallisation prevents the need to neutralise free acid, furthermore the iron is precipitated as heptahydrate and does not have to be neutralised either. With crystallisation processes a significant enhancement of the waste water releases and a reduction of the salt load can be achieved [131]. Figure A.4-14 shows a scheme of a conventional treatment plant for vacuum cooling crystallisation.

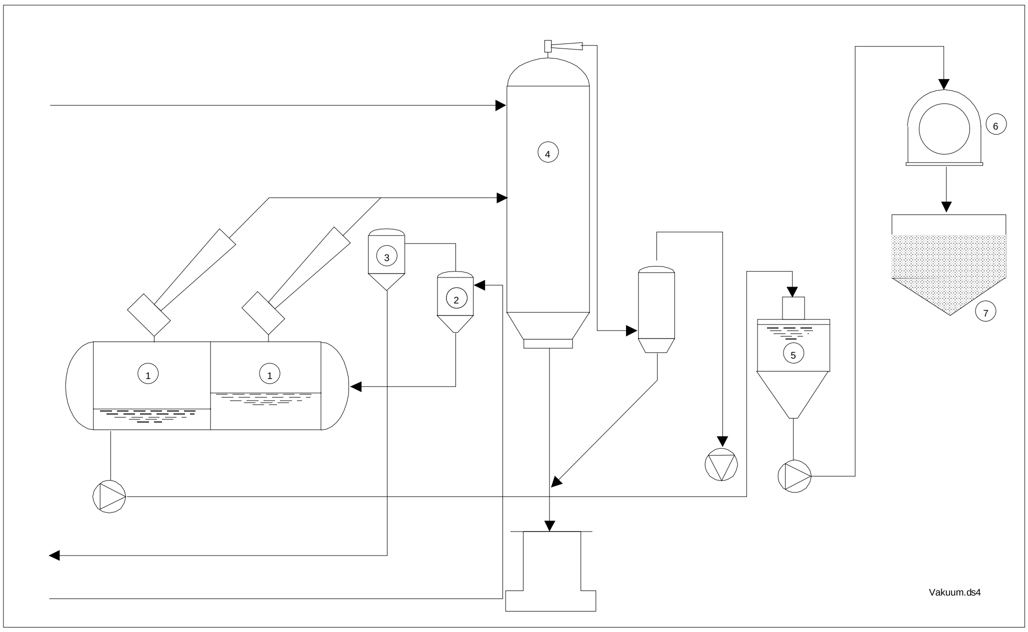


Figure A.4-14: Diagrammatic view of the vacuum cooling crystallisation process (H_2SO_4)

1. Crystallizer, 2. Pre-cooler, 3. Acid co-condensator, 4. Co-condensator, 5. Thickener, 6. Rotary screen, 7. Sulphate storage

Source: [4]

A.4.3.3.3 Waste prevention and management in the cold rolling section and subsequent processes

A good process control within the cold mill section, within the annealing furnaces and the temper mill helps to ensure uniformity of the gauge and properties and finally leads to reduced losses. Also factors like strip cleanness and the prevention of rusting have an impact on possible material losses [168].

A.4.3.4 Water management within cold rolling mills

Waste water within cold rolling mills mainly arises due to the processes pickling and cooling / lubricating during rolling. Pickling and related processes (rinsing, gas cleaning operations, acid regeneration) cause acidic waste water streams. Cooling and lubricating processes in the rolling sections give rise to oil and suspended solid loaded waste water streams. Depending on the steel grades processed, several measures are relevant. In general, the use of process water in loops or cascades, and the use of coolants / lubricants in loops as far as possible is advantageous in this context. However, in order to permit its use in loops, treatment measures have to be taken. Treatment procedures for waste water can be separated into processes for acidic streams and for those oil loaded streams.

If a recovery of the acid is not possible (cf. section A.4.3.3.2 for acid treatment and recovery processes), acidic waste water streams have to be neutralised. Neutralisation can be either carried out with lime milk or caustic soda. As caustic soda is economically less advantageous when used in increasing amounts (about 20t per year), mostly lime milk is employed for neutralisation in pickling stations processing ferrous materials [4].

A.4.3.4.1 Handling of acidic process water from pickling stations

One measure to minimise waste water from rinsing operations is to prevent entrainment losses from the pickling baths **(23)**. These losses can be reduced by several measures depending on the pickling process. Entrainment losses depend i.a. on the following parameters [131]:

- Geometry, size and surface of the workpiece
- Composition, temperature and physical properties of the pickling solution
- Process parameters, e.g. dripping time or speed of workpiece bath removal
- Wringing of workpiece to minimise the liquid layer on continuously processed materials, e.g. strip

In particular, the minimisation of entrainment losses by wringing or other measures to minimise the liquid layer on the strip as well as a good dripping and a suitable bath composition and temperature help to reduce waste water from the rinsing process for all types of pickle agents.

The rinsing process itself can be carried out using cascades **(23)**, which reduces the required amount of rinsing water for defined rinsing qualities. The higher concentration of acid in the rinsing water caused by the use of cascades is also beneficial for a treatment of the rinsing water in integrated acid regeneration plants **(23)**, which require higher acid concentrations. In the following, three diagrammatic views of case studies for using loops in pickling stations are briefly presented.

<u>Waste water handling for HCl pickling stations</u>

In an overview Figure A.4-15 shows an example of waste water free production in a pickling installation with an integrated acid regeneration installation [132].

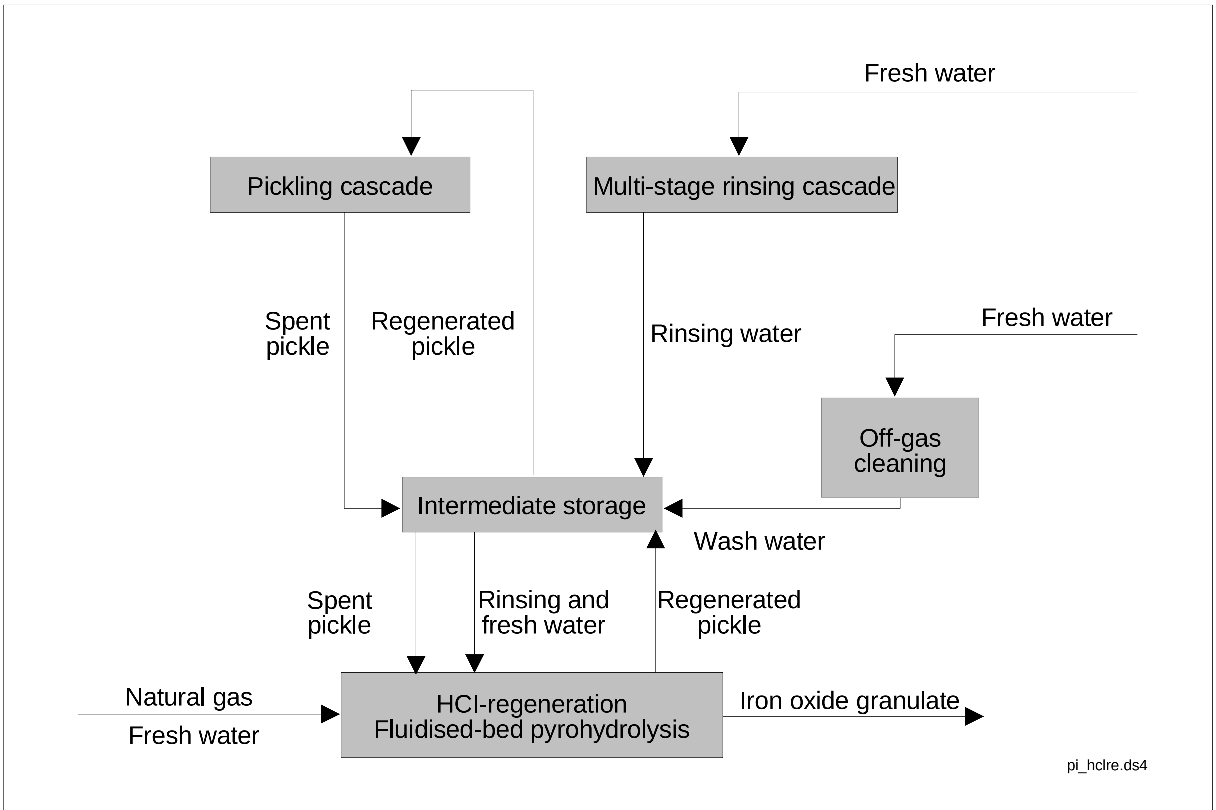


Figure A.4-15: Recycling loop for HCl-pickling plant

Source: [132]

<u>Waste water handling for sulphuric acid pickling stations</u>

Figure A.4-16 shows an overview of a pickling installation using H_2SO_4 with related treatment and neutralisation processes.

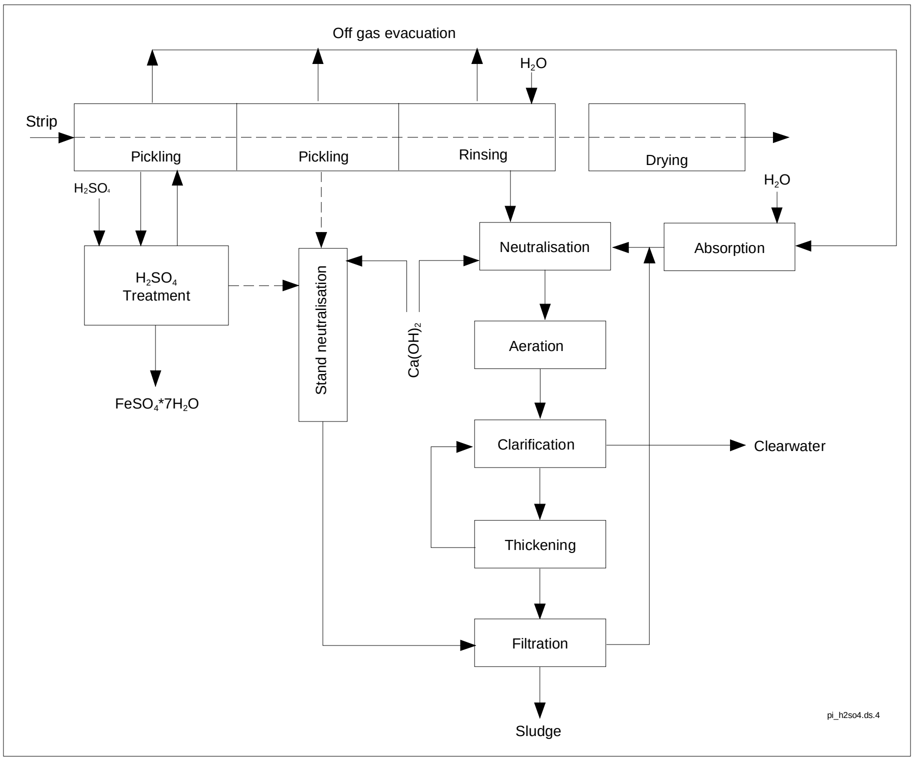


Figure A.4-16: Diagrammatic view of a pickling plant using H_2SO_4

<u>Waste water handling for mixed acid pickling stations</u>

Figure A.4-17 shows an overview of a stainless steel pickling installation including related treatment and neutralisation processes.

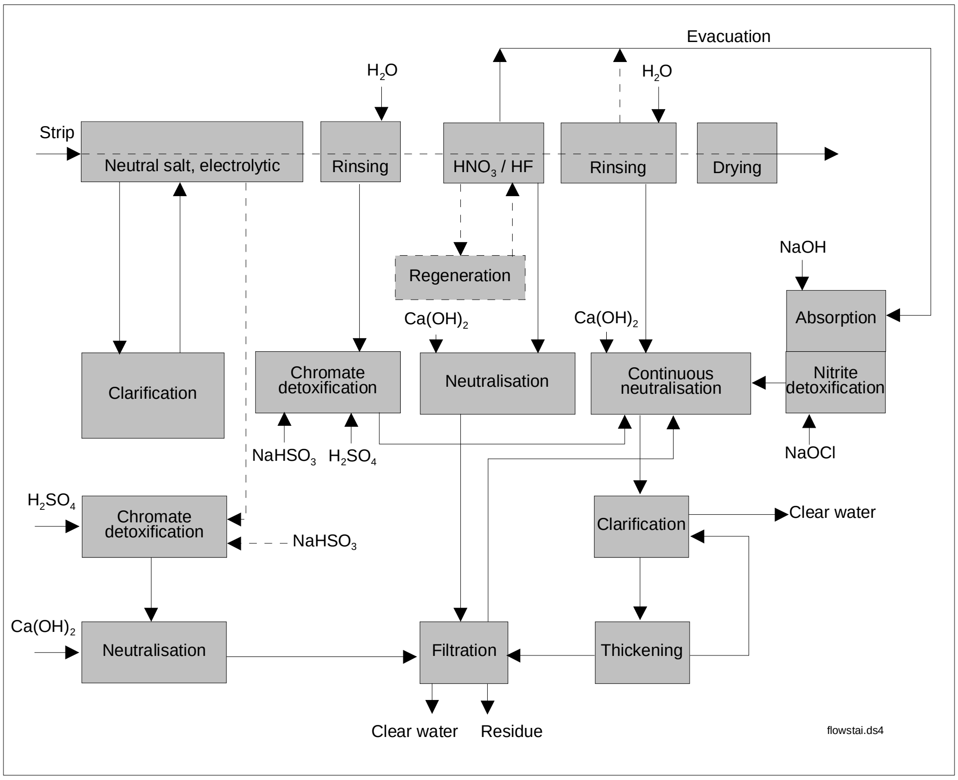


Figure A.4-17: Diagrammatic view of a stainless steel strip pickling plant

Source (Figure A.4-16 and Figure A.4-17): [4]

A.4.3.4.2 Treatment of oil loaded process water from rolling stands (coolants / lubricants)

Main components of coolants and lubricants from the cold rolling stands are water, oil and emulsifying agents. Oils have to satisfy high requirements concerning tribologic properties and temperature constancy, emulsifying agents need to support the forming of stable emulsions. Furthermore, emulsion can contain stabilisers, antifoaming agents, rust-preventive agents, biocides or other additives [4]. Coolants / lubricants are used in loops nowadays **(24)**. In order to maintain their properties as long as possible, they are cleaned and treated. Measures are [4, 70]:

- Removal of solid particles by means of magnetic separators, gravity separators, centrifugal separators, paper band filters, precoat filters, and microfilters
- Removal of non emulsified oils by skimming
- Monitoring of composition, aeration to prevent putrefaction and cooling of emulsion

Spent coolants / lubricants (emulsions) have to be treated. This is done by emulsion breaking. Emulsion breaking can be done thermal, chemical, mechanical and physical. Usually chemical breaking is done as a pre-separation. Subsequently the coolants / lubricants are further treated. Actually, many combinations of treatment steps are used. Available processes for emulsion treatment are [4, 70]:

- Chemical - addition of acid, salts or demulsifiers
- Physical - adsorbtion (for example by means of silicic acid), thermal (several types of evaporators), mechanical (coalescense, flotation, electro-flotation, dissolved air flotation or ultrafiltration)

Nowadays, spent oil emulsions are also given to external processing.

In any case it should be striven at using treatment processes for spent emulsions, that do not give rise to any other waste and yield useable water.

A.4.3.5 Waste management

-Treatment processes for spent oil emulsions

No information is available for this section, at the moment.

A.4.3.6 Overview of candidate BAT for cold rolling mills

The following figure gives an overview of the Candidate Best Available Techniques presented in the previous chapters.

Legend:

N°	Sub-Process(es)	Technique(s)	Reference	Applies to
1	Surface preparation (mechanical)	Cleaning of off-gas	4.3.1.1.	Air
2	Pickling	Optimisation of temperature, composition of pickle solution	4.3.1.1.	Air
3	Pickling	Good covering of bath and well operation of tank evacuation	4.3.1.1.	Air
4	Pickling	Cleaning of off-gas, depending on pickle	4.3.1.1.	Air
5	Spent pickle treatment	Cleaning of off-gas, depending on treatment / regeneration process	4.3.1.1.	Air
6	Cold rolling	Cleaning of exhausted oil mist	4.3.1.2.	Air
7	Annealing	Choice of fuel	4.3.1.3.	Air
8	Annealing	Good control of combustion conditions by computer aided control systems, reduction of waste gas heat losses	4.3.1.3. / 4.3.2.3.	Air, Energy
9	Annealing	Use of low-NO_x burners	4.3.1.3.	Air
10	Annealing	Use of high-convection annealing furnaces	4.3.1.3. / 4.3.2.3.	Air, Energy
11	Temper rolling	Cleaning of exhausted off-gases	4.3.1.4.	Air
12	Pickling	Use of steam / heat exchanger for bath heating, possibly strip preheating by condensate	4.3.2.1.	Energy
13	Pickling	Shallow bath pickling	4.3.2.1.	Energy
14	Pickling	Heat recovery from spent pickle or regenerate	4.3.2.1.	Energy
15	Pickling	Minimisation of heat losses from the tanks	4.3.2.1.	Energy
16	Pickling	Careful choice of pickling agent / acid	4.3.2.1.	Energy
17	Cold rolling	Use of control devices to minimise energy input for auxiliary equipment during delays	4.3.2.2.	Energy
18	Cold rolling / Pickling	Linking of pickling and cold rolling	4.3.2.2.	Energy
19	Annealing	Recovery of waste gas heat	4.3.2.3.	Energy
20	Total plant	Optimise product handling procedures and equipment to reduce damage; optimise quality of incoming hot strip	4.3.3.1.	Waste
21	Pickling	Regeneration / treatment of spent pickle	4.3.3.2.	Waste
22	Total plant	Good process control to minimise material losses	4.3.3.3.	Waste
23	Pickling	Minimisation of entrainment losses, rinsing in cascades, integrated pickle regeneration	4.3.4.1	Water
24	Cold rolling	Use of coolants / lubricants in loops	4.3.4.2	Waste
25	Total plant	Recycling of scrap to metallurgical processes		Waste

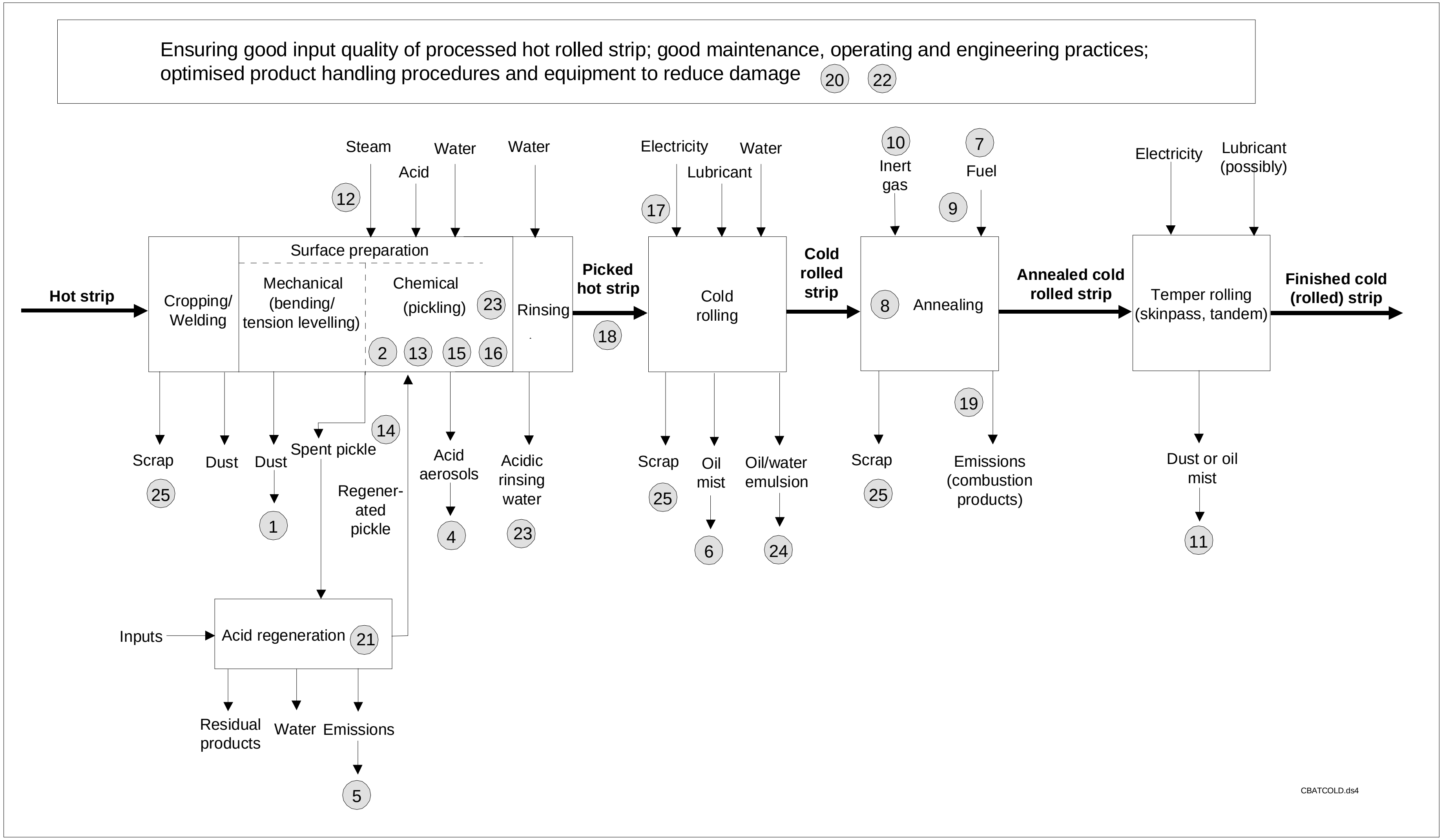


Figure A.4-18: Overview over candidate BAT for cold rolling mills

A.4.4 Case studies of modern hot and cold rolling mills

Table A.4-1 and Table A.4-2 present selected information on input / output levels of modern German hot and cold rolling mills [165, information by firms].

