Finnish Recovery Boiler Committee

SKYREC STEERING COMMITTEE MEETING VIII

TIME December 16th, 2009 10.00 – 16.00

PLACE Pöyry Industry Oy, Vantaa

PARTICIPANTS

Matti Tikka	UPM-Kymmene Oyj, Kymi, chairman
Lasse Koivisto	Andritz Oy, Varkaus
Timo Peltola	Sandvik, Helsinki
Keijo Salmenoja	Chairman of Finnish Recovery Boiler Association
Kalle Salmi	Metso Power Oy, Tampere
Timo-Pekka Veijonen	Stora Enso Oyj

Group members without a right to vote:

Reijo Hukkanen	Stora Enso Oyj, Oulu
Esa Vakkilainen	LUT, project coordinator
Markus Nieminen	Finnish Recovery Boiler Association, secretary

Other, during item 5.1

Patrik Yrjas	Åbo Akademi University, Turku
Dorota Bankiewicz	Åbo Akademi University, Turku

APPENDIXES

I	Project budget
II	Project schedule
III	LUT: Once-through and reheater recovery boiler concepts - presentation 15.12.2009
IV	LUT: Once-through and reheater recovery boiler concepts – report for comments 18.11.2009
V	ÅA: Corrosion behaviour of four steels under reducing conditions – test results and preliminary conclusions
VI	VTT: Mill tests of superheater materials - status report 26.11
VII	OY: Ceramic structural materials – accepted proposal
VIII	Teollisuuden Vesi Oy: TOC-removal methods and applicability for recovery boiler make-up water treatment – status report (in Finnish)
IX	OY: Reduction of TOC from recovery boiler make-up water – status presentation 19.11 (In Finnish)
X	To Be Done – presentation
XI	Nikolai DeMartini, Åbo Akademi: Co-firing black liquor and bio-mass-laboratory tests, phase 2 – proposal
XII	LUT: Pulp mill optimal steam pressure levels – proposal (In Finnish)

DISTRIBUTION

Steering committee and their substitutes
Durability Sub Committee, Black Liquor Sub Committee
Board of the FRBC
MNN, OMP, EPT/Files

1 CALLING MEETING TO ORDER

1.1 Abcences

Hiroshi Matsuo	Sumitomometal Industries,Ltd.
Mika Paju	Oy Metsä-Botnia Ab, Joutseno
Martti Korkiakoski	Tekes
Olli Talaslahti	Oy Metsä-Botnia Ab, Rauma

2 MEMO OF THE PREVIOUS MEETING (4/2009)

The memo of the previous meeting was accepted.

3 BUDGET

Updated budget (situation 16.12.2009) is presented in Appendix I. Current version shows costs that have been paid in 2008, 2009 and allocated costs to 2010 and 2011.

4 TIME SCHEDULE

Schedule (situation 16.12.2009) is presented in Appendix II. There have been setbacks in the furnace and superheater material field tests.

Extension application has been send to TEKES. Project requests one year extension due to the fact that pulp mills have had many temporary shutdowns during 2009 and these shutdowns have delayed the field test projects.

5 ONGOING PROJECTS

5.1 LUT, Once-through and reheater recovery boiler - concept studies (WP1, S3)

Esa Vakkilainen gave a presentation of the calculations results, see Appendix III.

Project report for comments, see Appendix IV. Comments should be given latest February 15th 2010.

Final report will be accepted in the next SKYREC jory meeting March 17th.

Conclusions:
- Electricity generation does not depend a lot on how the boiler steam side is configured. Once-through boiler (Case F) and assisted circulation (Case D) produces about same amount of extra electricity.
- Reheating (case E) seems not so profitable, it needs lot of superheating surface
- Increasing steam temperature and pressure is very profitable, but corrosion?

5.2 Åbo Akademi, Laboratory tests of superheater material (WP2, T3)

Dorota Bankiewicz and Patrik Yrjas reported preliminary results of superheater material corrosion tests, see Appendix V.

