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Identification of Water and Energy Conservation in the Iron & Steel Industry in China

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Identification of Water and Energy Conservation in the Iron & Steel Industry in China

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Forord

COWI China og China Iron and Steel Design Institute har undersøgt mulighederne for energi- og vandbesparelser i jern og stål industrien i Kina i et studie finansieret af Miljøministeriet's Program for Miljøeffektiv Teknologi.

Studiet fokuserede på udnyttelse af spildvarme i kølevand fra Anshan Steel Works, der ligger i Liaoning Provinsen nordøst for Beijing og er verdens største stålværk, og undersøgte hvordan kølevandet kan renses så det kan genbruges som kølevand og udledningen af spildevand reduceres.

Studiet udbyggede og styrkede en igangværende dialog mellem Danfoss og COWI China på den ene side og Anshan Municipality og Anshan Steel Works på den anden side, som i løbet af studiet resulterede i en kontrakt om anvendelse af spildvarme fra Anshan Steel Works til produktion af fjernvarme til dele af Anshan City.

Sammenfatning og konklusion

COWI China og China Iron and Steel Design Institute har undersøgt mulighederne for energi- og vandbesparelser i jern og stål industrien i Kina i et studie finansieret af Miljøministeriet's Miljøeffektiv Teknologi Fond.

Den ene del af studiet fokuserer på brug af energi fra lav temperatur kølevand som varmekilde for fjernvarme, den anden del på metoder til at rense kølevandet, maksimere genanvendelse og minimere udledning af spildevand.

Studiet viser:

- At der er et betydeligt potentiale for genvinding af energi fra lav temperatur kilder og at anvende den som varmekilde i anden industri eller til fjernvarme eller fjernkøling
- At det er muligt, men dyrt, at rense kølevandet til en kvalitet der gør det muligt at genanvende det i fabrikationen, bruge det som varmekilde for fjernvarme, koncentrere det til brug som af-isningsmiddel og reducere den nuværende udledning af forurenet spildevand med 90% eller ved komplet rensning med 99%.

For varmegenvinding og genbrug i jern- og stålværker anbefales:

- Systematisk kortlægning af lav-temperatur energikilder
- Undersøgelse af matchende varmebehov i omegnen af jern- og stålværkerne
- Fremhævelse af miljøforbedringer ved genbrug og genvinding
- Politik tiltag som fremmer genbrug og genvinding på nationalt, provins og by niveau
- Markedsføring af konceptet til lokale myndigheder.

Ved fremtidig støtte til lignende teknologi overførsel fra Europa til Kina anbefales det at prioritere:

- Overførsel af know-how om økonomisk analyse og institutionel balance med forskellige aktører
- Mekanismer til at balancere subsidier til statslige virksomheder og økonomisk udbytte i den private sektor
- Udveksling af erfaringer om effektive politikker kombineret med konkret teknisk vejledning i tværgående udnyttelse af energi besparende virkemidler.

Energi besparelser

I Kina klassificeres overskudsvarme efter temperaturniveau som lav temperatur energikilder med temperatur under 300°C, mellem niveau i intervallet 300°C-650°C og højt niveau ved temperaturer over 650°C.

Studiet fandt at i jern- og stålværker er genvinding af energi fra mellem og høj temperatur kilder er ved at ramme det maksimalt mulige, mens der er betydeligt potentiale for genvinding fra lav temperatur kilder og anvendelse af denne energi i andre industrier eller til fjernvarme. Genvinding af energi fra lav temperatur kilder blev derfor valgt som fokus for studiet.

Studiet undersøgte tre forskellige processer for genvinding af overskudsvarme fra afkøling af slagger, vask af røggas og fra køling ved valsning af stål:

1. Absorbtions varmepumper
2. Mekaniske varmepumper
3. Kombineret kraftvarmeproduktion i stedet for ren kraftproduktion.

De to første processer kan generere energi til fjernvarme med ”Coefficients of Performance” på 1.7 og 7.5 for henholdsvis absorbtionsvarmepumper og mekaniske varmepumper.

Vand besparelser

Studiet undersøgte også mulighederne for vandbesparelser og rensning af kølevand, som er nødvendig for genanvendelse som kølevand, genvinding og udnyttelse af dets energi i fjernvarmesystemer og reduktion af udledninger af forurenet kølevand.

De undersøgte rensemetoder omfattede:

1. Ionbytning
2. Omvendt osmose
3. Nano-filtrering

En teknisk løsning bestående af kombination af ionbytning, omvendt osmose, nano-filtrering, fordampning, forstøvere og krystallisering er beskrevet og analyseret.

Analysen viser sig at omkostningerne ved at rense kølevand til en kvalitet der gør det muligt at genanvende det som kølevand og anvende det til produktion af fjernvarme er relativt høje og at det også er dyrt, men teknisk muligt, at fjerne opløste salte til et niveau der tillader udledning.

Ionbytning er den billigste metode til at fjerne salte, mens omvendt osmose og nano-filtration er bedst, men også dyrest.

Den komplette løsning gør det muligt at genvinde og genbruge op til 99% af kølevandet, hvis det behandlede kølevand fordampes til tørhed, og op til 90% hvis forstøvning og udkrystallisering udelades. I begge tilfælde kan resterende salt eller saltlage bruges til afisning eller udledes til havet afhængigt af anlæggets lokalisering, lagerkapacitet og lokale behov for afisningsmaterialer.

Summary and conclusions

COWI China and the China Iron and Steel Design Institute (CISDI) have analysed the potential for energy and water savings in the Iron and Steel Industry in China in a study financed by the Danish Ministry of the Environment under the Environment Efficient Technology Fund (Miljøeffektiv Teknologi Fond).

One part of the study focused on energy recovery from low temperature sources in the iron and steel industry and its use as energy source for district heating. The other part of the study examined the treatment of cooling water that is required for recycling, use in district heating and reduction of discharges.

The study concludes that:

- there is a significant potential for recovery of energy from low temperature sources heat sources and for its application in other types of industry or in district heating and cooling.
- it is possible, but expensive to treat cooling water to a quality that enables recycling within the factory, use as heat source for district heating and reduces discharges by 90% or even 99%.

For heat recovery and reuse in iron and steel plants the following is recommended:

- Systematic mapping of surplus low-grade energy sources inside the plant
- Investigation of potential demands around the plant
- Emphasize the environmental benefits
- Supportive policies from state, provincial and local level
- Sell the concept to local municipalities.

For future support to similar technology transfer from Europe to China, it is recommended to emphasise:

- Introduction of experience in economic analysis and institutional balances between different stakeholders
- Instruments for balancing financial support to public facilities and economic profit of private industries
- Policy advice as well as technical guidelines for cross-cutting energy saving measures.

Energy savings

In China the quality of surplus heat is graded according to temperature levels. Low temperature energy sources have temperatures below 300°C, whereas the interval 300-650°C is classified as medium temperature level and that above 650°C as high temperature level.

The study found that energy recovery from medium and high grade sources is approaching its limitations at individual plants, whereas there is a significant potential for recovery of energy from low temperature sources and for its application in other types of industry or in district heating or cooling. Therefore the energy recovery from low temperature energy sources was chosen as focus of the study.

The study analysed three different processes for recovery of surplus heat from water from washing of slag, washing of flue gasses and from cooling in steel rolling processes:

1. Heat recovery by absorption heat pumps
2. Heat recovery by mechanical heat pumps
3. Application of Combined Heat and Power (CHP) generation instead of pure power generation.

The processes can provide heat to district heating systems with Coefficients of Performance of 1.7 and 7.5 for absorption and mechanical heat pumps, respectively.

Water savings

The study also assessed the potential for water savings and the treatment of low temperature cooling water that is necessary for recycling as cooling water, recovery and use of its energy in district heating systems and for reduction of discharges of polluted cooling water.

Possible water treatment solutions include:

1. Ion-exchange
2. Reverse osmosis
3. Nano-filtration

One technical solution presented includes a system of ion-exchangers, reverse osmosis, nano-filtration, evaporators, spray driers and crystallisers.

It is concluded that the costs of treating cooling water to meet the water quality requirements for district heating are very high, and that it also is expensive, though technically possible, to remove salts by further treatment of the cooling water to meet the water recycling and discharge requirements.

Ion-exchange is the cheapest process, whereas reverse osmosis and nano-filtration are the best, but also the most expensive methods to remove salts.

The complete solution may recover up to 99% of the cooling water, if the brine residue is evaporated to dryness, and around 90% if the final steps involving crystallizers and spray driers are omitted. In both cases the resulting salt or brine may be used for de-icing or disposed to the sea according to the location, storage facilities and local demands.

1. Introduction

COWI China together with China Iron and Steel Design Institute (CISDI) have investigated the utilization of surplus heat in the iron and steel industry in China, focusing on low-grade (low temperature) surplus heat and providing practical and financially viable solutions.

The study was financed by the Danish Ministry of the Environment under the Environment Efficient Technology Fund (Miljøeffektiv Teknologi Fond), and working results will be disseminated to relevant stakeholders.

The report is structured as follows:

Chapter 1	Introduction of the assignment
Chapter 2	Overview of water and energy conservation in the iron and steel industry in China
Chapter 3	Surplus heat mapping and relevant water systems
Chapter 4	Surplus heat application and case solutions
Chapter 5	Water treatment solutions
Chapter 6	Conclusions and recommendations

2. Industry overview

This chapter gives a brief introduction to the iron and steel industry in China. The purpose is to provide background information for the study as well as definition of the scope of the study. The presented information is based on a substantive survey, which is summarised in Appendix 1 to Appendix 3.

The Chinese iron and steel industry has seen a quick development since 2000. In recent years nearly half of the global crude steel production has taken place in China and since 2009 Chinese production has been over 40% of total world production (Figure 2-1). However, comparison of specific energy consumption in steel production shows that the Chinese industry still has considerable room for improving energy efficiency.

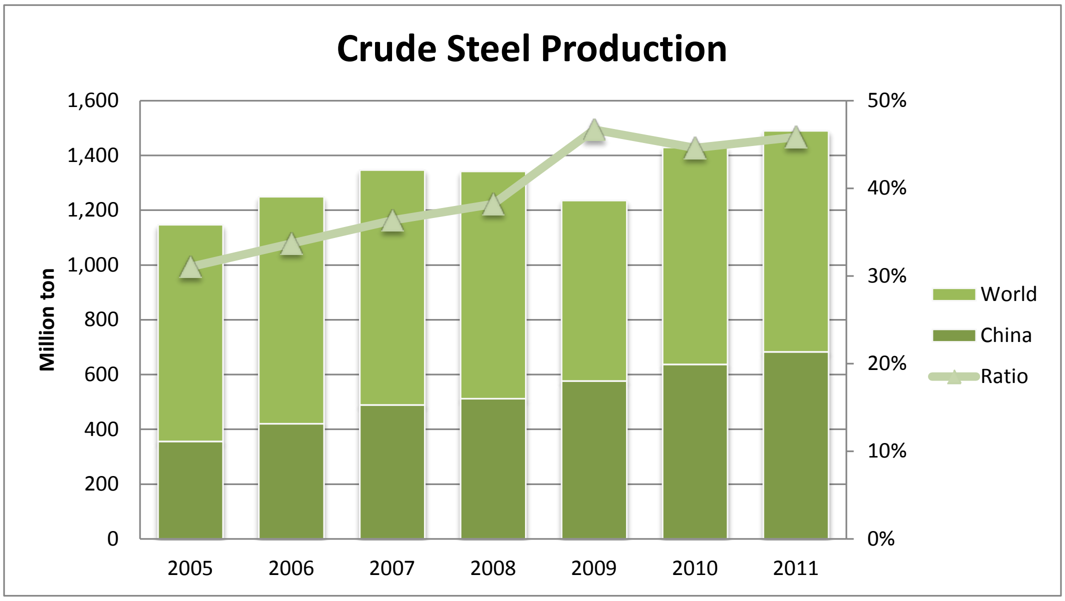

FIGURE 2-1 CHINESE SHARE OF GLOBAL CRUDE STEEL PRODUCTION (WSA: PREVIOUSLY IISI)

Three important aspects for improvement are:

- Reduce raw material consumption in the whole steel work process, because processing of raw materials consumes energy, and saving of materials is saving of energy
- Improve energy transfer and transformation efficiency
- Recycle, reuse and recover surplus energy from various production processes.

2.1 Overview of surplus energy recovery in the iron and steel industry in China

Studies on surplus energy utilization in Iron & Steel Industry are quite few as previous focus always has been on iron and steel production itself. Available information dates back to 1990's and the most recent data available are still relatively old, e.g. from 2006 to 2009, mainly coming from reports of different steel plants, research documents from China Iron & Steel Association (CISA) as well as an industry development report from Deloitte[1].

2.1.1 Surplus energy utilization

A survey was carried out in 2005 to investigate surplus heat recovery in the iron and steel industry[2]. Over 20 steel plants were investigated and surplus energy calculated based on certain assumptions, which may represent typical technical level of Chinese steel industry. The result is illustrated in Figure 2-2. Obviously the iron production process has biggest potential to save energy since it accounts for 60% of total surplus energy, while surplus heat in coking process accounts for 7%.

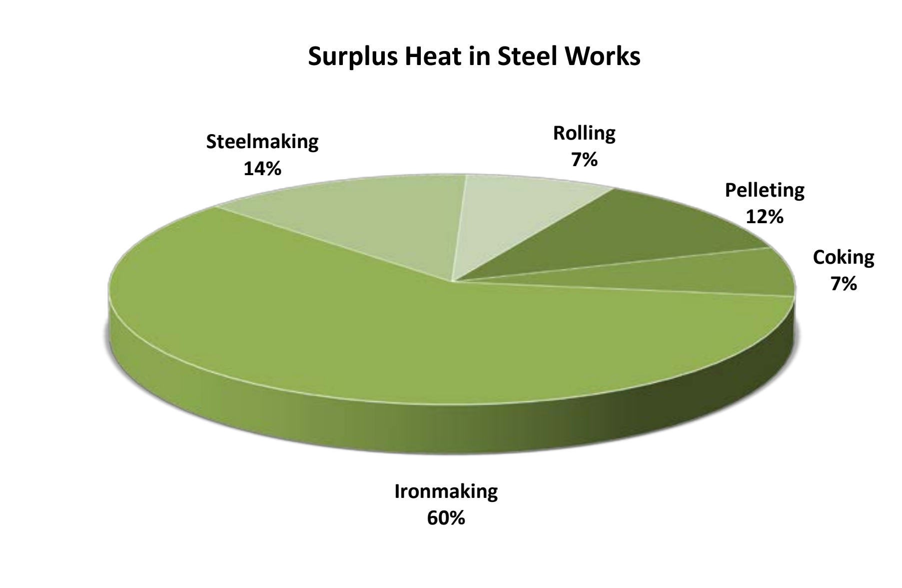

FIGURE 2-2 SURPLUS ENERGY AVAILABLE IN STEEL WORKS

Recovery of waste heat is estimated at only 15 %, while recovery of other types of surplus energy (pressure, chemical energy) is 80%. This result is considered to be optimistic for China as a whole, as most of the investigated steel plants are among the top level plants in China and thus have more advanced facilities and production processes than the multitude of small iron and steel plants.

One of the parameters characterising the quality of surplus heat is temperature, which in China is classified according to temperature levels, e.g. high temperature (>650°C), middle level temperature (300-650°C) and low temperature (<300°C).

Investigated *"sensible heat"*[3] resources in steel works (up to 2005) are shown in Figure 2-3. Sensible heat in products and semi-products accounts for 39% of total surplus heat in steel works, most of it being high temperature heat, only heat from sintering and pelleting is of middle level temperature. Sensible heat in flue gas accounts for 37% of total sensible heat, in which only converter flue gas is high temperature surplus heat. Slag has very high temperature and accounts for 9% of total sensible heat, while cooling water is low temperature heat sources, but with large circulation volume accounting for 15%[4].

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1 China Iron & Steel Industry Development 2010, Deloitte, http://doc.mbalib.com/view/58c2e4c10e699077208cac7d304d3348.html

2 Report on Residual Heat and Energy in Chinese Steel Industry, Wang Jiangjun et.al, Industry Heating, Vol. 36, No. 2, 2007

3 Sensible heat is heat exchanged by a body or thermodynamic system that has the sole effect of change of temperature (http://en.wikipedia.org/wiki/Heat). This is a term used in contrast to latent heat, which is an amount of heat exchanged that is hidden, meaning it occurs without change of temperature.

4 Energy Consumption Analysis and Energy Saving Measures Research in Integrated Networks, Cai Jiuju, Angang Technology, No. 356, 2009.

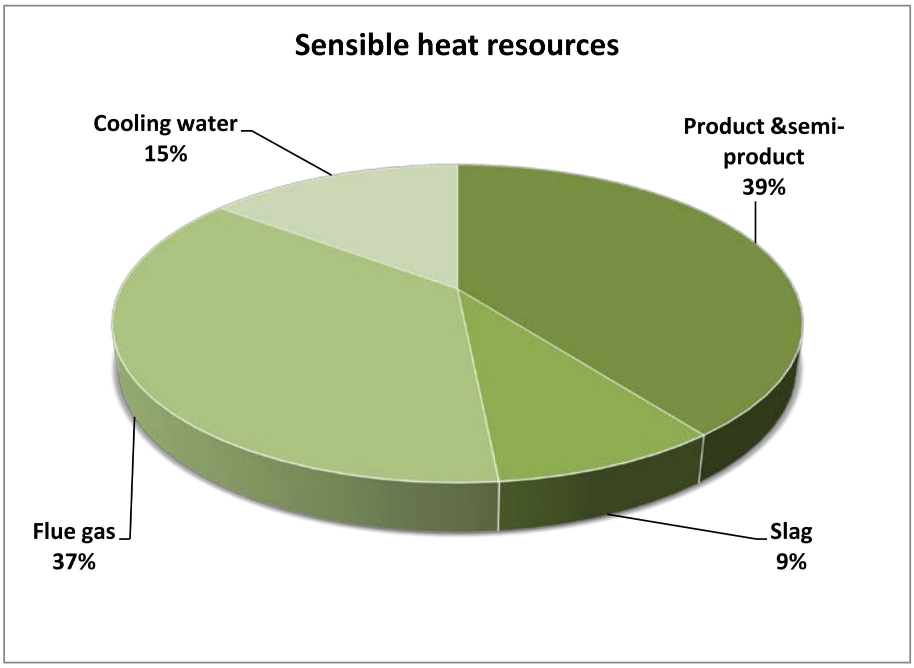

FIGURE 2-3 SENSIBLE HEAT CARRIERS

The investigation (in 2005) shows that 45% of high temperature surplus heat was recovered, that utilisation of surplus heat at middle temperature was 30%, whereas less than 1% of low temperature surplus heat was recovered. When comparing the recovered heat from various resources, 50% of sensible heat from products is utilized, recovered sensible heat from flue gas is 15% of total sensible heat of flue gas while less than 2% of heat from cooling water is collected, and even less heat is recovered from cooling of slag.

Normally coking, sintering and pelletizing can be separated from the steel plants. Major energy saving measures identified for these processes during the 11th Five-Year Plan period have been disseminated and applied by many steel plants. Therefore these production processes are not studied in further detail.

Other production processes are further investigated. The immense surplus heat found during iron production mainly comes from blast furnaces. Surplus energy and recovery possibilities are summarized in Table 2-1.

TABLE 2-1 RESIDUAL ENERGY AND UTILIZATION IN IRON PRODUCTION PROCESS, STATUS 2005

Unit: kg coal / ton steel	Available	Utilised	Ratio
Sensible heat			
Slag	18.5	0.4	2.2%
Cooling water	32.4	0	-
BFG	26.3	0	-
Hot Stove Flue Gas	12.3	3.7	30.1%
Residual Pressure of BFG (TRT)	12.7	3.2	25.2%
Chemical energy of BFG (fuel)	171.1	150.6	88.0%

Normally sensible heat from slag is transferred to slag washing water. During summer this part of energy is dissipated into the atmosphere via cooling towers, while some steel plants have sold slag water to district heating companies during winter time. In these cases slag water quality becomes a critical issue as common heat exchangers are very sensitive to water quality.

Angang Steel, one of the top ten steel producers in the world, is among the steel plants, which have applied direct district heating system with treated slag water from blast furnaces. Due to very poor water quality, the pipeline and radiators have to be replaced every 3-4 years. Similar systems can be found at other steel plants, e.g. Ben Xi Steel Plant and Tong Hua Steel Plant in Liaoning Province.

There is to date no utilization of sensible heat from blast furnace cooling water and flue gases, while 25% of top pressure of blast furnace flue gas is recovered for electricity generation by Top pressure Recovery Turbines (TRT), and 88% of blast furnace gas is collected and either used as fuel in the steel plant (reused in hot stove and other production processes) or sold to city gas networks.

It is expected that the steel production process actually would consume "minus" energy due to recovery of converter gas and steam. Although the investigation in 2005 shows that "minus" energy consumption was realized only in a few big scale converters, it is confirmed by CISDI that the rest of steel plants quickly have improved energy recovery in converters in recent years, thus iron production process will be more focused in the study.

In the rolling process, surplus heat includes sensible heat from flue gas and cooling water for the heating furnace, of which 35% of sensible heat of the flue gas and 8% of surplus heat from cooling water is utilised (Table 2-2).

TABLE 2-2 RESIDUAL ENERGY AND UTILIZATION IN ROLLING PROCESS, STATUS 2005

Unit: kg coal / ton steel	Available	Utilised	Ratio
Sensible heat			
Flue gas	24.5	8.6	35.1%
Cooling water	10	0.8	8.0%

2.1.2 Typical problems

Steel plants in China have tried to reduce raw material and energy consumption for years, however there is still considerable room for improvement.

Typical problems are:

- Lack of consideration of 'interfaces' between different production processes.
  Steel works represent integrated production processes, where material flow and energy flow interact with each other - a more reasonable flow scheme could generate synergized economic and environmental effects.
- Lack of knowledge of systematic energy conservation methodology and consideration of potential synergise
  Normally steel plants consist of several different factories, each of which has its own production plan. However, a systematic energy management plan is necessary with consideration of the whole steel work process.
- Overview of efficient utilization of recovered energy
  For individual production process, applied recovery solutions are neither efficient nor sufficient. The dissipated surplus heat is still tremendous, for example due to intermittent demand (e.g. heating demand only in winter time), insufficient temperature level (low temperature cooling water) or pressure level (evaporated steam at atmospheric pressure during slag washing).
- Lack of in-depth research on specific situation of each steel plant
  The simple introduction or copying of foreign technologies makes it impossible to ensure stable energy supply or to supply energy with good quality (e.g. not sufficient temperature), this situation hampers proper application of recovered energy.

These problems also reflect that high grade energy is much easier to recover than low grade energy.

It should be noted that most of the above mentioned figures are based on the situation in 2005. Available information in recent years (latest in 2009) shows improvements and higher demand for solutions for low grade energy recovery.

2.1.3 Scope of study

Based on discussion with CISDI and general survey of the Chinese steel industry, it is concluded that the scope of the study should be:

Solutions for low-grade surplus heat recovery focusing on iron production (blast furnace) and rolling

Further, based on the consultants' experience in the energy sector, especially in district heating, the focus is to apply the extracted heat for district heating systems, i.e. the study will provide solutions and tools for the steel plant to sell its surplus heat to external stakeholders in addition to internal optimization of production processes. The application is further described in Chapter 4.

2.2 Overview of water treatment in the iron and steel industry in China

2.2.1 Water with surplus heat in the iron and steel industry

Water, as one of the main media carrying surplus heat, is the focus of the inventory. It is common practice that water is used for cooling, heating, washing and cleaning in different steps in the integrated iron and steel production process. It is not only a medium for carrying the energy, but also for carrying other compounds. The existing forms of water (liquid or steam) have significant capacity for energy transfer while the quality of the water also affects the heat exchange process and facilities. It is a main factor for quantifying and qualifying the heat recovery.

Another reason to look into water with surplus heat is the mutual benefits of energy saving and water saving. As a medium of energy transport, saving water in the cooling system will increase the energy per unit water, hence the possibility and feasibility for surplus heat recovery could be optimized.