Table A.4-1: Case studies of input / output levels of German hot rolling mills

Hot rolling mill	Case study 1	Case study 2	Case study 3
General data:	**Data from 1998**	**Data from 1994, 1995/96**	**Data from 1994-1996**
Preceding production units	Integrated steelworks	Integrated steelworks	EAF
Type	Hot strip mill	Hot strip mill	Bar / wire rod
Processed steel grades	Carbon, high-grade steels: - austenite, - ferrite		Carbon steel
Product specification	Wide hot strip: thickness 15 - 25,0mm, width 600 - 2,150mm, coil weight max. 45t	Wide hot strip: thickness 15 - 25,0mm, width 650 - 1,180mm	Bar, wire rod
Output (final products)	max. 5,000,000t/a	about 4,000,000t/a	about 1,400,000
Year of construction Last revamp	1973 1997 (process computer)	n.a. n.a.	1966/68 n.a.
Scarfing			
Installation:			
Type	Manual scarfing / automatic scarfing	n.a.	-
Capacity scarfing shop	15 manual scarfing shops / automatic scarfer 63.000t/m	n.a.	-
Off gas cleaning system	Manual: none / automatic: bag filter	n.a.	-
Inputs / Outputs:			
Fuel input (type and amount)	Natural gas and oxygen / -	n.a.	-
Precipitated scale / relative material loss	Material loss by: scarfing 0,38%, burning 1,72%, scrap 0,19%	n.a.	-
Off gas volume flow Dust content	110.000m³(STP)/h <10mg/m³(STP)	n.a.	-
Waste (type and use)	Recycling of collected scale via sintering strand	n.a.	-
Reheating			
Installation:			
Furnace type	2 walking beam furnaces	2 pusher type furnaces	2 pusher type furnaces
Capacity	420t/h per furnace	300t/h per furnace (F1, F2)	n.a.
Special features	Combustion air preheating, top-side burners, low-NO_x-burners	Combustion air preheating (F1: 470°C, F2: 630°C), slab preheating to about 250°C by waste gas	Combustion air preheating
Operating practise	Partly hot charging	n.a.	Partly hot charging
Inputs / Outputs:			
Fuel type Amount	Natural gas 150 Mio. m³(STP)/a	Coke / natural gas Consumption (F1 / F2): 18,000 / 15,000m^3/h	Natural gas / LPG 35.5*10^7kWh (NG) / 65.8*10^6kWh (LPG)
Off gas volume flow NO_x CO C_{total} SO_2 Dust	130,000-150,000m³(STP)/h 500-700mg/m³(STP) n.a. mg/m³(STP) n.a. mg/m³(STP) n.a. mg/m³(STP) n.a. mg/m³(STP)	About 70,000m³(STP)/h 543mg/m³(STP) 4mg/m³(STP) 46mg/m³(STP) 93mg/m³(STP) n.a. mg/m³(STP)	About 30,000m³(STP)/h 330mg/m³(STP) n.d. 1.5mg/m³(STP) n.a. mg/m³(STP) n.a. mg/m³(STP)
Specific energy consumption for reheating	n.a.	n.a.	About 270kWh/t (NG) / about 30kWh/t (LPG)

Table 4-1: Case studies of input / output levels of German hot rolling mills (case studies 1-3, page 2)

Hot rolling mill	Case study 1	Case study 2	Case study 3
Hot Rolling			
Installation:			
Descalers	Vertical-descalers (140bar)	2	n.a.
Roughing mill	4 two-high-stands	1 four-high-stand	n.a.
Coil box ,coil furnace	none, none	none, none	-
Finishing mill	7 four-high-stands	7 four-high-stands	n.a.
Water cooling / Cooling bed	Laminar-water cooling	n.a.	Cooling bed
Reeling machine	3 under-floor reeling machines	n.a.	-
Special features	Thermal covers before finishing train	n.a.	n.a.
Inputs / Outputs:			
Specific energy consumption for rolling drives	n.a.	n.a.	n.a.
Rolling oil, grease	n.a.	n.a.	n.a.
Scrap	n.a.	n.a.	Total scrap return 45,992t/a
Waste (type, use)	Scrap recycling via converter	n.a.	Scrap recycling via EAF
Water Management			
Installation:			
Measures to prevent / reduce water use	Separate loops for cooling and process water	n.a.	Loops
Water cleaning system	Scale-pit, aerated fine scale traps, circular settling tank, sand filter, cooling tower, treatment of eluted water	n.a.	Sand filter (inter alia)
Inputs / Outputs:	Process water		Water use: mill and steelworks
Intake water	n.a.	n.a.	1,000m^3/h
Water in loop	18,000m³/h	n.a.	n.a.
Discharge volume flow Fe (mg/l) HC_{total} (mg/l, MKW) Zn (µg/l) Fish toxicity (dilution factor) COD (mg/l) P_{tot} (mg/l) N_{inorg} (mg/l) AOX (µg/l) Hg (µg/l) Cd (µg/l) Cr (µg/l) Ni (µg/l) Pb (µg/l) Cu (µg/l) Temperature (°C)	n.a. 0.01-0.24, av. 0.11 0.10-0.11, av. 0.10 20.00-65.00, av. 27.90 2.00-2.00, av. 2.00 15.30-29.10, av. 20.70 0.01-0.29, av. 0.14 4.08-7.99, av. 5.31 26.00-187.00, av. 68.50 0.20-0.20, av. 0.20 0.20-0.20, av. 0.20 2.00-20.00, av. 2.95 3.00-40.50, av. 22.78 1.00-20.00, av. 2.90 2.60-20.00, av. 7.69 12.70-30.50, av. 24.75	n.a. m³(STP)/h n.a. n.a. n.a. n.a. n.a. n.a. n.a. n.a. n.a. n.a. n.a. n.a. n.a. n.a. n.a.	970m³(STP)/h n.a. n.a. n.a. n.a. 0-6 n.d. 1-1.3 n.d. n.d. n.d. n.d. 15.0-21.0 n.d. 0.0-27 n.a.
Specific process water use	n.a.	n.a.	About 6m^3/t product
Cleaning chemicals	Coagulants, precipitants, auxiliary coagulants	n.a.	Coagulants
Waste (type and use)	Coarse sinter 48.400t/a, fine sinter 8.000t/a, scale sludge 6.000t/a; recycling via sintering strand and converter	n.a.	Continuous casting and mill scale 25.700t/a; external treatment for recycling to metallurgical processes

Table 4-1: Case studies of input / output levels of German hot rolling mills (case studies 4-6, page 1)

Hot rolling mill	Case study 4	Case study 5	Case study 6
General data:			
Preceding production units	Integrated steelworks		
Type	Hot wide strip mill		
Processed steel grades	Carbon steels, fine grained steel		
Product specification	Wide hot strip: thickness 1.5 - 13mm, width 600 - 1,640mm, coil weight max. 34t		
Output (final products)	900,000t/a		
Year of construction Last revamp	1997 -		
Scarfing			
Installation:			
Type	n.a.		
Capacity scarfing shop	n.a.		
Off gas cleaning system	n.a.		
Inputs / Outputs:			
Fuel input (type and amount)	n.a.		
Precipitated scale / relative material loss	n.a.		
Off gas volume flow Dust content	n.a.		
Waste (type and use)	n.a.		
Reheating			
Installation:			
Furnace type	Walking beam furnace		
Capacity	n.a.		
Special features	Combustion air preheating, several zones, heat recovery by steam production		
Operating practise	Partly hot charging		
Inputs / Outputs:	**Permit values**		
Fuel type Amount	Natural gas 90 Mio. m³(STP)/a		
Off gas volume flow NO_x CO C_{total} SO_2 Dust	Data in co-ordination		
Specific energy consumption for reheating	n.a.		

Table 4-1: Case studies of input / output levels of German hot rolling mills (case studies 4-6, page 2)

Hot rolling mill	Case study 4	Case study 5	Case study 6
Hot Rolling			
Installation:			
Descalers	2 (160bar)		
Roughing mill	Upsetting stand, 4-high-stand		
Coil box , coil furnace	yes, yes		
Finishing mill	5 four-high-stands		
Water cooling / Cooling bed	Laminar-water cooling		
Reeling machine	yes		
Special features			
Inputs / Outputs:			
Specific energy consumption for rolling drives	180 GWh/a		
Rolling oil, grease	Hydraulic oil: 30t/a Grease: 166t/a		
Scrap	n.a.		
Waste (type, use)	Scrap recycling via converter		
Water Management			
Installation:			
Measures to prevent / reduce water use	Separate loops for cooling and process water		
Water cleaning system	Scale-pit, horizontal settling tank, sand filter, cooling tower, combined flocculation and horizontal settling tank, decanter		
Inputs / Outputs:	Process water		
Intake water	m^3/h		
Water in loop	m^3/h		
Discharge volume flow Fe (mg/l) HC_{total} (mg/l, MKW) Zn (µg/l) Fish toxicity (dilution factor) COD (mg/l) P_{tot} (mg/l) N_{inorg} (mg/l) AOX (µg/l) Hg (µg/l) Cd (µg/l) Cr (µg/l) Ni (µg/l) Pb (µg/l) Cu (µg/l) Temperature (°C)	$11.4 m^3$(STP)/h 11.5 6.9 2,000 n.a. 113.5 n.a. n.a. n.a. n.a. n.a. 10.0 130.0 n.a. n.a. n.a.		
Specific process water use	n.a.		
Cleaning chemicals	Coagulants, precipitants, auxiliary coagulants: 12t/a total		
Waste (type and use)	Coarse sinter fine sinter, scale sludge		

Table A.4-2: Case studies of input / output levels of German cold rolling mills

Cold rolling mill	Case study 1	Case study 2	C 3
General data:			
Preceding production units	Integrated steelworks, hot rolling mill	Integrated steelworks, hot rolling mill	
Existing sub-processes at site	Pickling department, acid treatment, tandem mill, reversing / skin-pass mill, conventional hood-type annealing furnace, finishing shop, cont. galvanising line	Pickling department, acid regeneration, tandem mill, reversing / skin-pass mill, hood-type annealing furnace, finishing shop, continuous galvanising line	
Processed steel grades	Carbon steel, low-alloyed steel	Carbon steels, fine grained steel	
Product specification	Cold strip: width 50-2mm, thickness 0.5-2.8mm, weight max. 38t, coil ∅ 1.000-2.300mm	n.a.	
Output (cold rolling mill)	1,200,000t/a	1,250,000t/a	
Year of construction Last revamp	1962 1996 (pickling department)	n.a. 1996 (process automation)	
Surface preparation			
Installation:			
Pickling plant	Continuous pickling line	Continuous pickling line	
Capacity	1,200,000t/a	1,000,000t/a	
Mechanical descaling	Tension leveller	Tension leveller	
Pickle temperature	n.a.	55°C	
Rinsing station	Cascade rinsing	Cascade rinsing	
Off gas cleaning (mechanic)	n.a.	n.a.	
Off gas cleaning (pickling)	Mist eliminator	Packed scrubber	
Inputs / Outputs:			
Pickle agent / solution	H_2SO_4 (25 %)	HCl (n.a.)	
Fresh acid consumption	n.a. kg acid/t	1,300t/a (HCl)	
Off gas volume flow (mech. surface preparation) Dust content	n.a. m³(STP)/h n.a. mg/m³(STP)	Data in co-ordination	
Off gas volume flow (chem. surface preparation) Acid content	n.a. m³(STP)/h n.a. mg/m³(STP)	Data in co-ordination	
Effluents	n.a.	n.a.	
Acid regeneration			
Installation:			
Acid type	Sulphuric acid	Hydrochloric acid	
Process	Vacuum crystallisation	Spray roasting process	
Off gas cleaning	n.a.	Scrubber column with mist eliminator	
Inputs / Outputs:			
Arising outputs and handling	Iron sulphate (selling), neutralisation sludge (landfill)	Data in co-ordination	
Off gas volume flow Composition	n.a. n.a.	Data in co-ordination	
Effluents	n.a.	Data in co-ordination	

Table 4-2: Case studies of input / output levels of German cold rolling mills (case studies 1-3, page 2)

Cold rolling mill	Case study 1	Case study 2	C 3
Cold Rolling			
Installation:			
Cold rolling mill	80“-four-high-Tandemtrain (4 stands)	n.a.	
Exhaustion and gas cleaning	n.a.	Oil mist eliminator	
Water management	n.a.	Coolant /lubricant loop, spent emulsion breaking	
Inputs / Outputs:			
Specific energy consumption for rolling drives	n.a.	102.864GWh/a	
Oil (type, loop, use)	several, n.a., n.a.	n.a.	
Off gas volume flow C_{total}	n.a.	Data in co-ordination	
Effluents	n.a.	Spent emulsion to emulsion breaking plant	
Scrap	n.a.	n.a.	
Waste (type, use)	n.a.	n.a.	
Annealing			
Installation:			
Furnace type	Hood-type annealing furnaces	Hood-type annealing furnaces	
Capacity	1,200,000t/a	n.a.	
Special features	n.a.	Post-combustion	
Inputs / Outputs:			
Fuel input (type and amount)	Natural gas / 10,400t/a	Natural gas / $16.2x10^3m^3$(STP)/a	
Inert gas	DX, HNX-gas, hydrogen	H_2, N_2	
Off gas volume flow NO_x CO C_{total}	n.a. m^3(STP)/h 74mg/m^3(STP) 1,150mg/m^3(STP) n.a.	Data in co-ordination	
Waste (type, use)	n.a.	n.a.	
Skin-Pass Rolling			
Installation:			
Mill (number and type of stands)	90“-/56“-/80“-four-high-reversing-/skin-pass stands	n.a.	
Maximum final parameters of workpiece	Thickness: 0.5 - 4.0mm, width: 600 - 2,100mm, coil weight: max. 42t	n.a.	
Off gas cleaning	n.a.	Fibre mist eliminator	
Inputs / Outputs:			
Specific energy consumption for rolling drives	n.a.	n.a.	
Off gas volume flow concentration	n.a. m^3(STP)/h n.a. mg/m^3(STP)	Data in co-ordination	
Waste (type, use)	n.a.	n.a.	

Table 4-2: Case studies of input / output levels of German cold rolling mills (case studies 1-3, page 3)

Cold rolling mill	Case study 1	Case study 2	C 3
Water Management			
Installation:			
Special features	n.a.	Emulsion breaking plant	
Inputs / Outputs:		Discharge from neutralisation	
Emissions	n.a.	Emulsion breaking plant: fugitive emissions	
Discharge volume flow Fe HC_{total} NO_2-N Fluoride Cr VI Zn Fish toxicity COD P AOX Hg Cd Cr Ni Pb Cu	264,528m³/a 0.41mg/l 0.28mg/l n.a. mg/l n.a. mg/l n.a. mg/l 0.02mg/l n.a. as dilution factor n.a. mg/l n.a. mg/l n.a. mg/l n.a. mg/l n.a. mg/l 0.08mg/l 0.03mg/l n.a. mg/l n.a. mg/l	83,220m³/a 0.17mg/l *) 0.97mg/l *) 0.41mg/l n.a. mg/l n.a. mg/l 0.03mg/l n.a. as dilution factor 121mg/l *) 0.1mg/l n.a. mg/l n.a. mg/l n.a. mg/l 0.01mg/l 0.01mg/l 0.07mg/l 0.01mg/l	
Waste	n.a.	Sludge: 300t/a	

*) Waste water is additionally treated in a central waste water treatemnt plant.

A.5 Emerging techniques

This chapter presents innovative techniques for rolling mill plants that are of interest with respect to (integrated) pollution prevention. The mentioned techniques are either not yet commercially available on an industrial scale or are just not being applied in Germany, at the moment.

A.5.1 Efficient use of energy

Linking processes within rolling mills for continuous operation and the saving of complete process steps usually helps to reduce energy consumption required for steel forming. In particular, significant progress in near-net-shape production by casting and following direct rolling has been achieved within recent years. A couple of processes for thin slab casting (casting-direct rolling) are now available on an industrial scale and are in operation at various sites world-wide. Long products are already produced near-net-shape at some sites in Germany (e.g. so-called "dog-bones"), and this near-net-shape technology is still being improved[11]. However, so far no plant for near-net shape production for flat products is in operation (however, cf. footnote 1).

A.5.1.1 Efficient energy use by continuous hot strip rolling

Endless rolling is a new hot rolling process, in which the bars are joined, before they enter the finishing train [37]. This process has been implemented in one plant in Japan. It has the potential to increase the overall productivity of the mill, to reduce yield losses and improve the steel quality leading to an overall reduction in specific energy use [168]. The implementation of endless rolling requires particular care in order to join the bars properly in an economic manner. Also the control systems need to be adapted to new tasks, as mill idle times for pre-setting are no longer provided [37]. Figure A.5-1 shows a diagrammatic view of the endless hot rolling process at Kawasaki Steel Chiba Works.

[11] E.g., SMS has developed a technology called MPS (Multi-Purpose-Section), which produces several types of section products from near-net-shape cross-sections for section products in one installation [cf. i.a. 147].

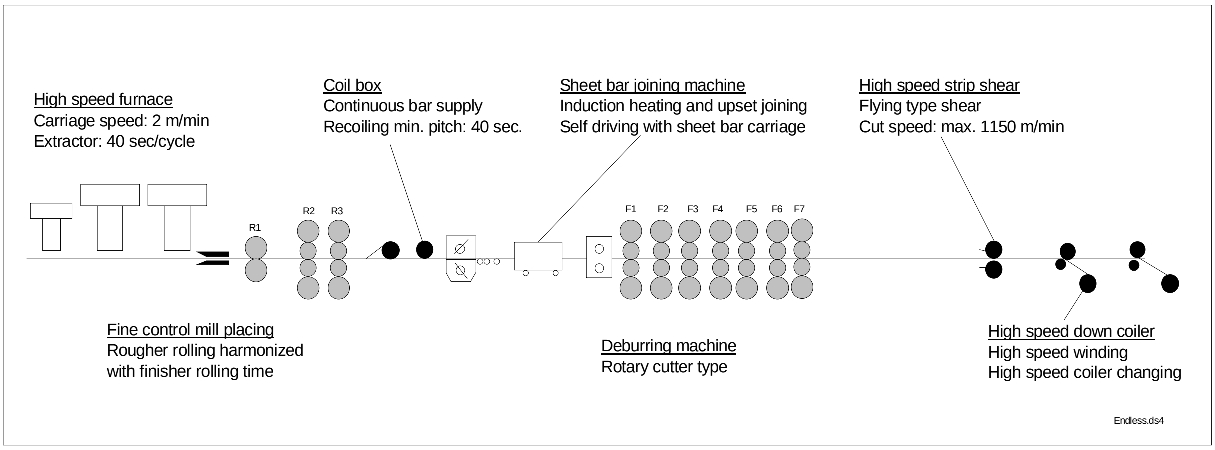


Figure A.5-1: Diagrammatic view of the endless hot strip rolling process

Source: [157]

Table A.5-1 shows the main specifications of endless hot strip equipment.