Test were made under alkali sulfates and chlorides containing synthetic ashes in reducing (5% CO + 95% N2 – 2 l/min) atmosphere. Results are compared to previous project (SOTU II) were similar tests were made in oxidising atmosphere.

Items to be clarified:
- Previous test results in oxidising atmosphere were pretty consistent, but test results in reducing atmosphere needs more explaining.
- Difference (0 vs. 62) in corr. prod. thickness with two samples of HR11N
- What does the corrosion thickness number mean; could corrosion be shown like steel loss from the base line?
- Oxygen partial pressure in those conditions
- Is nickel somehow affecting to the test results

Conclusions to be presented in the report.

Preliminary report was agreed to be delivered in week 5, durability subcommittee has meeting in week 6, February 10th 2010.

Report for comments will be send to the steering group 15th February 2010 and final report will be accepted in next meeting.

5.3 VTT, Mill tests of superheater materials, (WP2, T3)

VTT has received all the test materials and construction of the probe will be in completed by the end of December 2009. Mill tests will start in January 2010. Intermediate report (26.11.2009) in Appendix VI (in Finnish).

Secretaty will check from Markku Orjala and Pekka Pohjanne (VTT) that thickness of the material samples is measured before tests.

Mr. Orjala is invited to next durability sub-committee meeting in February 10^{th} 2010 in Varkaus. First 1000 hour test is almost finished by then.

5.4 FRBC's Material recommendation (WP3, P1)

Durability committee is preparing table of contents for material recommendation. It should be ready in February 10^{th} 2010.

Separate groups needs to be formed for preparing a furnace and superheater material recommendation and a water quality recommendation. Durability subcommittee will make a suggestion for persons to be included in each group. Each group's work to be reported to the steering committee

5.5 Oulun Yliopisto, Ceramic structural materials (WP3, P2)

Durability committee has ordered work, cost 15 000 €. Microstructure study cost extra 1025 € / sample.

Project will be executed in two phases. Quick (one to two weeks) test with all materials is done before mill shutdown in week 4, 2010. During shutdown specimens can be pulled off from the furnace for inspection without that the specimens get broken.

Results from the first test will be presented in durability sub-committee meeting in February 10^{th} 2010. Then 3-4 best materials are chosen to the longer test and after that is decided which samples microstructure is studied. Accepted proposal in appendix VII (in Finnish).

5.6 Boildec Oy, Field testing of furnace materials (WP3, P3)

The first experiment was failed third time, this time experiment had to be stopped because probe's temperature control didn't work. No report was received to the meeting but Karjunen told that modifications were made to the probe and they will do a test run this week without the specimens. If the test is successful they will start the fourth test.

5.7 VTT, Analysis of the furnace test materials (WP3, P3)

Secretary will check if VTT needs more test specimens, present contract includes four test material preparations and analyses.

5.8 VTT, Effect of water quality and different chemicals on magnetite layer properties (WP4, V3)

No status report from VTT. Secretary will contact Pekka Pohjanne.

5.9 Teollisuuden Vesi Oy, TOC removal methods and their applicability in make-up water treatment (WP4, V1)

Project is in schedule. Short report has been received from Teollisuuden Vesi Oy, see appendix VIII (in Finnish).

Report for comments is coming latest January 9th. Commenting is done in durability sub-committee meeting February 10th 2010.

5.10 Oulun Yliopisto, Reduction of TOC from recovery boiler make-up water (WP4, V1)

Project is underway and in schedule.

TOC-measurements have been made in four different water supply plants (Stora Enso, Kemira, Oulun vesi (Veitsiluoto and Kurkelanranta)). Also the affect of ion exchange resin lifetime to TOC-removal is studied. Next there will be pilot tests with activated carbon.

Project status presentation (20.11.2009), see Appendix IX (in Finnish).

5.11 FRBC's Water quality recommendation, (WP4, V1)

Durability committee is preparing table of contents for water quality recommendation. It should be ready in February 10th 2010.

Water quality recommendation should include practices what to analyse and how often and also operating instructions what to do when a value exceeds the limit.

Separate groups needs to be formed for preparing a furnace and superheater material recommendation and a water quality recommendation. Durability subcommittee will make a suggestion for persons to be included in each group. Each group's work will be reported to the steering committee.