This chapter aims at identifying the target process and existing problem water with surplus heat based on a general understanding of water flow in the iron and steel industry.

Generally, there are four types of water used in production. The types, according to utilization and consumption, are as follows:

- Cooling water - used in open, semi-closed and closed recycling systems
- Boiler water
- Washing water
- Air conditioning water.

The ratio of different types of process water in integrated iron and steel manufacturing is shown in Table 2-3.

TABLE 2-3 DISTRIBUTION OF WATER CONSUMPTION ACROSS PROCESSES

Process	Cooling water	Boiler water	Washing water	Air conditioning	Other
Percentage	85.4%	0.4%	9.8%	1.7%	2.7%

Cooling water is the main focus in the study. As cooling water constitutes more than 80% of total water consumption, recycling and reuse of cooling water has the largest potential for reducing total water consumption. Since cooling water contains large amounts of surplus heat, which needs to be extracted before reuse, efficient utilization of surplus heat naturally becomes part of the solution. On the other hand, knowledge of the pollutants in cooling water and its treatment is also required to fulfil the quality criteria for feed water and improve efficiency of surplus heat utilization.

According to CISDI, they started the research and tests to improve water treatment and water recycling efficiency of cooling water 20 years ago and now have reached a general cooling water recycling efficiency above 99%. The additional water saving by improving the quality of cooling water therefore is not attractive. Instead, the water treatment will focus on treatment, which can improve the recovery rate of surplus heat from water.

Although the key focus of water quality in heating systems is hardness and suspended solids (SS), the removal of pollutants are all related in water treatment. More efficient treatment could lead to a cost reduction for the heating system, despite increased costs for water treatment. In order to handle the interaction of pollutants and establish the most cost-effective treatment an integrated, cross-disciplinary study is required.

Major pollution figures and pollutants in the integrated iron and steel manufacturing are listed in Table 2-4.

TABLE 2-4 MAJOR POLLUTION FIGURES AND POLLUTANTS IN INTEGRATED IRON AND STEEL MANUFACTURING[5]

Process	Physical parameters				Major pollutants																
	Turbidity	Smell	Colour	Surplus heat	Phenol	Benzene	Sulphide	Fluoride	Cyanide	Oil	Acid	Alkali	Zn	Cd	As	Pb	Cr	Ni	Cu	Mn	V
Sintering	▲		▲																		
Coking	▲	▲	▲	▲	▲	▲	▲		▲	▲	▲	▲			▲						
Iron production	▲		▲	▲	▲		▲		▲				▲			▲				▲	
Steel production	▲		▲	▲				▲		▲											
Rolling	▲		▲	▲						▲											
Acid pickling	▲		▲					▲			▲	▲	▲	▲			▲	▲	▲		
Ferroalloy	▲		▲	▲	▲		▲										▲			▲	▲

2.3 Categories of cooling water

Cooling water systems in the iron and steel manufacturing are divided into three basic types according to the heat exchange process used on the heat source and the heat dissipation side.

The definitions are:

- Direct open recycling system
  At the heat source side, cooling water and heat target transfer heat directly; at the heat dissipation side; heat from cooling water is dissipated into the atmosphere, for instance in a cooling tower.

5 Research report on wastewater treatment market and technology of the iron and steel production industry in China (2011) from www.lanbailan.com

- Indirect open recycling system
  At the heat source side, cooling water and target transfers heat indirectly; at the heat dissipation side, the cooling water dissipated heat into the atmosphere, for instance in a cooling tower.
- Indirect closed recycling system
  At the heat source side, cooling water and target transfers heat indirectly; at the heat dissipation side, heat from the cooling water is exchanged indirectly with another cooling agent, for instance through a second heat exchanger.

Different cooling water systems are applied in different cooling processes based on the cooling demand and source and target characteristics. Specific criteria have been set for the water quality in each system.

Standard quality and application of cooling water in China are defined as follows:

- Recycled water
  Recycling water after treatment. It could be applied in direct open recycling systems.
- Industrial fresh water
  Fresh water after normal tap water treatment. It can be applied in direct and indirect open recycling systems.
- Softened water
  Industrial fresh water after softening. It can be applied in indirect closed recycling system.
- Desalinated water
  Industrial fresh water after desalination. It can be applied in some indirect closed recycling systems.

The quality requirements for feed water and recycled water in iron and steel manufacturing in China are shown in Table 2-5.

TABLE 2-5 QUALITY PARAMETERS FOR FEED AND RECYCLED WATER IN THE IRON AND STEEL INDUSTRY

Parameter	Unit	Reuse water	Industrial fresh water	Softened water	Desalted water
pH	——	6-9	7-9	7-9	6.5-9
Total Suspended Solids (SS)	mg/l	20	10	5	1
Total Hardness	mg/l	450	150	10	2
Ca Hardness	mg/l	300	100	2	1
Alkalinity	mg/l	330	110	110	1
Cl-	mg/l	660	220	200	1
SO42-	mg/l	240	80	80	Below detection
Iron	mg/l (Fe)	3	1	1	0.1
Dissolved SiO2	mg/l	18	6	6	0.1
Oil	mg/l	5	2	1	Below detection

Parameter	Unit	Reuse water	Industrial fresh water	Softened water	Desalted water
Conductivity	μs/cm	3000	500	500	10
Total Dissolve Solids (TDS)	mg/l	1000	300	300	5
NH_3-N	mg/l	10	10	10	1
COD_{Cr}	mg/l	100	——	——	——

Notes.

1 *Code for design of water supply & drainage of iron and steel enterprises (GB50721-2011)*

2 *The fulfilment of parameters should be > 90%*

3 *When the groundwater is used for main water source, the total hardness should be < 200mg/l*

Considering that the focus processes in this study have been selected as blast furnace and rolling, more requirements for specific parameters are listed in Table 2-6 and Table 2-7.

TABLE 2-6 WATER QUALITY PARAMETERS FOR DIRECT RECYCLING SYSTEM IN BLAST FURNACE AND ROLLING

Items	Unit	Criteria for application	Value
pH		Blast Furnace- flue gas washing water	≤20
		Rolling direct cooling system	≤10
Conductivity	μs/cm	Blast Furnace- flue gas washing water	≤3000
		Rolling direct cooling system	≤2000
SS	mg/l	Blast Furnace- flue gas washing water	≤100
		Rolling direct cooling system	≤30
Carbonate Hardness ($CaCO_3$)	mg/l	Blast Furnace- flue gas washing water	
		Rolling Indirect cooling system	≤500
Cl^-	mg/l	Rolling Indirect cooling system (1)	≤300
		Rolling Indirect cooling system (2)	≤500
Sulphate (SO_4^{2-})	mg/l	Blast Furnace- flue gas washing water	≤2000
		Rolling direct cooling system	≤1500
Oil	mg/l	Rolling Indirect cooling system (1)	≤5
		Rolling Indirect cooling system (2)	≤10

TABLE 2-7 WATER QUALITY PARAMETERS FOR INDIRECT OPEN RECYCLING SYSTEM IN BLAST FURNACE AND ROLLING (GB50050-2007CODE FOR INDUSTRIAL RECIRCULATION COOLING WATER TREATMENT)

Items	Unit	Criteria for application	Value
Turbidity	NTU	Based on process	≤20
		Heat exchanger: plate, Finned tube, spiral	≤10
pH		- low	6.8
		high	9.5
Ca Hardness ($CaCO_3$)	mg/l	Stable factor of $CaCO_3$ (RSI) ≥3.3	≤1100
		Heat transfer surface (water side) temperature >70℃	≤200
Total Fe	mg/l		≤1.0
Cu^{2+}	mg/l		≤0.1
Cl^-	mg/l	Carbon steel, Stainless steel heat exchanger, water running in pipe	≤1000
		Stainless steel heat exchanger, water running on container surface, heat transfer surface (water side) temperature≤70℃, cooling water outlet temperature <45℃	≤700
SO_4^{2+} + Cl^-	mg/l		≤2500
Silicic acid (in the form of SiO_2)	mg/l		≤175
$Mg^{2+} \times SiO_2$ (Mg^{2+} in form of $CaCO_3$)*	mg/l	pH≤8.5	≤50000
Free Chlorine	mg/l	Main entrance of returning water pipe	0.2-1.0
NH_3-N	mg/l		≤10
*: The concentration product of Mg^{2+} and silicic acid (SiO_2) is one of the parameters controlling scaling. $Mg^{2+}$is calculated as $CaCO_3$			

2.3.1 District heating water standards

Based on the scope of this study, the extracted surplus heat is supposed to be used for district heating or cooling systems. A few pilot projects have been conducted in China using cooling water for domestic heating with or without heat exchanger. In these cases, the quality of cooling water proved to be one of the crucial factors during design and implementation. In order to obtain the most cost-effective solution, the difference between the quality of cooling water and district heating water requires attention.

The minimum requirements for feed water and circulation water for domestic heating are that it is free of particles and that the hardness and the oxygen content are relatively low. The water quality in a district heating system can however be improved further. Table 2-8 and Table 2-9 show typical recommended water properties for feed water and circulating water in district heating systems from the Danish District Heating Association.

TABLE 2-8 WATER PROPERTIES RECOMMENDED BY THE DANISH DISTRICT HEATING ASSOCIATION (FEED WATER)

Index	Softened water	Demineralised water
Appearance	Clear-no colour	Clear-no colour
Smell	None	None
Particles	< 5mg/l	<1mg/l
pH-value(*)	9.8±0.2	9.8±0.2
Conductivity μs/cm	app. raw water	< 10
Residual hardness dH°	< 0.1	< 0.01
Oxygen / carbon dioxide content	< 0.1/10 mg/l	< 0.1/10 mg/l
Oil and fat content	None	None
Chloride content Cl^-	< 300 mg/l	< 0.1 mg/l
Sulphate SO_4^{2-}	___	< 0.1 mg/l
Total iron content Fe_{total}	< 0.05 mg/l	0.005 mg/l
Total copper content Cu_{total}	< 0.05 mg/l	< 0.01 mg/l
Bacteriological limit	___	___
(*) It is not recommended to adjust the pH-value with ammonia, as the corrosion of copper and copper alloys increase rapidly at pH-value above 9.0.		

TABLE 2-9 WATER PROPERTIES RECOMMENDED BY THE DANISH DISTRICT HEATING ASSOCIATION (CIRCULATING WATER)

Index	Softened water	Demineralised water
Appearance	Clear	Clear
Smell	None	None
Particles	< 10mg/l	< 1 mg/l
pH-value(*)	9.8±0.2	9.8±0.2
Conductivity μs/cm	< 1500	< 25
Hardness dH°	< 0.5	< 0.1
Oxygen content	< 0.02 mg/l	< 0.02mg/l
Oil and fat content	< 1mg/l	< 1mg/l
Chloride content Cl^-(*)	< 300mg/l	< 3mg/l
Sulphate SO_4^{2-}	____	< 1mg/l
Total iron content Fe_{total}	< 0.1 mg/l	0.05 mg/l
Total copper content Cu_{total}	< 0.02 mg/l	< 0.01 mg/l
Ammonia content NH_3	< 10mg/l	< 5mg/l
Bacteriological limit (**)	____	____
(*) as stainless steel however, is frequently used in district heating today, it should be underlined, that chloride contents above 7mg/l at elevated temperatures (94 or 108℃) will cause stress corrosion on AISI 304 and 316 steel. (**) be attentive however if the water has a smell of sewage, slime is found in the filters or an unusual increase in the consumption of chemicals.		

2.3.2 Cooling water treatment

Water treatment is essential for improving the water recycling efficiency and the recovery rate of surplus heat from cooling water.

Treatment facilities for cooling water and feed water are used widely, but due to the different designs of different cooling systems the complexity and integration vary. Typically, there would be one freshwater treatment plant and two centralized wastewater treatment plants, one for industrial processing water and one for mixed wastewater treatment. Specific and in-depth treatment would be conducted, according to required water quality. The typical freshwater treatment process and wastewater treatment process are shown in Figure 2-4 and Figure 2-5.

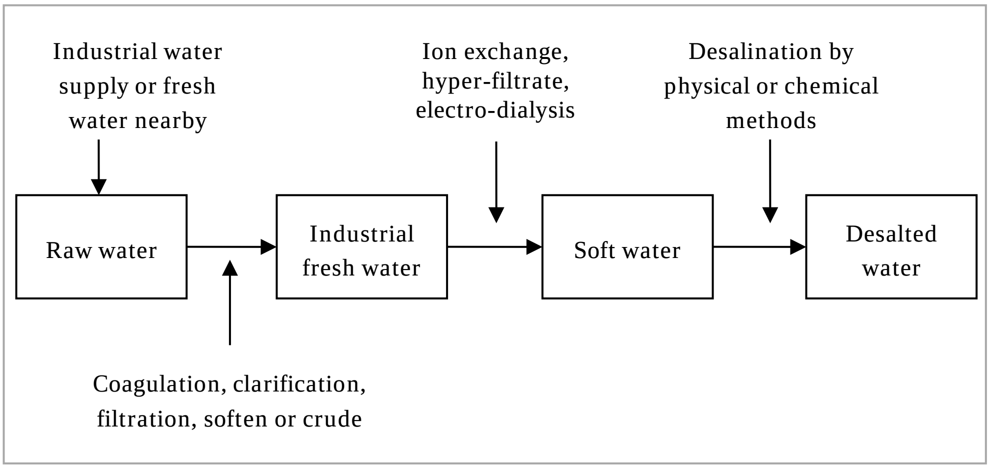

FIGURE 2-4 TYPICAL FRESH WATER TREATMENT PROCESS IN IRON AND STEEL MANUFACTURING

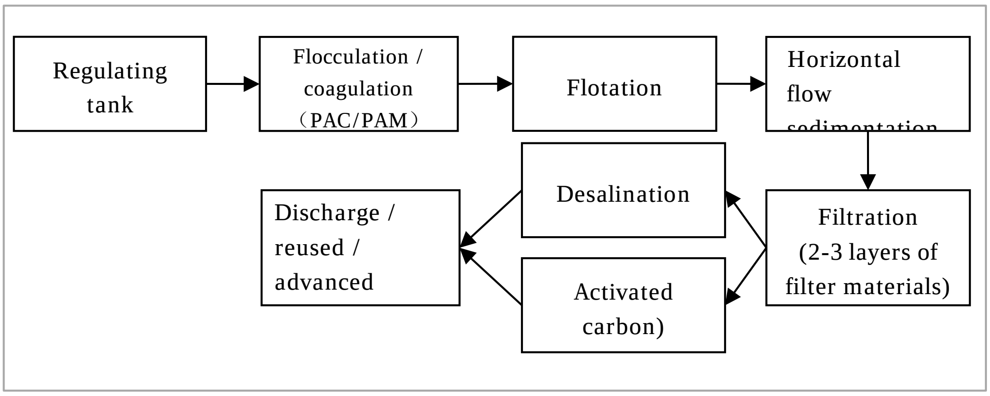

FIGURE 2-5 TYPICAL WASTEWATER TREATMENT PROCESS IN IRON AND STEEL PRODUCTION

Based on the interview and case study, the following 6 major issues regarding cooling water treatment have been identified:

- Poor quality of recycled water from central cooling water treatment plants due to high salt concentration.
- Cooling water of blast furnace gas is difficult to treat by standard mechanical methods, e.g. filtration, flotation or sedimentation, therefore it is not reused.
- Desalination may be used for removal of salt and activated carbon may be used for removal of organic contaminants. These processes are not in common use and therefore reuse of high quality cooling water is not very common.
- Water quality problems may remain after treatment of slag washing water, for instance high suspended solids (SS), high hardness and high salinity.

- Loss of hydraulic head for indirect cooling water systems is critical since a certain head is needed for the lifting pump of the system.
- The focus parameters for cooling water used in rolling process are the suspended solids and oil.

The most serious issue is the high concentration of salt in the cooling water because it is not permitted to discharge water with high salt concentration into rivers and many steel works are located away from the sea. This issue is mentioned because it affects the extraction and utilization of surplus heat as described in Chapter 4.1. According to the study objective, solutions for these problems would be the priority.

3. Surplus heat mapping and description

The studied production processes are iron production and steel rolling. The production process itself will be looked as a black box, only external utilization of surplus heat will be studied.

In the following the recovery of surplus heat available in iron-production (blast furnace) and rolling are summarized based on detailed information which can be found in Appendix 1. It should be noted that the technical data are based on common design practice by CISDI and represent the most common practice in China. The operational data in each steel plant may vary according to actual operational conditions.

As most of the low grade surplus heat comes from cooling water, water treatment becomes an issue, because heat transfer capacity will be influenced by water quality. A financial balance must be found between investment to improve water quality and to apply specific heat exchangers, which require more frequent maintenance. Water cycles are also checked and summarized in Chapter 3.2.

3.1 Surplus heat mapping

Most of the energy resources with medium and high temperature level (>300°C) are utilized internally by the steel plants, therefore the surplus heat identified in the two production processes refers only to the low temperature resources (<300°C), whose temperature is more than sufficient to be applied in light industry and not-industrial areas. Until 2005 less than 1% of low temperature surplus heat was recovered, so the potential for energy recovery is considerable.

All types of surplus heat are considered during mapping of available surplus heat resources, but the main categories are:

- Cooling water
- Flue gas/hot air
- Hot products
- Hot iron/steel slag

Available surplus heat in iron production process is summarised in Table 3-1 and Table 3-2 .

TABLE 3-1 SURPLUS HEAT IDENTIFIED FROM BLAST FURNACE COOLING WATER

Water system	Cooled components	Flow rate m3/h	Pressure drop Mpa	Supply temp. C	Return temp. C	Operation duration
soften water system						
I	Cooling plate at furnace hearth	4400	0.65	<=40	<=48.4	continuous
	water supply to hearth bottom and copper plate	1400		<=40	<=48.4	continuous
II normal pressure	Tuyere medium sleeve	950	0.65	<=48.4	<=53.4	continuous
	Cross temperature					
	Throat camera					
	Downdraft check valve					
	Tuyere blowpipe	290		<=48.4	<=53.4	continuous
	Hot blast stove	800		<=48.5	<=53.5	continuous
II high pressure	Tyuere	1330	1	<=48.6	<=53.6	continuous
Total	Main circulation	5800				
	Normal pressure circulation	2040				
	High pressure circulation	1330				
Clean water sytem						
Medium pressure	Furnace top cooling station	218		33	43	
	Cross temperature					
	Top hydraulic station					
Low pressure	Furnace hydraulic station	527		33	43	
	TRT					
	Filter fan					
Blast fan	Blast fan	285				
		570				
Gas scrubber	Blast furnace gas	250	1	<=45		continuous
Slag wash	Granulation tank	2400	0.23			continuous
	Drum cleaning	50	0.7	<=60		continuous
	Recirculation pump	200	0.2	<=60		continuous

TABLE 3-2 SURPLUS HEAT IDENTIFIED FROM BLAST FURNACE, FLUE GAS, AND SLAG WASHING WATER

	Flow rate m³/h	Pressure drop Mpa	Temperature °C
Blast furnace flue gas	177,570		130 – 160
Slag washing water (INBA Cold)			≤ 60
Slag washing water (INBA Hot)			≤ 90

The surplus heat mapped is representative of a typical blast furnace and comes mainly from cooling water. The noticeable part is that the temperature is very low at 40-60 °C, and can only be used directly in applications below this temperature level. However, there are various technologies to boost the temperature level and enlarge the scope of application, as introduced and investigated in Chapter 4.1.

The heat recovery from flue gas from hot stove, one of the main components of the blast furnace, highly depends on the composition of flue gas. The higher the acidic gas content, the higher the required exhaust gas temperature. If there is no sulphur content the flue gas temperature can be lowered to 57-58˚C, which is typical flue gas temperature of natural gas fired boilers. Therefore it is possible to extract heat from hot stove flue gas, if the sulphur content is very low. Normally if coking gas or blast furnace gas is applied then the possibility to recover flue gas heat is marginal as sulphur (SO_2, H_2S) always is present, although the emitted flue gas has to fulfil national emission standard (Integrated Emission Standard of Air Pollutants, GB16297-1996).

Based on the consultant's experience, not all of the steel plants have technically fulfilled requirements on flue gas quality during daily operation, e.g. the sulphur content in flue gas is not regulated, which means the potential to extract heat from flue gas is very low. Furthermore, package solutions such as desulfurization including heat recovery already exists in market, therefore recovery of flue gas heat at this temperature level is not considered in the study.

The temperature of slag from the iron melting process is commonly over 1300 °C. The molten slag is sprayed with high pressure water for quenching and granulation as raw materials for construction or road paving. The flash steam generated during granulation of slag, normally at atmospheric pressure, is not recovered. Although there are various trials implemented to collect the water vapour condensate as well as latent heat, the technology is still not mature. The slag washing water, after some treatment, is recycled for slag washing, or sent to the wastewater treatment plant for treatment and discharge.

Surplus heat identified in rolling process is mainly coming from cooling water, with temperature level ranging from 40°C to 90°C, but averaging 42°C, as shown in Table 3-3.

TABLE 3-3 SURPLUS HEAT IDENTIFIED FROM ROLLING PROCESS COOLING WATER

Water System	Component	Flow rate m^3/h	Pressure drop Mpa	Supply temp. °C	Return temp. °C
Indirect cooling	Hot stove	312	0.4	35	50
	Equipment room	4,130	0.4	33	38
Direct cooling	Roller table	4,766	0.4	35	42
	Roller	5,670	1	35	42
	Iron scaling washing	1,000	0.3		
	Laminar cooling	9,450	0.07	38	42
	Laminar cooling – roller table	530	0.07	38	42
	Laminar cooling – side jet	245	1	38	42

3.2 Surplus heat related water system

As the processes identified in the study are blast furnace and rolling, the heat recovery from these two processes will be assessed.

The relevant water recycling systems considered are:

- Blast furnace process related water recycling:
  - Softened water system
  - Clean water recycling system
  - Gas cooling water
  - Slag washing water

- Rolling process related water recycling:
  - Direct cooling system
  - Indirect cooling system

All the relevant water recycling systems and standards are further described in the following sections that are based on a Chinese standard design.

3.2.1 Softening water system - Surplus heat in blast furnace

Softened water system is a closed recycling system using softened water for blast furnace cooling.

There are two types of softened water system identified in the study:

- Softened water system I with normal pressure
- Softened water system II with normal or high pressure.

A blast furnace has five parts from the top to the bottom:

- blast furnace throat
- blast furnace stack
- blast furnace bosh
- blast furnace belly
- blast furnace hearth.

Softened water system I

Figure 3-1 shows the softened water system I. Cooling water is distributed to the blast furnace hearth and blast furnace bosh with a flow of 4400m³/h and 1400m³/h respectively, then collected separately after cooling of the blast furnace. The combined flow exchanges heat with secondary side through a heat exchanger. On the secondary side, 3 basic options are available for heat dissipation, depending on actual condition: cooling tower, spray cooling or heat exchanger.

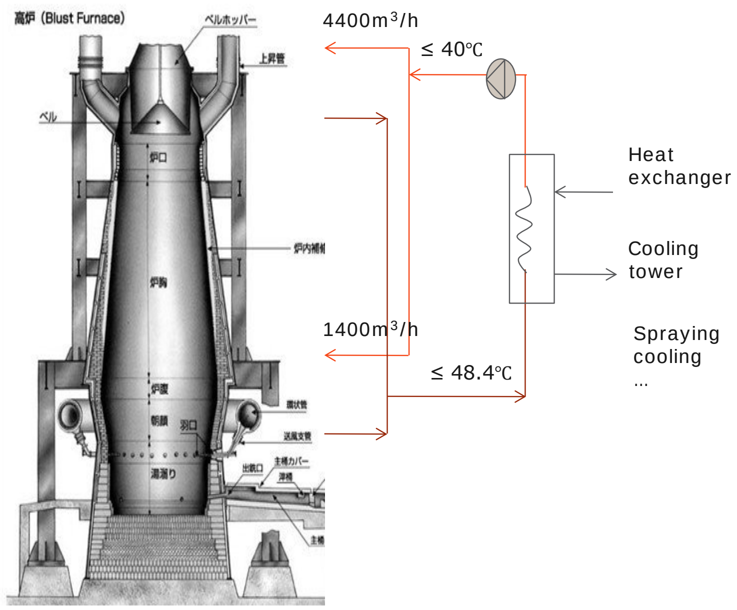

FIGURE 3-1 SOFTENED WATER SYSTEM I

The outlet water temperature from the furnace is < 48.4°C, and the return inlet water temperature is below 40°C. The water flow of the cooling system for blast furnace hearth is 4400 m³/h, while that for blast furnace bottom is 1400 m³/h.