Table A.5-1: Main specifications of endless hot strip equipment

Item	Specification
Transfer bar	
Thickness, mm	20-40
Width, mm	800-1,900
Frequency (min.), s	45
Coilbox	
Number peelers	2
Coiling speed (max), metres/min	340
Recoiling speed (max), metres/min	150
Bar joining machine	
Type	Self-driven with carriage
Driving speed (max), metres/min	60
Heating	Induction
Deburring machine	
Type	Rotary cutter
Strip shear	
Shearing speed, metres/min	1200
Shearing thickness, mm	0.6-6.0

Source: [157]

Reported benefits at the plant mentioned have been an increase in strip quality (slight thickness change over the entire length of strip, a slight width change over the entire length of strip: ± 3-6mm, little coiling temperature fluctuation over the entire length of strip: deviation ± 15-30°C), an increase in productivity (increase 20%, decrease in unexpected roll change time of 90%) and an increase in yield (decrease in shape rejects from head and tail end of 80% and decrease in surface defects due to pincher marks of 90%) [157].

A.5.1.2 Efficient energy use in thin slab casting and directly connected rolling

Direct strand reduction processes, which link a thin slab caster and a following hot rolling mill, are commercially available from different plant manufacturers. Several concepts have been developed, e.g. CSP ("Compact Strip Production") by SMS, ISP ("In-line Strip Production") by MDH or CONROLL ("CONtinuous thin slab casting and ROLLing") by VAI. These concepts, combining continuous casting and hot rolling, take advantage of the heat contained in the cast steel. Thin slabs are cast with a thickness of about 50mm (CSP), 60mm (ISP, directly soft reduced to about 45mm) and 75-130mm (CONROLL) and are then further reduced in rolling stands [52, 51, 72, 73]. In the following, the above-mentioned three concepts are briefly presented. All of them have in common, that they aim to minimise the number of process steps from liquid steel to the coiled hot strip, while still achieving a good surface quality. The steps required to produce hot rolled coil with these technologies are [52, 134, 140]:

- Casting
- Soaking
- Forming
- Cooling
- Reeling

Another process, which directly links casting with hot rolling is the TSP-process (Tippins Samsung Process) by Tippins Incorporated. This technology combines a thin slab caster (strand thickness about 100-125mm) with a Steckel-mill. Cf. i.a. [137, 183, 184] for more detailed information on this process.

A.5.1.2.1 CSP - Compact Strip Production

Figure A.5-2 presents a diagrammatic view of the CSP process.

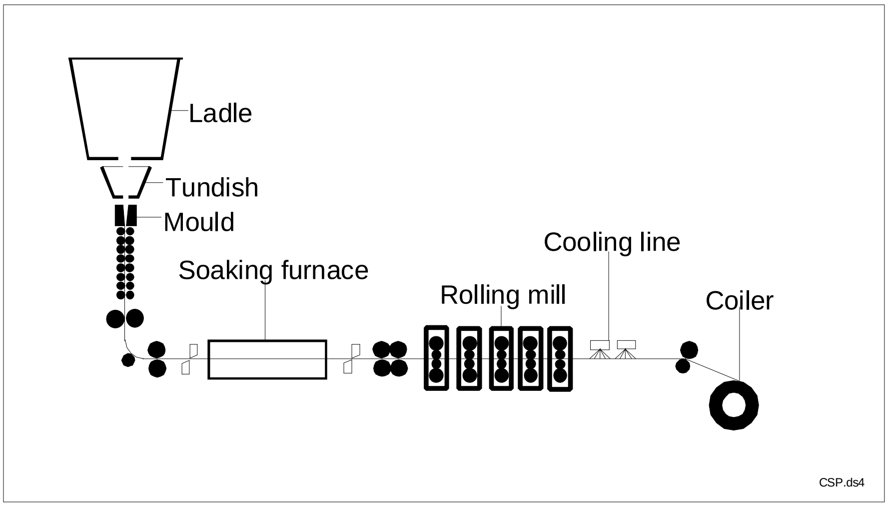


Figure A.5-2: Diagrammatic view of a CSP plant

Source: [73]

The basic features of the CSP technology are: A continuous caster with a specially designed mould shape and vertical strand guide producing a 50mm thin slab, which is cut into individual lengths according to the required coil weight. These slabs enter an equalising furnace (e.g. roller-hearth furnace) at a constant speed. After equalisation, the thin slab is accelerated to the considerably higher rolling-mill entry speed and is fed to the mill after passing through a high-pressure descaling facility [50]. The energy requirement for soaking within the CSP process is limited to compensation of idle running losses within the roller hearth furnace. It amounts to about 25kWh/t [134]. Figure A.5-3 presents an energy balance for a single strand CSP plant.

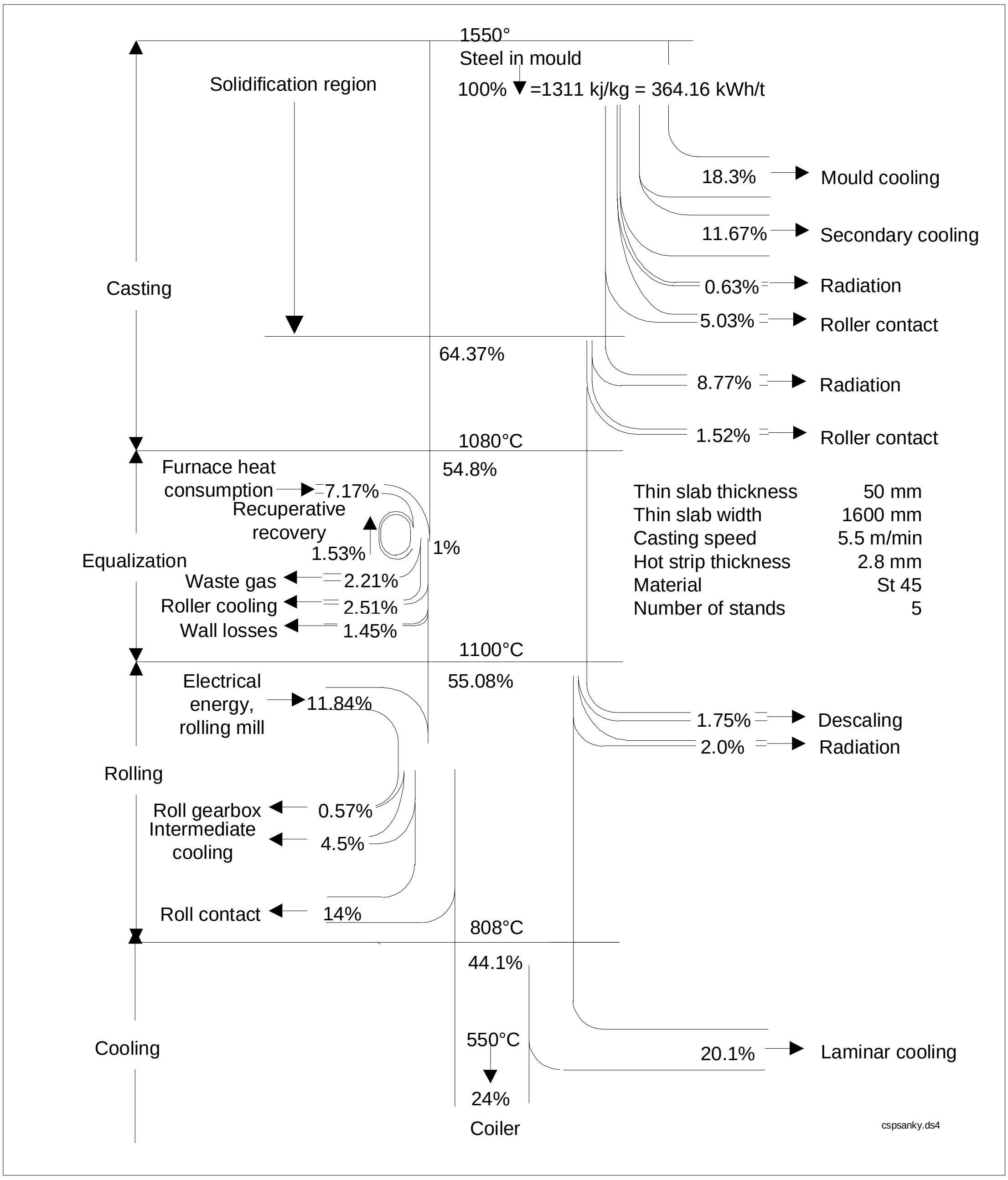


Figure A.5-3: Energy balance for a single-strand CSP plant

Source: [50]

Products that have already been produced with the CSP technology show a thickness range from 25mm down to 1mm for many steel grades (e.g. next to carbon steel also micro-alloyed steel and Si-alloyed steel for electro-plate; cf. [134] for a detailed list of steel grades, that have been processed by CSP technology). CSP plants allow a production of hot strip of about 1-1.5 million tons per strand per year [147]. For a more detailed covering of the CSP-technology cf. i.a. [49, 130, 134].

A.5.1.2.2 ISP - In-line Strip Production

Figure A.5-4 shows a diagrammatic view of an ISP plant. ISP plants have production capacities of about 1.5 million tons hot strip per strand per year [139].

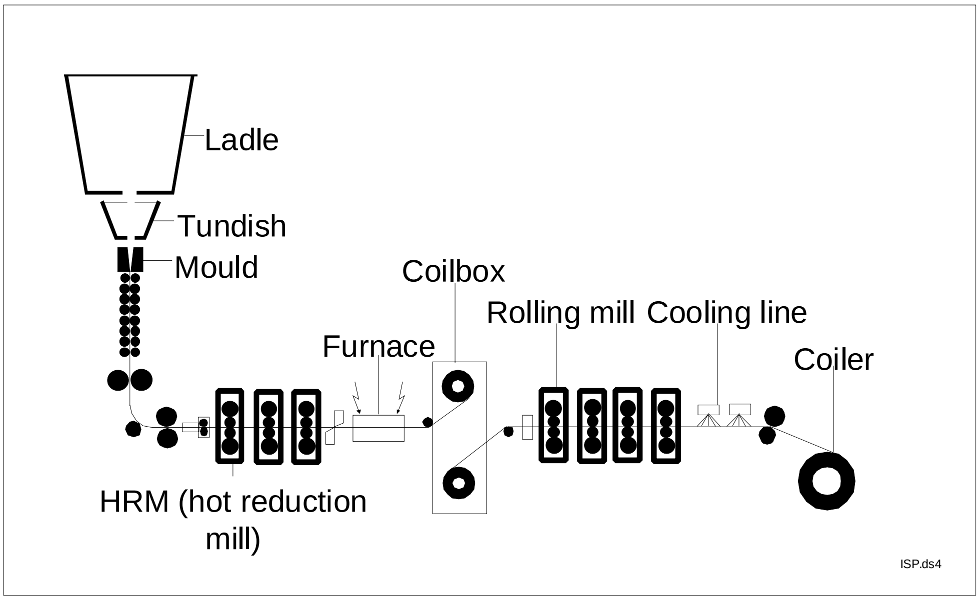


Figure A.5-4: Diagrammatic view of an ISP plant

Source: [73]

The main steps of the ISP process are cast-rolling with liquid core (liquid core reduction), cast-rolling with solid core, intermediate heating, transfer bar coiling and finish rolling. It is possible to roll the hot strip down to a thickness of about 1.0mm with this process, also satisfying deep-drawing requirements [139]. For intermediate heating in the ISP process, often induction furnaces are used. Depending on the strip thickness to be achieved and the rolling technology (e.g. austenitic or ferritic rolling, cf. Figure A.5-5 and Figure A.5-6), the required temperature elevation differs considerably.

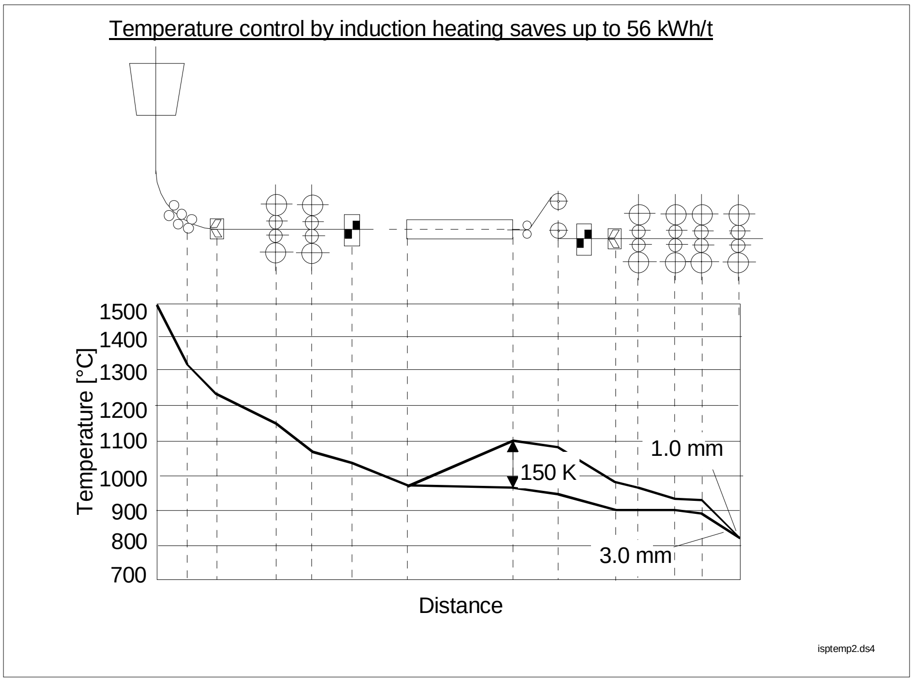


Figure A.5-5: Flexible temperature control by induction heating

Source: [139]

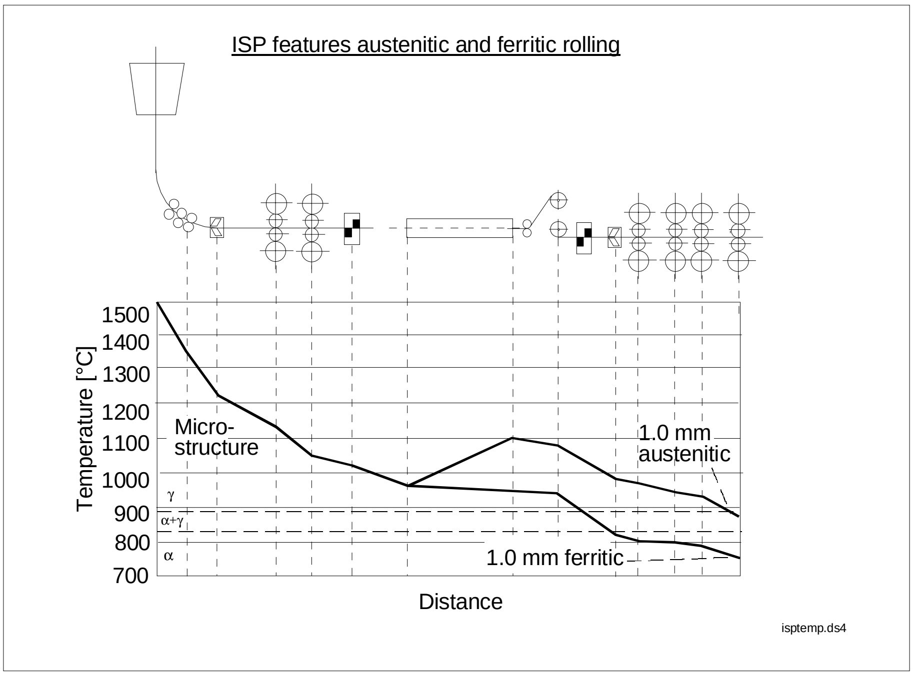


Figure A.5-6: Flexible temperature control yields new rolling technologies

Source: [139]

An induction furnace allows a flexible control of the temperature elevation and may save energy up to 56kWh/t [139]. Figure A.5-7 shows three different plant concepts employing the ISP technology.

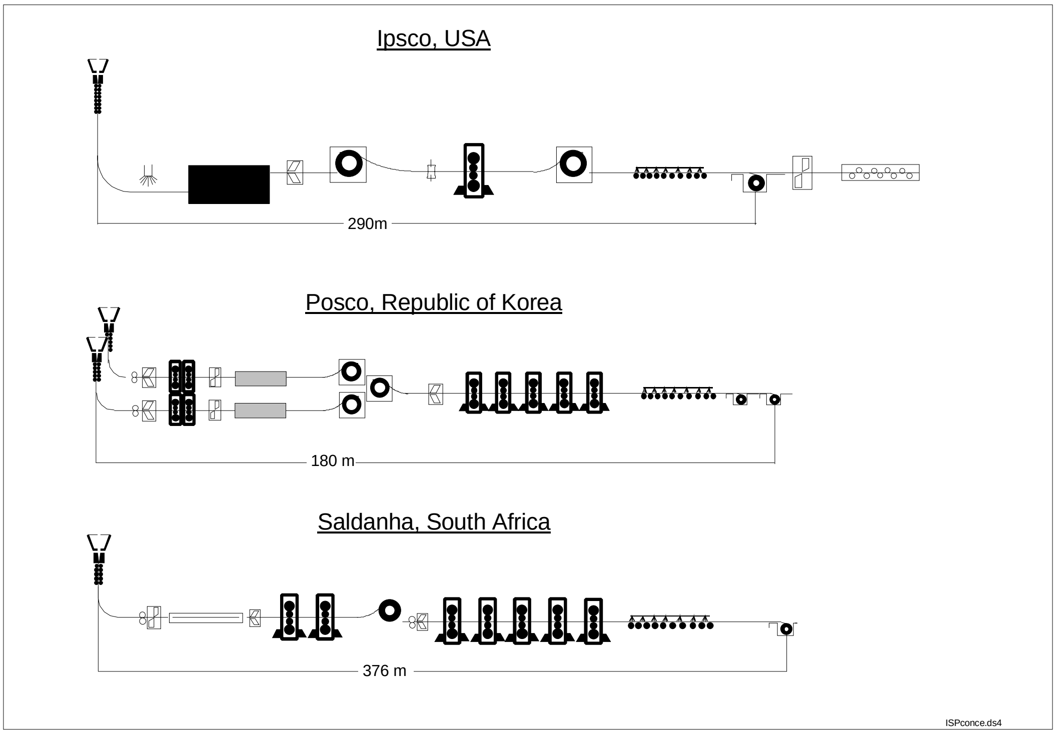


Figure A.5-7: Different plant concepts using the ISP technology

Source: [73]

A.5.1.2.3 CONROLL - Continuous thin slab casting and Rolling

The CONROLL plant aims to produce high quality hot strip by a continuously operating mill. CONROLL plants have capacities of about 1.5Mt/y per strand [51]. According to plant manufacturers' information, in order to achieve an excellent surface quality, a minimum mould thickness of 90 to 100mm is necessary [51]. Directly after casting follows a soft reduction of the strand, while the core is still liquid. After equalising the strand in a roller hearth furnace, rolling is carried out in two steps. The main data of a case study is presented in Table A.5-2.