5.12 Others

5.12.1 LUT: Effect of the furnace heat load on the recovery boiler designing (WP1, P2)

Final report was accepted. Report is published in the FRBC's home page.

6 PROPOSALS

Project coordinator has prepared a presentation how well we are fulfilling the proposal and what was stated there, see appendix X.

Missing items:
WP1, S2: Increasing electricity generation from current recovery boilers
- will be fullfilled in ordered project: Optimal steam pressure levels of pulp mill, see offer in appendix XII (In Finnish).

WP3, P2: recovery boiler furnace heat flux measurements
- this is covered in Boildec measurements

International co-operation
- Keijo Salmenoja will contact Jim Keiser, ORNL

6.1 Åbo Akademi, Co-firing of black liquor and biomass – laboratory combustion tests, phase 2 (WP1, S1)

Phase 1 studied the combustion of mixtures of black liquor with either bark, wood, peat or biosludge. The proposed phase 2 would focus on bark and wood, see Appendix XI.

Decision:
Keijo Salmenoja will ask revised proposal were "clean" fuels (wood, biosludge) will be tested, not bark. Also tests with lignin extracted black liquor would be insteresting to see, extraction should possible by lowering the black liquor pH.

6.2 Other offers

6.2.1 LUT: Pulp mill optimal steam pressure levels (WP1, S2)

Lappeenranta University of Technology has offered work: Pulp mill optimal steam pressure levels, see appendix XII (In Finnish).

Project will have 3 parts:
Part 1.
Collect data from the the mills: steam pressure levels in use and reasons for those levels.

Part 2.
Calculate annual averege balances for both modern and traditional about 600 000 ADT/a pulp mill. Estimate investments costs between different

pressure levels and affect of various electricity price to the chosen pressure levels.Calculations with/without power boiler and with fine paper integrate.

Part 3.
Work out possibilites and ways to increasing electricity generation from current recovery boilers.

Decision
It was decided to order the work. Work will be done in English but reported in Finnish. Secretary will send the proposal to black liquor sub-committee for comments.

6.2.2 Project idea: Taking out pyrolyse gas from recovery boiler

Idea is to take out pyrolyse gases from RB and use it as fuel lime kiln. There is many open items like emissions, gas cleaning..

Esa Vakkilainen will think what could be done and Keijo Salmenoja will contact Åbo Akademi about their RB model.

7 OTHER ISSUES

8 NEXT MEETINGS (MEETING CALENDAR FOR 2010)

The next meeting will be held at Pöyry Industry Oy, Vantaa, on March 17th at 10.00 a.m.

APPENDIX I

Project budget

SKYREC

INCREASING RECOVERY BOILER ELECTRICITY GENERATION TO A NEW LEVEL

		Ordered	Offers	2008 Paid	2009 Paid	2010 Ordered	2010 Reserved
WP1	**New recovery boiler concepts**						
S1	Increasing the range of fuels to be fired in recovery boilers						
	- ÅA: Increasing the range of fuels to be fired in recovery boil	7 500,00 €			7 500,00 €		
	- ÅA: Increasing the range of fuels to be fired in recovery boilers (reservation)		16 000,00 €				16 000,00 €
S2	Increasing electricity generation from current recovery boilers						
	- project reservation		25 000,00 €				25 000,00 €
S3	Recovery boiler as once-through boiler						
	- LTU: Recovery boiler as once-through boiler	33 800,00 €				33 800,00 €	
	110000		**82 300,00 €**				
WP2	**Increasing superheated steam temperature**						
T1	Analyzing and utilizing existing knowledge						
	- TKK (reservation)		25 000,00 €				25 000,00 €
T2	New superheater materials, choosing						
T3	Corrosion chemistry with high steam values						
	- ÅA: Chemistry of recovery boiler flue gas side, laboratory m	37 000,00 €			15 000,00 €	22 000,00 €	
	- VTT: Corrosion study of recovery boiler superheater materi	108 000,00 €			20 800,00 €	87 200,00 €	
	- VTT: Analyzes for test materials						
T4	Choosing superheater materials for high temperatures						
	175000		**170 000,00 €**				
WP3	**Increasing recovery boiler pressure**						
P1	Analyzing and utilizing existing knowledge						
	- FRBC material recommendation (KTR)		25 000,00 €				5 000,00 €
P2	Ceramic and metallic components						
	- OY: Ceramics in furnace	15 000,00 €				15 000,00 €	
P3	Effect of furnace operation						
	- LTU: Dynamic char bed	14 800,00 €			14 800,00 €		
P4	Furnace materials in high pressure materials						
	- Boildec: Material testing in furnace	98 000,00 €		19 600,00 €		78 400,00 €	
	- Boildec: Material testing in furnace (reservation)		50 000,00 €				
	- VTT: Analyzes for Boildec tests	29 000,00 €			9 000,00 €	20 000,00 €	
	- VTT: Analyzes for Boildec extra tests		20 000,00 €				20 000,00 €
	250000		**251 800,00 €**				