The main characteristics of the softening water system I are :

- Closed recycling system
- Cooling water loss: 2-3%
- Pump head: depends on the height of target components
- Continuous operation
- Softened water system I and II are connected systems, but not all the outflow from system I goes into system II, but partly goes directly to the heat exchanger
- Secondary side: Recycled wastewater + fresh water.

Softened water system II (normal pressure)

Figure 3-2 shows the softened water system II (normal pressure). The cooling water has three circuits. The first cools monitoring equipment for the tuyere medium sleeve, tuyere cross beam temperature measurement equipment, camera at blast furnace throat and draft back valve, the second the tuyere blowpipe, and the third for the hot stove system. The heat of the collected cooling water is then exchanged by a heat exchange with the secondary side, where 3 basic options are available for heat dissipation: cooling tower, spray cooling or heat exchanger.

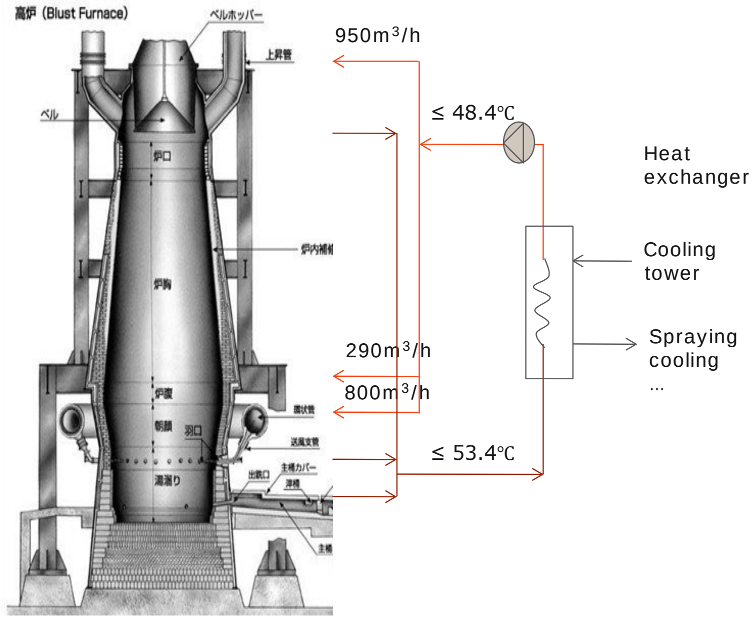

FIGURE 3-2 SOFTENED WATER SYSTEM II (LOW PRESSURE)

The outlet water temperature is around 53.4°C, and the inlet water temperature is below 48.4°C.

The main characteristics of softening water system II (normal pressure) are:

- Closed recycling system
- Water loss: 2-3% of secondary side
- Pump head: depends on the height of target components (normal pressure)
- Continuous operation
- Heat exchanger: Mainly evaporative air cooler, partly plate heat exchanger, rarely shell or tube heat exchanger
- Second side: Recycled wastewater + fresh water

Softened water system II (high pressure)

Figure 3-3 shows the softened water system II (high pressure).

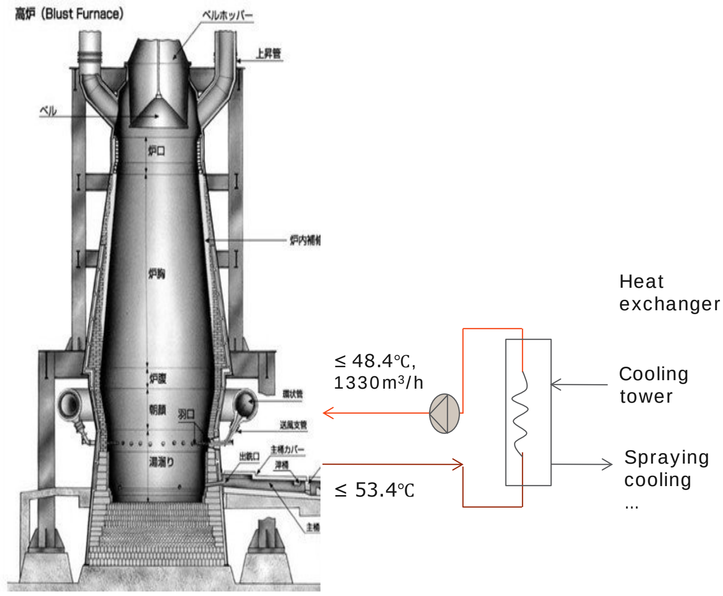

FIGURE 3-3 SOFTENED WATER SYSTEM II (HIGH PRESSURE)

The cooling water from the cooling system for tuyere small sleeve is collected and its heat extracted and exchanged with the secondary side through a heat exchanger. On the secondary side, 3 basic options are available for heat dissipation, depending on actual condition: cooling tower, spray cooling or heat exchanger.

The outlet water temperature is <53°C, and the inlet water temperature below 48°C. The water quantity of the cooling system is 1330 m^3/h.

The main characteristics of soften water system II (high pressure) are :

- Closed recycling system
- Water loss: 2-3% of second side
- Pump head: depends on the needed pressure
- Second side: Recycled wastewater + fresh water
- Continuous operation
- Anti-sludging agent is used for softening water.

The inlet water used in the softened water system is recycled wastewater and fresh water, the quality of which should meet to the quality standard for soft water in Table 2-5.

The water in softening water system is clean soft water, and there is no need for treatment for recovery of surplus heat.

3.2.2 Clean water recycling system - Surplus heat in blast furnaces

The clean water recycling system in the blast furnace is a semi-closed system shown in Figure 3-4. The cooling water from the medium-pressure clean recycling system, low pressure clean recycling system and the clean recycling system for the blast furnace fan station is collected and transported to a hot water tank. Then the water is cooled in a cooling tower, and the cooled water is collected in a cool water tank, where supplementary water is added to make up for water losses. Finally the cooled water is returned to the furnace cooling systems.

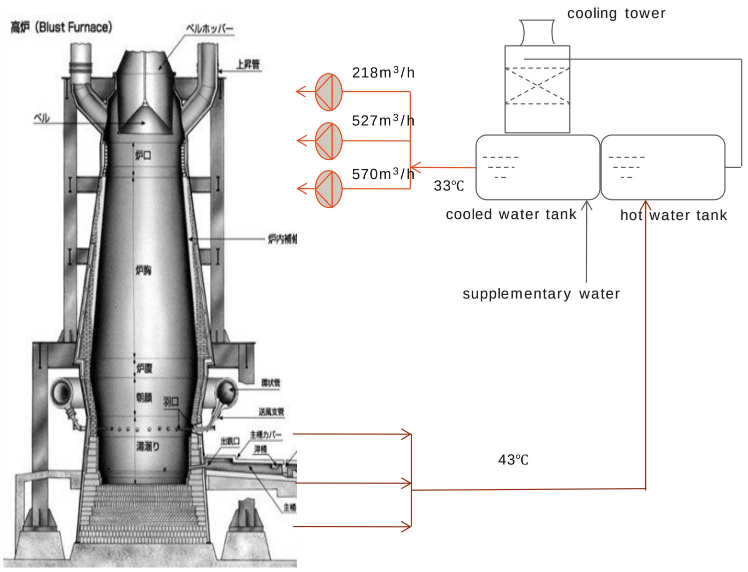

FIGURE 3-4 CLEAN RECYCLING SYSTEM

The medium-pressure clean recycling system is the cooling system for the cooling station, hydraulic pressure station and the cross beam temperature measurement at the top of the blast furnace, while a low pressure clean recycling system cools the hydraulic pressure station, the Top-pressure Recovery Turbines (TRT) and the de-dusting fan at the blast furnace stock.

The outlet water temperature is <43°C, and the return water temperature is < 33°C. The water flow of the cooling system for the medium-pressure clean recycling system, the low pressure clean recycling system and the clean recycling system for the blast furnace blower station are 218 m^3/h, 527 m^3/h, and 570 m^3/h, respectively.

The main characteristics of the system are :

- Semi closed system
- Supplementary water: Recycled wastewater / fresh water, but recycled wastewater causes scale problem
- Continuous operation
- Water loss: approximately 3% of total recycling amount
- Pump head: depends on the system (high / medium / low pressure system)
- Fresh tap water is used for supplementary water.
- Temperature of supply and return water changes significantly because cooling tower is used as heat dissipation.

This recycling system has been implemented in the Anshan Steel Plant to separate recycling water according to different water quality requirement

The water quality of the inlet water for the system should comply with the standard for industrial fresh water in Table 2-5.

3.2.3 Gas cooling water - Surplus heat in the blast furnace

The flue gas of the blast furnace is collected from the top of the blast furnace to a TRT power generation system. After the TRT power generation, the temperature of the gas is 130-160°C, which can be cooled by water. The temperature of the cooled gas should be less than 55°C, before transport to a gas pipe system for further utilization.

The gas cooling water system is a direct recycling system using spray cooling, the design of which is shown as Figure 3-5. The cooling water with a temperature of 40°C is collected by a cooling water tank after treatment, and then recycled to the spraying system for gas cooling with a temperature of 33°C. Supplementary water is added to the cooling water tank.

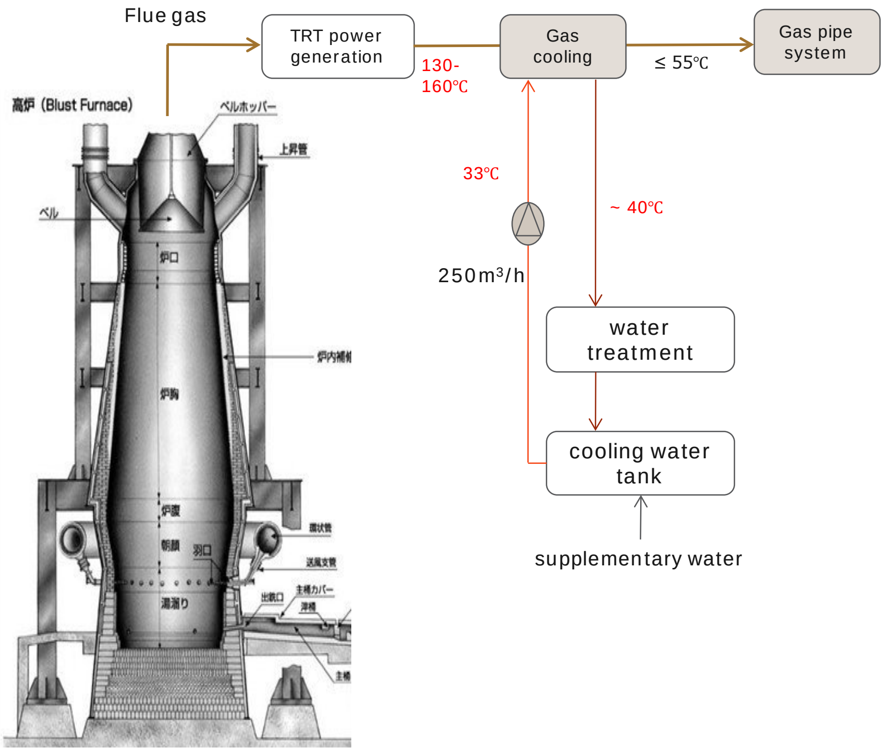

FIGURE 3-5 GAS COOLING WATER

The main characteristics of the system are:

- Spraying system (Direct recycling system)
- Supplementary water: Recycled wastewater / fresh water
- Requirement for water treatment: oil / tar / chemical compound removing
- Continuous operation
- Water pressure: 1Mpa
- TRT: Top-pressure recovery turbine, driven by pressure of flue gas, little change in the temperature or chemical compounds in flue gas
- Supplementary water: new tap water or recycling water
- Water quality problem: too high concentration of Cl-.

The water quality of the cooling water supplied to the blast furnace should meet the reuse water quality standard in Table 2-5.

3.2.4 Slag washing water - Surplus heat in blast furnace

The molten slag from the blast furnace is cooled (quenched) with water, which afterwards is drained from the slag for recycling.

The slag washing water recycling system is a direct open recycling system shown Figure 3-6. The separated water is treated, collected and stored in a water tank with a water temperature of 50-70°C to be recycled as slag washing water. Supplementary water is added to the recycling water tank.

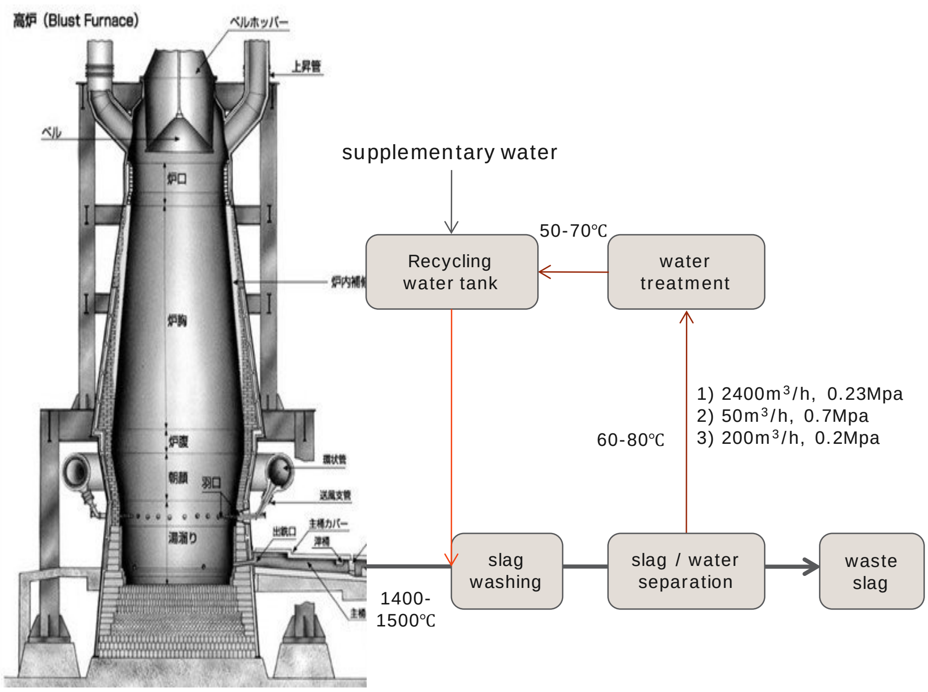

FIGURE 3-6 SLAG WASHING WATER

The slag washing water system is mainly re-used for the slag granulation tank, drum cleaning and recirculation pump of the slag processing system.

The main characteristics of the system are :

- Semi closed recycling system
- Supplementary water: Recycled wastewater / industrial fresh water
- Requirement for water treatment: Total solid / tar / chemical compound / Ca2+, Mg2+ removal
- Intermittent operation, normally 20-24 times/day
- Sensible heat from hot slag: 0.35 GJ/t

- Slag / water ratio: 1/6 – 1/10
- Evaporation: Approximately 60%
- The water may be used for district heating, but causes problems due to poor water quality
- The evaporated volume: 2% of recycling amount
- The evaporation could be applicable, but with challenges for collection
- The temperature of steam is 100°C.

3.2.5 Direct cooling system - Surplus heat from rolling

There are two kinds of direct cooling system in the rolling process, which both are relatively unclean systems.

System 1 cooling process equipment

System 1 is for process equipment cooling shown as Figure 3-7. The cooling water includes laminar flow cooling water, roller table cooling water and side jet water. The inlet cooling water with temperature of 38°C flows through the process equipment with different flow rate, and then the outlet cooling water with a temperature of 42°C is collected and treated. The treated water is stored in a cooling water tank to be recycled in the cooling system.

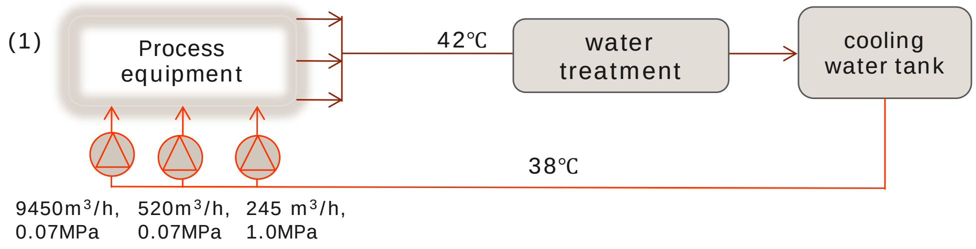

FIGURE 3-7 DIRECT COOLING SYSTEM IN THE ROLLING PROCESS (1)

The main characteristics of system 1 are:

- Direct cooling system
- Polluted system
- Suspended solids (mg/l):
  - Outlet: < 80 mg/l
  - Inlet: 50 mg/l
- Oil (mg/l): 0 mg/l

System 2 for the rolling machine

System 2 is for the rolling machine including the roller table, roller and iron scale washing process of rolling production line, as shown in Figure 3-8. The outlet cooling water after iron scale washing with temperature of 42°C passes a sedimentation tank, and is then directly recycled as cooling water for iron scale washing. The outlet cooling water with temperature of 42°C for rolling machine firstly passes the sedimentation tank and is then further treated for removal of grease, oil, fine particles and emulsifier. The treated water flows through a cooling tower, and is then collected and stored in a cooled water tank. The stored water with a temperature of 35°C is then used as inlet rolling machine cooling water.

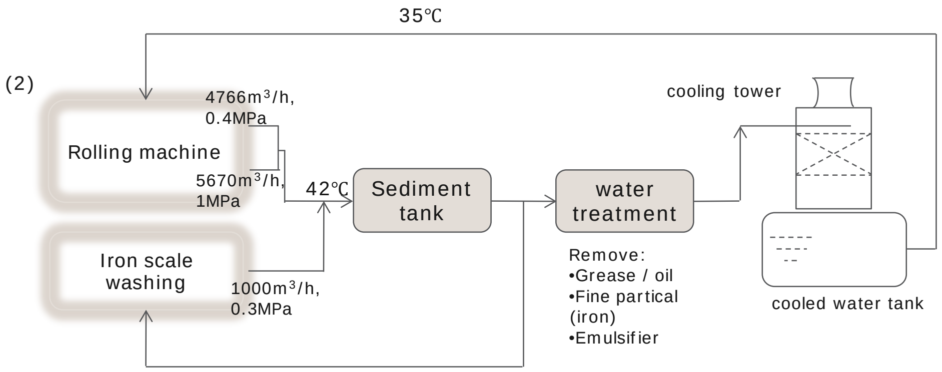

FIGURE 3-8 DIRECT COOLING SYSTEM IN ROLLING PROCESS (2)

The flow of cooling water for the roller table cooling, roller cooling and iron scale washing processes are 4776 m^3/h, 5670 m^3/h and 1000 m^3/h, respectively.

The main characteristics of system 2 are:

- Suspended solids (mg/l):
  - Inlet: 20mg/l
  - Outlet: 20mg/l
- Oil (mg/l):
  - Inlet: 5mg/l
  - Outlet: 5mg/l
- Iron scale washing: No specific requirement for water quality

The applied inlet water quality for the two kinds of systems should correspond to reuse water in Table 2-5.

3.2.6 Indirect cooling system - Surplus heat from rolling

There are two kinds of indirect cooling systems in the rolling process as shown in Figure 3-9 and Figure 3-10. Both are indirect cooling systems, which are relatively clean systems.

System 1 for heat stove

System 1 is for heat stove (heating furnace) cooling. The outlet cooling water with temperature of > 50°C is collected in a hot water tank and then cooled in a cooling tower. The water from the cooling tower is collected in a cool water tank with a temperature of 35°C, and returned to the furnace for cooling.

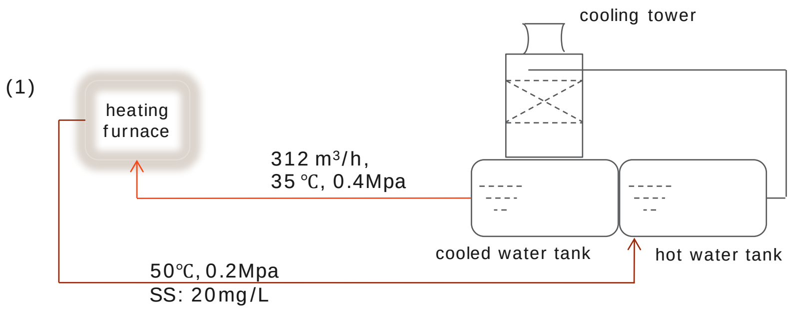

FIGURE 3-9 INDIRECT COOLING SYSTEM IN ROLLING PROCESS (1)

System 2 for the rolling process

The second system is for the rolling process equipment room cooling. The inlet water with temperature of 35°C flow through the process equipment, and then the heated water with temperature of 38°C is transported to a cooling tower before recycling directly as inlet cooling water.

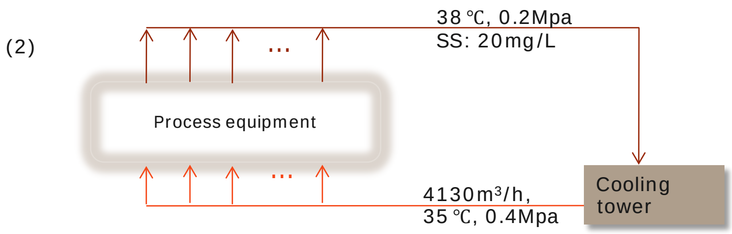

FIGURE 3-10 INDIRECT COOLING SYSTEM IN ROLLING PROCESS (2)

The main characteristics of the system are:

- Indirect cooling system
- Relatively clean system
- Water quality in system:
  - SS (mg/l): 20 mg/l
  - Oil (mg/l): 0 mg/l
- Cooling tower is used for both system 1 and 2.

The inlet water quality for the two kinds of systems should meet the industrial fresh water standard in Table 2-5.

4. Surplus heat application

4.1 Introduction of possible applications

It should be noticed that in the iron and steel industry, the temperature level below 300°C is deemed as low grade energy and currently only a very small part is recovered by the steel plant. However this type of low grade energy is good energy resources for various applications both in industrial and public sectors.

The identified surplus energy resources come from four types of energy carriers:

- hot products
- hot steel/iron slag
- hot flue gas/air
- cooling water.

Of these more than 50% of the flue gas as well as cooling water are low temperature energy resources.

Typical applications include:

- Direct heat recovery with energy transfer in heat exchangers
- Indirect heat recovery with an intermediate circuit, e.g. Carnot Cycle facilities

The possible application is highly depending on whether energy demands can be identified, with reasonable demand requirement and within feasible distribution distance. The demand identification for various industrial production processes would be a systematic study, a good reference can be found from a solar energy solution provider, Sunmark A/S from Denmark, who has identified possible application of different temperature sets of hot water in the industry sector, as shown in Figure 4-1.