Table A.5-2: Main technological data of a CONROLL case study

Plant configuration	
Meltshop:	2 EAF, 1 AOD, 1 L MF
CONROLL plant:	Thin slab caster, walking beam furnace, roughing stand, 6 finishing stands
Casting thickness:	75-130mm
Max. heat size:	135t
Width range:	635-1283mm
Thickness hot strip:	1.8-12.7mm
Processed steel grades	
Low carbon, peritectic carbon, medium carbon, high carbon	
HSLA grades, alloyed grades, stainless grades, silicon grades	

Source: [52]

The main advantages of this process are energy savings and an increase in productivity [52]. Figure A.5-8 shows a comparison of the time-temperature course between cold charging and hot charging in a conventional plant and direct charging in a CONROLL plant [37].

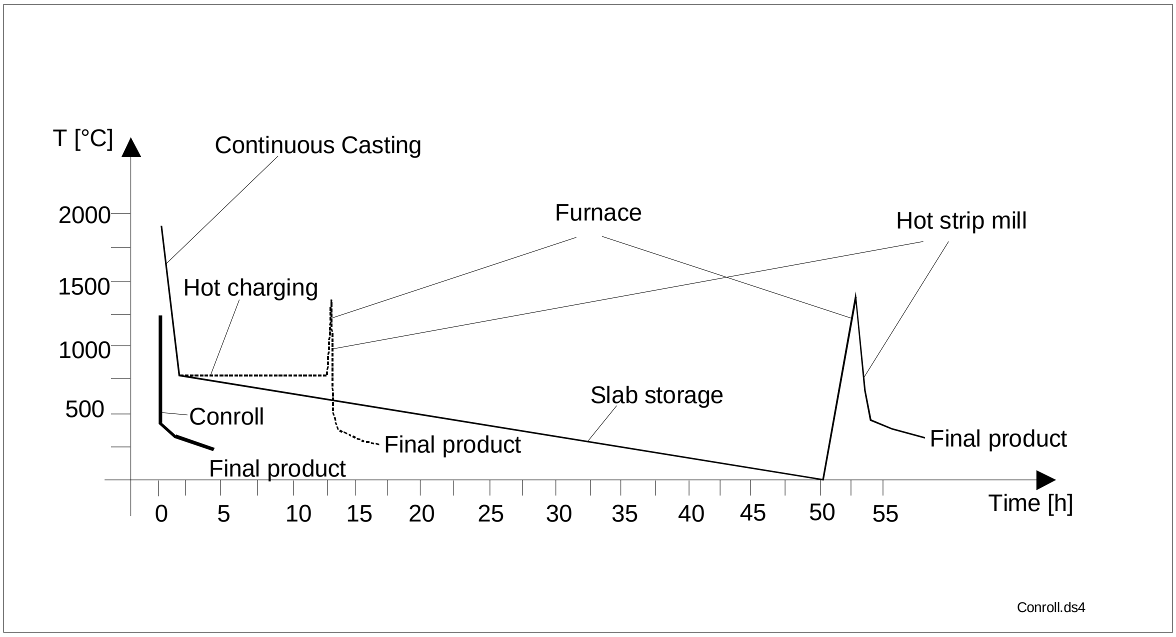


Figure A.5-8: Course of temperature and time for several plant configurations

Source: [37]

A.5.1.3 Efficient energy use by strip casting (hot forming)

While thin slab casting and directly connected rolling technologies can still be seen as an (significant though) improvement of the conventional rolling technology, the realisation of direct strip casting technologies on an industrial scale represents a change in technology. By direct casting of strip, which can be subsequently cold rolled, the process chain from liquid steel to the final product is shortened substantially. Table A.5-3 lists a comparison of characteristic parameters between slab casting, thin slab casting and strip casting technologies.

Table A.5-3: Comparison of selected parameters between different casting technologies

Technology	Continuous casting	Thin slab casting	Strip casting
Product thickness	150-300mm	20-60mm	2-4mm
Solidification time	>600s	about 60s	<1s
Casting speed	1-2.5m/min	4-6m/min	30-90m/min
Average heat flux in the mould	1-3MW/m^2	2-3MW/m^2	8-10MW/m^2
Metallurgical length	>10m	>5m	<0.5m
Melt weight in the caster	>5,000kg	about 800kg	<400kg

Source: [145, 146]

A lot of research has been and is still being done in order to develop strip casting plants on an industrial scale. Figure A.5-9 and Figure A.5-10 show diagrammatic views of pilot plants, which have been developed by a co-operation of several firms.

In particular the research project "Myosotis", carried out jointly by Thyssen-Krupp Stahl AG and Usinor-Sacilor, seems to be very promising [145, 146]. This plant employs the double-roller technique (Figure A.5-9), while the plant depicted in Figure A.5-10 employs a CPR (Casting Pressing Rolling) process.

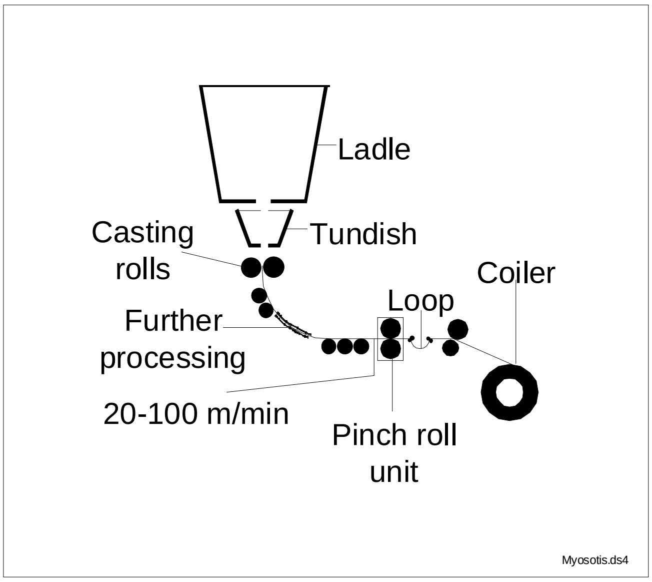


Figure A.5-9: Double-roller pilot plant

Source: [73]

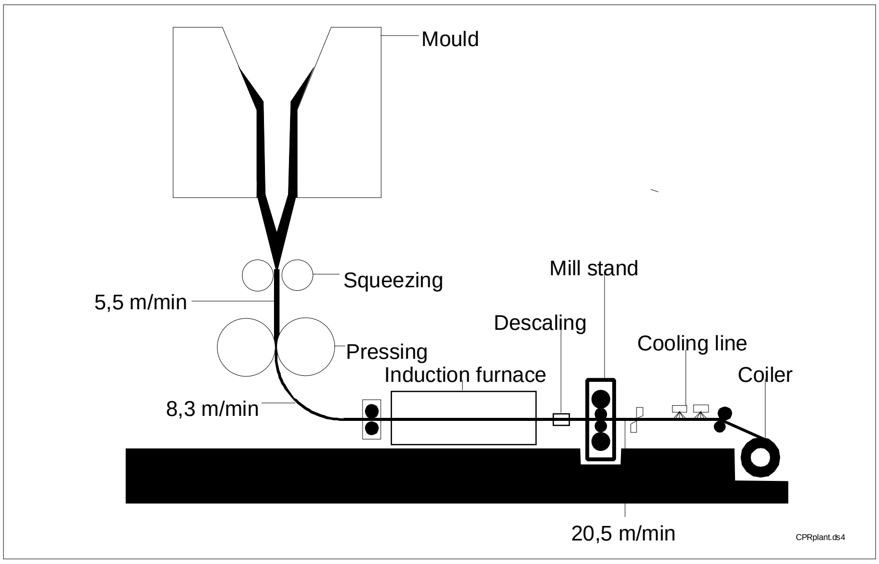


Figure A.5-10: CPR pilot plant

Source: [73]

Table A.5-4 lists technological data related to the "Myositis" pilot plant in Isbergues, France [98].

Table A.5-4: Characteristic data of a strip caster (case study, double-roller technology)

Plant configuration	
Casting ladle capacity:	92t
Distributor capacity:	12t
Current / possible width:	865 / 1,300mm
Roll diameters:	1,500mm
Roll material:	Nickel-coated copper
Casting speed:	20-80m/min
Thickness:	2-4mm
Outlet line:	2 pinch rolls
	1 loop
	1 parting shears
	2 winders (15t)
Cast steel grades	
Stainless, Si steel, carbon steel, alloys	

Source: [98]

Further information on developments in near-net-shape casting / direct strand reduction can i.a. be found in [72, 108].

A.5.2 Techniques concerning waste

A new process for the treatment and use of oily mill scale is the CARBOFER-process. According to plant manufacturer' s information [117], treated oily mill scale can be injected into the blast furnace or the EAF.

A.5.3 Techniques concerning water

Savings of up to 40% water consumption for descaling hot rolled products have been reported by using newly developed nozzles. These nozzles incorporate a specially designed jet stabiliser on the water entry side that leads the spray water to the nozzle mouth in a turbulence-free smooth stream. This technology allows a drastically reduced spray depth on the surface and therefore a liquid flow nearly free of losses. If there is no need for an increase in impact within the existing descaling process, it is possible to use a nozzle size that is one or two sizes smaller than the original nozzle. This permits the above mentioned saving of spray water [21].

B Continuous Galvanising

B.1 General information on the German continuous galvanising industry

This study deals with the production zinc metal coated steel strip, which is processed in continuous galvanising lines directly following rolling mills (electro galvanising and hot dip galvanising lines). The scope of the study will be set out in more detail in Chapter B.2.1. This chapter provides basic economic information on German continuous galvanising plants. It contains production figures and the geographical distribution of selected plants of larger capacities.

Economic aspects

Table B.1-1 shows output figures for hot dip coated and electroplated strip in Germany for the time period 1992-1997. Additionally, the share of zinc coated strip is given.

Table B.1-1: Output of zinc coated strip in Germany in 1,000 t (1992-1997)

Year	1992	1993	1994	1995	1996	1997
Hot dipped strip (total)	2,432	2,657	3,257	3,672	3,672	3,867
Of that zinc coated strip	2,225	2,454	3,008	3,443	3,458	3,626
Electrolytically coated strip	1,455	1,451	1,609	1,610	1,673	1,812
Of that zinc coated strip	1,171	1,174	1,322	1,323	1,351	1,494
Total zinc coated strip	**3,396**	**3,628**	**4,330**	**4,766**	**4,809**	**5,120**

Source: [152, 151]

Next to the production of continuously working galvanising lines for mass sheet production, job galvanising contributes to another 1.15 million tons (as at 1994) of galvanised steel products to the production of zinc coated steel in Germany [88]. This industry is not considered in this study, as production processes differ considerably.

Figure B.1-1 shows locations of selected continuous galvanising lines in Germany.

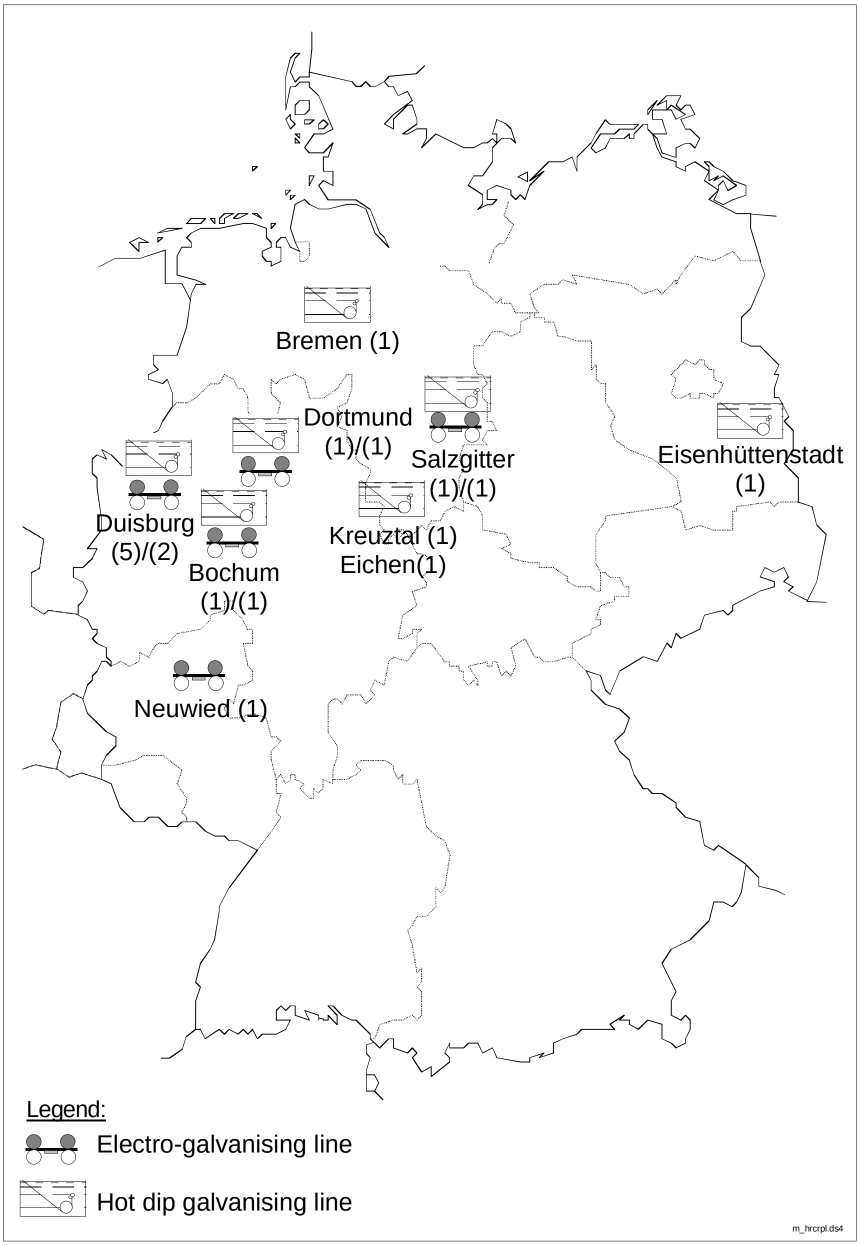


Figure B.1-1: Locations of continuous galvanising lines in Germany (examples)

Zinc coated strip is used mainly in the construction area, in the automobile industry and for household ware production. Production of zinc coated strip increased steadily within the last couple of years [152, cf. Table A.1-1]. One driving force was the growing use of electro galvanised sheet in the automobile industry, as its material properties corresponded especially to the properties of cold rolled sheet [111]. Also because of this reason, a couple of high performance electro galvanising lines have been built in the eighties. Nowadays, also modern continuous hot dip galvanising lines are able to produce sheets fulfilling the requirements of the car industry for most applications. The increase in production of zinc coated strip in steelworks can be seen as part of a general trend towards an increase in depth of production in the steelworks (cf. Figure B.1-2), when it is profitable, while the processors focus on their competence [143].

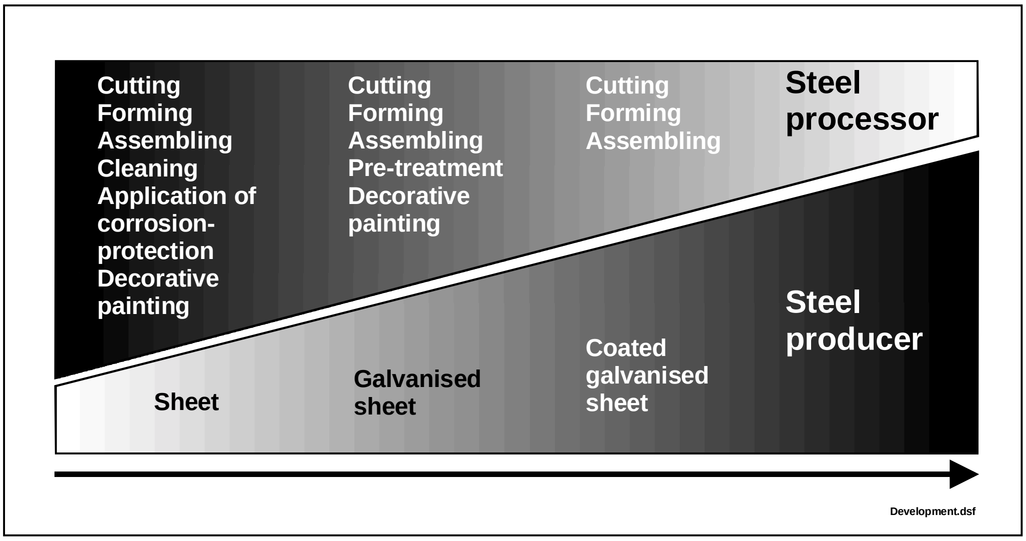


Figure B.1-2: Tendency towards a shift in depth of production from strip processors to steel producers

Source: [63]

Figure B.1-3 and Figure B.1-4 show the increase in production and in production facilities for zinc coated products in Western Europe.

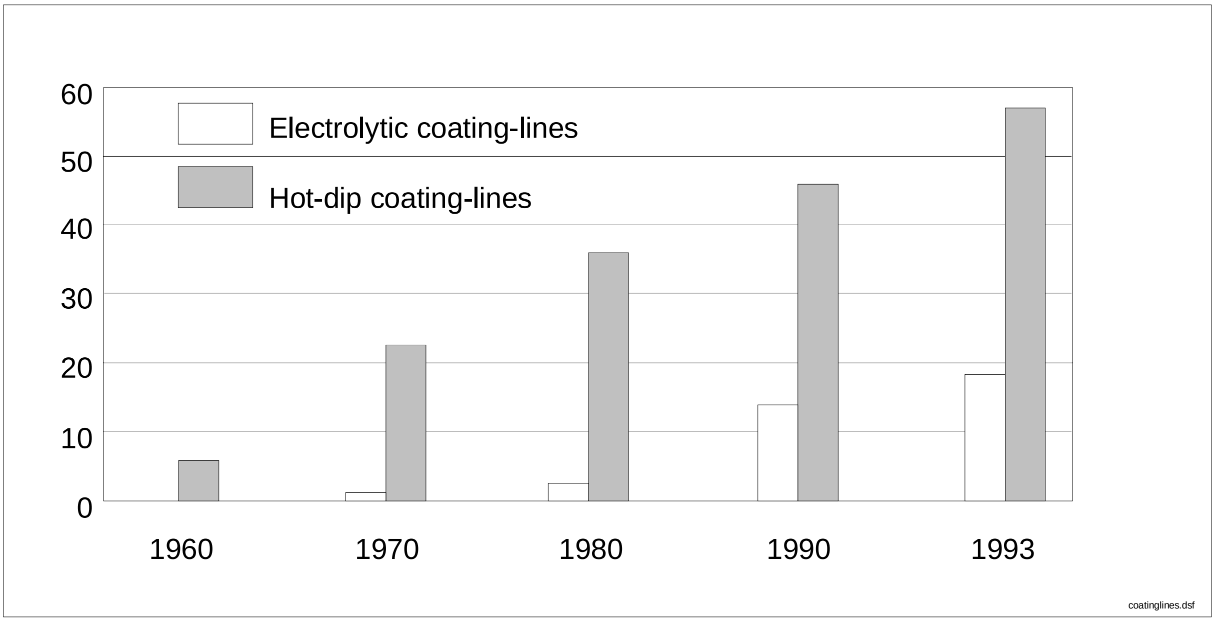


Figure B.1-3: Number of coating lines in Western Europe

Source: [143]

Figure B.1-4 shows in detail the growing importance of special zinc coated sheets like Galvalume or Galfan.