WP4	**Ensuring boiler and feedwater quality**						
V1	Analyzing and utilizing existing knowledge						
	- water quality and water treatment recommendations		25 000,00 €				5 000,00 €
	- Boildec: Recommendation for water quality control in recovery boilers		- €				
	- VTT: Literature study amines	17 700,00 €		5 310,00 €	12 390,00 €		
			~~59 200,00 €~~				
	- Teollisuuden vesi: Effect of water quality to airheater corros	24 600,00 €			24 600,00 €		
	- Teollisuuden vesi: TOC-research a + b	45 500,00 €			18 000,00 €	27 500,00 €	
V2	Development of chemicals testing						
	- VTT (reservation)		40 000,00 €				40 000,00 €
V3	Testing oxygen scavenging chemicals						
	- VTT: Magnetite formation	65 000,00 €			19 500,00 €	45 500,00 €	
V4	Formation of magnetite layer in autoclave						
V5	Formation of magnetite layer in recovery boiler						
	220000		**217 800,00 €**				
WP5	**Co-ordination etc.**						
K1	Coordinator	4 000,00 €			2 000,00 €		
K2	Secretarial work						
K3	Meetings, information distribution		24 227,25 €	2 690,00 €	8 537,25 €		8 000,00 €
K4	Translations		10 000,00 €				
	30000						
Sumr	785000		**760 127,25 €**	**27 600,00 €**	**152 127,25 €**	**329 400,00 €**	**144 000,00 €**
						473 400,00 €	
	Ordered work	**499 900,00 €**					
	Reservations	260 227,25 €					
	Paid work (16.12.2009)	179 727,25 €					
	Reported to TEKES (31.10.2009)	139 559,00 €					
	Difference	40 168,25 €					

	Reserved
	Offer
~~12345~~	~~not ordered~~
2011	Ordered
	Paid

20 000,00 €

50 000,00 €

20 000,00 €
2 000,00 €
5 000,00 €
10 000,00 €
107 000,00 €

APPENDIX II

Project schedule

SKYREC - schedule

2010 | Extented time -> | **2011**

Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr

Original start date for project 1.1.2008
Decision from TEKES 24.4.2008
Organisation meeting 5.6.2008
Second meeting 18.9.2008
First order 30.10.2008

WP1 New recovery boiler concepts

S1 Increasing the range of fuels to be fired in recovery boilers
- ÅA: Increasing the range of fuels to be fired in recovery boilers, part 1
- ÅA: Increasing the range of fuels to be fired in recovery boilers, part 2

S2 Increasing electricity generation from current recovery boilers
- Project reservation

S3 Recovery boiler as once-through boiler
- LUT: Recovery boiler as a once-through boiler – concept study   px

WP2 Increasing superheated steam temperature

T1 Analyzing and utilizing existing knowledge
- TKK (reservation)

T2 New superheater materials, choosing

T3 Corrosion chemistry with high steam values
- ÅA: Chemistry of recovery boiler flue gas side, laboratory measurements   p
- VTT: Corrosion study of recovery boiler superheater materials