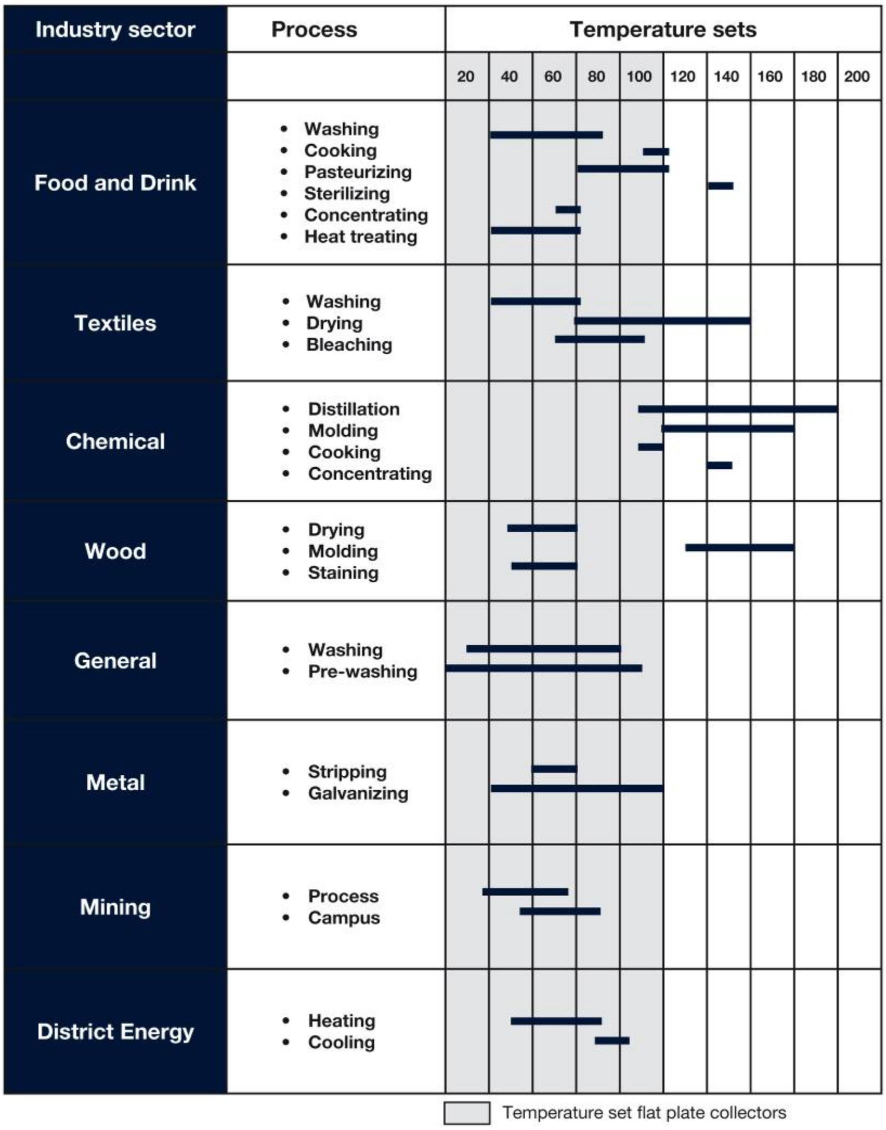

FIGURE 4-1 POSSIBLE APPLICATIONS WITH LOW TEMPERATURE ENERGY RESOURCES (SOURCE: WWW.SUNMARK.COM)

It can be seen that hot water in the range 40-100°C can be applied in widely different areas. The major task is to identify potential uses outside the steel plant that will make it possible to assign a value to the low temperature energy. Cooling demands may also be relevant, when adsorption cycles are applied as intermediate circuits and the temperature level is sufficient to drive the absorbent-refrigerant working pairs in the circuit.

For direct heat recovery the surplus heat resource should be fairly close to the system on demand side, water is most commonly applied as heat transfer medium. Sometimes phase changeable media are applied, heat tubes for example have been applied for flue gas heat recovery.

When there are limitations to apply direct heat recovery, an intermediate circuit can work as a safety barrier, which also brings flexibility and reduced dependence on the heat source. Additionally the intermediate circuit is able to use multiple heat sources and supply heat to multiple heat sinks.

4.2 Identified solutions

Generally the external demand can be categorized as heating or cooling demand. In China there are nearly 1000 iron and steel plants, the economic locations are differentiated case by case. Some of the steel plants are located in industrial areas, some are located in remote suburb areas, while some of them are located near to downtown area. How to identify heating or cooling demand around the plant would require systematic investigation with the local stakeholders, as well as consultation with local authorities.

Based on communication with various steel plants in China, it is quite common that part of the low temperature resources are used to supply heat for buildings within the periphery of the plant. Some of the larger steel plants, which occupy large land area over thousands hectares, have internal district heating system covering residential buildings, offices, as well as some storerooms.

In north China, such district heating systems are always designed according to relevant standards and regulations, and therefore easy to expand or integrate with the local district heating systems. While in cities along Yangtze River, where no district heating facilities are provided to citizens, the internal plant district heating system is considered as additional benefits provided to the staff. The system is designed with reference to district heating system regulations, but not so nicely tuned to local climate, partly due to lack of technical guidance as well as relevant monitoring by municipal authorities. However the typical climate along the Yangtze River is cold winters and hot summers. Nearly every family uses electric driven air-to-air heat pumps for space heating and cooling, and the indoor climate is far from comfortable level especially during winter.

In context of Chinese energy utilization regulations, the iron and steel industry is one of the top ten energy intensive industries in China and has obligation to fulfil the atmospheric pollutants emission reduction objective set out by the state. Each steel plant has its own yearly energy saving target, which is stringently monitored by governmental authorities. Packaged solutions are recommended and adopted directly, such as TRT, Coke Dry Quenching (CDQ), etc., and more systematic energy management is required.

This study has revealed strong willingness of the steel plants to seek measures for better energy recovery. The consultant has found good opportunities for the steel plants to reach the obligatory emission reduction by expanding the district heating system with utilisation of low grade surplus heat, which now is dissipated, to replace coal-fired boilers in north of China, and to replace individual electric driven air-conditioners along the Yangtze River. Meanwhile the citizens will benefit from cleaner environment due to less coal combustion. For cities which currently have no district heating system, the citizens may now be provided with facilities to have more comfortable indoor climate and improved living standards.

On the other hand, it is difficult to find obvious industrial demands to match to the identified surplus heat resources. Moreover the possibility of replication of such kind of application is very low as very few similarities can be found in respect of geographical distribution, industry types, as well as the level of demand.

Therefore it is decided to study alternative solutions to supply heat to district heating system. There is still potential for cooling, if the surplus heat temperature level can fulfil the minimum technical requirements, however, in the two targeted production processes, no such resources have been identified.

The value of solutions to supply heat to district heating system is obvious:

- The feasible solution can be replicated in northern China. No matter how big the capacity would be, the surplus heat can substitute existing coal fired heat production, thereby bringing remarkable energy savings, coal saving and pollution reduction.
- The solution can also be introduced in cities along Yangtze River, where the citizens are expecting better indoor climate during severe winters, and where several sizable steel plants are located, for instance Wuhan and Chongqing.
- The solution may give considerable CO2 emission reduction at regional level, thus receiving government support. Consequently the dissemination can be more effective, and possible replication can be expected to be realised in the near future.

4.3 Options for heat supply to district heating systems

This chapter focuses on indirect heat recovery with intermediate circuits.

The principle of the technical solutions is to apply mature and commercial technologies, which may assure both technical and financial feasibility. However the system design will be innovative to ensure maximum efficiency in energy recovery and emission reduction.

The Carnot Cycle is selected as the intermediate circuit. Two cases of applying heat pumps to supply heat to district heating systems are studied and presented in this chapter. Another option explored is to apply conventional Combined Heat and Power (CHP) instead of pure power generation plants to supply heat, the optional possibilities are introduced.

Both cases extract surplus heat from one blast furnace and rolling process, and have heat supply capacity over 100MW, which corresponds to heating of 2 million m^2 floor area in northern China.

Case 1 - heat recovery by absorption heat pumps

The case is based on experience from a project implemented in Denmark using lithium-bromide absorption heat pumps as the main equipment. The steel plant surplus heat is used as heat source, but it is necessary to supply additional energy to drive the heat pump. The system Coefficient of Performance (COP) for heat is calculated to be 1.73. Simple pay-back time is 4 years for the plant itself compared with heat supply to District Heating (DH) systems from Combined Heat and Power (CHP) plants. The estimate is based on data from a real system and is very conservative, because it is expected that both the investment and operating costs are likely to be lower in China.

It is noticeable that the necessary driving energy also can be provided by the steel plant, which means the heat supply stakeholder can be one entity simplifying the implementation.

Case 2 - heat recovery by mechanical heat pumps

Another option is to apply conventional mechanical heat pumps. Ammonia (NH_3) is selected as heat transfer medium in this study, but it can be replaced with other environmental benign refrigerants, in which case the system performance (COP) should be calculated case by case.

The system is designed for heat COP of 7.5, with some electricity consumption. Totally four heat pumps are applied. The unit capacity is relatively large compared with normally installed systems, and COP calculation is relatively ideal, therefore it is expected during implementation the plant needs to be equipped with additional heat pump units.

Case 3 CHP instead of pure power generation

According to the consultant's experience, all the steel plants in China have various internal CHPs, either coal-fired or driven by surplus heat or pressure from production. Additionally a medium pressure steam system, normally a 7 bar(abs), is always applied to supply steam to various production processes. Back-pressure units and condensing units are commonly applied providing good possibilities to convert the power generation units into CHPs.

Based on information provided by several big steel plants, various options for converting power generation units to CHPs have been investigated, and a power loss/heat generation ratio is applied to show, indicatively, the feasible level of each option.

4.3.1 General assumptions

The targeted application is to supply heat to district heating systems, with the following parameters:

- Supply temperature: > 80˚C
- Return temperature: < 45˚C
- The identified surplus heat resources should be applied as much as possible
- Financial estimation will be based on real prices in a reference area or from real cases.

The main local prices applied in the estimation are provided in Table 4-1.

TABLE 4-1 PRICE REFERENCE FROM ONE OF THE NORTHERN CITIES IN CHINA

	Type	Unit	Price
Resource			
Coal	NCV ~ 5000kcal/kg	RMB/ton	800
City water		RMB/ton	3.5
Treated sewage water		RMB/ton	1.8
Electricity Industry		RMB/MWh	838
Electricity Residential		RMB/MWh	490
Steam	7 bar(abs) – 165℃	RMB/ton	150
Chemical cost for water treatment		RMB/ton	3
Heat tariff			
Heat from coal fired boilers		RMB/m²	28
Heat from CHP		RMB/MWh	133
Surplus heat from steel plant	(57°C/45°C)	RMB/m²	22
Design parameters			
Heat load index		W/m²	50
Annual heat demand per m²		kWh/m²	113

A typical northern city in China is selected as reference representing typical characteristics of district heating systems.

It is further assumed:

- that the district heating network exists, so the cost for district heating distribution is not included in this study
- that the average electricity price is 600 RMB/MWh
- that the heat demand is sufficiently high to utilise the available surplus heat from the steel plant (one blast furnace and rolling process)
- that the necessary energy resources are available (electricity or other type of energy) for heat pump solutions.

4.3.2 Absorption heat pump solution

An absorption heat pump solution can produce district heating (44.0˚C / 82.6˚C) by use of 6-7 bar steam and input of heat from following surplus heat streams:

1. Flue gas from furnaces (Slide 9 in Appendix 1)
2. Cooling water from softened water system I (Slide 2 in Appendix 1)
3. Cooling water from softened water system II (Slide 3 in Appendix 1).

A diagram of the suggested heat recovery plant with energy streams, figures, etc. is shown as Figure 4-2.

The sample plant generates 156 MW of district heating energy by using 90 MW steam and condensate – hence the overall efficiency of the heat pump – the COP factor – is 1.73.

The solution is based on a concept which is under implementation in a Danish town.

The Danish project has following main technical data:

- Cooling capacity: 14 MW
- Heating capacity: 43 MW
- Heat input from boiler: 20 MW (25 MW based on fuel lower heating value).

The heat absorption plant consists of 4 absorption heat pumps and the total installation cost is approximately 16 million RMB.

The proposed Chinese plant has a cooling capacity of 57 MW producing an output of 156 MW – hence it is 4 times larger than the Danish one.

The installation will therefore require 16 absorption heat pumps and have an implementation cost of approximately 72-73 million RMB.

The exact solution will vary from steel plant to steel plant and will very much depend on the possibility to feed the surplus heat into a district heating network.

The heat production cost, based on investment cost in Demark, will be 131 RMB/MWh, which shall be lowered by the savings from reduced chemicals, electricity and water consumption in the cooling towers, which otherwise are used to dissipate the heat from the softened water systems.

Assuming an open evaporative cooling tower is applied, then the saving can be estimated based on common practice resulting in a saving of 19-21 RMB/MWh, therefore the production cost is reduced to approximately 110 RMB/MWh.

In comparison with CHP heat the savings by use of an absorption heat pump is only some 23 RMB/MWh, and the pay-back period is around 4 years for the heat pump plant itself.

In comparison with coal fired heat production the savings by use of an absorption heat pump is some 138 RMB/MWh. The pay-back period is then less than 1 year for the heat pump plant itself.

Since the investment cost is estimated according to Danish prices, it is expected that in China such cost will be lower, therefore the payback time will be shortened as well.

Obviously it is crucial whether the DH supplied from the absorption heat pump shall compete with CHP or coal fired heat.

Likewise, the annual production of DH is really an important factor in the economics of the absorption heat pump plant. Therefore sizing the absorption heat pump must be done with due consideration of the possibility to feed heat into the local DH network.

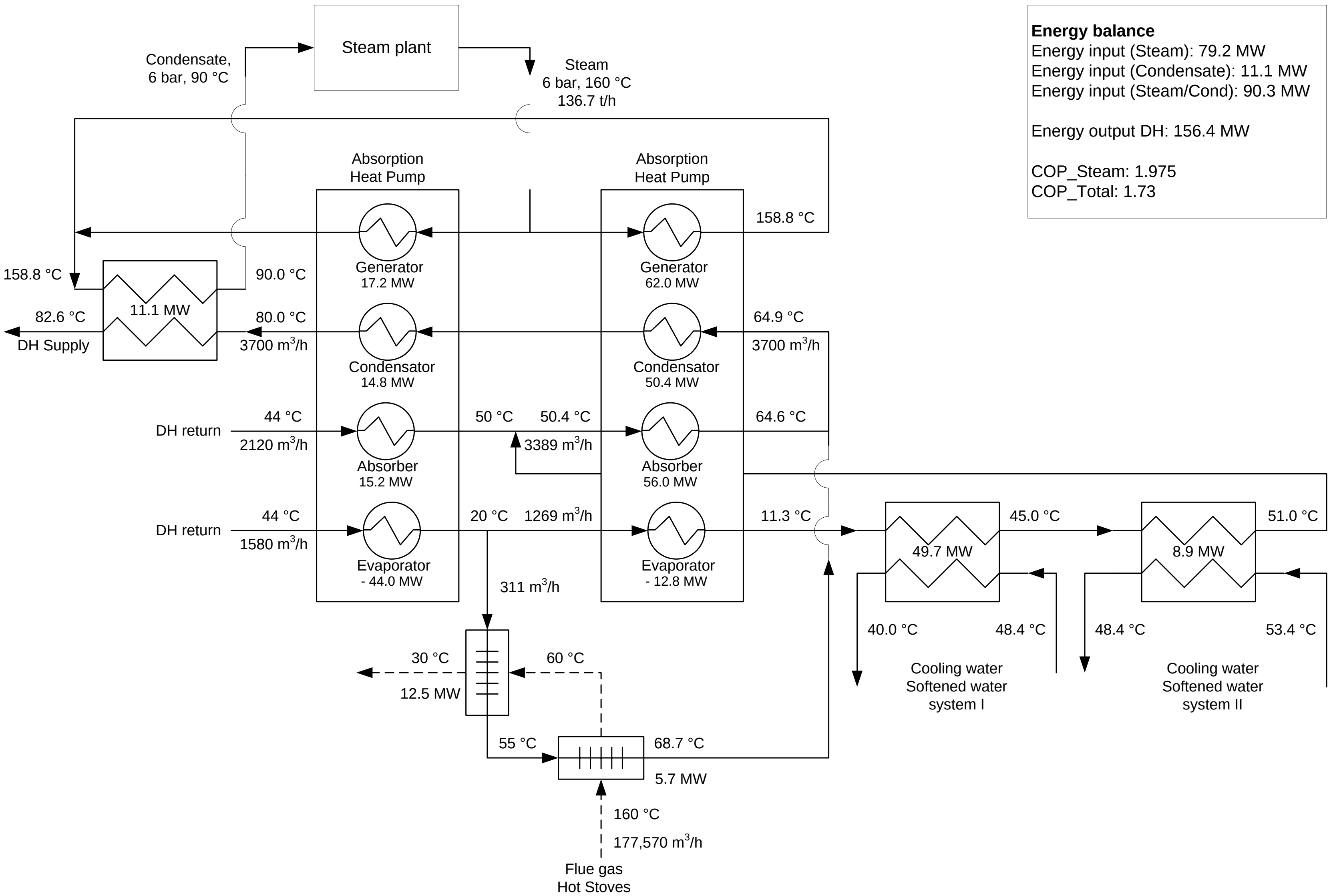

FIGURE 4-2 FLOW DIAGRAM OF SURPLUS ENERGY RECOVERY WITH ABSORPTION HEAT PUMP, COP=1.73, HEATING CAPACITY=150MW

4.3.3 Mechanical heat pump solution

Alternatively a mechanical ammonium (NH_3) heat pump solution is considered. This solution produces district heating (44.0°C / 80.0°C) by use of electricity and input of heat from the following waste heat streams:

1. Cooling water from softened water system I (Slide 2 in Appendix 1)
2. Cooling water from softened water system II (Slide 3 in Appendix 1).
3. Cooling water from rolling process I (Indirect cooling, Slide 10 in Appendix 1)

A diagram of the suggested heat recovery plant with energy streams is presented as Figure 4-3.

The cooling plant delivers 96.2 MW cooling to the steel plant by using 14.8 MW electricity for the compressors.

More importantly the plant generates 111 MW of district heating energy by using 14.8 MW electricity – hence the overall efficiency of the heat pump solution – the COP factor – is 7.5.

Based on the assumed energy prices, the saving potentials compared with CHP and Heat Only Boilers (HOB) may be estimated.

With 4000 heating hours this heat pump plant can deliver 444,000 MWh per year, meanwhile 385,000 MWh cooling is delivered. Electricity consumption is 59,200 MWh, with price of 600 RMB/MWh, the total cost for electricity is 35.5 million RMB/year, this gives a specific heating cost price of 80 RMB/MWh.

In addition to this cost the savings on power, water and chemicals consumption for the cooling towers should be added, it is estimated that cooling cost by cooling tower is 40 RMB/MWh cooling, therefore saving on cooling tower is 40 RMB/MWh x 385,000 MWh=15.4 million RMB/year.

Net cost of producing heat by the mechanical ammonium (NH_3) heat pump can then be calculated at 20.1 million RMB/year. This gives a heating price of approximately 45 RMB/MWh heat.

The capital cost, however, will be high. In Denmark it is 2000 RMB/MWh heat output for the NH_3 heat pump and the cost of such a plant will approach 240 million RMB.

It should be noted that the maintenance cost of running a mechanical heat pump plants versus the maintenance savings by not running the cooling towers are not included in this cost calculation.

As the maintenance cost of running mechanical heat pumps are considered to be higher than running cooling towers, it is assumed that the heat cost could be up to 5 RMB/MWh higher – hence giving a total cost price of 50 RMB/MWh heat.

Compared with CHP heat supply, the savings by the mechanical heat pump system is 133 RMB/MWh – 50 MB/MWh = 83 RMB/MWh

Based on 4000 heating hours per year the annual savings amount to 444,000 MWh x 83 RMB/MWh = 37 million RMB per year.

Compared with coal fired heat only boilers (HOB), the savings by the mechanical heat pump is: 248 RMB/MWh – 50 MB/MWh = 198 RMB/MWh

Based on 4000 heating hours per year the annual savings amount to 444,000 MWh x 198 RMB/MWh = 88 million RMB per year.

Total investment cost of a 111 MW mechanical heat pump plant will be approximately 240 million RMB. Therefore the pay-back time is 2.7 years for replacing a coal fired HOB, and 6.5 years for replacing a CHP heat supply.

It is expected the payback time should be shorter as the investment cost is estimated based on Danish experience, in China the investment cost is expected to be lower.

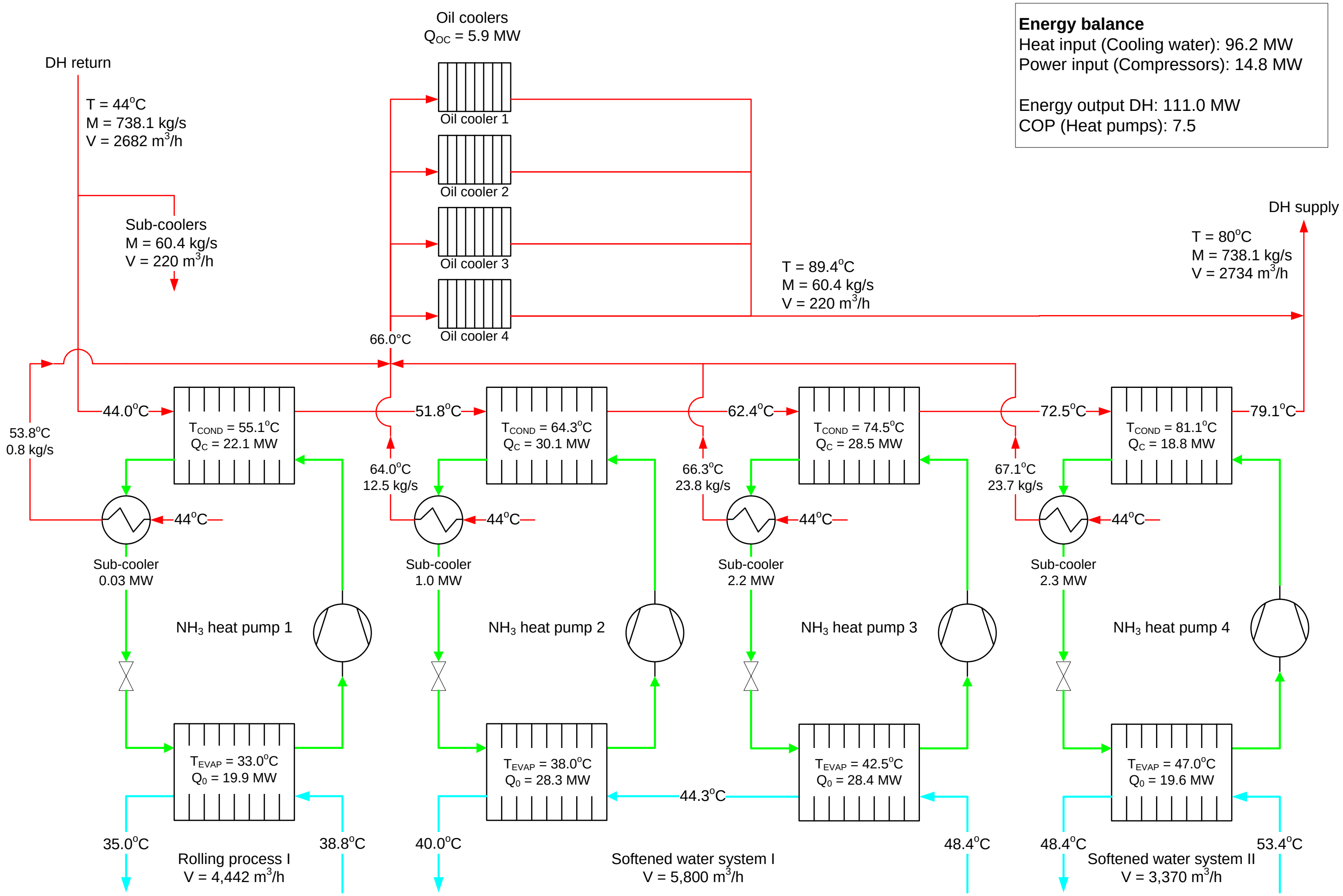

FIGURE 4-3 FLOW DIAGRAM OF SURPLUS ENERGY RECOVERY WITH ABSORPTION HEAT PUMPS, COP=7.5, HEATING CAPACITY=111MW

4.3.4 CHP options

The CHP options are based on the real situation from an existing steel plant. The targeted power generation unit is a 110MW steam turbine, 3 stages, reheated after the high pressure chamber, and steam is extracted at the medium pressure chamber and sent to general steam system (7 bar(abs) steam system) in the plant.