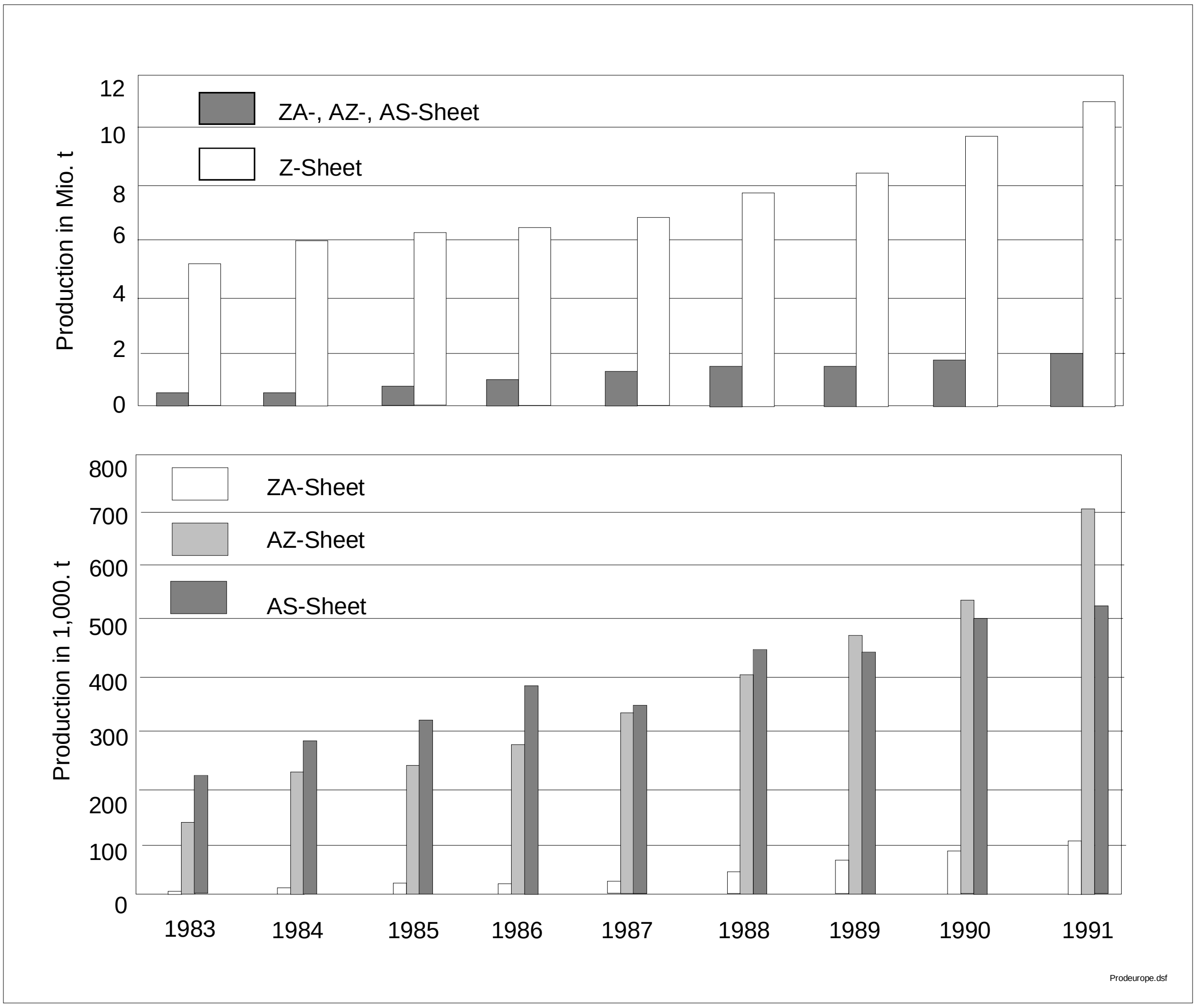


Figure B.1-4: Production of hot dip coated sheets in Western Europe

Legend: Z - hot dip galvanised, ZA - Galfan, AZ - Galvalume, AS - hot dip aluminised

Source: [144]

B.2 Applied processes and techniques

This section gives a brief overview of processes and techniques employed within hot dip and electrolytic galvanising lines. First of all, the scope of the study is set out in the following sub-section.

B.2.1 Scope of the study

Galvanising is carried out in order to protect the steel from corrosion. It belongs to the passive corrosion protection processes. Table B.2-1 provides an overview of steel corrosion protection processes with zinc. Hot dip galvanising processes are distinguished according to process technology into continuous and discontinuous processes. For mass output, continuous processes are economical. This report gives information only on continuous galvanising processes. It deals with continuous hot dip and electro galvanising processes following rolling mills.

Table B.2-1: Corrosion protection processes for steel with zinc

Hot dip galvanising	
Job galvanising	Discontinuous protection process, within each workpiece is dipped into molten zinc
Continuous galvanising	Protection process for strip, plate and wire; galvanising is performed in automatic continuously operating plants.
Electro galvanising	Protection process by coating of workpiece with electrolytically precipitated metal
Thermal spraying with zinc	The coating, which consists of molten metal, is sprayed onto the metal to be protected
Metallic coating with zinc dust (mechanical plating / sheradising)	Protection processes using zinc dust; zinc coatings or Fe + Zn alloy junctions are applied by mechanical plating or by diffusion (sheradising)
Zinc dust coatings	Zinc dust pigmented coating substances are applied on steel for structural work
Cathodic corrosion protection	Protection process for steel by contact of a zinc anode in presence of an electrolyte.

Source: [103]

Important zinc coated products grouped by the coating process and main areas of use are presented in Table B.2-2.

Table B.2-2: Zinc coating processes, zinc coated products and their main areas of use

Process	Product	Short name	Main compounds	Use: Construction	Use: Automobile	Use: Household
Hot dip galvanising	Hot dip galvanised sheet	Z	Zn - 0.2% Al	X	X	X
	Galvannealed	ZF	Fe-Zn alloy with about 10% Fe	-	X	-
	Galfan	ZA	Zn-Al alloy, about 5% Al	X	X	X
	Galvalume	AZ	Al-Zn alloy with 55% Al, 1.5% Si	X	-	-
Electro galvanising	Electro galvanised sheet	ZE	Zn	X	X	X
	Zinc-nickel coated sheet	ZNE		X	-	X

Sources: [63, 143, 144, 189]

B.2.2 Production processes for continuous galvanising

Figure B.2-1 gives an overview of possible routes of production for coated sheets following steelworks. Depending on the production processes, different surface qualities and properties are achieved.

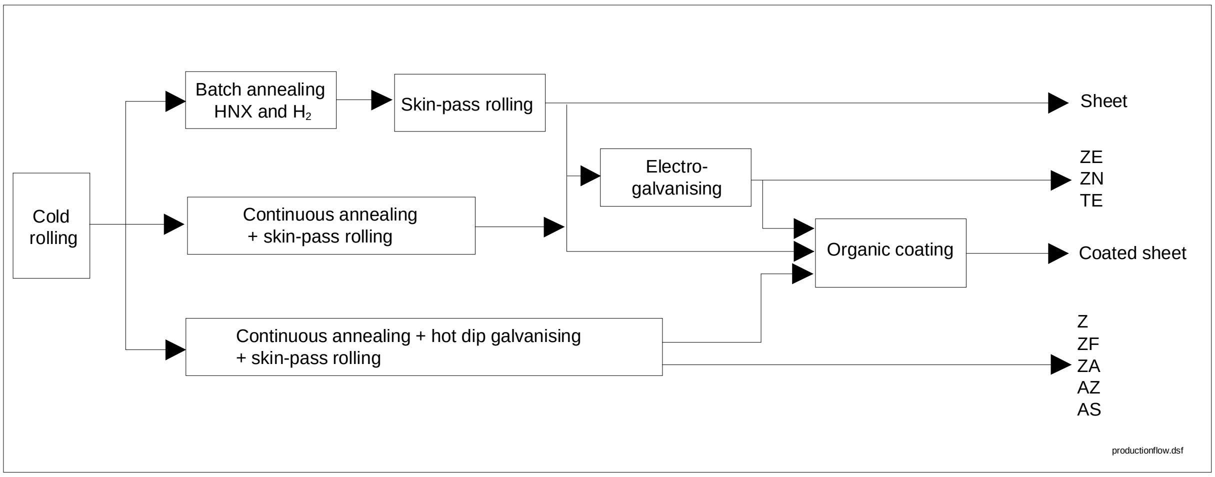


Figure B.2-1: Routes of production for coated sheets

Source: [143]

Figure B.2-2 gives respective ranges of the thickness of different coatings achieved by continuous metal coating plants. Overall coatings from 2.5-25µm are applied. Depending on the process, one side or both sides of the strip can be coated, also a different thickness on each side is possible by modern production technology [55]. Modern hot dip galvanising lines produce both thick (up to 25µm) and thin coatings (below 5µm) with a high quality, nowadays [143]. Electro galvanising lines are mainly used to apply thin coatings (below 10µm).

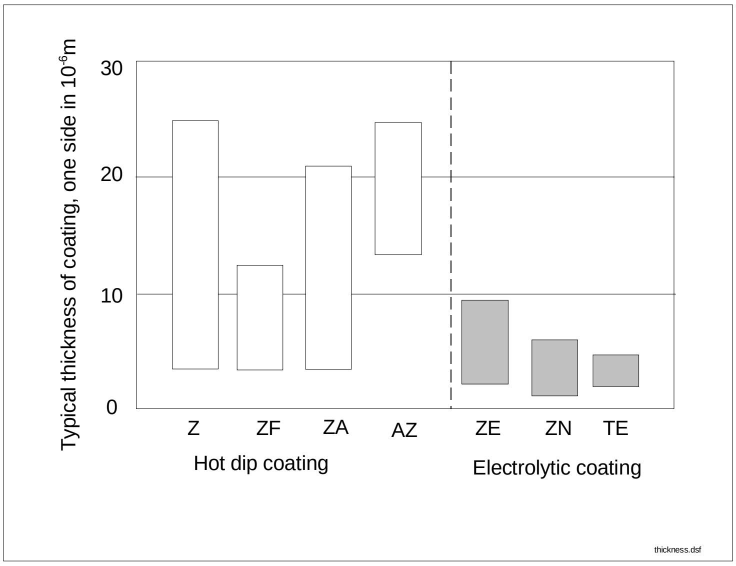


Figure B.2-2: Thickness of metallic coatings

Source: [143]

Table B.2-3 gives a list of examples of locations and operators of continuous hot dip galvanising plants and electro galvanising plants operated in Germany, at the moment.

Table B.2-3: Hot dip galvanising and electro galvanising plants in Germany (examples)

Operator at the moment	Location	Type	Strip width / thickness	Cell type/anodes
Salzgitter Stahl AG	Salzgitter	electro	900-1850 / 0.40-2.00	V / US
Rasselstein Hoesch GmbH	Neuwied	electro	max. 1600 / n.a.	V / LS
Thyssen Krupp Stahl AG	Beeckerwerth	electro	600-1900 / 0.35-2.50	H / US
Thyssen Krupp Stahl AG	Bochum	electro	750-1600 / 0.30-3.00	H / US
Thyssen Krupp Stahl AG	Bruckhausen	electro	600-1570 / 0.40-3.00	n.a.
Thyssen Krupp Stahl AG	Dortmund	electro	900-1950 / 0.30-1.60	V / LS
BREGAL GmbH	Bremen	hot dip	900-2080 / 0.40-2.80	
EKO Stahl GmbH	Eisenhüttenstadt	hot dip	max. 1500 / 0.35-2.25	
Salzgitter Stahl AG	Salzgitter	hot dip	900-1650 / 0.40-3.00	
Thyssen Krupp Stahl AG	Beeckerwerth	hot dip	700-1650 / 0.40-4.00	
Thyssen Krupp Stahl AG	Beeckerwerth	hot dip	950-2000 / 0.60-1.50	
Thyssen Krupp Stahl AG	Bochum	hot dip	800-1650 / 0.50-2.00	
Thyssen Krupp Stahl AG	Duisburg-Finnentrop	hot dip	600-1525 / 0.40-3.50	
Thyssen Krupp Stahl AG	Duisburg-Finnentrop	hot dip	15-200 / 1.00-5.00	
Thyssen Krupp Stahl AG	Kreuztal-Eichen	hot dip	max. 1650 / 0.40-3.0	
Thyssen Krupp Stahl AG	Kreuztal-Ferndorf	hot dip	max. 1520 / 0.40-3.00	
Thyssen Krupp Stahl AG	Bruckhausen	hot dip	600-1250 / 0.40-3.00, add. aluminised	
Thyssen Krupp Stahl AG	Dortmund	hot dip	max 1550 wide, add. Terne plate	

Legend: V - vertical cell, H - horizontal cell, U - insoluble anode, L - soluble anode, S - sulphite electrolyte

Source: [53, 79, 111, 120, 144]

B.2.2.1 Continuous hot dip strip galvanising

Figure B.2-3 shows a diagrammatic view of a continuous hot dip galvanising line.

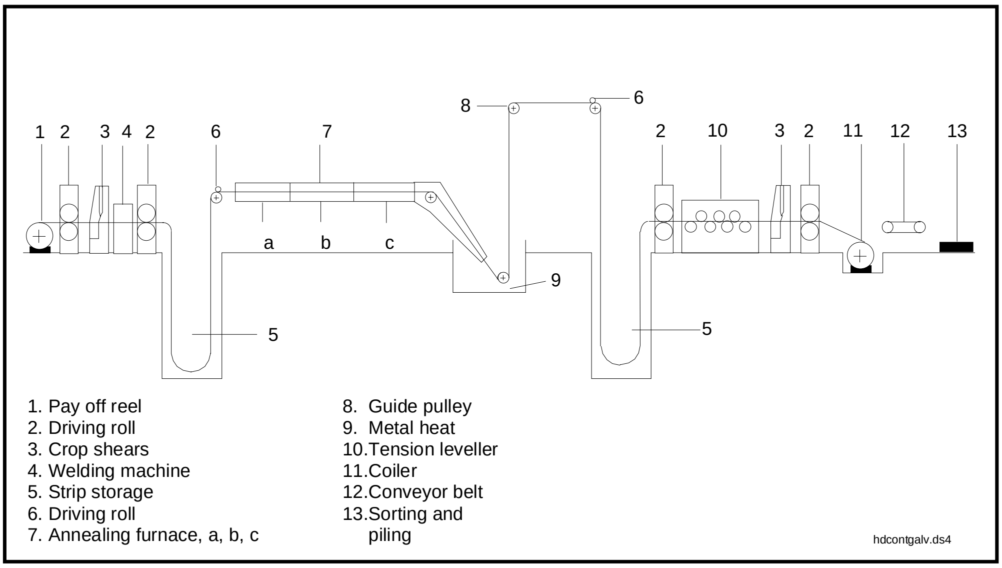


Figure B.2-3: Diagrammatic view of a continuous hot dip galvanising line

Source: [103]

Hot dip galvanising plants usually comprise the process steps pre-cleaning of processed cold rolled strip, annealing, galvanising and post treatment. Modern plants for high quality requirements include most of the following features, depending on the product quality to be achieved [121]:

- automatic or semi-automatic welding machine
- cleaning section
- entry section accumulator
- pickling plant (for IF steel)
- furnace (often vertical, with directly heated pre-heater or radiant-tubes)
- interchangeable pot system for different coatings
- dross treatment
- enhanced air knife technology
- Galvannealing-furnace
- intermediate section accumulator
- temper mill
- tension leveller
- extended post-treatment section for chromating, phosphate-coating and further inorganic coating
- exit section accumulator
- trimming shear
- inspection
- dividing shear

Continuous hot dip galvanising lines are usually operated with strip speeds between 90-150m/min; modern plants with speeds of up to 150-220m/min [63, 144]. Figure B.3-5 shows a detailed diagrammatic view of the coating section of a modern hot dip galvanising line. This line features a Galvannealing-furnace after the metal heat, which allows an additional heat treatment of the strip yielding enhanced properties (better weldability of strip, better bonding of organic coating on strip) [64, 144].

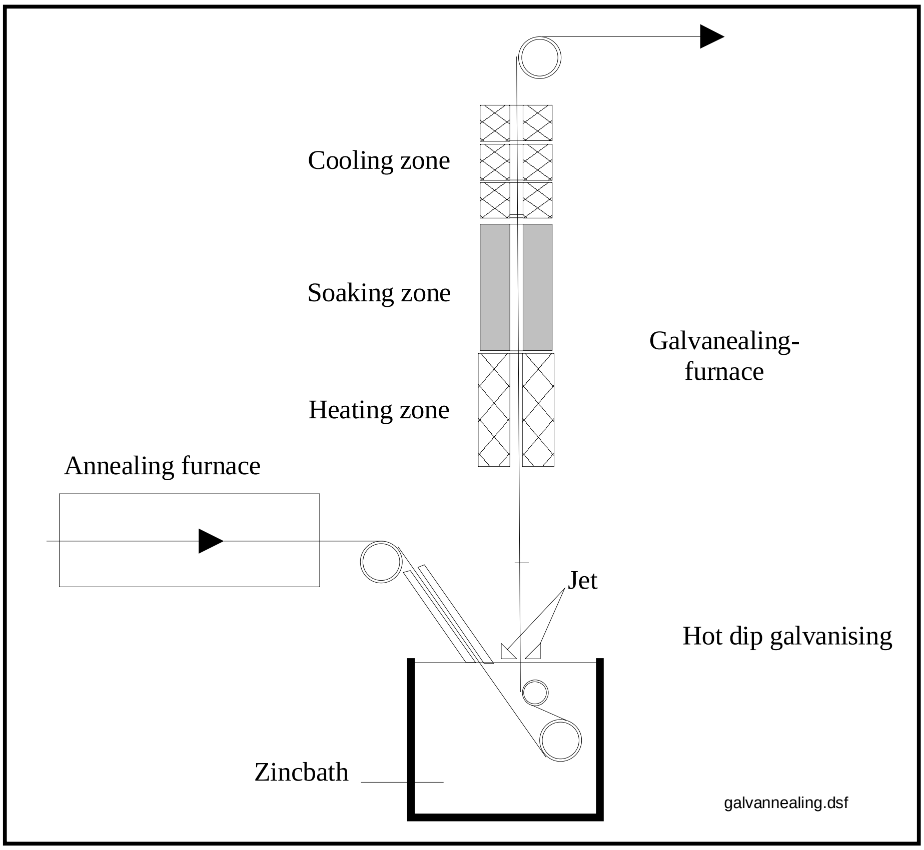


Figure B.2-4: Diagrammatic view of the coating section of a HDG line (galvannealing)

Source: [121]

B.2.2.2 Continuous electrolytic strip galvanising

Figure B.2-5 shows a diagrammatic view of a continuous electro galvanising plant.

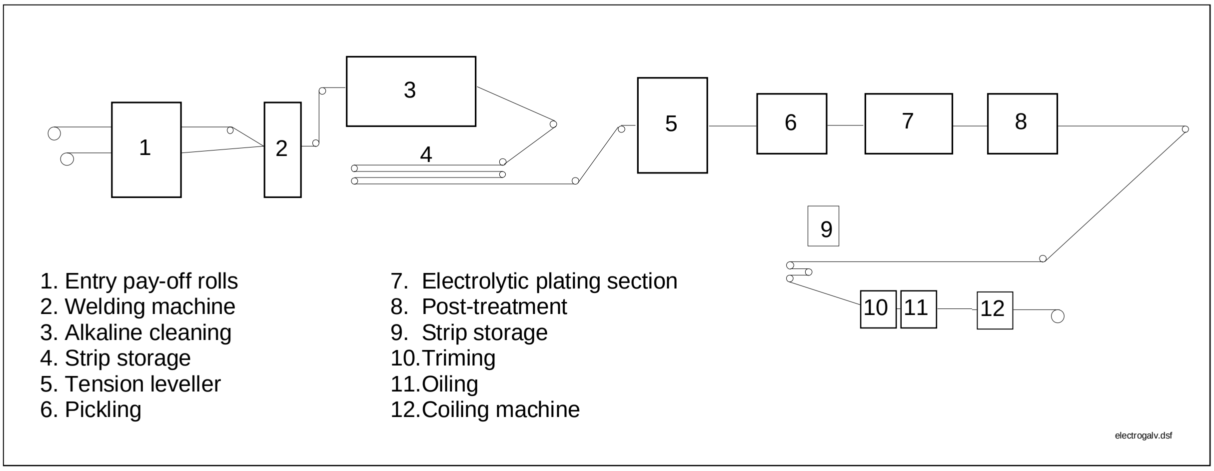


Figure B.2-5: Diagrammatic view of a continuous electro galvanising line

Source: [79]

Continuous electrolytic galvanising comprises the process steps pre-treatment, electrolytic metal precipitation and post-treatment. Prerequisite for achieving a good bonding of the coating on the strip is a clean strip surface. For this reason, electrolytic galvanising lines are equipped with an extensive strip cleaning section. A good strip cleanliness is achieved by spray-, brush- and electrolytic degreasing (hot) with alkaline solutions. The degreased strip is subsequently activated by pickling for subsequent electroplating. Following the treatment zones, multi-stage rinsing zones with brushing machines are used. The cleaned and pickled strip passes several precipitation cells. Sulphuric or hydrochloric acid mostly serves as an electrolyte. Following the galvanising step, the strip is intensively rinsed in order to remove rests of the electrolyte. Finally, several treatment steps, like phosphating are carried out [79]. Figure B.2-6 shows a diagrammatic view of different cell types for electrolytic coating lines.