T4 Choosing superheater materials for high temperatures

WP3 Increasing recovery boiler pressure

P1 Analyzing and utilizing existing knowledge
- FRBC's material recommendation (KTR)

P2 Ceramic and metallic components
- OY: Ceramics in furnace

P3 Effect of furnace operation
- LUT: Dynamic char bed   a

P4 Furnace materials in high pressure materials
- Boildec: Material testing in furnace
- Boildec: Material testing in furnace (reservation)
- VTT: Analyzes for Boildec tests (4 tests)

- VTT: Analyzes for Boildec extra tests

WP4 Ensuring boiler and feedwater quality

V1 Analyzing and utilizing existing knowledge
- water quality and water treatment recommendations
- VTT: Literature study amines
- Teollisuuden vesi: Effect of water quality to airheater corrosion, TOC-balance
- Teollisuuden vesi: TOC-research a + b x
- University of Oulu: TOC research

V2 Development of chemicals testing
- VTT (reservation)

V3 Testing oxygen scavenging chemicals
- VTT: Magnetite formation

V4 Formation of magnetite layer in autoclave

V5 Formation of magnetite layer in recovery boiler

WP5 Coordination and other

K1 Coordinator

K2 Secretary services

K3 Meetings and communication

K4 Translations

May Jun

	reservation
	original schedule
	extended schedule (if needed)
	forecast
p	presentation
x	preliminary report
a	final report accepted

APPENDIX III

LUT:
Once-through and reheater recovery boiler concepts – presentation 15.12.2009

Once-through and reheater recovery boiler concepts

Report on progress 15.12.2009

Esa K. Vakkilainen

Progress report

- Studied concepts redefined 26.6.2009
- All recovery boilers dimensioned
- Requirement to do mill balances for No Power boiler concepts
- Mill balances for all concepts finished
- Reheater concept
- Comparison of profitability
- APROS runs
- Comparison of preheater concepts

Concepts studied (redifined, 26.6.2009)

A. Natural circulation 82 %, 490 ^oC, 9.0 MPa (Joutseno)

B. Natural circulation 85 %, 505 ^oC, 10.2 MPa (Kymi)

C. Natural circulation 85 %, 515 ^oC, 12.0 MPa (Yonago)

Future boiler concept

D. Assisted circulation 85 %, 540 ^oC, 16.0 MPa (SoTu)

Reheat boilers

E. Natural circulation 85 %, 515/515 ^oC, 12.0/3.0 MPa (SkyRec)

F. Once-through 85 %, 540/540 ^oC, 26.0/5.4 MPa (Skyrec+)

Case		A	B	C	D	E	F
Capacity	tds/d	5500	5500	5500	5500	5500	5500
capacity (virgin)	tds/d	5005	5005	5005	5005	5005	5005
Dry solids	%	82.0	85.0	85.0	85.0	85.0	85.0
ds (virgin)	%	80.6	83.8	83.8	83.8	83.8	83.8
recycle ash	%	9.0	9.0	9.0	9.0	9.0	9.0
HHV	MJ/kgds	13.00	13.00	13.00	13.00	13.00	13.00
LHV	MJ/kgds	12.28	12.28	12.28	12.28	12.28	12.28
O2 in dry flue gas	%	2.8	2.8	2.8	2.8	2.8	2.8
Primary air percentage	%	23.0	22.0	22.0	22.0	22.0	22.0
Primary air temperature	°C	150.0	190.0	190.0	190.0	190.0	190.0
Secondary air percentage	%	50.0	54.0	54.0	54.0	54.0	54.0
Secondary air temperature	°C	120.0	190.0	190.0	190.0	190.0	190.0
Tertiary air percentage	%	27.0	12.0	12.0	12.0	12.0	12.0
Tertiary air temperature	°C	30.0	190.0	190.0	190.0	190.0	190.0
Quartenary air percentage	%	0.0	12.0	12.0	12.0	12.0	12.0
Quartenary air temperature	°C	30.0	190.0	190.0	190.0	190.0	190.0
Total air temperature	°C	102.6	190.0	190.0	190.0	190.0	190.0
Reduction	%	95.00	96.00	96.00	96.00	96.00	96.00
Main steam pressure RB	bar(a)	91.0	102.0	120.0	160.0	105.0	260.0
Main steam temperature RB	°C	490.0	505.0	515.0	540.0	505.0	540.0
Main steam pressure PB	bar(a)	91.0	102.0	102.0	102.0	102.0	102.0
Main steam temperature PB	°C	490.0	505.0	505.0	505.0	505.0	505.0
Feedwater pressure	bar(a)	110.0	121.0	146.0	182.0	290.0	290.0
Feedwater temperature	°C	120.0	148.0	148.0	148.0	148.0	148.0
		511.3	630.9	632.5	634.8	641.8	641.8
Reheater inlet pressure	bar(a)					36	56
Reheater inlet temperature	°C					348	337
Reheater outlet pressure	bar(a)					34	54
Reheater outlet temperature	°C					400	460
HP FWpreheater inlet temperature	°C	200	200	200	200	200	200
HP FWpreheater outlet temperatu	°C	200	200	220	220	220	220
Flue gas temperature (eco out)	°C	155	197	197	197	197	197
Flue gas temperature (to stack)	°C		155	155	155	155	155
Sootblowing	kg/s	6.0	6.0	6.0	6.0	8.0	8.0

