Global Unit Generation

Operation Experience, Operation Procedures In Supercritical And Ultra Supercritical Boilers

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Company Profile

The service scope of E.ON Anlagenservice comprises planning and maintenance expertise for complex power generation and industrial plants.

The EAS core business is securing existing power plants. Furthermore, EAS is involved in the construction business for new power plants.

EAS is one of the largest Non-OEM service providers in Western Europe.
E.ON Anlagenservice

E.ON Anlagenservice is a part of Global Unit - Generation

E.ON group structure

Global Units

- Generation
- Renewables
- Global Gas
- Trading
- New Build & Technology
Global Unit Generation

Content

1. Steam Generator – Overview and Examples
2. Material Map
3. Experiences
1 Steam Generator Systems

Heat requirement for:
1 Preheat
2 Evaporation
3 Overheat
4 Reheat

Systems:
a Natural circulation boiler
b Assisted-circulation boiler
c Assisted-circulation with add. recirculation
d once-through boiler

[Strauß, 2001]
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1 Steam Generator Systems

Working h-p-lines of an actual USC-once-through-boiler:
- 100% Load
- 80% Load
- 40% Load

Super-critical-boiler (SC-Boiler)
Ultra-super-critical-boiler (USC-Boiler)

1976

[Whv Reference Book]
1 Steam Generator Systems

Inclined evaporator membrane wall
(once-through boiler)

Vertical wall tubes in the evaporator:
(fixed evaporation point; → natural circulated or assisted-circulation boiler)
1 Examples for Benson® Steam Generators – Two Pass Boiler

Old Design:

The high was limited by the construction (installation) capabilities.
1 Examples for Benson® Steam Generators – Single Pass Boiler

Design from the end of 70s:

Single pass boiler

Better functionality

Special feature:
Additional ring header – to reduce the thermal and pressure differences between the single tubes of the membrane wall

[Babcock - Reference Sheets]
Discussion Points For The Comparison Of Single Pass And Two Pass Steam Generator:

- Overall height
- Constructive expenses (boiler structural steelwork, suspension)
- Suspension of expansion by the own weight, the fluid weight, the heat
- Working with the 3D-differential expansion in the edge and at the boundaries of the heating surface sections of the evaporator and the super heater
- Arrangement of the catalyst and the regenerative air heater
- Arrangement of the economizer
- Furnace outlet temperature
- Arrangement of the final super heater
- Prevention of an over heating of convection heating surface during the igniting phase before start of the evaporation
- Flue gas flow: avoiding of deposition of ash
- Accessibility of the combustion chamber (inspection platform)
- Accessibility of the convection heating surface tubes
- Height of the fall of slag
1 Comparison Of Lignite And Hard Coal Fired Steam Generator

Lignite:
- Lower ash softening temp.
  → bigger combustion chamber for lignite
- Lower inlet temp. into convective heating surface
  → bigger heating surface dim. (reheater)
- Higher SiO2 content in ash
  → increased wear (flue gas duct should be bigger)
- Lower fuel gas speed
  → bigger heating surface dimension (Eco)
- Greater flue gas volume flow (+45%)
  → bigger volume of convective part
1 Development Of Lignite Coal Fired Steam Generator

M. Bader; Operational Experiences - Steam Generators   2013-03

[HPE, Alstom, RWE; Götte et. al.]
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1 Actual Status - Lignite Coal Fired Steam Generator (p-h-Diagram)

[HPE, Alstom, RWE; Götte et. al.]
1 Boiler House And Boiler Structural Steel Work

Steel:
- Most common
- additional masonry lift gear and stair tower necessary (emergency exit)

Concrete:
- Pylons are usable as lift gear and stair tower

Decision:
cost related
1 Superheater (Schotten) – Arrangement

KW Farge, Kiel, 325 MW, Ge

KW Amager 1, DK

Enough space for combustion / influence of the radiation zone
1 Examples for Benson® Steam Generators – Two Pass Boiler