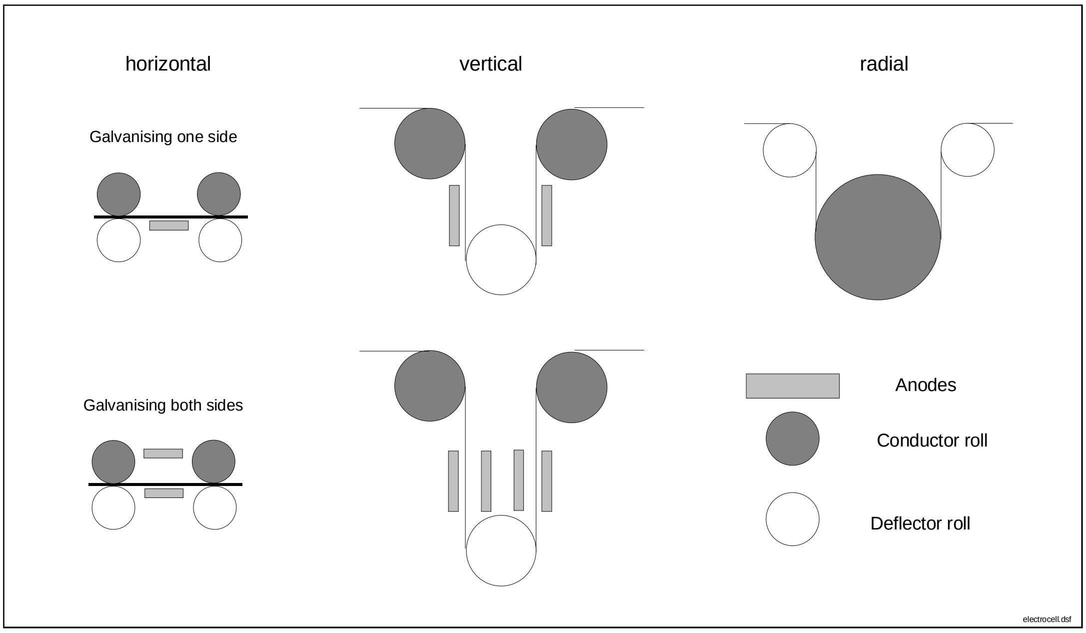


Figure B.2-6: Diagrammatic view of different cell types for electrolytic coating lines

Source: [79, 189]

The mechanical parts of modern plants can handle strip speeds of up to 180m/min [79, 111]. Figure B.2-7 provides a more detailed view of a horizontal cell of a continuous electro galvanising line.

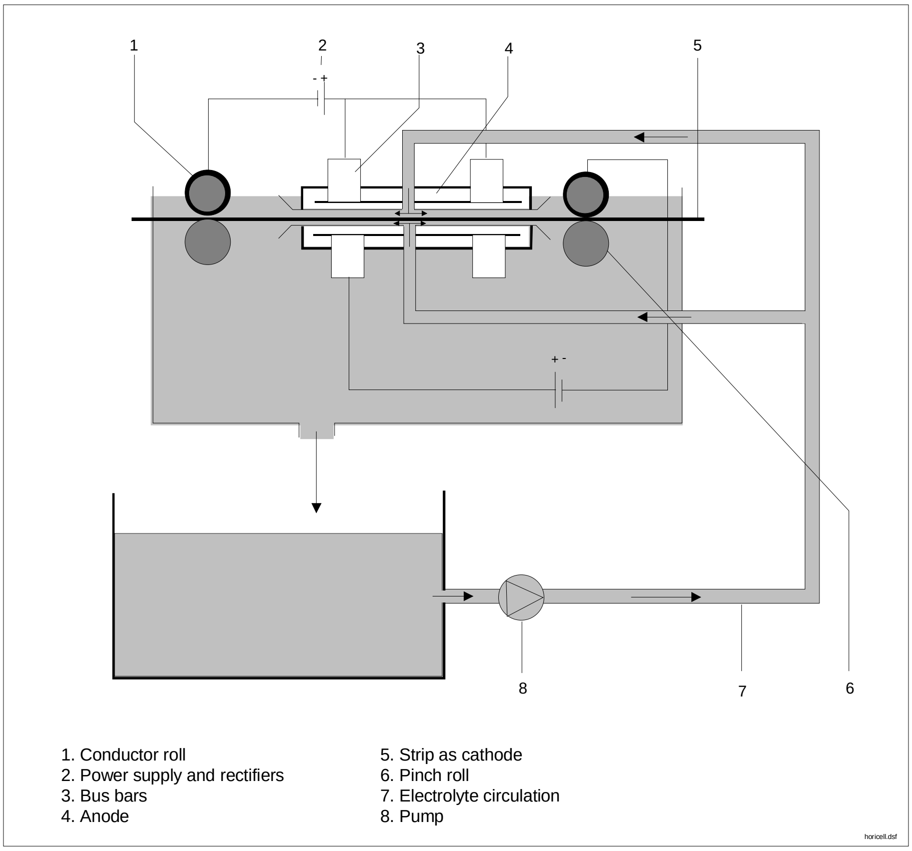


Figure B.2-7: Diagrammatic view of a horizontal cell in an electrolytic coating line

Source: [161]

B.3 Information on mass streams and selected measures for pollution prevention and control in continuous galvanising lines

This chapter gives information on inputs and outputs of continuous galvanising plants as well as measures, which foster integrated pollution prevention and control within these plants.

B.3.1 Overview of mass streams related to continuous galvanising

In this section a brief overview of inputs and outputs of the respective continuous galvanising plants is given. At the moment, mainly qualitative information on input/output levels is available, rather than quantitative. Different inputs and outputs are related to the respective steps in the process chain of galvanising plants.

B.3.1.1 Continuous hot dip strip galvanising

The following Table B.3-1 shows relevant inputs and outputs for continuous hot dip galvanising, related process steps are indicated in brackets.

Table B.3-1: Selected inputs and outputs of hot dip strip galvanising lines

Inputs	Outputs
Cold rolled strip	Galvanised strip
Alkaline degreasing agents (strip cleaning)	Rinsing water, loaded with oil, grease, etc. (degreasing/strip cleaning)
Acid (pickling)	Acidic aerosols (pickling)
Water (rinsing, cooling, scrubbing)	Spent pickle, rinsing water (pickling)
Fuels (annealing, galvannealing)	Off gas loaded with combustion products, e.g. NO_x, (annealing)
Electrical energy (driving rolls, fans, bath heating, ...)	Zinc dross (galvanising)
Inert gas (annealing)	Off gas loaded with dust (galvanising)
Zinc (coating metal)	Waste water (post-treatment)
Fluxes (galvanising)	Scrap (trimming)
Rolling oil (skin-passing)	Sludge (water treatment)

B.3.1.2 Continuous electrolytic strip galvanising

The following Table B.3-2 shows main inputs and outputs for continuous electro galvanising, related process steps are indicated in brackets.

Table B.3-2: Selected inputs and outputs of electro galvanising lines

Inputs	Outputs
Cold rolled strip, annealed and skin-passed	Galvanised strip
Alkaline degreasing agents (strip cleaning)	Rinsing water, loaded with oil, grease, etc. (degreasing/strip cleaning)
Acid (pickling)	Acidic aerosols (pickling)
Water (rinsing, cooling, scrubbing)	Spent pickle, rinsing water (pickling)
Electrical energy (electrolysis, driving rolls, fans, ...)	Sludge (galvanising)
Electrodes/anodes for zinc precipitation (galvanising)	Scrap (trimming)
Electrolyte (galvanising)	Acidic rinsing water (galvanising)
	Waste water (post-treatment)

B.3.2 Techniques for integrated pollution prevention and control in continuous galvanising lines

For continuous hot dip galvanising (HDG) and electro galvanising (EG) lines several techniques are available to prevent or reduce pollution. The following Table B.3-3 gives a list of corresponding techniques.

Table B.3-3: Techniques for integrated pollution prevention and control in continuous galvanising lines

Process	Techniques HDG	Techniques EG
Degreasing	Optimised cleaning, cascade rinsing, loop	Optimised cleaning, cascade rinsing, loop
Pickling	Depending on acid, cf. cold rolling	Depending on acid, cf. cold rolling
Annealing	Choice of furnace type and fuel	-
Coating	Efficient pot heating system	-
Surface control	Treatment of dross	-
Galvannaeling	Choice of heating system)	-
Electroplating	-	Rinsing water recycling, zinc recovery
Post treatment	Chromate detoxification	-

In the following, some of the mentioned techniques are described in more detail. Information on techniques related to pollution prevention and control in the pickling section are given in the Part A of the *Report on BAT in the German Ferrous Metals Rolling Industry*. Techniques for post treatment are not covered by this report, as there are a multitude of possible post-treatment steps, which vary from site to site.

B.3.2.1 Strip cleaning

Strip cleanliness is one of the main factors determining the quality of the final (zinc coated) product. The factors, which mainly determine the quality are [68]:

- quality of strip as an input
- *pre-treatment of strip surface before galvanising*
- coating process

High quality zinc coated strip requires a clean, metallic strip surface before the coating step. For this reason, a cleaning step in aqueous solutions is mostly carried out before the galvanising step in modern lines. Cleaning agents have to be chosen according to the actual quality of the input material, which is usually determined in laboratory investigations. Characteristics of (alkaline) cleaning agents used in surface treatment lines (builder and tenside systems) are further discussed in [68]. The layout of cleaning lines depends on several factors (cf. Table B.3-4).

Table B.3-4: Important parameters for the layout of cleaning lines

<table>
<tr><th>Parameter</th><th colspan="3">Characteristic</th></tr>
<tr><td>Stage of production of strip</td><td colspan="2">before annealing</td><td>before galvanising</td></tr>
<tr><td>Residues on the strip surface</td><td>rolling oil</td><td>corrosion protection oil</td><td>ferrous particles</td></tr>
<tr><td>Strip thickness</td><td colspan="2">sheet</td><td>black sheet</td></tr>
<tr><td>Strip speed</td><td colspan="2">time for treatment</td><td>space requirement</td></tr>
</table>

Source: [68]

Figure B.3-1 provides a diagrammatic view of two different layouts of modern cleaning lines. Corresponding to quality requirements the number of each cleaning stage can be varied. Spray cleaning and brushing are rather course cleaning steps, which help in particular to remove ferrous particles. Electrolytic cleaning is a fine cleaning, providing optimal surface quality. The final step of cleaning is rinsing, which is important to remove remaining detergents and other dirt from the surface.

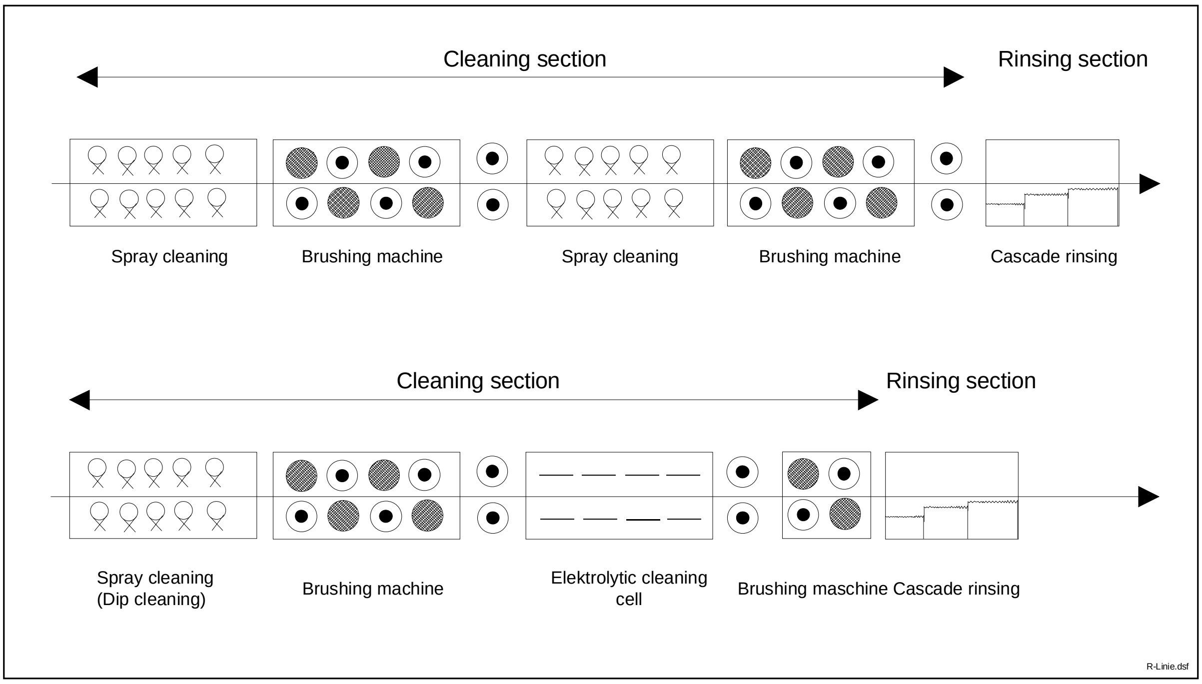


Figure B.3-1: Diagrammatic view of different types of cleaning lines

Source: [68]

A thorough rinsing is required to ensure optimal quality for the following galvanising steps. In order to save rinsing water, cascade rinsing systems can be used. Figure B.3-2 provides a diagrammatic view of a cascade rinsing system.

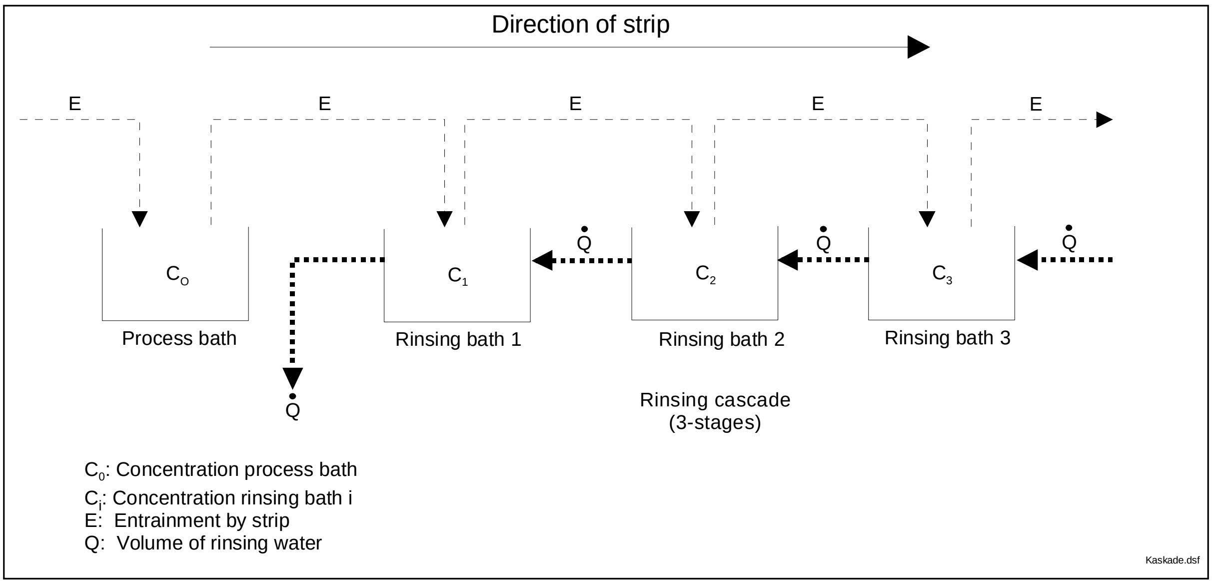


Figure B.3-2: Diagrammatic view of a cascade rinsing system

Source: [71]

A general measure to prevent waste water is to lower entrainment losses. The amount of entrained liquid can be lowered by:

- letting drop liquids
- squeezing off
- air knifes and stripping devices
- blowing off
- sucking off

Further factors, which have an impact on the result of cleaning, and should be optimised to minimise pollution, are [68]:

- bath concentration (recommended concentrations by supplier, mostly between 10-40g/l, should not be exceeded; use of cleaning agents can be estimated at 2-10g/m^2 treated strip, depending on type and extension of surface contamination)
- bath temperature (higher bath temperatures usually increase cleaning performance, however, evaporation and energy losses by too high bath temperatures should be avoided)
- bath load (maximum bath contamination has to be determined for the particular case, bath maintenance measures should be applied)

B.3.2.2 Annealing in HDG lines

Environmentally relevant aspects of annealing furnaces in continuous galvanising lines are energy consumption and related air emissions. Measures with respect to integrated pollution prevention and control include the increase of energy efficiency and to lower air emissions by an adequate burner design.

Furnace and burner design as well as the choice of fuel are options to reduce energy consumption and emissions. Two heating methods are commonly used, nowadays:

- direct-fired heating and
- indirect heating (radiant-tube furnaces).

Both systems are applied in praxi. Direct-fired furnaces are shorter and the system allows a more direct control of the heat. For surface requirements, that are non-critical, the cleaning effect of direct-fired furnaces is reported to be sufficient [121]. Furnaces can be built as horizontal or vertical furnaces. Figure 3-3 shows a diagrammatic view of a horizontal and a vertical furnace.

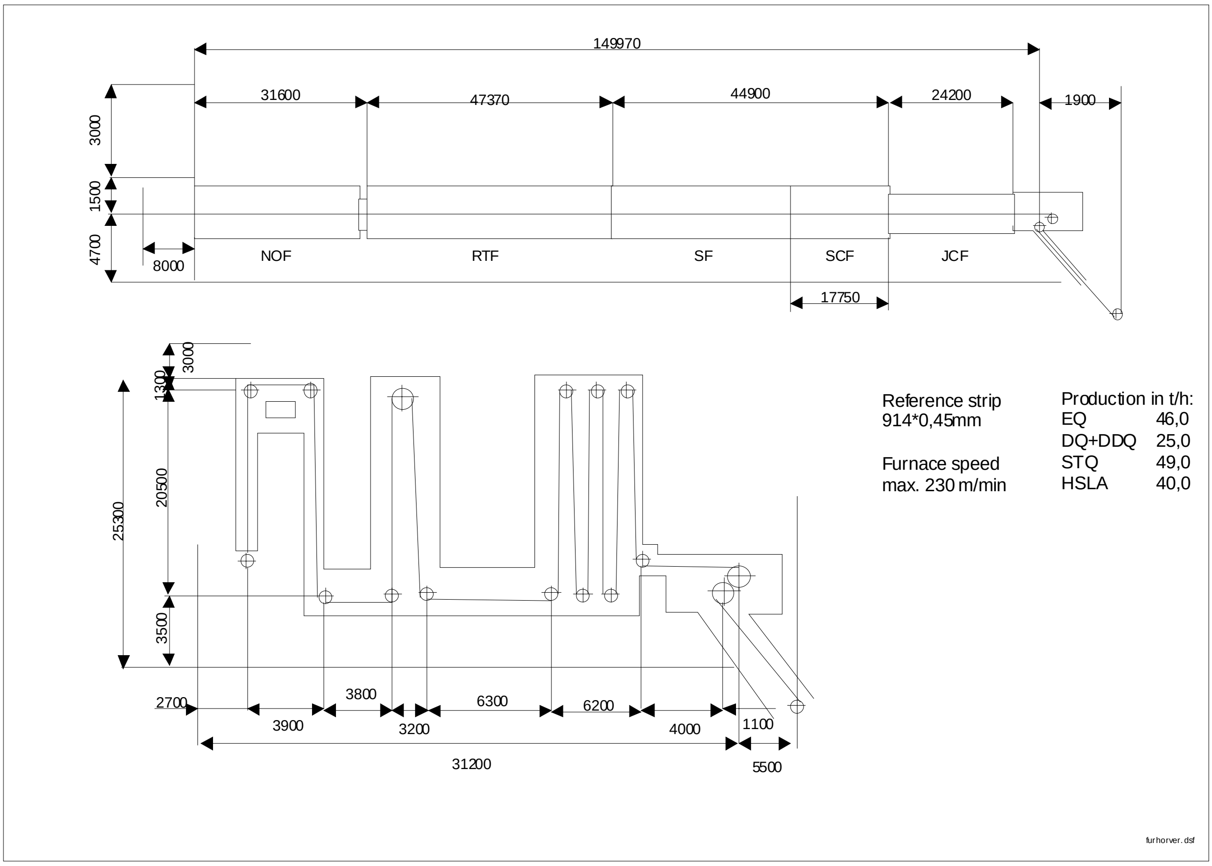


Figure B.3-3: Comparison of dimensions of a horizontal and a vertical furnace

Source: [121]

Modern plants for the production of galvanised strip are usually equipped with vertical furnaces, as these supply products for highest quality requirements [121]. Figure 3-4 shows a comparison of heat balances between a direct-fired horizontal and a direct-fired vertical furnace. A good furnace control also helps to prevent emissions [168].