The studied options include extraction of steam to heat up cooling water from the steel plant with several possibilities:

- Extract steam from the 7 bar(abs) steam system
- Extract steam from the connection pipe between medium and low pressure turbines
- Extract steam at the end of the turbine (near to the outlet after power generation, but still sufficient to fulfil required temperature level of the DH system)
- Increase back-pressure to 0.38 bar and then heat up the cooling water with steam from the 7 bar(abs) system
- Increase back-pressure to 0.58 bar and then heat up the cooling water with steam from 7 bar(abs) system

In comparison with the mechanical heat pump solution the electricity generation capacity will be reduced, because steam is used to heat up the cooling water. Therefore a factor is defined as generated useful heat/power loss ratio, the higher the ratio, the higher income the solution would provide. The comparison is summarized in Table 4-2.

A simple diagram of increasing back-pressure to 0.58bar(abs) and extracting steam from the 7 bar(abs) steam system is shown in Figure 4-4. The solution has proved to be able to supply 100MW heat, with 1/8 electricity loss.

Similar conclusions can be drawn from other options. It should be noticed that the investment cost for each solution highly depends on the actual situation in the plant. However, it may be concluded that the investment costs for mechanical heat pump solutions is higher than all the other steam abstraction solutions. Hence the consultant recommends that priority is given to investigate, whether it is possible to apply low grade steam for DH heat supply (CHP solution).

TABLE 4-2 COMPARISON OF VARIOUS CHP OPTIONS

	Steam extraction at 7 bar(abs) / connection to low pressure steam network	Steam extraction at 1.8 bar(abs) / (between medium pressure and low pressure turbines	Steam extraction at 1.4 bar(abs)	Increased backpressure to 0.38 bar(abs) and steam extraction at 7 bar(abs)	Increased backpressure to 0.58 bar(abs) and steam extraction at 7 bar(abs)	Ammonium (NH_3) Heat Pump
Useful Heat [MW_{heat}]	100	100	100	100	100	111
Power loss or power consumed [MW_{power}]	20.4	13.5	12.5	19.2	12.5	15.3
Useful heat /power loss ratio [MW_{heat} / Mw_{power}]	4.9	7.4	8.0	5.2	8.0	7.3

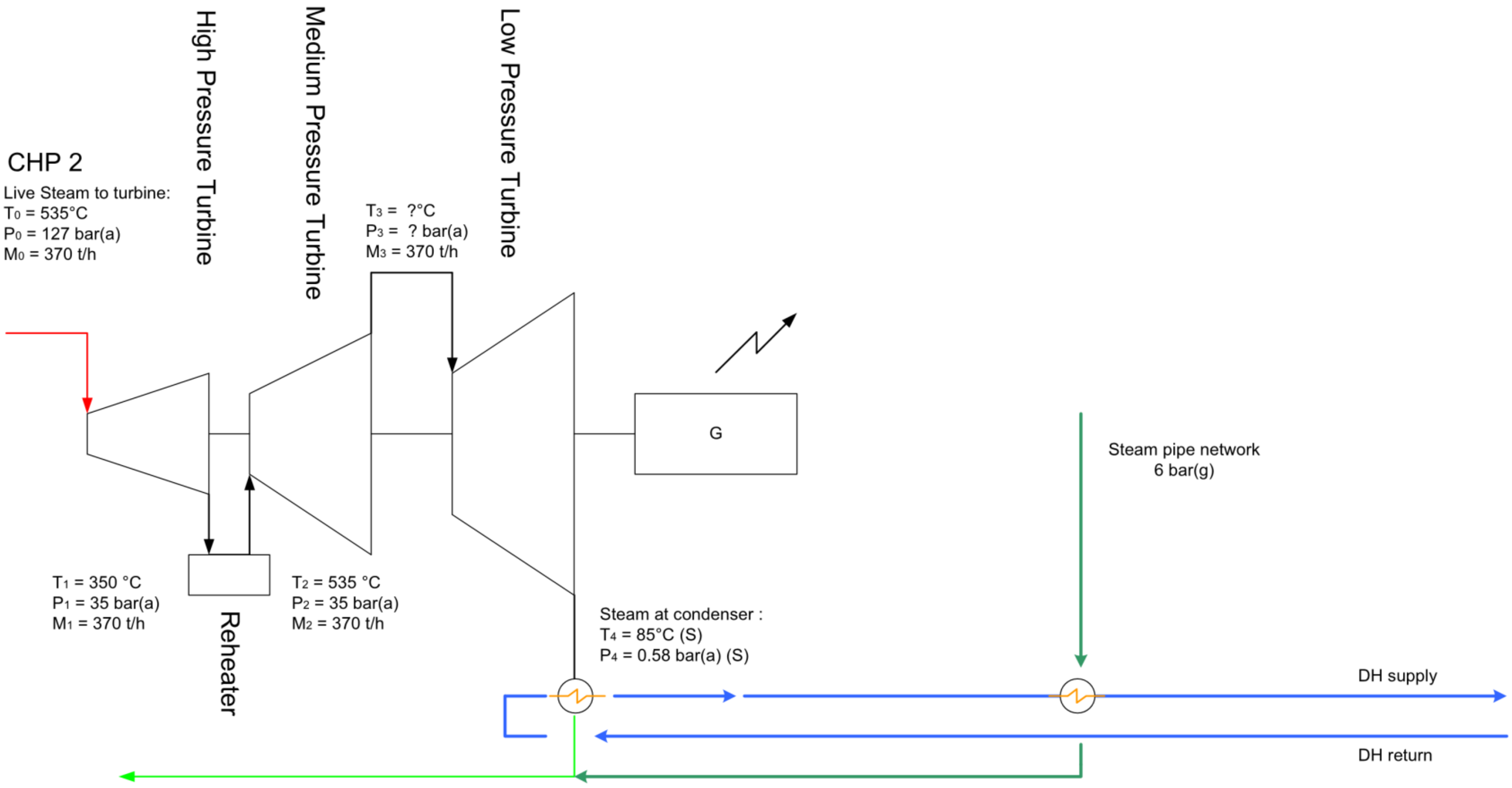

FIGURE 4-4 ILLUSTRATIVE FLOW DIAGRAM OF INCREASING BACKPRESSURE TO 0.58BAR(ABS) AND HEAT UP COOLING WATER BY 7BAR(G) STEAM

5. Water treatment

Water treatment for recycling of water and wastewater from processing in iron and steel production and processing generally includes the following methods according to different compositions of the water and wastewater:

- Pre-treatment of wastewater
  - Physical methods (screen, filter, oblique sieve, etc.)
  - Removal of large suspended particles and oils will be conducive to the operation of the following processes and save reagents.

- Treatment of suspended solids in wastewater is mainly by coagulating sedimentation and filtration:
  - Sedimentation is improved by flocculation of particles by adding poly-aluminium chloride (PAC) and / or an organic flocculating agent such as poly-acrylamide (PAM). This will help to remove particles and reduce SS, but it will increase the salt concentration in the water.
  - The majority of the suspended solids are discharged from the tank bottom in the form of sludge while water is discharged from the tank top.
  - After treatment, SS < 30 mg/ml[6].

- Treatment of oils in wastewater includes flotation, adsorption, biological, chemical and membrane methods:
  - The treatment effect of conventional methods (oil gravity separation, adsorption, coagulation with flotation, biological treatment) is not always sufficient and the treatment efficiency will depend on the oil characteristics - especially emulsified oil will cause problems.
  - Ultra filtration (UF) and Micro Filtration (MF) can provide a better treatment - especially for emulsified oil. It seems that ceramic membranes or silica carbide (SIC) membranes often will be superior to normal polymer membranes.

- Removal of salts from wastewater may include ion-exchange, distillation desalination, membrane separation technology and evaporation, etc.
  - The cost of using ion exchange technology is high because of the high concentration of salt in wastewater from the iron and steel industry. Furthermore the salt will reappear in higher concentrations in the eluate, which is generated by regeneration of the ion exchanger.
  - Distillation desalination is only suitable for the treatment of small amounts of wastewater, and operating costs for this method are high.
  - Membrane processes, i.e. Reverse Osmosis (RO) and Nano-filtration (NF) can be used in combination with ion-exchange and evaporation for removal of salt from cooling water.

- If suspended solids are present in the cooling water pre-treatment by flocculation, sedimentation or filtration should be used.

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[6] Z. Zhang, L. Zhao, X. Zhou, Treatment and recycling of waste water in iron and steel industry, Encyclopaedia Forum, 300

5.1 Cooling water issues

Based on the interviews and the case study, the following issues have been identified concerning cooling water treatment during practical operation:

- Removal of salt and dissolved organic contaminants
  This is not generally applied as a post-treatment process for wastewater treatment in the Chinese iron and steel works due to its relatively high cost. Therefore wastewater and cooling water are not reused very much.
- Limited quantities of cooling water
  Due to the poor quality, the recycled water from cooling water treatment is used only as supplementary water for once-through cooling systems and direct open recycling system. However, the cooling water quantity requirement for these kinds of cooling systems is very small.
- No chemicals are used for cooling water of blast furnace gas scrubber.

The main issues are listed in Table 5-1.

TABLE 5-1 THE MAIN PARAMETERS OF THE COOLING WATER OF BLAST FURNACE GAS SCRUBBER

Issue	Content	Concentration	Density
High salinity	Cl^-	600 mg/l	-
High hardness	Calculated using $CaCO_3$	500-600 mg/l	-
Fine particles	≤ 20 µm	200 mg/l	specific density: 1.4-1.7

Because of the above problems, it is difficult to treat the cooling water by filtration, flotation or sedimentation. The cooling water is either used as slag washing water, or discharged to central WWTP. It is easier to treat after mixing with larger particles, whereas fine particles will remain a serious problem.

Normally, 2-3 stages of sedimentation are used (plain sedimentation with longer hydraulic retention time) for treating of slag washing water. Solid bowl centrifuge and sand filtration are also used. The efficiency of sand filtration is the highest, while that of solid bowl centrifuge is the lowest.

The water quality problems, which remain after treatment, include high SS, high hardness and high alkalinity. In the case study the water quality after standard treatment (Table 5-2) generally could not meet the inlet cooling water quality requirements mentioned in Table 2-5.

TABLE 5-2 WATER QUALITY REQUIREMENTS FOR COOLING

Parameter	**Concentration (sedimentation and sand filtration)**	**Concentration (Solid bowl centrifuge)**
SS	200 mg/l	1000-2000 mg/l
Hardness as $CaCO_3$	1200-1400 mg/l	1200-1400 mg/l
Chloride, Cl^-	1000 mg/l	1000 mg/l

As mentioned in above section, the Anshan Steel Plant, which is one of the top ten steel producers in the world, has applied direct heating systems with treated slag washing water from the blast furnace. However, due to poor water quality, the pipeline and room radiators have to be replaced every 3 to 4 years, which could indicate that the water quality of slag washing water requires further treatment for efficient surplus heat recovery.

Cooling water used in the rolling process combines two functions: 1) cooling of equipment and production lines, and 2) washing of scales. Both direct and in direct cooling systems are applied. The key parameters are the suspended solids and oil content (Table 5-2).

TABLE 5-3 WATER QUALITY FOR COOLING WATER IN ROLLING PROCESS

	Indirect cooling	Direct cooling (process cooling)	Direct cooling (scale washing)
SS (mg/l)	20 mg/l	Inlet: 50 mg/l Outlet: <80 mg/l	Inlet: 20 mg/l Outlet: 20 mg/l
Oil (mg/l)	0 mg/l	0 mg/l	Inlet: 5 mg/l Outlet:5 mg/l

Indirect cooling water is treated by ordinary flocculation and sedimentation (Figure 5-1).

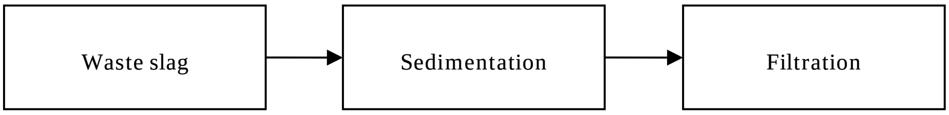


FIGURE 5-1 THE TREATMENT OF COOLING WATER IN ROLLING PROCESS

The data indicate that the cooling water quality generally is not very good by using existing treatment methods. This can be a problem for recovery of surplus heat from the cooling water.

The heat recovery efficiency will be substantially increased, if the water quality requirement of feed water and recycled water for iron and steel industry as recommended by the Danish District Heating Association is achieved. However, the costs to achieve the requirements are normally very high, and the practice is on one hand to choose a heat exchanger, which can tolerate a certain level of water quality, and on the other hand to improve the water quality, which could further increase the heat recovery efficiency and prolong the lifetime of the heat exchanger. Therefore, in practice, the surplus heat of cooling water from the softened water systems, the clean recycling system in the blast furnace and the indirect cooling system in the rolling process could be efficiently recovered without further water treatment, while the gas cooling water, slag washing water and polluted cooling water from the rolling process need to be further treated for surplus heat recovery.

The quantity of slag washing water is 2650 m^3/h with the temperature of the slag washing water at 60-80°C and that of the treated slag washing water at 50-70°C. There are several heat recovery practices in iron and steel production industries, but the water quality problem affects the heat recovery efficiency much. The water quantity of flue gas cooling water is only 250m^3/h, the temperature of which is 40°C. According to the above analysis, only the SS of polluted cooling water from the rolling process exceed relevant water requirement for recycling. This water flow is 10,000 m^3/h and the temperature is 42°C. Therefore, it is concluded that there is a high possibility for surplus heat recovery from slag washing water and polluted cooling water by further treatment.

5.2 Additional water treatment

Additional treatment of slag washing water and polluted cooling water is necessary to achieve the required quality of inlet water for reuse and to achieve higher efficiency of surplus heat recovery. As the cost of water treatment of the two kinds of cooling water is very high, the purpose of further treatment of the two kinds of cooling water will be to meet the water reuse quality standard.

The treatment of slag washing water will be addressed and described in detail since the slag washing water has high levels of suspended solids, hardness, and Cl^-, while polluted cooling water in the rolling process only has SS problem. This treatment also applies to the cooling water from the rolling process.

5.2.1 Slag washing water system

Figure 5-2 shows the slag cooling system schematically.

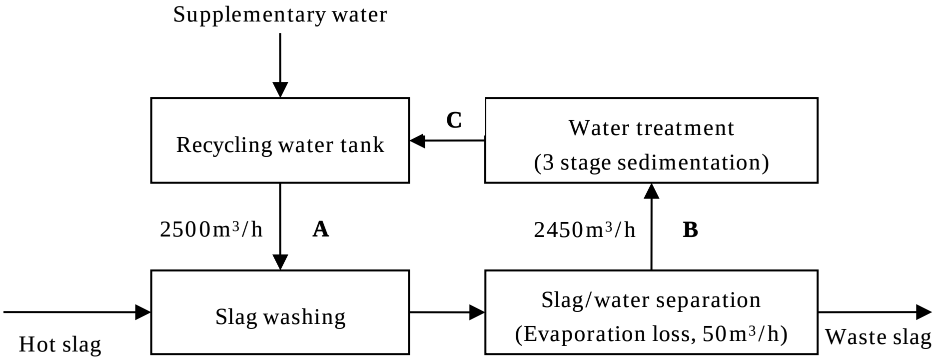


FIGURE 5-2 DIAGRAM OF MECHANICAL TREATMENT AND RECYCLING OF SLAG WASHING WATER

The polluted water from slag washing contains high concentration of SS, calcium, sodium, sulphate and chloride. Today the water is treated in a treatment plant with 3-stage sedimentation and filtration. Below the relevant treatment methods are presented and evaluated.

5.2.2 Water quality criteria

According to CISDI the concentrations in Table 5-4 are the most important water quality parameters for slag washing water. Other pollutants may be present in minor concentration, but no information is available of the complete composition of the slag washing water.

TABLE 5-4 WATER QUALITY OF SLAG WASHING WATER (SOURCE: CISDI)

	Inlet A	Outlet B	Outlet C	Required removal kg/h
Flow, m^3/h	2500	2450	2450	
Suspended Solids, mg/l	20	200	20	441
Hardness ($CaCO_3$), mg/l	450	1200	450	
Calcium, mg/l *	180	400	180	539
SO_4, mg/l	240	750	240	1250
Chloride, mg/l	660	1000	660	833
Sodium, mg/l **	334	541	334	507
Total Dissolved Solids	**1414**	**2691**	**1414**	**3128**

* Calculated value from hardness, ** Calculated from ion balance

The inlet concentration (A) is the required concentration for slag washing water. The outlet concentration (B) is the concentration after slag washing. This is also the inlet concentration to the wastewater treatment plant (WWTP). The outlet from the treatment plant (C) should meet the quality requirements for slag cooling water. However, the steel works cannot achieve this quality because they have no suitable methods to remove the dissolved salts from the water.

A lot of suspended solids have to be removed in the WWTP to reduce SS from 200 mg/l to 20 mg/l. Filtration and sedimentation are able to remove SS. No flocculating agents are added, but this may be done, if separation is difficult.

Gypsum ($CaSO_4 \cdot 2H_2O$) will precipitate as particles when the solubility product is exceeded. It can be calculated that gypsum precipitation will reduce calcium from 480 mg/l to 323 mg/l and sulphate from 750 mg/l to 374 mg/l, if precipitation is complete. Equilibrium conditions are required to achieve this reduction, however, calcium and sulphate will not come down to 180 mg/l and 240 mg/l as required.

As far as we can see the steel works cannot remove chloride from the wastewater today, because only sedimentation and filtration is used for wastewater treatment.

5.2.3 Solutions for slag washing water

Based on experience in water treatment, the mature technologies for slag washing water can be identified as softening, reverse osmosis and nano-filtration.

Softening

Softening of the treated water in an ion-exchanger will remove calcium and magnesium from the water as well as heavy metals. If half of the treated wastewater is softened this will make it possible to reduce calcium to an average of 180 mg/l and thereby fulfil the hardness limit. Softening is a cheap and safe process used for many years by industry all over the world.

Notice that in the ion-exchange sodium will replace calcium. Therefore sodium will gradually accumulate in the wastewater during recycling, because no simple process is available for removing sodium.

If the slag water has to be cooled in a heat-exchanger a total softening of all wastewater is recommended to avoid scaling in the heat exchanger.

Softening requires sodium chloride for regeneration of the ion-exchange resin and the resulting eluate with high concentration of NaCl and some $CaCl_2$ has to be disposed of, typically by discharge to the sea.

Reverse Osmosis and Nano-filtration

Reverse osmosis (RO) and nano-filtration (NF) are both membrane processes. NF will typically retain large molecules and divalent ions like Ca^{+2} and SO_4^{-2} while monovalent ions like Cl^- and Na^+ will pass the membrane. However some NF membranes will also let a great part of Ca^{+2} pass.

By using NF in several stages it is possible to purify approximately 90 % of the water, while 10 % of the water is retained as concentrated brine with high concentration of salts.

Membrane filtration (NF and RO) is probably the only cheap method for removal of sodium and chloride from the wastewater. However, organic pollutants and other toxic components may not be present in the wastewater, because they will accumulate in the concentrate together with high concentrations of sulphate and calcium as well as minor amounts of chloride and sodium. If membrane filtration is to be used, it will be necessary to find a solution for treatment or disposal of this concentrate. Discharge to the sea is a cheap and realistic solution, if the steel work is located close to the sea, whereas salt concentrations are too high for disposal to rivers and inland waters.

5.3 Case solution for water treatment

5.3.1 Technical solution

A technical solution is illustrated in Figure 5-3. The principle is to concentrate the salt solution into a brine, which may disposed or used for special applications. Membrane processes like reverse osmosis are the cheapest way to concentrate the salt and deliver pure water that may be reused. However, there is a limit to the degree of concentration, where the osmotic pressure will be too high. Another problem is that calcium, sulphate and carbonate in the water also will be concentrated and will generate scales on the membranes. This must be prevented.

The following process has been used in design of the system (Figure 5-3):

1. The treated cooling water should first be filtered to remove all particles and then cooled to 20oC (not shown in the flow-sheet).
2. Before entering the membrane processes it is necessary soften the water to prevent precipitation of calcium sulphate (gypsum) and calcium carbonate in the membranes. This is done in an ion-exchanger, where Ca^{+2} is replaced by Na^{+}.
3. In the first membrane stage it is important to separate sulphate and chloride, because we want use NaCl for regeneration of the ion-exchanger. By using a special nano-filter (NF) it is possible to retain 90 % of the sulphate in the concentrate and get 76 % of the chloride (NaCl) into the permeate.
4. The permeate with NaCl must be further concentrated, so it can be used as a NaCl-brine for regeneration of the ion-exchanger. First the permeate is concentrated in a reverse osmosis (RO) unit where NaCl is concentrated 10 times. Unfortunately some minor concentration of Na_2SO_4 is also present in the concentrate. The new permeate from RO is almost pure with very low concentration of salt.
5. The concentrate from RO is next evaporated in Evaporator 1 (MVR = Mechanical Vapour Recompression). The concentrate is a NaCl-brine that can be used directly for regeneration of the softener ion-exchanger. The condensate is pure water that can be reused as washing water for regeneration of the ion-exchanger or as slag cooling water.
6. By regeneration of the ion-exchanger an eluate is generated. The eluate contains NaCl and $CaCl_2$ and must be treated before it is disposed or reused. One solution is to concentrate it to a brine, which can be used for salting the roads during winter time or it can be discharged into the sea. Another solution is to evaporate it to dryness and discharge it into the sea.
7. To concentrate the salt in the eluate it is evaporated whereby the brine volume is reduced to 10% of the eluate volume. This is done in Evaporator 3.
8. The concentrate from Evaporator No. 3 can be totally dried in a spray dryer
9. By regeneration of the ion-exchanger an eluate is generated. The eluate contains NaCl and $CaCl_2$ and must be treated before it is disposed or reused. One solution is to concentrate it to a brine, which can be used for salting the roads during winter time or it can be discharged into the sea. Another solution is to evaporate it to dryness and discharge it into the sea.
10. To concentrate the salt in the eluate it is evaporated whereby the brine volume is reduced to 10% of the eluate volume. This is done in Evaporator 3.
11. The concentrate from Evaporator No. 3 can be totally dried in a spray dryer
12. The concentrate from the nano filter is only 2.5% of the total flow. It is first evaporated in Evaporator 2. Here 4.5 m^3/h of pure water is generated and 0.5 m^3/h of brine with NaCl and Na_2SO_4.
13. The brine is cooled from 100°C to 5°C in a cooling crystallizer with centrifuge. Hereby 90 % of the Na_2SO_4 is removed as $Na_2SO_4 \cdot 10H_2O$
14. Next the water from the crystallizer is dried in a spray dryer whereby a dry powder of salt (77% NaCl and 23% Na_2SO_4) is generated.