Wilhelmshaven (720 MW)
Super Critical Power Plant

High Pressure Part
Steam rating 2170 t/h
Allowed working pressure 210 bar
SH-outlet temperature 530 °C

Reheater
Allowed working pressure 55 bar
RH-outlet temperature 530 °C

Fuel
Bituminous coal, oil

Manufacturer
Babcock

Commissioning Year 1976
1 Examples For An Assisted-Circulation Boiler – (Two Pass boiler)

MPP1/MPP2 (540MW)
Power Plant

High Pressure Part
Steam rating: 470 kg/s
Working pressure: 180 bar
SH-outlet temperature: 540 °C

Reheater
Allowed working pressure: 46 bar
RH-outlet temperature: 540 °C

Fuel
Bituminous coal, oil

Commissioning Year
1987 / 1988 (COD)
1 Examples for Benson® Steam Generators – Two Pass Boiler

Heyden Unit 4 (900 MW)
Super Critical Power Plant

High Pressure Part
Steam rating 2405 t/h
Allowed working pressure 215 bar
SH-outlet temperature 535 °C

Reheater
Allowed working pressure 53 bar
RH-outlet temperature 535 °C

Fuel
Bituminous coal

Manufacturer
Babcock

Commissioning Year 1987
1 Examples for Benson® Steam Generators – Single Pass Boiler

Actual Design 600/620°C
For Hard Coal:

- 1100 MWel
- Steam 2939 t/h
- Once-through steam generator, Benson®

- Design parameters:
  SH: 600 °C / 285 bar
  RH: 620 °C / 58 bar
2 Material For Steam Generators – Development Status 2002

Membranwall

- 1995: 13CrMo4-5 (T12)
- 1998: 7CrMoVTiB10-10 (T24)
- 2010: HCM12 (?), Nickel Base Alloy

SH and RH

- 1995: 13CrMo4-5 (T12)
- 1998: 9 - 12 % Chrom Steel
- 2010: Nickel Base Alloy

SD-Outlet-Header

- 1995: X20CrMoV12-1
- 1998: Austenite
- 2010: Nickel Base Alloy

[Based on source: Alstom, 2002]
2 Material For Steam Generators - Status 2012

Membranwall
- Tests: P91, P92, VM12, A617
- Use: 13CrMo4-5 (T12), T24
- Temperatures: 260, 270, 290, 350 bar

SH and RH
- Tests: A617, A263, A740
- Use: DMV 304, 310, Super 304, HR3C
- Temperatures: 260, 270, 290, 350 °C

SD-Outlet-Header
- Tests: A617, A263, A740
- Use: P91
- Temperatures: 260, 270, 290, 350 °C

Materials:
- A617, A263, A740
- P91, P92, VM12
- 13CrMo4-5 (T12)
- T24
- DMV 304, 310, Super 304, HR3C
- X20CrMoV12-1

Tests:
- P91, VM12
- X20CrMoV12-1
2 600°C/620° Power Plant The Material Mapping

\[ S_{\text{wall}} = \frac{p \cdot D}{2 \cdot R_{m,2 \cdot 10^5}} \]
2 Piping – Material P91
(Qualification and application in Germany)

Discussion about different visual nature of martensitic structure, especially thick walled parts

HAZ is weak At ~ 600°C

Mechanical test especially creep test also weld specimens

Main Steam Piping Hot Reheat Piping

Longitudinally welded P91 pipes for hot reheat piping

Creep Damage Analysis ➔ Reflection for Replica ➔ VGB TW 507

VdTÜV $R_{165,600°C}=90$MPa

X20CrMoV12-1 P91 P92 E911
2 Piping Material - P92 for the 600/620°C power plants

Creep Strength for $10^5$h

Best-in-class material for piping of USC-PP
Characteristic data of the actual 1.100 MW-PP-generation
- Capacity: 1100 MW (gross) / 1055 MW (net)
- Efficiency: 45.6%
- Parameter MS: 600°C / 285 bar
- Significant reduction of the CO₂-emissions