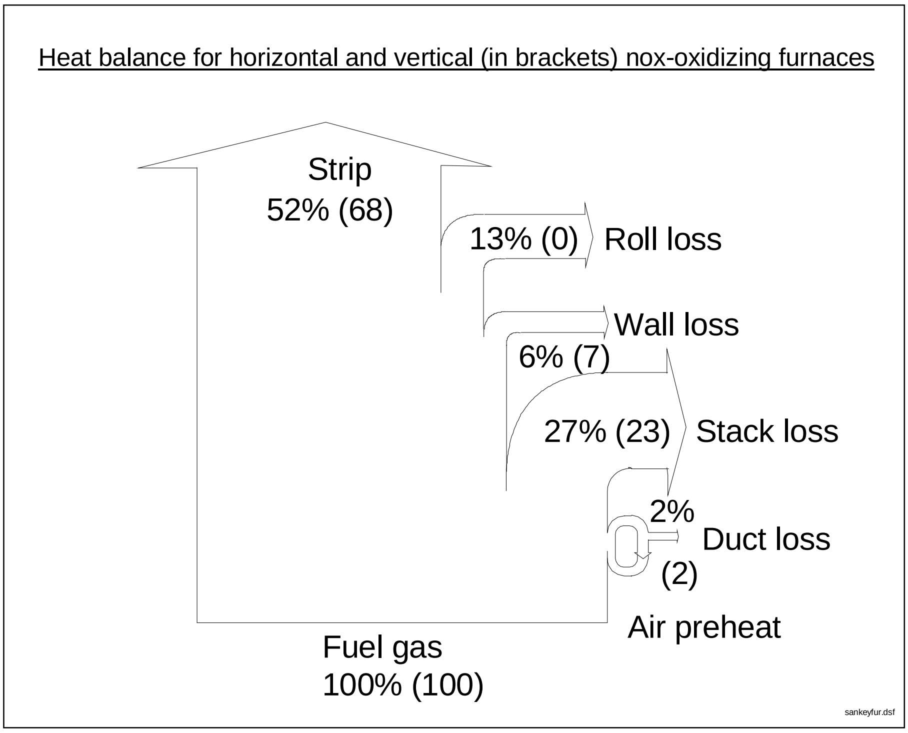


Figure B.3-4: Heat balance for non-oxidising furnaces

Source: [179]

Energy savings may be made by waste gas heat recovery from the preheat and radiant tube furnaces to preheat combustion air for the non-oxidising and radiant tube furnaces [168].

B.3.2.3 HDG and EG sections

Energy consumption of electrolytic processes will be dependent on a variety of factors including bath temperature, coating thickness, solution concentration, bath geometry, cathode - anode distances, etc. These factors should be optimised for the particular process.

Modern HDG lines mostly are equipped with interchangeable pot systems, which are heated by induction heating. Figure 3-5 shows the coating system of a HDG line.

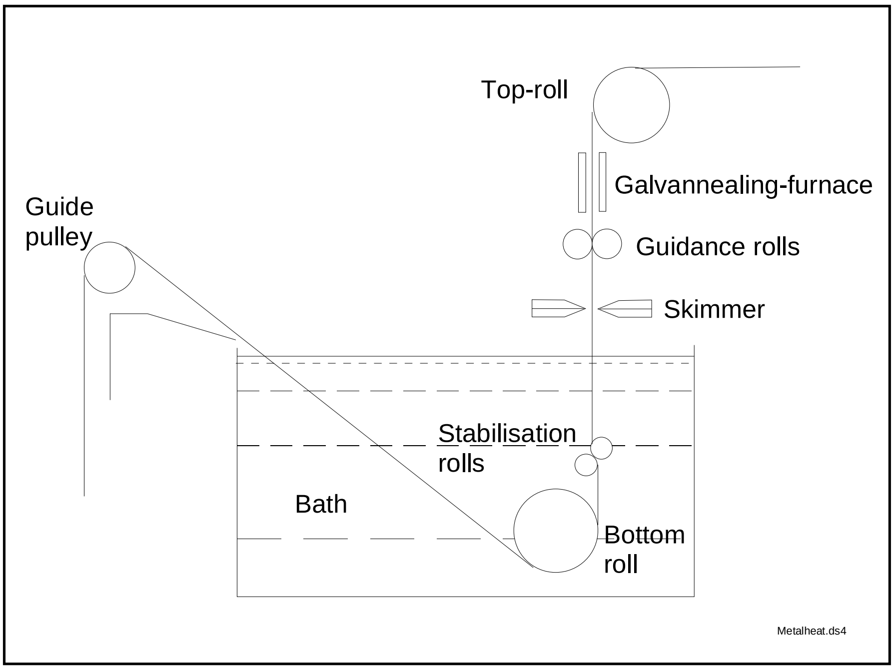


Figure B.3-5: Diagrammatic view of the metal bath of a continuous hot dip galvanising line

Source: [113]

B.3.2.4 Dross treatment

On hot dip galvanising lines, more than 10% of the metallic zinc consumed appears as dross, mainly Zn and ZnO, on top of the molten zinc bath [81]. Because of likely adverse effect on the galvanised steel sheet, it is manually removed. The arising residual product can be sold to zinc smelters or being treated to receive a zinc ash, which has only 20% of the former volume and can then be sold to the zinc producing industry [81]. Figure B.3-6 shows a diagrammatic view of a zinc recovery plant.

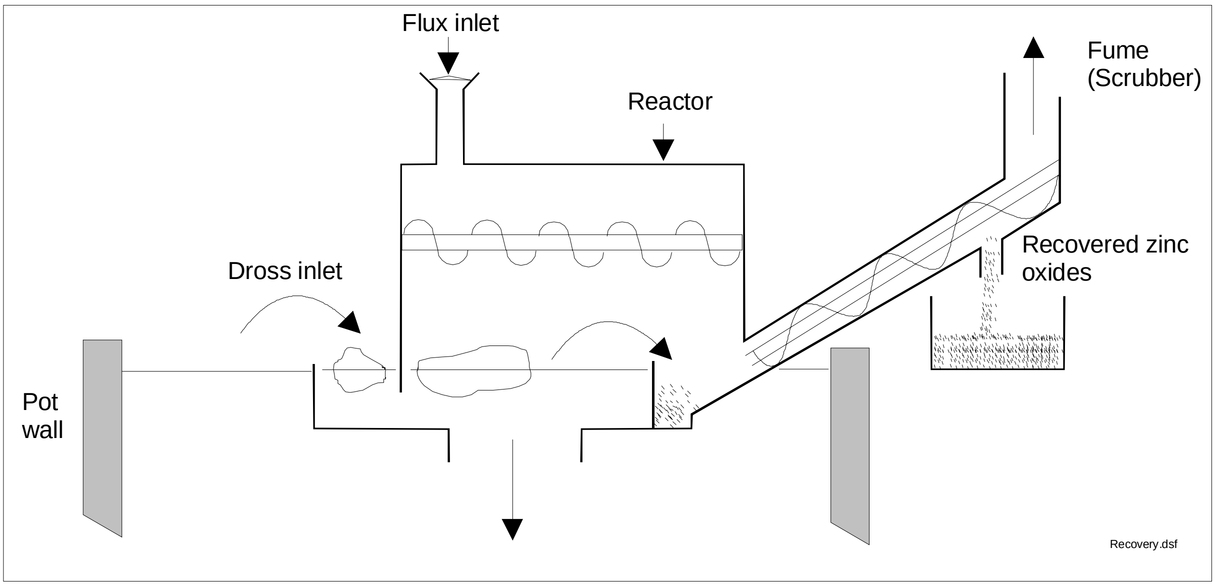


Figure B.3-6: Diagrammatic view of a recovery system for zinc from dross

Source: [81]

To treat the dross, a suitable flux is added. The pure zinc oxide is dissolved by reaction and the metallic zinc is separated [121].

B.3.2.5 Treatment of rinsing water from EG lines

Rinsing water from EG lines is one of the main potential sources for waste water. After the treatment zones with chemical solutions (electrolyte), rinsing stations, stripping and brushing stations to remove the rest of the process solution from the strip surface are installed. Although an intense squeezing of entrainment would be desirable at the last process bath, this is not possible unlimitedly, as non repairable surface defects may arise, if the strip surface is completely dry before entering the rinsing station [komm anhang 24].

There exist several methods to treat and recycle acidic rinsing water. One case study of a treatment plant for acidic rinsing water is described in [87]. A diagrammatic view of this plant is provided in Figure B.3-7. It allows to fully recycle the entrained zinc and the sulphuric acid into the EG process. The plant employs the short bed ion exchange technology. No by-products are arising in this process.

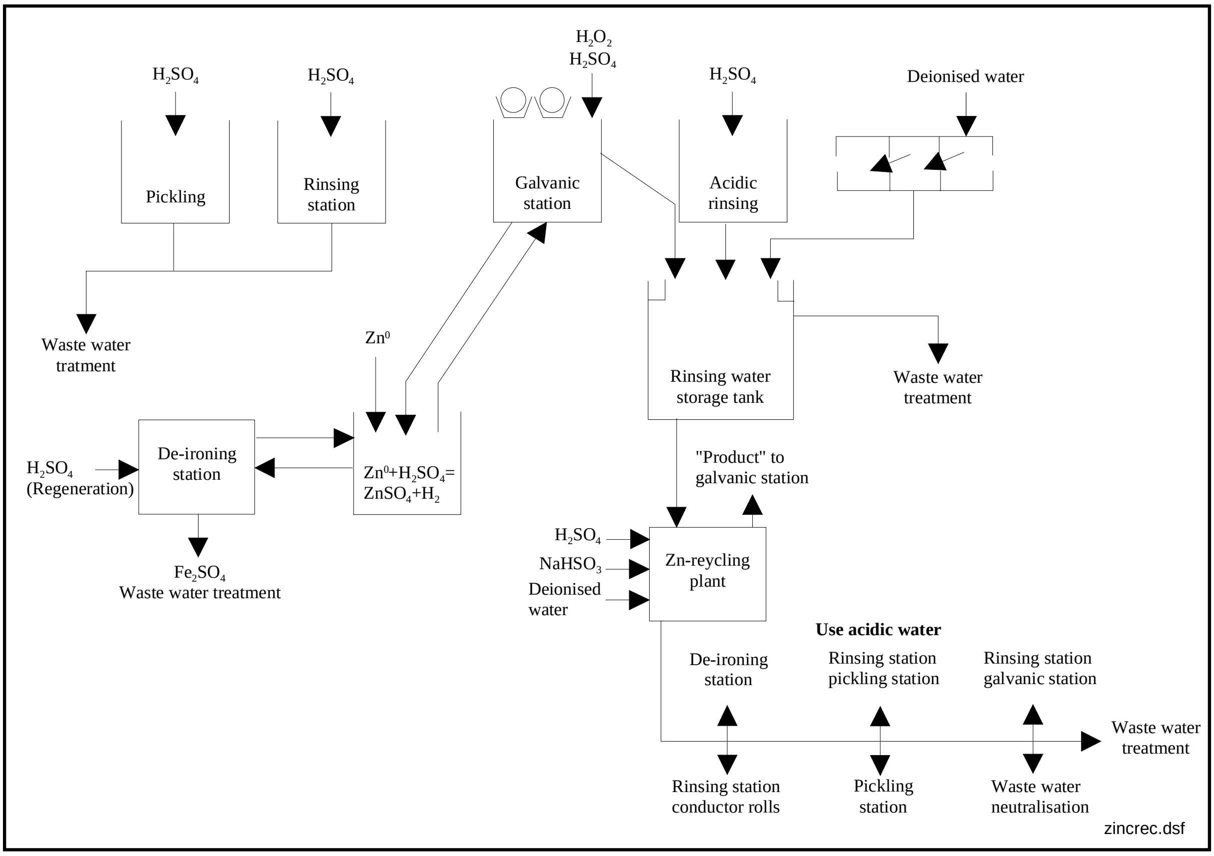


Figure B.3-7: Diagrammatic view of a treatment station for effluent from an electrolytic galvanising line

Source: [87]

C Annex

C.1 Infomation on current German legislation relevant to ferrous metals processing activities[12]

This section gives an overview of current legislation relevant to ferrous metals processing activities on a national (German) level. Existing national regulations lay down standards for:

- air quality,
- water quality,
- waste management and disposal of hazardous materials.

Important regulations relevant to ferrous metals processing activities in Germany are laid down in the BImSchG (Federal Immission Control Act), the WHG (Federal Water Act) and the KrW-/AbfG (Waste Avoidance, Recycling and Disposal Act for the Promotion of Closed Substance Waste Management and Ensuring Environmental Compatible Waste Disposal). Germany uses a segregated media licensing system for different environmental media, but the final decision on an installation is reached by the assessment of environmental impacts to all media by the local authorities. Also noise requirements are considered in the licensing procedure. Germany aims at favouring pollution prevention in the licensing procedure. The „precautionary principle“ has a legal status which permitts the setting of standards. Legal standards are not subject to any negotiation in the licensing process in Germany.

In compliance with the federal structure of Germany, the implementation of environmental laws and decrees is under the responsibility of the federal states (Bundesländer), which may implement the administrative procedure differently. For new plants, that are regarded as relevant with respect to emissions and releases into the environment, also an environmental impact assessment is required during the licensing procedure (cf. Gesetz über die Umweltverträglichkeitsprüfung, UVPG).

Table 8-1 gives an overview of the German legal basis and regulations for environmental protection in Germany alongside the product line. In the following, a selection of most important acts, regulations and requirements concerning air and water quality for ferrous mteals processing activities is presented.

[12] The study does not intend to cover all the regulations related to this industry sector completely or in full detail. Regulations may be looked up in corresponding laws, ordinances, or other documents.

Table C.1-1:Legal basis and regulations alongside the product line

Area	Legal Basis	Regulations and ordinances
Transport	Verkehrsrecht	Gefahrgutverordnung Straße Gefahrgutverordnung Schiene Gefahrgutverordnung Binnenschifffahrt
Health and safety at work	Chemikaliengesetz (ChemG)	Chemikalienverbotsordnung Gefahrstoffverordnung
	Gewerbeordnung	TA Lärm Arbeitsstättenverordung und -richtlinien
Emissions	Bundes-Immissionsschutzgesetz (BImSchG)	Bundes-Immissionsschutzverordnungen Bundes-Immissionsschutzverwaltungsvorschrif-ten TA Luft TA Lärm
	Wasserhaushaltsgesetz (WHG)	Katalog wassergefährdender Stoffe Abwasserverwaltungsvorschriften Indirekteinleiterverordnungen der Länder
Waste	Abfallgesetz (AbfG)	Abfall- und Reststoffüberwachungsverordnung Abfallbestimmungsverordnung Reststoffbestimmungsverordnung TA Abfall TA Siedlungsabfall
	Kreislaufwirtschaftsgesetz (KrW.-/AbfG)	

C.1.1 German regulations concerning air quality

The basic law for air pollution control and noise abatement in Germany is the Federal Immission Control Act (Bundes-Immissionsschutzgesetz, BImSchG). It primarily aims towards the protection of the medium air, but it also applies to the media water and land in case pollution is introduced via the air. The BImSchG is complemented by 21 ordinances and the Technical Instructions on Air Quality (TA Luft). Especially the TA Luft specifies in more detail requirements to be met by installations subject to licensing. The next sections present important acts and ordinances of German air pollution prevention in more detail.

C.1.1.1 Federal Immission Control Act (Bundes-Immissionsschutzgesetz, BImSchG)

The BImSchG is the legal instrument for monitoring air pollution. Immission as defined within the law comprises air pollutants, and also noise, vibration, light, heat, radiation and associated factors affecting humans as well as animals, plants or other things. This concept already implements the idea of cross-media effects to a certain extent. The BImSchG requires federal authorities to issue ordinances identifying the types of facilities, which are subject to licensing, set licensing requirements for these facilities, and impose emission limit values and technical control requirements for all facilities, whether licensed or not.

Especially article 5(1)3 BImSchG aims at the avoidance and minimisation of wastes and residues. The paragraph emphasises the cross-media effects of industrial production.
The concept of "state of the art technology" defined in the BImSchG is similar to the one of BAT:

State of the art as used herein shall mean the state of development of advanced processes of facilities or modes of operation which is deemed to indicate the practical suitability of a particular technique for restricting emission levels. When determining the state of the art, special consideration shall be given to comparable processes, facilities or modes of operation that have been successfully proven in practical operation. (Article 3 paragraph 6 BImSchG)

In principle, "state of the art technology" is stated in terms of emission limits set by the licensing authority, the choice of technology to comply with the emission limit levels is left to industry. Necessary precautions against harmful effects on the environment are to be taken in particular by using control measures corresponding to the state of the art. Depending on the mass flow, some substances have to be measured continuously (eg. SO_x, NO_x, and particulates). Some relevant ordinances as well as selected requirements of the BImSchG are briefly presented in the following.

C.1.1.2 Ordinance on installations subject to licensing (4. BImSchV)

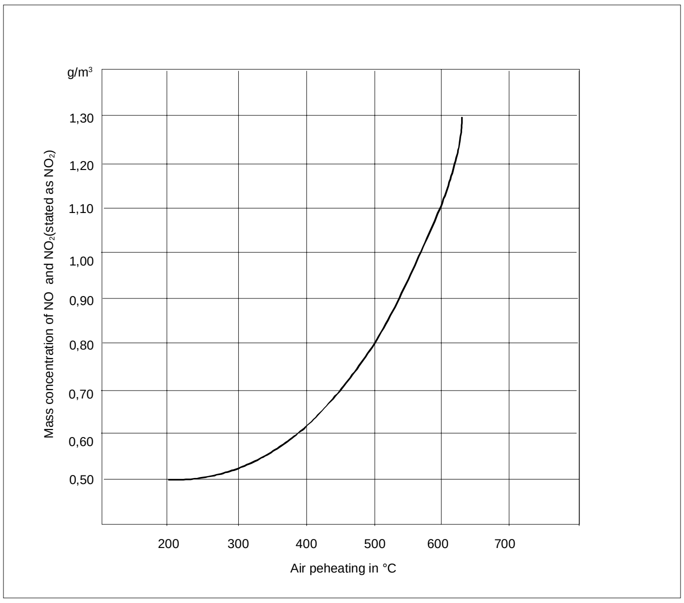
The 4. BImSchV (Ordinance on installations subject to licensing) lists all installations that are subject to licensing under the BImSchG. According to this ordinance (cf. Annex, row 1, N° 3.5 and 3.6) installations for the rolling of metals and for scarfing have to undergo a formal licensing procedure, regardless if they are new installations or substantial alterations to location, nature or operation of existing installations.