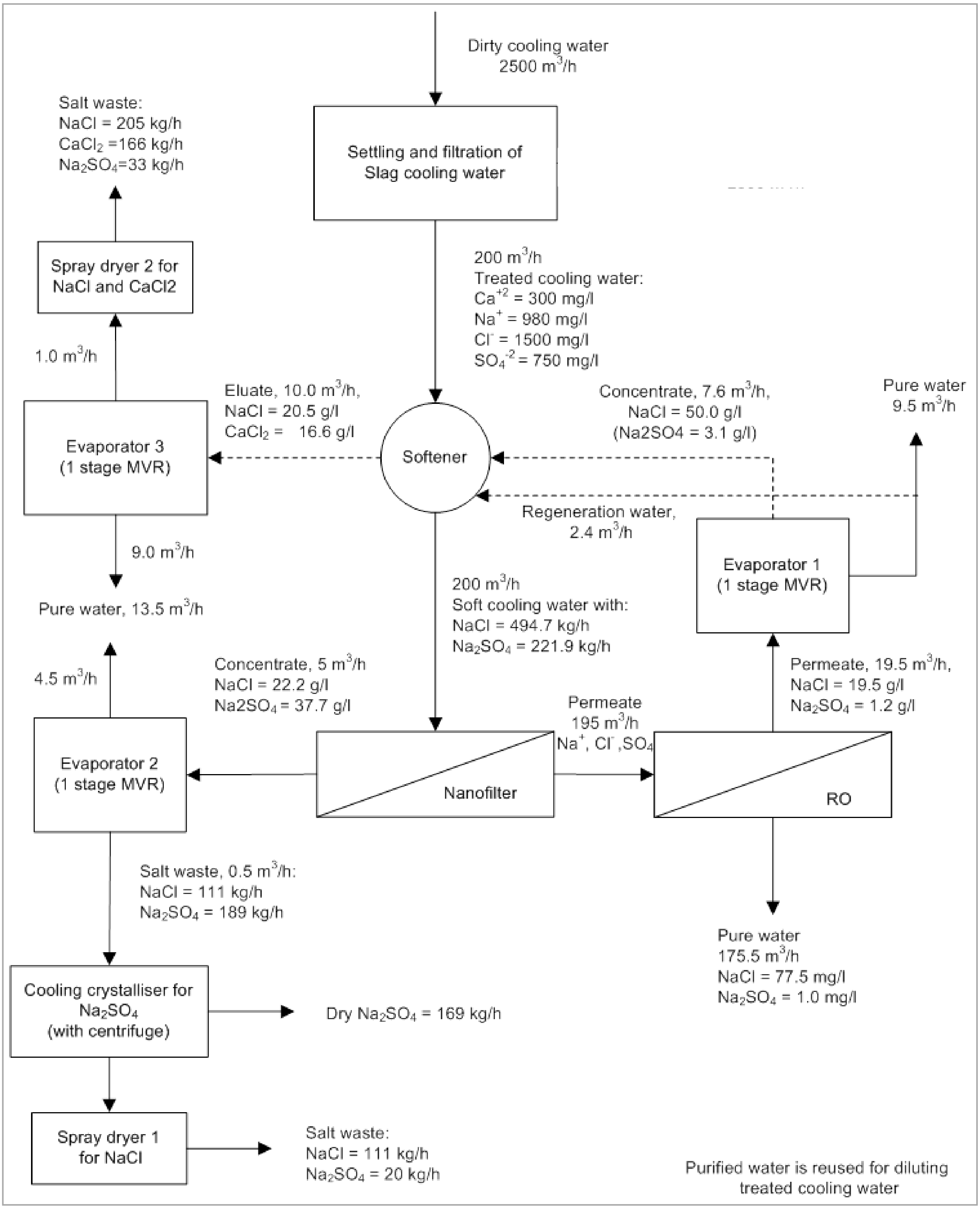


FIGURE 5-3 FLOW SHEET FOR SALT REMOVAL FROM COOLING WATER

The mass balance is summarised in Table 5-5, which shows that at a flow of 200 m^3/h we can remove 706 kg/h of salt (TDS) comprising NaCl = 316 kg/h, Na_2SO_4 = 222 kg/h and $CaCl_2$ = 166 kg/h. In Table 5-4 it is calculated that 3,125 kg/h of salt (TDS) has to be removed to achieve the required inlet water quality. This means that the proposed option must be scaled up by about 4 times and at full-scale treatment plant must be able to treat a flow of 800 m^3/h.

TABLE 5-5 REMOVAL OF SALT FROM POLLUTED COOLING WATER AT FLOW OF 200M³/H

Parameter	Untreated cooling water		Salt removal (waste) kg/h			
	mg/l	kg/h	Sprayer 1	Sprayer 2	Crystalliser	Sum
NaCl	1589	318	111	205	0	316
$CaCl_2$	832	166	0	166	0	166
Na_2SO_4	1109	222	20	33	169	222
Total	**3530**	**706**	**131**	**404**	**169**	**704**

We are aware that the composition of the untreated cooling water is more complex than shown in Table 5-5, because other ions such as bicarbonate, magnesium, potassium, etc. have been omitted.

5.3.2 Details of technical solution

The described solution does not consume chemicals, because NaCl for regeneration of the ion-exchanger is produced from the cooling water. However, washing chemicals must be used now and then for cleaning of the NF- and RO-membranes.

Membrane equipment and ion-exchanger

The dimensioning of NF and RO has been done by ROSA Version 8.0.3, which is a programme developed by DOW Chemicals for calculation of NF and RO equipment. The Danish company Silhorko Eurowater (http://www.eurowater.com/) has according to these calculations proposed the following equipment:

RO: 4 units each for 50 m^3/h
Each unit contains 10 pressure vessels each with 4 RO-elements
Including automatic washing system
Including PLC controller

NF: 4 units each for 50 m^3/h
Each unit contains 10 pressure vessels each with 4 RO-elements
Including automatic washing system
Including PLC controller

The introduction of RO and NF from Silhorko Eurowater is shown in Appendix 4 and Appendix 5.

Silhorko Eurowater also proposes an ion-exchange softening plant including:

- 3 coated steel columns each with 2650 litres resin and flow capacity of 100 m3/h
- Automatic regeneration system (2 columns operating all the time)

Evaporators

The Danish Company Envotherm (Appendix 6) has calculated the evaporation systems, crystallizers and spray driers. Envotherm manufactures MVR-evaporators, which are suitable for this purpose. The evaporator consumes relatively little energy for evaporation (15-35 kWh per m^3 evaporated water). Because of the high salt concentration the material should be corrosion resistant stainless steel of quality ANSI 904L.

Energy consumption

The energy consumption for the treatment plant is estimated in Table 5-6.

TABLE 5-6 OVERVIEW OF ENERGY CONSUMPTION FOR INDIVIDUAL PROCESS EQUIPMENT FOR A TREATMENT PLANT WITH A CAPACITY OF 200 M³/H

	Water flow	Evaporation	Energy consumption	
	m^3/h	m^3/h	kWh/m^3	kWh/h
Treatment plant, other	200		0.4	80
Softening plant	200		0.1	20
NF	200		0.46	92
RO	195		0.7	135
Evaporator 1	19.5	11.9	35	417
Evaporator 2	5.0	4.5	25	113
Crystallizer 2	0.5		232	116
Spray dryer 2	0.5	0.5	1945	973
Evaporator 3	10.0	9	25	225
Spray dryer 3	1.0	1	1945	1,945
Total				4,114

Notice that the 2 spray driers consume 71 % of the total energy. Therefore it should be considered whether the salt brine can be disposed of or reused instead of evaporated to dryness.

Water balance

In Table 5-7 a rough water balance is shown. By treating 200 m^3/h of dirty cooling water 198.5 m^3/h is recovered as pure water with approximately 35 mg/l TDS.

TABLE 5-7 WATER BALANCE FOR SALT REMOVAL TREATMENT PLANT WITH A CAPACITY OF 200M3/H

Water balance	Water in m^3/h	Water out m^3/h	Water recovery Cumulative %
Polluted cooling water	200		
Pure water from RO		175.5	87.8
Pure water from EVAP1		9.5	93.5
Pure water from EVAP2		4.5	95.3
Pure water from EVAP3		9.0	99.3
Total	**200**	**198.5**	

Investment costs

Table 5-8 presents an estimate of investment cost for a complete salt removal plant with a capacity of 200 m^3/h.

TABLE 5-8 INVESTMENT COST BUDGET FOR SALT REMOVAL TREATMENT PLANT (CAPACITY 200M3/H)

Equipment	**Capacity m^3/h**	**Budget price million RMB**
Ion-exchanger	200	0.6
NF-equipment	200	3.7
RO-equipment	195	3.7
Evaporator 1	19.5	15.0
Evaporator 2 + crystallizer + spray dryer	4.5	15.0
Evaporator 3 + spray dryer	9.0	21.0
Additional equipment*		6.0
Subtotal equipment		65.0
Installation (20%)		13.2
Engineering design (20%)		13.2
Contingency (5%)		5.0
Total investment		**96.4**

* Additional equipment includes pumps, pipes and tanks

From the figures in Table 5-8 it is clear that the membrane separation process equipment is relatively cheap compared to evaporators, driers and crystallizers. However, in China it is very difficult to dispose large volumes of salt concentrate and therefore it will often be necessary to concentrate the salt solution to concentrated brine or to complete dryness as powder.

6. Conclusions and recommendations

Based on the study results, conclusions and recommendations for energy conservation, water saving, recycling and treatments are provided in this chapter.

6.1 Energy savings

China is promoting energy conservation continuously. Since the 11th Five Year Plan period (2006-2010), the top ten energy intensive industries, including the iron and steel industry, have been devoted to increase energy efficiency and reduce environmental impacts. After 8 years' effort, the energy saving measures are spreading more and more to cross-cutting areas.

In this study it is found that energy recovery at individual plants is approaching its limitations, which are determined by the characteristics of the product. However, we have found huge potentials for energy savings in cross-cutting applications, e.g. the low temperature surplus energy in the iron and steel industry can be a good energy resource for other light industries or for public application.

The challenging parts fall into three main aspects:

- Identification of applicable demands
- Systematic/cross-cutting technical concepts for surplus energy utilisation
- Institutional barriers for cross-industry cooperation.

The three case solutions presented in this study can provide heat to district heating systems. This is particularly applicable for cities in northern China, but also possible to apply for either heating or cooling in cities along the Yangtze River.

During the study, the consultant had opportunities to discuss and promote the concept with several steel plants and potential customers, who have heat demands and are located around steel plants.

For the steel plants the following is recommended:

- Systematic mapping of low-grade surplus energy inside the plant
- Investigation of potential demands around the plant
- Emphasize the environmental benefits
- Supportive policies from state, provincial and local level
- Sell the concept to local municipalities.

For the future support to similar technology transfer from Europe to China, the following is recommended:

- Introduction of experience on economic and institutional balance between various stakeholders
- Instruments for balancing financial support to public facilities and profit of private sector industries
- Advice on policy measures as well as technical guidelines for cross-cutting energy saving measures.

6.2 Water savings

The Chinese steel works use large amounts of water for cooling and washing of hot slag from the blast furnaces. In the washing process the concentrations of suspended solids (SS), hardness, sulphate and chloride increase, and also minor amounts of other pollutants accumulate in the water.

Currently the slag washing water is treated in a 3 stage sedimentation and filtration process in which no chemicals are added. This will also remove some calcium and sulphate, which precipitate as gypsum, but chloride will not be removed by the separation process. COWI assesses that SS, calcium and sulphate can be reduced considerably, if the separation is optimised.

If the treated wastewater shall be used for heat recovery, a heat exchanger must be used, but then it is necessary to avoid scaling by lime and gypsum from remaining calcium. In this case the water must be softened by ion-exchange or by membrane filtration (reverse osmosis or nano-filtration).

Ion-exchange is the cheapest process. It replaces calcium ions by sodium ions, which will accumulate in the treated water and increase its salinity and conductivity, which may be unacceptable for reuse as cooling water. It may, however, be used for regeneration of the ion-exchanger gradually producing a concentrated brine that eventually must be disposed of.

Reverse osmosis and nano-filtration are the best, but also the most expensive methods to remove calcium, chloride and sulphate, because they will not add any other ions to the treated water. However, membrane processes are sensitive to scaling by gypsum and lime, so a good pre-treatment of the cooling water is required. Furthermore, the brine with all the salts has to be disposed of which is difficult for factories located away from the sea.

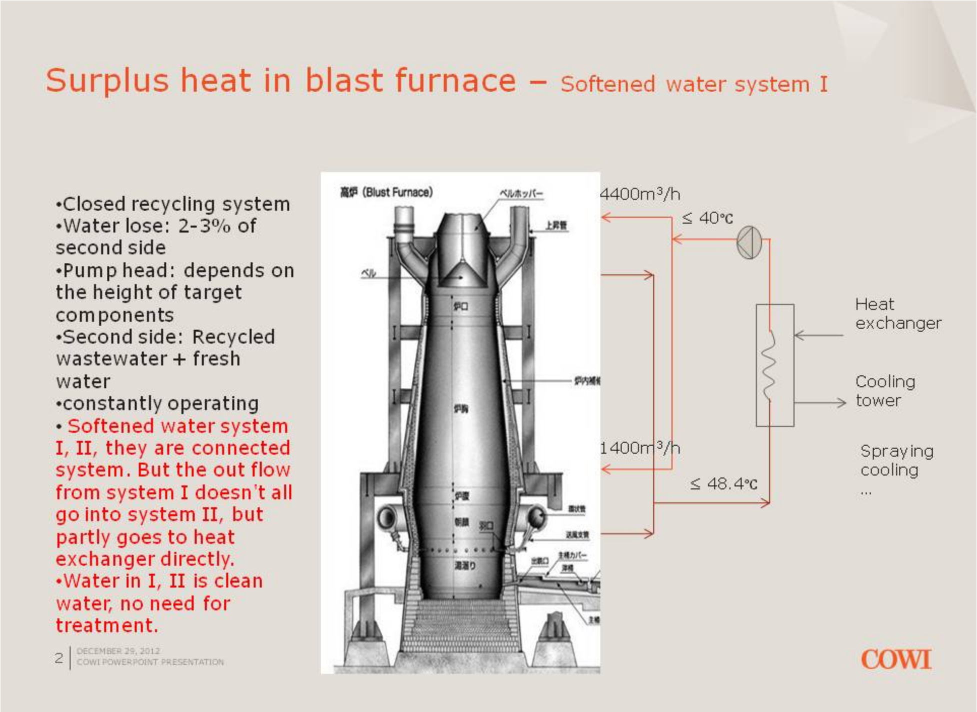
A technical solution is presented using a combination of ion-exchangers, reverse osmosis, nano-filters, evaporators, crystallizers and spray driers. In the presented example 200 m^3/h of cooling water is treated. The treatment process can remove 706 kg/h of salt (TDS) consisting of NaCl = 318 kg/h, Na_2SO_4 = 222 kg/h and $CaCl_2$ = 166 kg/h. However, this is only 23 % of the TDS to be removed in order to meet the quality requirements for recycling, but the process can be scaled up.

The complete solution may recover up to 99% of the cooling water, if the brine residue is evaporated to dryness, and around 90% if crystallizers and spray driers are omitted. In both cases the resulting salt or brine may be used for de-icing or disposed to the sea according to the location, storage facilities and local demands.

The investment for the complete solution will be approximately 100 million RMB and it will consume 4000 kWh per hour. If the brine can be disposed or used without processing in crystallizers and spray driers the investment can be reduced by approximately 50% and the energy consumption by 70%.

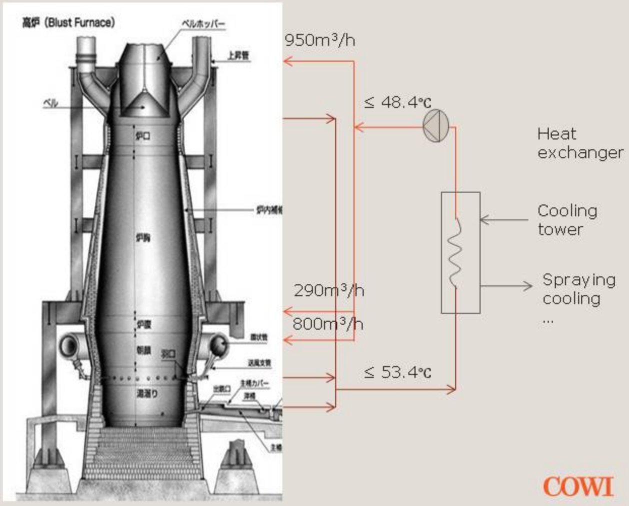
Not all details have been discussed and clarified in the proposed solution and there are still some issues to be solved. The solution, however, demonstrates that it is technically possible, though rather expensive, to remove all salts. It may be possible to apply only some of the ideas from the example with success.

Appendix 1: Surplus heat in iron production and rolling processes



Surplus heat in blast furnace – Softened water system II (normal pressure)

- Closed recycling system
- Water lose: 2-3% of second side
- Pump head: depends on the height of target components (normal pressure)
- Second side: Recycled wastewater + fresh water
- constantly operating
- Heat exchanger: Mainly evaporative air cooler, partly plate heat exchanger, rarely shellandtube heat exchanger



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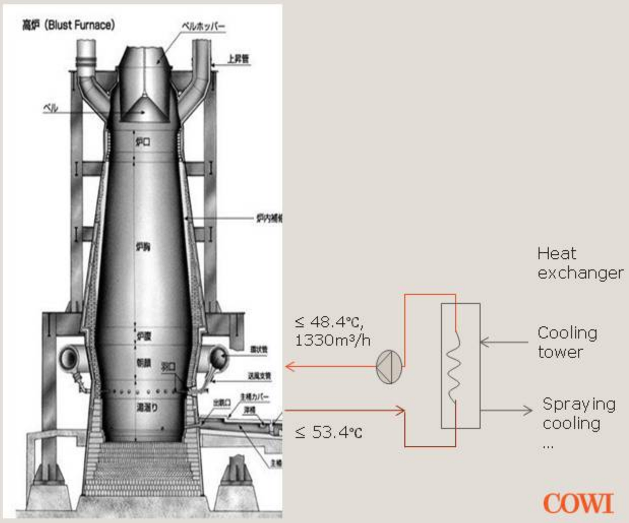
Surplus heat in blast furnace – Softened water system II (high pressure)

- Closed recycling system
- Water lose: 2-3% of second side
- Pump head: depends on the needed pressure
- Second side: Recycled wastewater + fresh water
- constantly operating
- Antisludging agent is used for softening water.