Material used or high pressure piping: (PN>40bar)
- X10CrWMoVNb9-2 (P92)
- 10CrMo9-10 (P22)
- 13CrMo4-5 (P12)
- 15NiCuMoNb5-6-4 (1.6368)
- 16Mo3 (P01)
- P235GH (~H1)

High end material for 360°C HP-feedwater line
3 Experiences: Slag
3 Experiences: Slag

Combustion of bituminous coal from international sources, a common problem on many sites

- Broad fuel range with varying quality
- Change of fouling behaviour
- Slagging at the burners
- Increase of furnace exit gas temperature

[Clyde Bergmann, 2013]
3 Experiences: Slag- Cleaning With Water Canon

Sudden evaporation

Cleaning Mechanism
- Water impacts on surface
- Water penetrates into pores of deposit
- Deposit layer “explodes” from wall
- Parameter for successful cleaning
  - Impact water quantity
  - Impact area
  - Jet progression speed
  - Characteristics of deposits

The goal:
Optimum penetration of deposits

[Clyde Bergmann, 2013]
3 Experiences: Slag

Cleaning Effect

View into 2nd pass

[Cl Clyde Bergmann, 2013]
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3 Experiences: Flow Accelerated Corrosion (FAC)

[Kastner et. al., 1990]
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3 Experiences: Flow Accelerated Corrosion (FAC)

Prevention of FAC by Correct Process Engineering

Correct Water Chemistry

![Graphs showing the relationship between flow acceleration, corrosion, and water chemistry parameters](image)

*Carbon Steel Plate with 3% Mo*

[Kastner et al., 1990]
3 Experiences: Flow Accelerated Corrosion (FAC)

Prevention of FAC by material selection

Influence of the geometry

[Graph showing FAC prevention and influence of geometry]
3 Experiences: Corrosion Fatigue (CF)

44,5 mm ä Ø x 5,0 mm

Example: drain line

T~250°C; p=260bar; t=200,000h
3 Experiences: Stress Corrosion Cracking (SCC)
3 Experiences: High Temperature Corrosion (HTC)

- High temperature corrosion in the steam generator

\[ d_{top} = \sqrt{k_D \cdot t} \]
The creep velocity increases with the scaling growth.
3 High-Temperature Corrosion - Special Effects \(\rightarrow\) Exfoliation

**Boiler parameters:**

- Nominal heat rate: 437 MW
- Nominal rate: 547 t/h
- Maximum continuous rate: 575 t/h
- Superheated steam pressure: 18.1 MPa
- Superheated steam temp.: 575°C
- Hot reheated steam pressure: 3.6 MPa
- Hot reheated steam temp.: 580°C
- Feed water temperature: 249.5°C

Deposit of the delaminated magnetite layer

[VGB, Lüdenbach, 2011]
3 Exfoliation Of Magnetite Layer Of Austenitic RH-Material

[Dong, Larsen, 2008]
3 Exfoliation Of Magnetite Layer Of Austenitic RH-Material

Esbjergværket Unit 3

Year of commissioning: 1992
Fuel: Pulverised coal
Capacity: 400MW_{el}
Steam data: 260 bar/560 °C / 560 °C

[Dong, Larsen, 2008]
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3 Exfoliation Of Magnetite Layer Of Austenitic RH-Material

[Dong, Larsen, 2008]
3 Special Application Of Super304H And DMV304HCu

**Practise**
- Small Cr$_2$O$_3$-layer
- High deformation region – high dislocation density, more subgrains and smaller grains
- Cr-Diffusion
- Only small islands of Cr$_2$O$_3$ in the inner oxide layer
- A closed Cr$_2$O$_3$ layer

**Theory**
- High deformation region – high dislocation density, more subgrains and smaller grains
- More grain boundaries – more faster ways to bring Cr to the surface

[Based on source: HPE, Husemann, 2007]
Résumé

- EU: Small steam generators are generally natural circulation boiler or forced circulation boiler. Big steam generators are mostly once-through boiler.
- The single pass boiler are more popular since the late 70s.
- The different load situation in the boiler leads to different failure mechanism and also to different failure chains.
- Most of the actual issues are related to the flexibility.