C.1.1.3 Technical Instructions on Air Quality (TA Luft)

The Technical Instructions on Air Quality (TA Luft) [1] have been set up as general administrative regulations related to §48 BImSchG [cf. 32]. The TA Luft further specifies the requirements to be met by installations subject to licensing. It prescribes limit values for most air pollutants as well as structural and operational requirements designed to limit diffuse emissions. Specific regulations for ferrous metals processing activities by the TA Luft, directing at the avoidance and minimisation of air pollution, are laid down in N° 3.3.3.6.1 (plants for rolling metals, heating and heat treatment furnaces) in N° 3.3.3.9.1. (galvanising installations), and in N° 3.3.3.10.1 (installation for surface treatment of metalls using HNO_3). Requirements set out are listed in Table 8-2.

Table C.1-2: Special requirements by TA Luft applying to installations for the rolling of metals, for heating and heat treatment furnaces as well as for galvanising

N° in TA Luft	Reference	Specification
3.3.3.6.1 (rolling)	Reference quantity	Emissions values refer to a volume content of oxygen in waste gas of 5 out of 100
3.3.3.6.1 (rolling)	Nitrogen oxides *)	Emissions of nitrogen monoxide and nitrogen dioxide in the waste gas of plants operating air preheating of 200°C or more must not exceed the mass concentration given in the figure below (Fig. 8-1), given as nitrogen dioxide; possibilities, to control emissions by fuel engineering and other state of the art measures are to be employed.
3.3.3.6.1 (rolling)	Sulphur oxides	If burnable gases are used in an interrelated production between an iron and steel works and a coking plant, sulphur oxide emissions may not exceed the emission value according to enclosure 1 to §16, 13th BImSchV.
3.3.3.9.1 (galvanising)	Waste gas cleaning	Installations for galvanising, using fluxes, are to be equipped with waste gas capturing devices like encapsulation or hoods; waste gases need to be ducted to a waste gas cleaning facility.
3.3.3.9.1 (galvanising)	Dust	Dustlike emissions in waste gases must not exceed 10mg/m³(STP).
3.3.3.9.1 (galvanising)	Chlorine compounds	Emissions of gaseous inorganic chlorine compounds in waste gas must not exceed 20mg/m³(STP), given as hydrogen chloride.
3.3.3.9.1 (galvanising)	Emission measurements	The result of a single measurement is to be determined by several dipping processes; measuring time corresponds to the sum of single dipping times and shall cover usually ½ hour; dipping time is the period between the 1st and the last contact of the galvanised piece with the galvanising bath.



*): The German *Länderausschuß für Immissionsschutz (LAI)* agreed on the 6th and 8th Mai of 1991 in Bayreuth to put in concrete terms the making dynamic of the TA Luft for heating and heat treatment furnaces and settled the following emission values for NO_x:
new plants - 500mg/m³
existing plants with combustion air preheating
- up to 450°C: 500mg/m³
- over 450°C: target value 500mg/m³

In case of using coke oven gas:
- investigation of the individual case with a target value of 500mg/m³

Figure C.1-1: NOx emission limits TA Luft

Since the TA Luft was enacted in 1986, local authorities sometimes demand stricter emission limit values.

C.1.1.4 Technical Instruction on Noise Abatement (TA Lärm)

The Technical Instruction on Noise Abatement (TA Lärm) [5] sets limits for noise emissions by the operation of a facility, specified for various areas. The construction, operation or altering of a facility is granted only if the emission limits allowed for a specific area are not exceeded and if state-of-the-art noise protection measures are employed.

C.1.2 German regulations concerning the water quality

With respect to water management, each discharge, wherever it is located, has to comply with the Federal Water Act (Wasserhaushaltsgesetz, WHG [58]). The WHG is the legal instrument for water pollution control, analogous to the BImschG for control of air pollution. Regulations of the WHG cover waste water streams generated by various industrial processes, including ferrous metals processing activities. According to the WHG, the use of surface, coastal, and ground waters requires approval of the competent authority. Water protection legislation in Germany is implemented by the Ordinance on Waste Water (Abwasserverordnung, AbwV) and by general administrative regulations concerning minimum requirements to be met by discharges, irrespective of the quality of the receiving medium. Generally, frame regulations for water protection are provided on a federal level, but the federal states also add to water legislation by complementary regulations. The WHG is furthermore complemented by the discharge levy act (Abwasserabgabengesetz: AbwAG) [56]. Tariffs are related to the mass and possible hazard of the discharged waste water according to Table 8-3. For discharge of sewage, that exceeds the mentioned threshold values for concentrations or annual freights, the discharging party has to pay a fee related to the given units of measurement.

Table C.1-3: Thresholds according to the discharge levy act

Hazardous Substances	Units of measurement (relating to a unit of hazard)	Threshold values	
		Concentrations	Annual freights
Oxydizable substances (given as COD)	50 kg Oxygen	20 mg/l	250 kg
Phosphor	3 kg	0.1 mg/l	15 kg
Nitrogen	25 kg	5 mg/l	125 kg
Organic Halogen compounds as AOX	2 kg Halogen, calculated as Cl	100 µg/l	10 kg
Mercury & compounds.	20 g	1 µg/l	0.1 kg
Cadmium & compounds	100 g	5 µg/l	0.5 kg
Chromium & compounds	500 g	50 µg/l	2.5 kg
Nickel & compounds	500 g	50 µg/l	2.5 kg
Lead & compounds	500 g	50 µg/l	2.5 kg
Copper & compounds	1000 g	100 µg/l	5 kg
Fish toxicity	3,000 m^3 discharges / G_F	G_F =2 (dilution factor for non-lethality for fishes of the discharge)	

Minimum requirements are placed on sewage lines from certain legally fixed sources. Annex 24a of the AbWV (Abwasserverordnung, AbWV) deals inter alia with ferrous metals processing activities. This Annex applies inter alia to waste water generated by the following processes: continuous casting, hot forming, hot production of tubes, cold production of strip, cold production of tubes, sections, bright steel, wire, continuous surface treatment of semi finished and finished steel products. In section 2.1.2 of that Annex requirements are stated to minimise the level of harmful substances in the waste water. Table 8-7 provides important restrictions established by the AbWV, especially for warm and cold forming. Excluded from this regulation is waste water from cooling systems for the indirect cooling of industrial processes and process water treatment. Waste water obtained by these activities is subject to the provisions laid down in Annex 31, AbWV. Table 8-8 gives relevant requirements to discharges of this Annex 31 [175]. If the stated values are not observed, approval for the discharge of waste water will be denied. Effluents of batch galvanising installations also need to comply with the provisions of Annex 40, AbWV.

Table C.1-4: Requirements to discharges from the iron and steel production (Annex 24,AbwV)

Hazardous Substances / Process	Hot forming	Hot production of tubes	Cold production of strip	Cold production of tubes, ...	Cont. surface treatment
Chemical Oxygen Demand COD	40 mg/l	200 mg/l	200 mg/l	300 mg/l	300 mg/l
Iron	5 mg/l	5 mg/l	3 mg/l	5 mg/l	5 mg/l
Hydrocarbons	5 mg/l	10 mg/l	10 mg/l	10 mg/l	5
Nitrogen from nitrite (NO_2-N)	-	-	5 mg/l	5 mg/l	-
Total phosphorus	-	-	2 mg/l	2 mg/l	2 mg/l
Fluoride	-	-	30 mg/l	30 mg/l	-
Lead	-	-	-	-	0.5 mg/l
Chromium, total	0.2 mg/l	0.5 mg/l	0.5 mg/l	0.5 mg/l	0.5 mg/l
Chromium VI	-	-	0.1 mg/l	0.1 mg/l	0.1 mg/l
Copper	-	-	-	-	0.5
Nickel	0.2 mg/l	0.5 mg/l	0.5 mg/l	0.5 mg/l	0.5 mg/l
Zinc	2 mg/l	2 mg/l	2 mg/l	2 mg/l	2 mg/l
Tin	-	-	-	-	2 mg/l
Cyanide	-	-	-	-	0.2 mg/l
Fish toxicity as thinning factor	2	2	6	6	6
AOX	-	-	-	-	1 mg/l

Most federal state constituted complementary regulations for indirect discharges [174]. These Directives usually are applicable to industrial plants, as long as no federal regulations are provided. However, as most plants concerned are directly discharging waste water and therefore have to comply with the corresponding regulations for direct discharge, the Directives on Indirect Discharges are of minor interest.

Table C.1-5: Requirements to discharges from cooling systems of industrial processes (Annex 31, AbwV)

Hazardous Substances	Minimal Requirements
Chemical Oxygen Demand COD	40 mg/l
Phosphor compounds, given as P	3 mg/l
Zinc	4 mg/l
AOX	0.15 mg/l
Available residual chlorine	0.3 mg/l
Chromium compounds	must not be contained
Mercury compounds	must not be contained
Nitrite	must not be contained
Metal organic Compounds (Metal-Carbon-Compound)	must not be contained

C.1.3 German regulations concerning the waste management and disposal of hazardous materials

Waste legislation in Germany is laid down in the Act on Waste Prevention and Treatment (Abfallgesetz, AbfG [59]). It is applied to the use and storage of waste, i.e. to substances to be disposed of by the processor or to substances whose proper treatment is necessary to protect the environment. Additional requirements refer to waste from particular installations.

Legislation laying down measures aiming towards „avoidance, utilisation and disposal" of waste is set down in the Recycling and Waste Management Act (Kreislaufwirtschafts- und Abfallgesetz, KrW-/AbfG [57]), which came into force in October 1996 and is the most important part of the new AbfG. It broadens the entire national waste concept and sets new priorities with regard to the avoidance of and the duty to utilise waste. The KrW-/AbfG also codifies manufacturer's product responsibility [105].

For administrational procedures, technical guidelines on waste (TA Abfall) [2] and on municipal waste (TA Siedlungsabfall) [3] are of relevance. Furthermore, an administrative instruction, technical guideline on special wastes (TA Sonderabfall), regulates the handling of special waste. Facilities for treating waste have to fulfil requirements regulated in special decrees, based on Art. 5 BImSchG.

A working group of the federal states on waste (Länderarbeitsgemeinschaft Abfall, LAGA) issued a categorisation of waste types, comprising 589 types of waste, of which 333 have priority for control [93] (*LAGA-Abfallartenkatalog*). This catalogue was valid till 12/31/1998 and has been replaced by the European waste catalogue (EWC) in the following [104]. To facilitate the change from the LAGA catalogue to the EWC, the German *LAGA* worked out an interim catalogue (*LAGA-Umsteigekatalog*) [94]. Table 8-9 summarises the classification of selected relevant substances generated within ferrous metals activities (cf. [93, 94]).

Table C.1-6: Selected LAGA/EWC numbers for wastes resulting from selected FMP activities

Type of Waste	LAGA Waste Key[13]	EWC Waste Key / remarks
Scale	351 02	120199
Dismantled refractories	31103	100206
Eisenhaltiger Staub ohne schädl. Beim.	35101	120102
Ferrous scrap	35103	170405
Zinc dross	35309	170404
Iron hydroxide	51309	110104, 190201
Iron chloride ($FeCl_3$)	51519	060305
Spent pickle	52102	060101, 060102, 060103, 060105, 110105
Cooling agents	54401	120110
Rolling mill sludge	54701	130501
Sludge from oil separation	54703	130502

13 Classification with reservation

C.2 Additional information

C.2.1 Comparison of treatment and regeneration processes for spent pickle

The following Tables 8-7 to 8-9 give information on several processes for the regeneration of different type of spent pickle (H_2SO_4, HCl, as well as HF / HNO_3). The tables gives information on the following aspects:

- principle of regeneration,
- resulting regenerate / regenerated acid
  - other products to regenerate
  - waste to dispose
- regeneration ratio total acid / free acid
- required inputs for regeneration
- field of application (size in l/h)
- complexity of required installations
- required space for implementation
- benefit / cost ratio
- number of plants (world-wide, as at 1990, production and pilot plants)

C.2.2 Processes for spent sulphuric acid

Table C.2-1: Processes for regenerating spent acids from pickling plants using H_2SO_4

	Heptahydrate crystallisation (with indirect cyclone- or vacuum cooling)	Retardation	Dialysis
1. Principle of regeneration	Regeneration of free H_2SO_4	Regeneration of free H_2SO_4	Regeneration of free H_2SO_4
2. Regenerate / reg. acid	Free H_2SO_4	Free H_2SO_4	Free H_2SO_4
Other products to regenerate	$FeSO_4$; $7H_2O$	-	-
Waste for disposal	(If Cr, Ni, Zn present)	Acidic $FeSO_4$ for neutralisation	Acidic $FeSO_4$ for neutralisation
3. Regeneration ratio total acid			
Free acid	> 99%	80-90%	75-85%
4. Required inputs for regeneration	- Electrical energy - Steam - Cooling water	- Electrical energy - VE-water	- Electrical energy - VE-water
5. Field of application l/h	> 200	> 40	> 60
6. Complexity of required installations	Middle/ high	Low	Middle
7. Required space	Middle/ big	Small	Middle
8. Benefit / cost ratio	Middle	Middle	Middle
9. # plants (world-wide, as at 1990, prod. + pilot)	ca. 80	ca. 30	ca. 5

	Electrolytic oxidation	Process with HCI and pyrolysis	Crystallisation and roasting	Precipitation with solvents
1. Principle of regeneration	Electrolysis	Total regeneration	Total regeneration	Regeneration of free H_2SO_4
2. Regenerate / reg. acid	Total H_2SO_4	Total H_2SO_4	Total H_2SO_4	Free H_2SO_4
Other products to regenerate	Ferrous shots	Iron-oxide	Iron-oxide	Iron-oxide
Waste for disposal	-	-	-	(If Cr, Ni, Zn present)
3. Regeneration ratio total acid	> 99%	> 95%	> 95%	
Free acid				> 99%
4. Required inputs for regeneration	- Electrical energy - Additional electrolyte in loop	- Electrical energy - Natural gas - Cooling water - HCl in loop by fresh- and rinsing water	- Electrical energy - Steam - Natural gas - Cooling water - Fresh- and waste water	- Electrical energy - Steam - Cooling water - Solvent in loops
5. Field of application l/h	> 20	> 500	> 500	> 200
6. Complexity of required installations	Middle	High	High	High
7. Required space	Middle	Big	Big	Middle
8. Benefit / cost ratio	Middle	Low	Low	Low
9. # plants (world-wide, as at 1990, prod.&pilot)	2	1	1	n.a.

Source: [131]

C.2.3 Processes for spent hydrochloric acid

Table C.2-2: Processes for regenerating spent acids from pickling plants using HCl

	Pyrohydrolysis	**Retardation**	**Dialysis**
1. Principle of regeneration	Total regeneration	Regeneration of free muriatic acid	Regeneration of free muriatic acid
2. Regenerate / reg. acid	Total HCI	Free HCI	Free HCI
Other products to regenerate	Iron-oxides	-	-
Waste for disposal	-	Acidic $FeCl_2$ solution	Acidic $FeCl_2$ solution
3. Regeneration rate total acid	> 99%	For neutralisation	For neutralisation
Free acid		75-90 %	75-90 %
4. Required inputs for regeneration	- Electrical energy - Natural gas - Fresh- and waste-water	- Electrical energy - VE-water	- Electrical energy - VE-water
5. Field of application l/h	> 300	> 40	> 60
6. Complexity of required installations	High	Low	Middle
7. Required space	Big	Small	Middle
8. Benefit / cost ratio	High	Middle	Middle
9. # plants (world-wide, as at 1990, prod. + pilot)	ca. 250	ca. 15	ca. 5

	Electrolytic oxidation	**Electrolytic Fe.-precipitation**	**Chemical oxidation**	**Ion exchange**
1. Principle of regeneration	Transformation of $FeCl_2$ to $FeCl_3$	Electrolysis	Transformation of $FeCl_2$ to $FeCl_3$	Regeneration of free muriatic acid
2. Regenerate / reg. Acid	-	Total HCI	-	Free HCI
Other products to regenerate	$FeCl_3$	Ferrous shots	$FeCl_3$	$FeCl_3$
Waste for disposal	-	-	-	
3. Regeneration rate total acid	> 95%	> 95%	> 95%	
Free acid				50-70 %
4. Required inputs for regeneration	- Electrical energy - muriatic acid	- Electrical energy	- Electrical energy - HCI + air or Cl_2 or HCI + H_2O_2	- Electrical energy - VE-water - Oxidation agents as for chemical oxidation
5. Field of application l/h	> 20	> 20	> 20	> 40
6. Complexity of required installations	Low	Middle	Middle	High
7. Required space	Small	Small	Middle	Middle
8. Benefit / cost ratio	Middle	Middle	Low	Low
9. # plants (world-wide, as at 1990, prod.&pilot)	2	???	???	1

Source: [131]

C.2.4 Processes for spent mixed acids

Table C.2-3: Processes for regenerating spent acids from pickling plants using HNO_3 / HF

	Solvent extraction	Crystallisation	Pyrohydrolysis	Process with bipolar membranes
1. Principle of regeneration	Total regeneration	Regeneration of free acids	Total regeneration	Total regeneration
2. Regenerate / reg. acid	Total HNO_3 and HF	Free HNO_3 and HF	Total HNO_3 and HF	Total HNO_3 and HF
Other products to regenerate	-	Metal fluorides	Metal oxide	Metal hydroxides
Waste for disposal	Metallic salt solution			
3. Regeneration rate total acid	HNO_3 80-95% HF 50-65%		HNO_3 80-90% HF 90-99%	HNO_3 90-95% HF 90-97%
Free acids		HNO_3 80-95% HF 50-55%		
4. Required inputs for regeneration	- Electrical energy - H_2SO_4 - Cooling water - TBP in loop - Activated carbon	- Electrical energy - Cooling water	- Electrical energy - Natural gas - Cooling water - Fresh- and wastewater - H_2O_2 or similar	- Electrical energy - Caustic potash solution in loop - Diatom earth
5. Field of application l/h	>300	>300	>500	>100
6. Complexity of required installations	Middle	Middle	High	High
7. Required space	Middle	Middle	Big	Middle
8. Benefit / cost ratio	Middle	Low	Middle	Middle
9. # plants (world-wide, as at 1990, prod.&pilot)	2	1	2	2
	Retardation	**Dialysis**	**Outokumpu process**	**Kawasaki-process**
1. Principle of regeneration	Regeneration of free acids	Regeneration of free acids	Total regeneration	Total regeneration
2. Regenerate / reg. acid	Free HNO_3 and HF	Free HNO_3 and HF	Total HNO_3 and HF	whole HNO_3 and HF
Other products to regenerate	–	–	$Ni(OH)_2$	Ironoxide
Waste for disposal	Metallic salt solution	Metallic salt solution	Jarosite and $Cr(OH)_3$	Metallic salt solution
3. Regeneration rate total acid			HNO_3 90-95% HF 96-99%	HNO_3 75-90% HF 85-95%
Free acid	HNO_3 80-95% HF 80-90%	HNO_3 85-95% HF 80-90%		
4. Required inputs for regeneration	- Electrical energy - VE-water	- Electrical energy - VE-water	- Electrical energy - H_2SO_4 in loop - Natural gas - Soda, - Limestone - Steam, - Cooling water	- Electrical energy - Extraction agents TBP und D2EHPA in loop - NH_4HF_2 in loop - Natural gas, - Freshwater
5. Field of application l/h	>40	>60	>1000	>1000
6. Complexity of required installations	Low	Middle	Very high	Very high
7. Required space	Small	Middle	Middleery big	Very big
8. Benefit / cost ratio	Middle	Middle	Middle	Middle
9. # plants (world-wide, as at 1990, prod.&pilot)	ca. 30	ca. 5	1	1

Source: [131]

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