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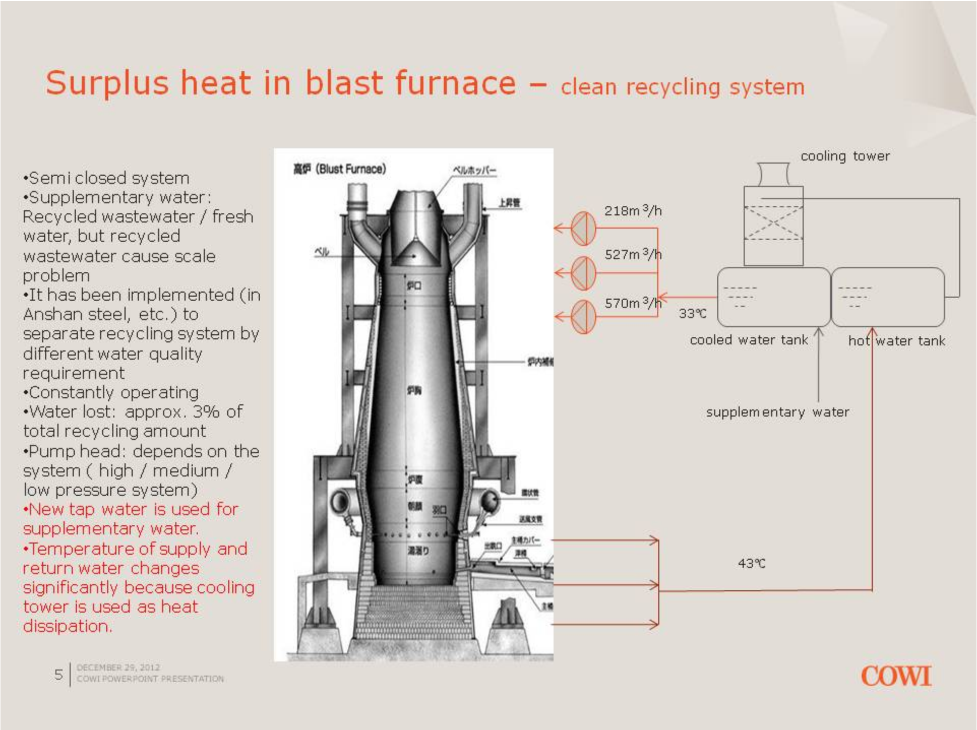
Surplus heat in blast furnace – clean recycling system
•Semi closed system
•Supplementary water: Recycled wastewater / fresh water, but recycled wastewater cause scale problem
•It has been implemented (in Anshan steel, etc.) to separate recycling system by different water quality requirement
•Constantly operating
•Water lost: approx. 3% of total recycling amount
•Pump head: depends on the system (high / medium / low pressure system)
•New tap water is used for supplementary water.
•Temperature of supply and return water changes significantly because cooling tower is used as heat dissipation.
高炉 (Blust Furnace)
cooling tower
218m³/h
527m³/h
570m³/h
33℃
cooled water tank
hot water tank
supplementary water
43℃
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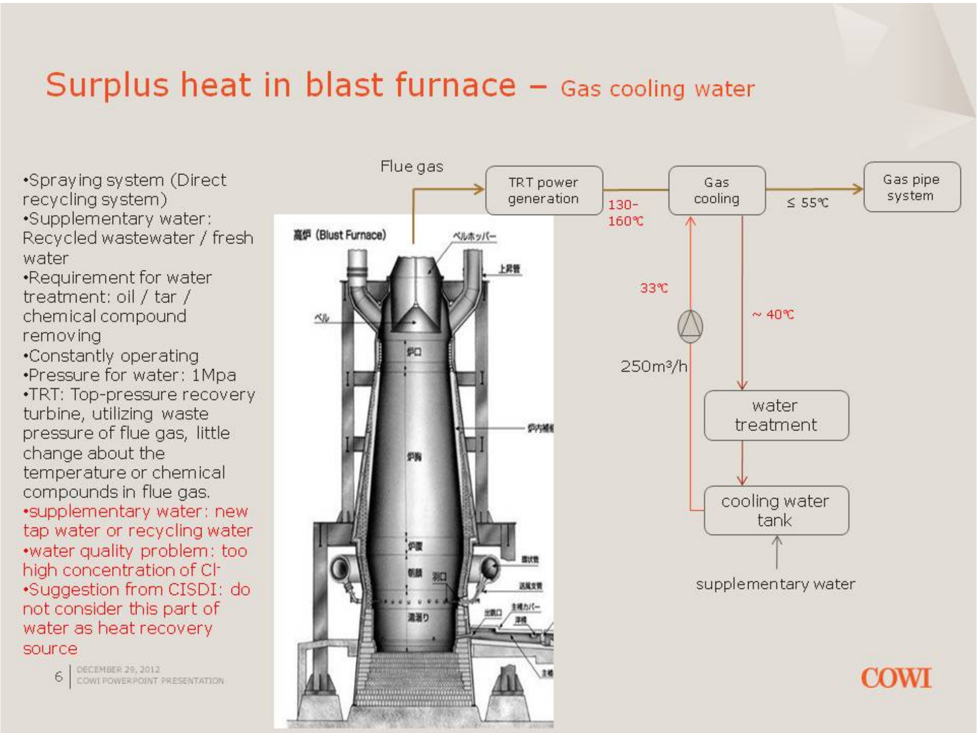
Surplus heat in blast furnace – Gas cooling water
•Spraying system (Direct recycling system)
•Supplementary water: Recycled wastewater / fresh water
•Requirement for water treatment: oil / tar / chemical compound removing
•Constantly operating
•Pressure for water: 1Mpa
•TRT: Top-pressure recovery turbine, utilizing waste pressure of flue gas, little change about the temperature or chemical compounds in flue gas.
•supplementary water: new tap water or recycling water
•water quality problem: too high concentration of Cl-
•Suggestion from CISDI: do not consider this part of water as heat recovery source
Flue gas
TRT power generation
130-160℃
Gas cooling
≤ 55℃
Gas pipe system
高炉 (Blust Furnace)
33℃
~ 40℃
250m³/h
water treatment
cooling water tank
supplementary water
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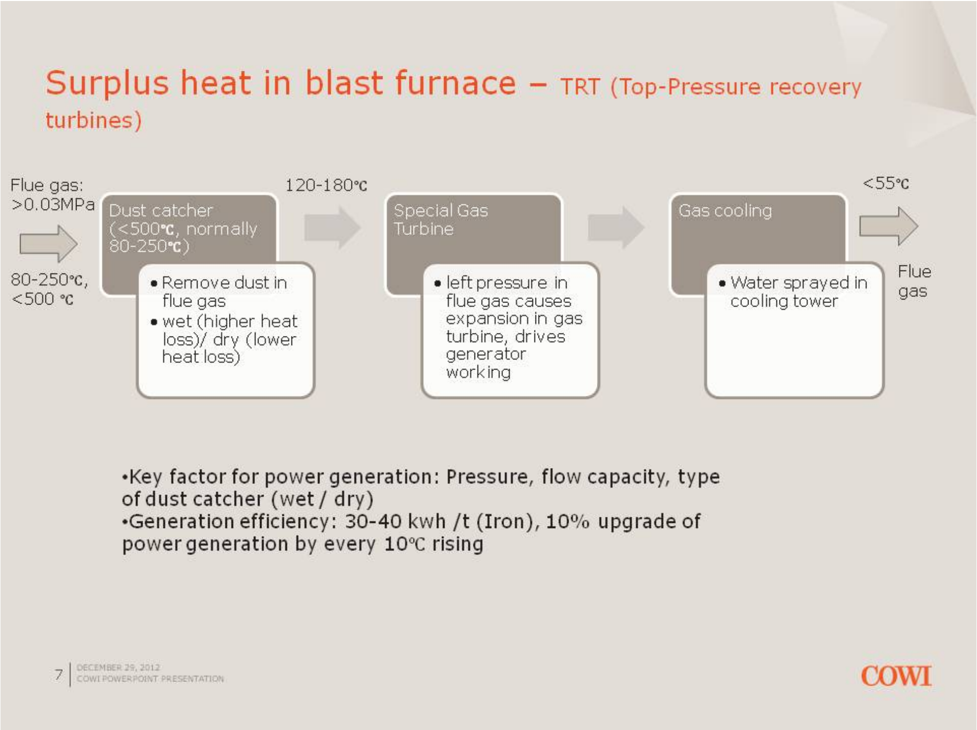
Surplus heat in blast furnace – TRT (Top-Pressure recovery turbines)
Flue gas: >0.03MPa
80-250℃, <500 ℃
Dust catcher (<500℃, normally 80-250℃)
• Remove dust in flue gas
• wet (higher heat loss)/ dry (lower heat loss)
120-180℃
Special Gas Turbine
• left pressure in flue gas causes expansion in gas turbine, drives generator working
Gas cooling
• Water sprayed in cooling tower
<55℃
Flue gas
•Key factor for power generation: Pressure, flow capacity, type of dust catcher (wet / dry)
•Generation efficiency: 30-40 kwh /t (Iron), 10% upgrade of power generation by every 10℃ rising
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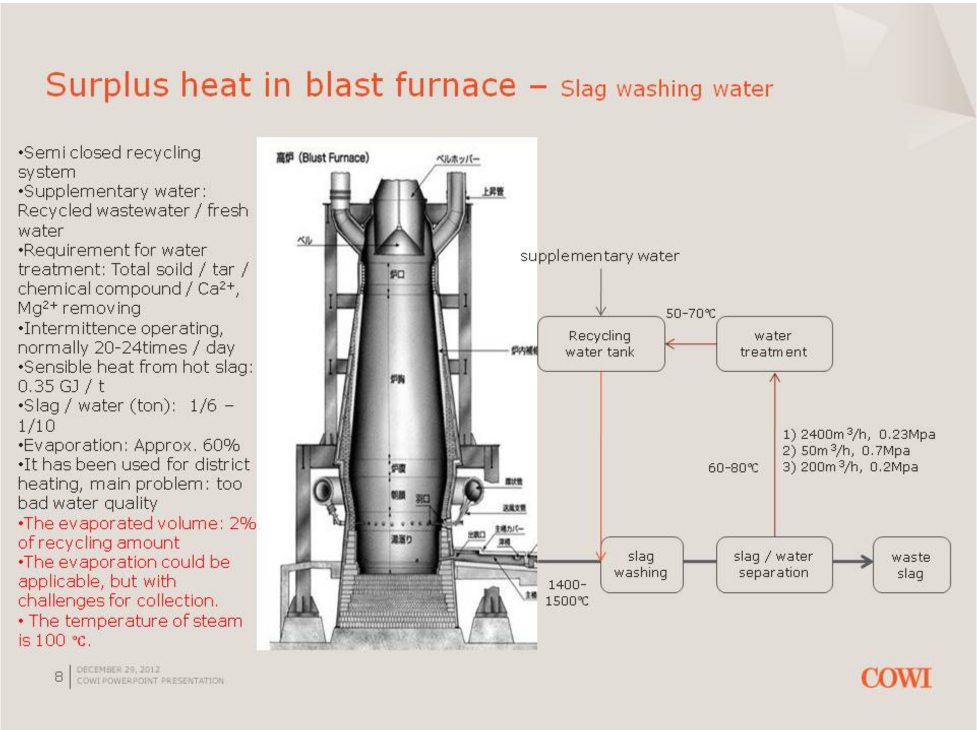
Surplus heat in blast furnace – Slag washing water
•Semi closed recycling system
•Supplementary water: Recycled wastewater / fresh water
•Requirement for water treatment: Total soild / tar / chemical compound / Ca²+, Mg²+ removing
•Intermittence operating, normally 20-24times / day
•Sensible heat from hot slag: 0.35 GJ / t
•Slag / water (ton): 1/6 – 1/10
•Evaporation: Approx. 60%
•It has been used for district heating, main problem: too bad water quality
•The evaporated volume: 2% of recycling amount
•The evaporation could be applicable, but with challenges for collection.
• The temperature of steam is 100 ℃.
高炉 (Blust Furnace)
supplementary water
Recycling water tank
50-70℃
water treatment
1) 2400m³/h, 0.23Mpa
2) 50m³/h, 0.7Mpa
3) 200m³/h, 0.2Mpa
60-80℃
slag washing
slag / water separation
waste slag
1400-1500℃
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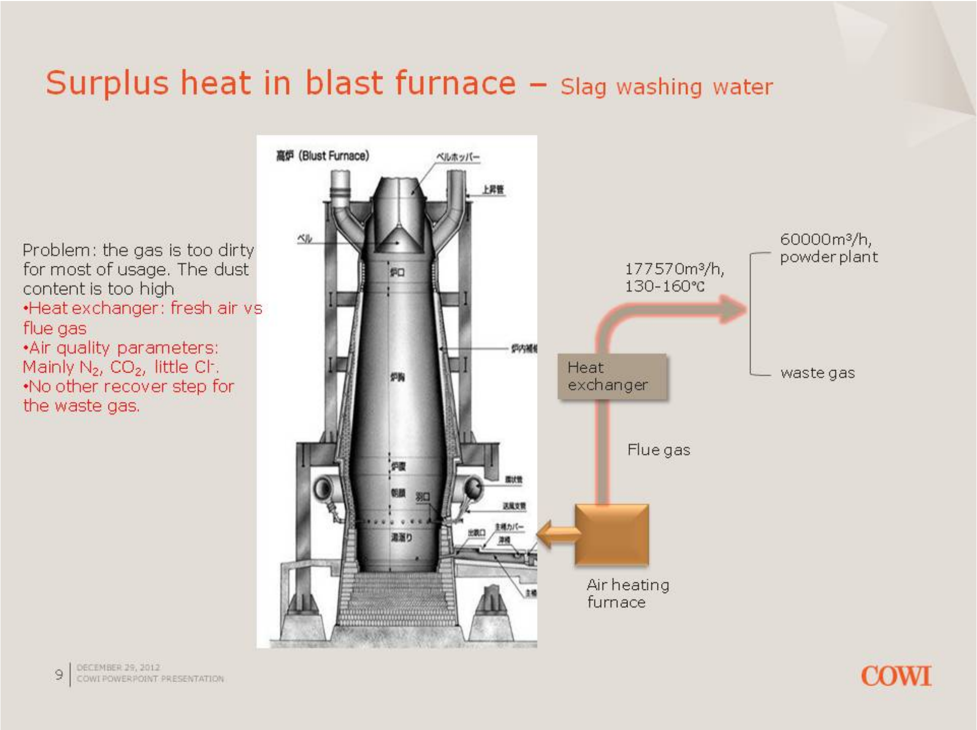
Surplus heat in blast furnace – Slag washing water
Problem: the gas is too dirty for most of usage. The dust content is too high
•Heat exchanger: fresh air vs flue gas
•Air quality parameters: Mainly N_2, CO_2, little Cl^-.
•No other recover step for the waste gas.
(Blust Furnace)
177570m³/h, 130-160℃
60000m³/h, powder plant
waste gas
Heat exchanger
Flue gas
Air heating furnace
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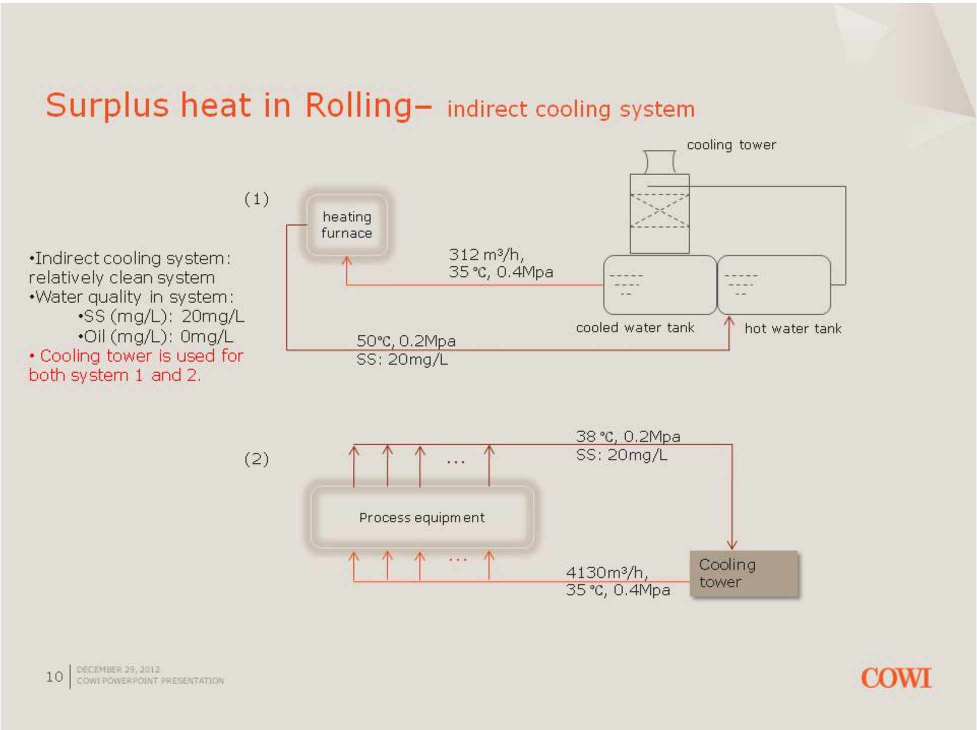
Surplus heat in Rolling– indirect cooling system
•Indirect cooling system: relatively clean system
•Water quality in system:
•SS (mg/L): 20mg/L
•Oil (mg/L): 0mg/L
• Cooling tower is used for both system 1 and 2.
(1)
heating furnace
cooling tower
312 m³/h, 35 ℃, 0.4Mpa
cooled water tank
hot water tank
50℃, 0.2Mpa
SS: 20mg/L
(2)
38 ℃, 0.2Mpa
SS: 20mg/L
Process equipment
4130m³/h, 35 ℃, 0.4Mpa
Cooling tower
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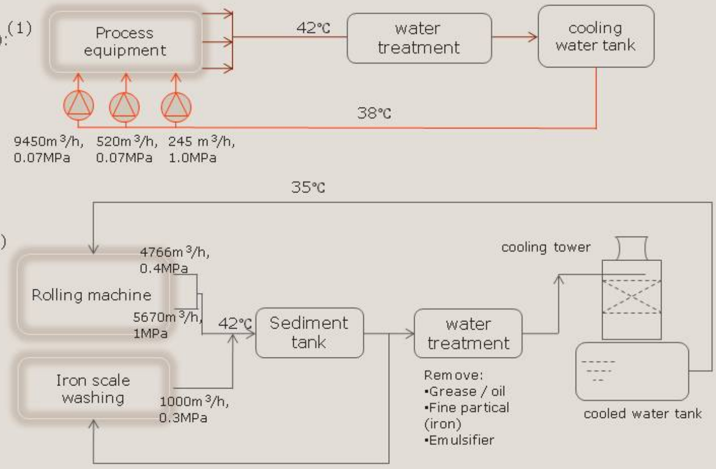
Surplus heat in Rolling–Direct cooling system

•Direct cooling system: unclean system

•Water quality in system (1):
•SS (mg/L):
  •Inlet: 50mg/L
  •Outlet: <80mg/L
•Oil (mg/L): 0mg/L

•Water quality in system (2):
•Rolling machine:
• SS (mg/L):
  •Inlet: 20mg/L
  •Outlet: 20mg/L
• Oil (mg/L):
  •Inlet: 5mg/L
  •Outlet: 5mg/L
•Iron scale washing: No specific requirement for water quality



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Water quality parameters–Design criteria

› Water system:

- › Indirect open recycling system (semi closed system): cooling water and cooling target transfers heat indirectly, and dissipation of cooling water is exposed into air (e.g. cooling tower).
- › Indirect closed recycling system (closed recycling system): cooling water and cooling target transfers heat indirectly, and dissipation of cooling water is conducted indirectly with other cooling agent (e.g. heat exchanger).
- › Direct open recycling system (directly recycling system) : cooling water and cooling target transfers heat directly, and dissipation of cooling water is exposed into air.

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Water quality parameters–Design criteria

› Indirect open recycling system

Items	Unit	Criteria for application	Value
Turbidity	NTU	Based on process	≤20
		Heat exchanger: plate, Finned tube, spiral	≤10
pH			6.8-9.5
Ca Hardness ($CaCO_3$)	mg/L	Stable factor of $CaCO_3$ (RSI) ≥3.3	≤1100
		Heat transfer surface (water side) temperature >70℃	≤200
Total Fe	mg/L		≤1.0
Cu^{2+}	mg/L		≤0.1
Cl^-	mg/L	Carbon steel, Stainless steel heat exchanger, water running in pipe	≤1000
		Stainless steel heat exchanger, water running on container surface, heat transfer surface (water side) temperature≤70℃, cooling water outlet temperature <45℃	≤700
$SO_4^{2+}+Cl^-$	mg/L		≤2500
Silicic acid (in the form of SiO_2)	mg/L		≤175

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Water quality parameters–Design criteria

› Indirect open recycling system

Items	Unit	Criteria for application	Value
$Mg^{2+} \times SiO_2$ (Mg^{2+} is in form of $CaCO_3$)	mg/L	pH≤8.5	≤50000
Free Chlorine	mg/L	Main entrance of returning water pipe	0.2-1.0
NH_3-N	mg/L		≤10
Total Petroleum	mg/L		≤5

› Closed recycling system
- › Total Hardness: ≤2 mg/L

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Water quality parameters–Design criteria

› Direct recycling system

Items	Unit	Criteria for application	Value
pH		Blast Furnace- flue gas washing water	6.5-8
		Rolling direct cooling system (1), (2)	7-9
Conductivity	μs/cm	Blast Furnace- flue gas washing water	≤3000
		Rolling direct cooling system (1), (2)	≤2000
SS	mg/L	Blast Furnace- flue gas washing water	≤100
		Rolling direct cooling system (1), (2)	≤30
Carbonate Hardness (In the form of $CaCO_3$)	mg/L	Rolling Indirect cooling system (1), (2)	≤500
Cl^-	mg/L	Rolling Indirect cooling system (1)	≤300
		Rolling Indirect cooling system (2)	≤500
Sulfate (In the form of SO_4^{2-})	mg/L	Blast Furnace- flue gas washing water	≤2000
		Rolling direct cooling system (1), (2)	≤1500
Oil	mg/L	Rolling Indirect cooling system (1)	≤5
		Rolling Indirect cooling system (2)	≤10

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Quality parameters for Industrial fresh water and reuse water (iron and steel industry)

Parameter	Unit	Industrial fresh water	Soft water	Desalt water	Reuse water
pH	——	7-9	7-9	6.5-9	6-9
Total SS	mg/L	10	5	1	20
Total Hardness	mg/L	150	10	2	450
Ca Hardness	mg/L	100	2	1	300
Alkalinity	mg/L	110	110	1	330
Cl^-	mg/L	220	200	1	660
SO_4^{2-}	mg/L	80	80	Limit	240
Iron	mg/L (Fe)	1	1	0.1	3
Solved SiO_2	mg/L	6	6	0.1	18
Oil	mg/L	2	1	Limit	5
Conductivity	μs/cm	500	500	10	3000
Solute evaporates	mg/L	300	300	5	1000
NH_3-N	mg/L	10	10	1	10
CODcr	mg/L	——	——	——	100

Notes： 1. The fulfilment of parameters should be > 90%
2. When the groundwater is used as main water source, total hardness should be < 200mg/l

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Appendix 2: Innovative heat exchangers

It is concluded that the treatment of slag water will be cost intensive. If the water needs to be treated to the criteria of district heating supply system, the solution will not be economically viable due to the huge investment.

The alternative is to find a moderate cost solution, which may combine partial water treatment, together with innovative heat exchanger technologies.

In practice such heat exchangers are available. Three typical heat exchangers are introduced, which are considered to be feasible and easily available in the market. The technology is under development and innovative design is appearing day by day, there are always possibilities to have better design to fulfil actual situations.

Combined with the water treatment method introduced in Chapter 5, it is possible to find a feasible combination of technology to extract heat from slag water.

Twisted tube heat exchanger

The twisted tube heat exchange was invented and introduced in 1984 by Allares in Sweden for application in industries such as electricity, chemical as well as paper and pulp. It is developed from conventional shell & tube heat exchanger and characterized with low pressure drop, high heat transfer efficiency, as well as less scaling and blockage.

THE STRUCTURE OF THE HEAT EXCHANGER IS SHOWN FIGURE 6-1. THE TUBE IS OVAL FLAT IN THE MIDDLE BUT REMAINS BOTH CIRCULAR ENDS, WHICH ENSURES PROPER CONNECTION TO THE TUBE PLATE. FURTHERMORE THERE ARE NO BAFFLES IN THE SHELL, THE TUBES ARE SUPPORTED EACH OTHER BY THE FLAT PART, AS SHOWN IN
FIGURE 6-2 SPIRAL FLAT TUBE SUPPORT EACH OTHER

. Working medium in the spiral flat tube heat will have spiral flow with much higher efficiency than the normal shell & tube heat exchanger. A cleaning device is installed on the shell in case the impurities of slag water, especially threadlike suspensions, get stuck in the heat exchanger, the cleaning device may remove it and impurities may be drained away through blow down valve.

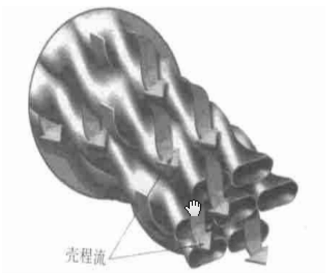


FIGURE 6-1 TUBE BUNDLE OF THE HEAT EXCHANGER AND FLOW DIRECTION IN THE SHELL

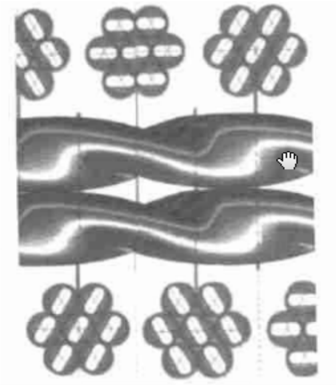


FIGURE 6-2 SPIRAL FLAT TUBE SUPPORT EACH OTHER

There are over 400 applications around the world, however, local reference are still very limited, 10 applications were found being put into operation. The operating cost has been reduced considerably.

Spiral Heat Exchanger

A typical energy recovery heat exchanger is applied in chemical industries due to its high heat transfer efficiency and good possibilities for anti-corrosion. As shown in Figure 6-3, various prototypes of spiral heat exchanger can be applied in different production processes, and facilitate heat exchange between different media.

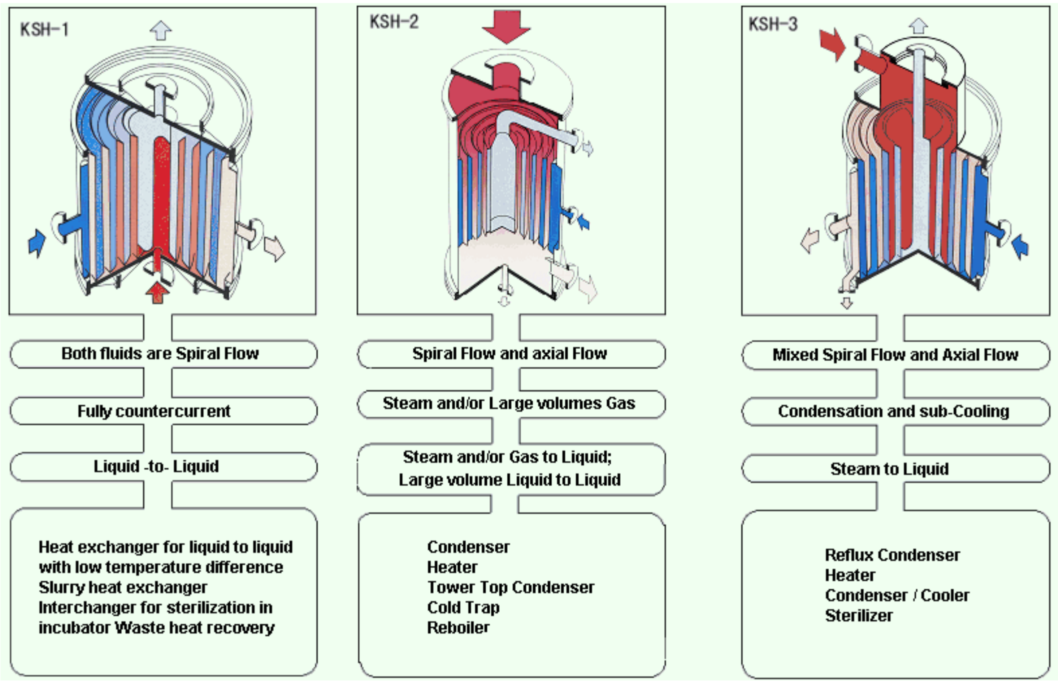


FIGURE 6-3 SPIRAL HEAT EXCHANGER APPLIED IN CHEMICAL INDUSTRY (SOURCE: HTTP://WWW.KUROSE.CO.JP/SH_MERIT_E.HTM)

The fully counter current type is typically applied in processes where the temperature difference is very small, and the general heat exchange coefficient is high due to turbulent flow. For the same reason the heat exchanger has self-cleaning character. Furthermore the maintenance is easy and the heat exchanger is designed in a compact way therefore required installation space is relatively small.

Application in China can be traced back to 1990s, steel works is one of typical applications. Detailed information can be found from Alfa Laval (www. alfalaval.com).

Self-cleaning plate heat exchanger

A new plate heat exchanger has been invented specifically for application for heat exchange with highly polluted surplus energy resources, e.g. flue gas with high dust content, slag water from steel plant, black water from paper and pulp industries.

The design is demonstrated in Figure 6-4. The clean heat medium, will pass through channel inside the plate, the channel is welded and may sustain high pressure as required by DH system. The plates are assembled in small groups and the space between plates can be adjusted according to the quality of energy carriers e.g. flue gas or black water. For flue gas the low-frequency sound wave is applied to remove dust, and high-pressure water spray will be used for fluid medium. Due to the relative smooth surface of the plates, the fouling problem can be avoided with very low maintenance cost. Moreover the outline dimension of the heat exchanger can be designed in a compact and flexible way, which may enhance wider application.

The prototype of the heat exchanger was invented and tested by a university, and it is reported that the shell resistance will be reduced by 50%, and energy saving, comparing with conventional heat exchangers, can approach over 30%. The technology is under commercialization, a manufacturing factory will be set up in Siping city, Jilin Province (http://www.jl.gov.cn/tzjl/jcssjqt/201208/t20120808_1254581.html; http://csi.ecust.edu.cn:8080/choice_detail.jsp?id=68).

FIGURE 6-4 STRUCTURE OF SELF-CLEANING PLATE HEAT EXCHANGER

Appendix 3: Study Dissemination

Following the study progress, three disseminations have been carried out regarding three study milestones.

Concept introduction
Topic:
General introduction of low temperature surplus heat utilization in Scandinavian countries

Date: 13th January 2012

Participants:

- COWI: Mikael Jakobsson, Flemming Dahl, Henrik Kragerup, Cheng Jie
- CISDI: Process engineers of energy supply and water system in steel works
  Outcome:
- Available surplus heat resources in Chinese steel works for concept establishment
- Fixed questionnaire for surplus heat and recycling water system mapping

Adjustment of focus
Topic:
Adjustment of established process model and initial heat recovery concept.

Date: 26th March 2012

Participants:

- COWI: Cheng Jie
- CISDI: Process engineers of energy supply and water system in steel works
  Outcome:
- Adjusted system model for cooling water systems in focused process
- Description and category of applicable surplus heat

Introduction and discussion of provided scenarios
Topic:
Introduction and discussion of the technical and economical applicability of provided two scenarios

Date: 18th June 2012

Participants:

- COWI: Cheng Jie
- CISDI: Process engineers of energy facilities and systems, engineer of recycling water systems

Outcome:

- Introduction and explanation of provided two scenarios
- Verification of availability for demanded facilities and implementation capacity in China
- Evaluation of economical interests from potential Chinese clients

Appendix 4: Reverse Osmosis – Eurowater

(Inserted overleaf)

EUROWATER

A GROUP OF CO-OPERATING EUROPEAN WATER TREATMENT SPECIALISTS

REVERSE OSMOSIS

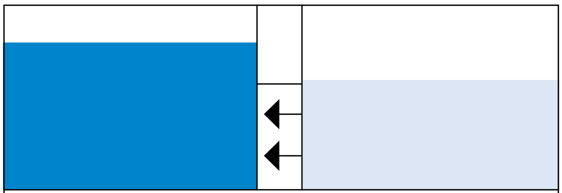
EUROTEC SERIES 01, 02 & 03
REVERSE OSMOSIS PLANTS

- **DEMINERALIZED WATER WITHOUT ACID & CAUSTIC REGENERANTS**
- **REMOVES PYROGENS AND BACTERIA**
- **LOW OPERATING COSTS**
- **NO EFFLUENT NEUTRALIZATION REQUIRED**
- **NO HANDLING WITH HAZARDOUS REGENERANTS**
- **NO REGENERATION DOWN TIME**
- **ELECTRONIC QUALITY CONTROL**
- **CORROSION RESISTANT MATERIALS OF CONSTRUCTION**
- **COMPACT DESIGN**

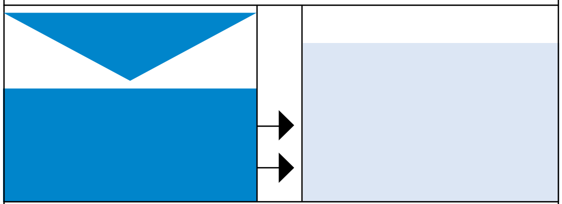
Type 01-3

APPLICATION FIELDS

- **HOSPITALS AND DIALYSIS CENTRES**
- **PUBLIC AND PRIVATE LABORATORIES**
- **PROCESS WATER FOR FOOD AND DRINK INDUSTRIES**
- **PROCESS WATER FOR PHARMACEUTICAL AND CHEMICAL INDUSTRIES**
- **PROCESS WATER FOR METAL FINISHING AND PAINT INDUSTRIES**
- **RINSE WATER FOR THE PRODUCTION OF ELECTRONICS, GLASS AND MIRRORS**
- **COOLING AND BOILER FEEDWATER**
- **FEEDWATER FOR HUMIDIFICATION**

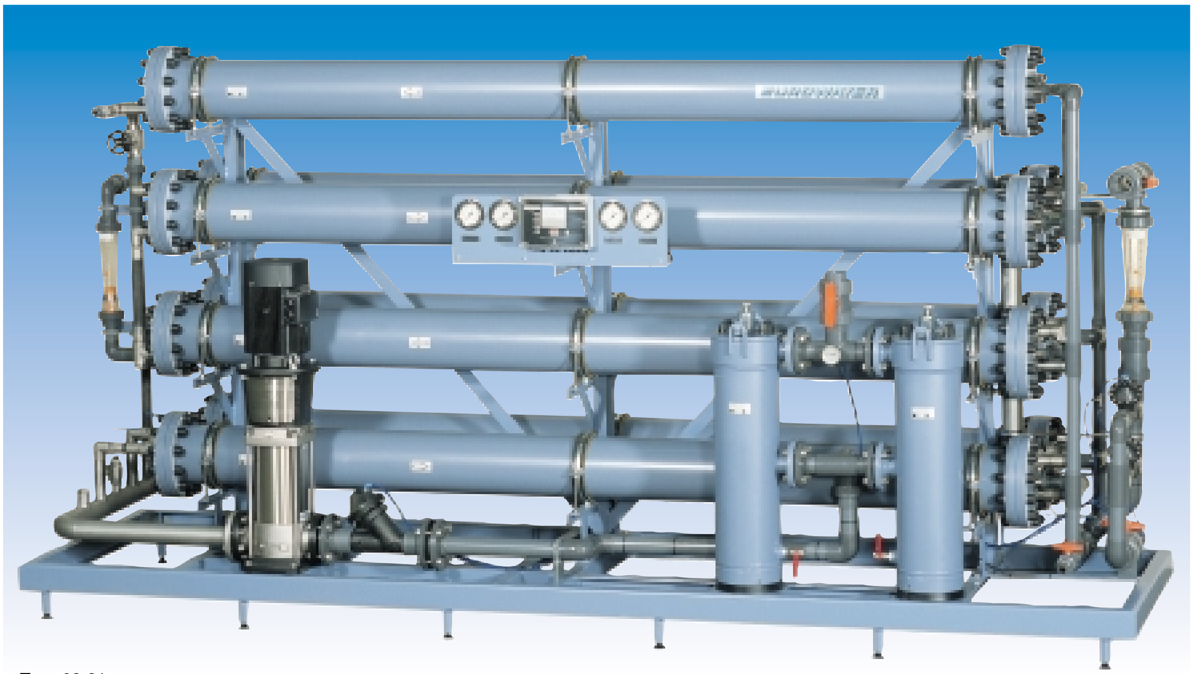


OSMOSIS
When a semi-permeable membrane separates two solutions with different salt concentrations, pure water from the low concentrated side will pass through the membrane to reach equilibrium in salt concentration on both sides.



REVERSE OSMOSIS
By applying pressure on the more concentrated solution, the water flow is reversed and pure water is forced through the membrane into the less concentrated solution.

Type 02-12



Type 03-21

REVERSE OSMOSIS PLANT

PRINCIPLE OF OPERATION
Pretreated water is pumped into the membrane housings along the membrane surface. Pure water is permitted to pass through the membrane while ionic, organic, colloidal and bacterial contaminants are swept away in concentrated solution. Consequently, a reverse osmosis system always creates two continuous exit streams: pure water (permeate) and brine (concentrate). Normally up to 80 per cent of the feedwater can be recovered as permeate.

DEMINERALIZATION
Salts are repelled from the surface of the membrane while water molecules are allowed to diffuse freely through the membrane creating a purified product stream. Higher valence ions (salts) are rejected to a greater degree. Average rejection of dissolved salts ranges between 98 and 99 per cent.

ULTRAFILTRATION
The mechanism for organic retention is different from the mechanism for salt rejection. Dissolved organic materials with a molecular weight over 200 daltons but also colloidal matter, bacteria, pyrogens and viruses are widely removed because of their size and geometry, i.e. they are physically too large to pass through the pores of the membrane.

PRETREATMENT
Proper pretreatment of the feedwater to a RO system is an essential factor for smooth long-term operation. Clogging of the membranes by suspended solids, scale-forming minerals and other impurities has to be prevented by appropriate measures. Hardness minerals can be removed in a softener, suspended solids in a mechanical filter while free chlorine can be removed in an activated carbon filter.

SYSTEM DESIGN
In order to protect the RO membranes against foulants a complete system usually consists of a softening plant and a reverse osmosis unit equipped with a prefilter. An activated carbon filter has to be added if free chlorine is present in the feedwater. To further improve the water quality in terms of conductivity permeate can be polished downstream.

DOSING SOLUTION
Dosing of antiscaling agents is an alternative to softening. Antiscaling agents prevent salt precipitations on the membranes. The dosing solution can effect major economies with large plants. Local regulations and recipient conditions determine and limit the dosing solution.

POLISHING
Polishing of permeate in a mixed-bed unit (cf. special brochure) is normally required when high purity water is needed.

PROJECTING
Besides the reverse osmosis unit, EUROWATER has a complete programme for pretreatment of RO feedwater and posttreatment of permeate. Based on a water analysis or on measurements on the spot, a complete system can be designed.

EUROTEC UNIT
Softened water is pre-filtered (1-5 µm) in a cartridge type filter or in a filter with filter bag and flows through an inlet solenoid valve to the pump. A high-pressure pump made of stainless steel drives the water through the membranes. The membranes of series 01 and 02 are mounted in stainless steel pipes whereas series 03 has pressure pipes of metal finished steel. Permeate and concentrate streams are led through flow meters to outlet and drain connections, respectively. All connections are made of pressure hoses or PVC pipes. A comprehensive set of interlocks is provided to control and protect the equipment, e.g. pre-rinse, quality rinse, post-rinse, quality monitoring, low pressure cut-off. The EUROTEC unit is skid-mounted and ready for installation.

CONTROL PANEL
The electronic control panel can be programmed according to actual demand. The duration of pre-rinse, quality rinse, and post-rinse can be set individually. The conductivity meter continuously indicates the quality of the permeate measured in µS/cm. Special features include various control and alarm lamps as well as potential-free contacts for external signals and for remote alarm. The control panel operates on low voltage (12 V).

QUALITY RINSE
After a period of standstill, the conductivity of the water in the membranes increases, i.e. the quality decreases. A restart of the unit triggers a quality rinse to drain until the permeate has reached the present quality limit. When the desired conductivity is reached the unit automatically switches to service.

POST-RINSE
When water consumption is interrupted the high-pressure pump stops working and the membranes are rinsed with pretreated water at normal waterworks pressure for a preset number of minutes. This post-rinse reduces the risk of insoluble salt precipitations and minimizes algae and bacteria growth during standstill.

CLEANING
EUROTEC reverse osmosis units are equipped with connections for a cleaning and sterilization device. Membranes are cleaned and disinfected periodically in order to avoid malfunctions of the plants due to high bacterial count and/or precipitations on the membrane surface. The frequency of cleaning depends on the composition of the raw water and on the type of pretreatment applied to the feedwater. Cleaning and sterilization agents are effected by circulating cleaning or sterilization agents through the membranes. A cleaning and sterilization unit can be offered as optional extra.

CAPACITY
The unit capacity depends upon pressure, salt content and temperature of the feed-water. The capacity increases with increasing pressure and temperature and decreasing salt content. Capacities for individual membrane elements may vary by +/- 15 per cent.

QUALITY
An EuRotec reverse osmosis unit will usually retain 95 to 99 per cent of all inorganic dissolved solids and more than 90 per cent of all organic contaminants. Carbonic acid, however, will penetrate through the membrane into the permeate.

MEMBRANES
The membranes are of Thin Film Composite (TFC) type and packed in a spiral wound module configuration. TFC membranes have high salt rejections and good performances under wide-ranging pH and temperature conditions. They are not degradable by microorganism and hold their productivities over long periods of time.

New membrane types are developed all the time. EUROWATER continuously optimizes the plant range in accordance with the requirement of the individual customers. Usually, low-energy membranes are the best solution when both operating costs and water quality are considered. Several membrane types of various makes can be employed in our flexible plants without more ado.

PLANTS CONNECTED IN SERIES
To further improve water quality two plants can be connected in series so that the second plant further treats the water from the first plant. Plants connected in series will be built together to a so-called double-pass plant.

SERIES 01. 1-5 MEMBRANES
The membranes are mounted in vertical pressure vessels made of stainless steel (AISI 304). Each membrane is housed in one vessel giving a compact, spacesaving design. To reduce the risk of fouling the membranes, the unit is equipped with an adjustable recirculation facility.

SERIES 02. 6-24 MEMBRANES
The horizontally mounted pressure vessels contain two membranes each. Placing two membranes in one pressure vessel means reduced pressure loss and consequently increased capacity.

SERIES 03. 6-24 MEMBRANES
This series is designed for flow rates from 5 to 30 m^3/hour. The plants are equipped with membranes of eight inches unlike series 01 and 02 that contain membranes of four inches. Each pressure pipe has three membranes of eight inches.

SPECIAL PLANTS
Plants with other capacities and choice of material are designed according to demand.

SPECIFICATIONS

TYPE	STANDARD CAPACITY 1)	PUMP-MOTOR 2)	CONNECTIONS				FRAME MEASURES 3)		
			Inlet	Outlet DN/mm	Drain DN/mm	Rinse DN/mm	Height	Width	Depth
	m^3/hour	kW	PVC	PVC	PVC	PVC	mm	mm	mm
01-1	0,35	2,2	Rp ¾	20/25	20/25	25/32	1620	800	400
01-2	0,70	2,2	Rp ¾	20/25	20/25	25/32	1620	800	400
01-3	1,05	2,2	Rp ¾	20/25	20/25	25/32	1620	800	400
01-4	1,40	2,2	Rp ¾	20/25	20/25	25/32	1620	1140	400
01-5	1,75	2,2	Rp ¾	20/25	20/25	25/32	1620	1140	400
02-6	2,1	4,0	DN 32/40 mm	25/32	25/32	40/50	1560	2500	550
02-8	2,8	4,0	DN 32/40 mm	25/32	25/32	40/50	1560	2500	550
02-10	3,5	4,0	DN 32/40 mm	25/32	25/32	40/50	1950	2500	550
02-12	4,2	4,0	DN 40/50 mm	25/32	25/32	40/50	1950	2500	550
02-16	5,6	5,5	DN 40/50 mm	40/50	25/32	40/50	1560	2650	700
02-20	7,0	5,5	DN 40/50 mm	40/50	25/32	40/50	1950	2650	700
02-24	8,4	7,5	DN 40/50 mm	40/50	25/32	40/50	1950	2650	700
03-6	8,4	11,0	DN 40/50 mm	40/50	25/32	40/50	1700	4000	1100
03-9	12,6	11,0	DN 40/50 mm	40/50	25/32	40/50	1700	4000	1100
03-12	16,8	15,0	DN 50/63 mm	50/63	25/32	50/63	1700	4000	1100
03-15	21,0	15,0	DN 50/63 mm	50/63	25/32	50/63	1700	4000	1100
03-18	25,2	18,5	DN 50/63 mm	50/63	40/50	50/63	2050	4000	1100
03-21	29,4	22,0	DN 50/63 mm	50/63	40/50	50/63	2050	4000	1100
03-24	33,6	22,0	DN 50/63 mm	50/63	40/50	50/63	2050	4000	1100

1) The standard capacities apply to low energy membranes at a temperature of 10°C and a salt content in the inlet water of 500 mg/l. Also see the section CAPACITY.
2) Wiring: 3x400 V, 50 Hz. The stated pump power is for your guidance. The actual power will often be less.
3) Dimensioned sketch with exact installation dimensions is available.

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Appendix 5: Nanofiltration Unit - Eurowater

(Inserted overleaf)

Nanofiltration unit

Application

- Reduction of organic matter, colour, sulphate, chloride, fluoride, bacteria and vira.
- Partial softening.

Designed for exactly your needs

EUROWATER offers a broad product range of fully automatic nanofiltration units – based on our well-known modular standard system, which makes it possible for us to combine an optimal plant for exactly your needs.

A variety of applications

Typical applications for a nanofiltration unit:

- Drinking water: Reduction of sulphate, chloride and fluoride.
- Drinking water: Partial softening without use of regeneration chemical.
- Industrial process water: Partial softening and reduction of colour and humus from surface water in e.g. the iron and metal industry and paper mills.

Advantages

Furthermore, use of nanofiltration is an advantage if

- you want a certain hardness, because a potential demineralization will make the water aggressive and lead to problems with corrosion in the supply network.

- you want a purposive reduction of unwanted components and reverse osmosis is to overshoot the mark. Where reverse osmosis requires a high-pressure pump, nanofiltration applies a lower pressure, typically under 7 bar, resulting in a lower energy consumption compared with a reverse osmosis plant with the same productivity.

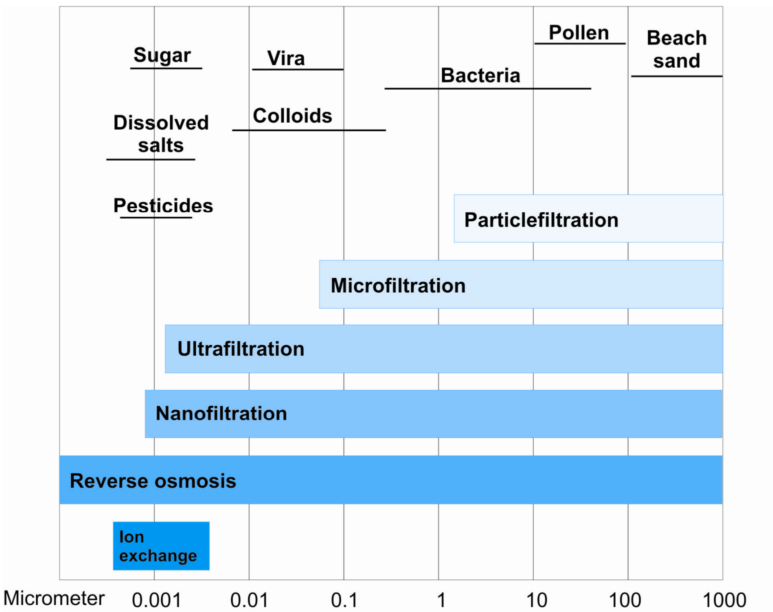
How does it work?

Nanofiltration (NF) is a membrane technology, which in its mode of operation and construction is very similar to reverse osmosis (RO). A nanofiltration membrane primarily restrains divalent ions and larger molecules. When it comes to the filtration process, a NF unit is placed between RO and UF – see the diagram below.

Swedish drinking water plant of 48 m^3/h. The plant consists of 2 x NF 03-24, prefilter and fully automatic cleaning unit. Application: softening of ground water.

More information

Contact your local EUROWATER sales and service office for more information.



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Our World is Water

Appendix 6: Water regeneration - Envotherm

ENVOTHERM >>>>>THE PRODUCT

zero emission

ENVOTHERM®

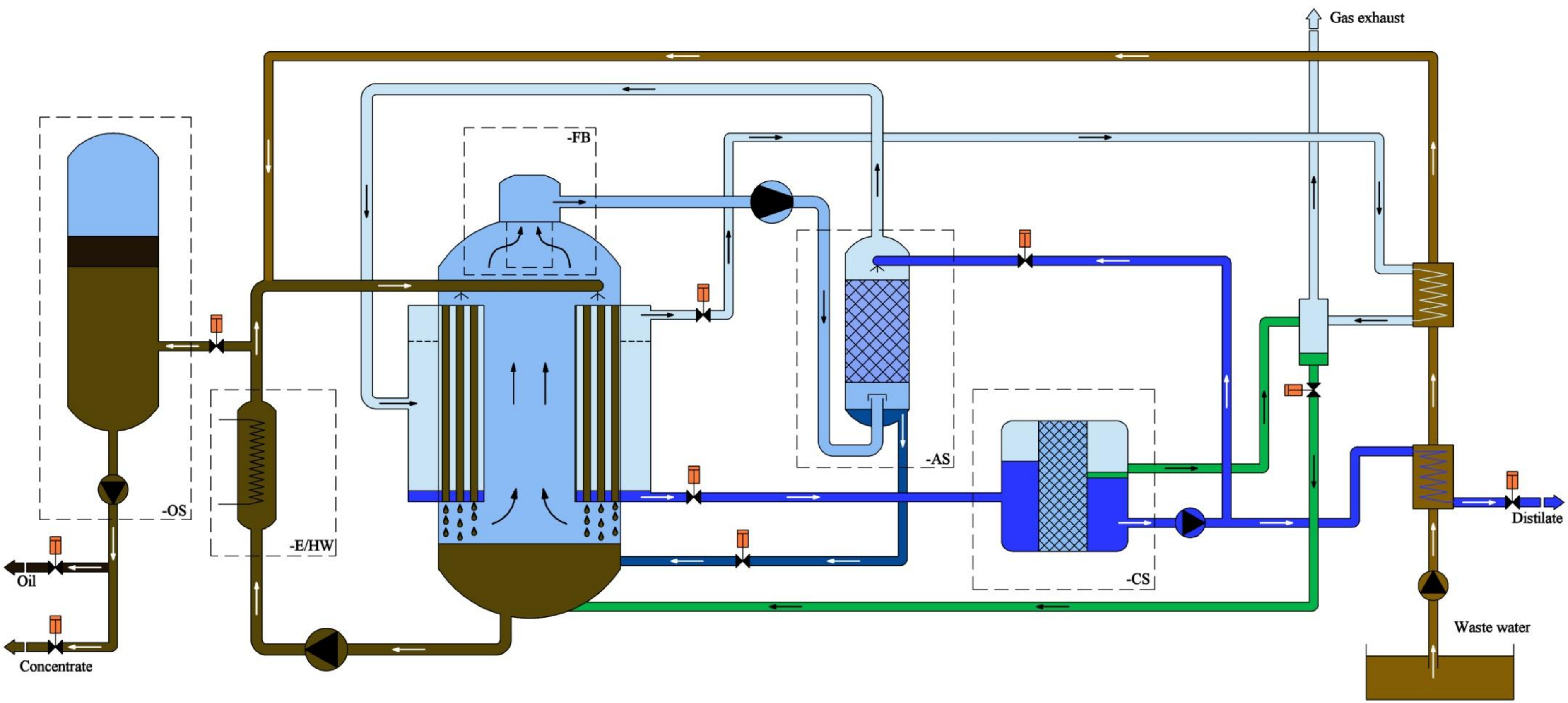
The ET – 50:

- Cycles between 90 - 99% of your wastewater
- It simply transforms the dirty water into distilled water
- Reduction of COD up to 95 %
- The capacity 1000 Liter per day
- Energy consumption 15 - 35 kWh/m^3
- Dimension LxBxH: 110 cm x 68 cm x 220 cm
- Smaller models Flexible on wheels, can be moved around to any location
- Easy Plug & Play installation.
- Internet connection standard
- Can be connected to other machines e.g. , Alkaline cleaning machines, tanks etc.
- A Clean Solution …. Why not ☺

Water: IT'S PURE BUSINESS / envotherm.com

CORE TECHNOLOGY

EVAPORATION


Gas exhaust
-FB
-AS
-CS
-OS
-E/HW
Oil
Concentrate
Distilate
Waste water

zero emission

ENVOTHERM®

Machine sizes	Unit	DW
ET 50	L/day	1,000
ET 75	L/day	1,500
ET 100	L/day	2,000
ET 200	L/day	4,000
ET 300	L/day	6,000
ET 400	L/day	8,000
ET 500	L/day	10,000
ET 1000	L/day	20,000
ET 2500	L/day	50,000

zero emission

ENVOTHERM®

Known application	Industry
Floor wash water	Pharmaceutical, Chemistry, Metalworking, food, petro-chemistry, surface treatment, Hospitals
Carwash water	
Oil emulsion	Metalworking, Silicon wafer production,
Waste water from alkaline cleaning	Petro – chemistry, Metalworking
Rinsing water from **surface treatment**	Metalworking
Oil-bearing waste water	Metalworking
Wash water carrying **Teflon and heavy metals**	Petro – chemistry, Metalworking
Coolant recovery e.g. **ethylene glycol**	Airports
Separation of **organic matter** in general	Petro – chemistry, Metalworking
Leachate treatment and recovery	Landfills, Composting processes
Separation of **oil, soap, heavy metals**	Petro – chemistry
Wastewater containing **Hormones, medicals, additives**	Pharmaceutical, Chemistry
Wastewater containing **Toxins**	Pharmaceutical, Chemistry
Additives food	Food and Dairy industry

zero emission

ENVOTHERM®

Water Quality	Unit	DW
pH	$[H^+]$	8 – 9
Conductivity	µS/cm	< 45
Odor	-	NO

Identification of Water and Energy Conservation in the Iron & Steel Industry in China

COWI has conducted a study about the possibilities for energy and water savings in the steel industry in China. The study shows that there are great potential in terms of energy and water savings in Chinese steel industry and that surplus of energy can be used for district heating.

Danish Ministry of the Environment
Environmental Protection Agency

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