Electricity generation (with PB)

Case		A	B	C	D	E	F
Capacity	tds/d	5500	5500	5500	5500	5500	5500
Dry solids	%	82.0	85.0	85.0	85.0	85.0	85.0
Main steam	bar(a)	94.0	104.0	124.0	164.0	124.0	264.0
Main steam	°C	490.0	505.0	515.0	540.0	515.0	540.0
Steam flow	kg/s	215.0	226.4	232.5	232.0	224.0	218.5
	%	0.0	5.3	8.1	7.9	4.1	1.6
Pulping usage	MW	87.6	88.1	88.9	90.2	88.2	93.2
Mill usage total	MW	95.5	96.1	96.9	98.2	96.2	101.2
Electricity prod.	MW	234.4	239.5	249.8	262.9	250.1	263.4
Electricity sales	MW	138.9	143.3	153.0	164.7	153.8	162.2
Efficiency	%	23.2	23.1	24.1	25.4	24.1	25.4
Additional electricity	MW	0.0	4.4	14.0	25.8	14.9	23.2
	%	0.0	3.2	10.1	18.5	10.7	16.7

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Electricity generation (No PB)

Case	**A**	**B**	**C**	**D**	**E**	**F**	
Capacity	tds/d	5500	5500	5500	5500	5500	5500
Dry solids	%	82.0	85.0	85.0	85.0	85.0	85.0
Main steam	bar(a)	94.0	104.0	124.0	164.0	124.0	264.0
Main steam	°C	490.0	505.0	515.0	540.0	515.0	540.0
Steam flow (RB)	kg/s	215.0	226.4	232.5	232.0	224.0	218.5
	%	0.0	5.3	8.1	7.9	4.1	1.6
Pulping usage total	MW	87.6	88.1	88.9	90.2	88.2	93.2
Mill total usage	MW	91.1	91.7	92.4	93.8	91.8	96.8
Electricity prod.	MW	149.3	153.9	161.8	175.6	162.3	177.9
Surplus electricity	MW	58.2	62.2	69.4	81.7	70.5	81.1
Efficiency	%	20.4	20.4	21.4	23.2	21.5	23.5
Change in electricty	MW	0.0	4.0	11.2	23.6	12.3	22.9
%	0.0	6.8	19.3	40.5	21.1	39.4	26.2

Recovery boiler own power usage

Case		A	B	C	D	E	F
Air fan power	kW	2275	2296	2296	2296	2296	2296
Flue gas fan	kW	2570	2534	2534	2534	2534	2534
Feedwater pump	kW	3055	3556	4347	5719	4187	8606
Other power	kW	1500	1500	1500	1500	1500	1500
Total power	kW	9401	9886	10677	12049	10518	14937

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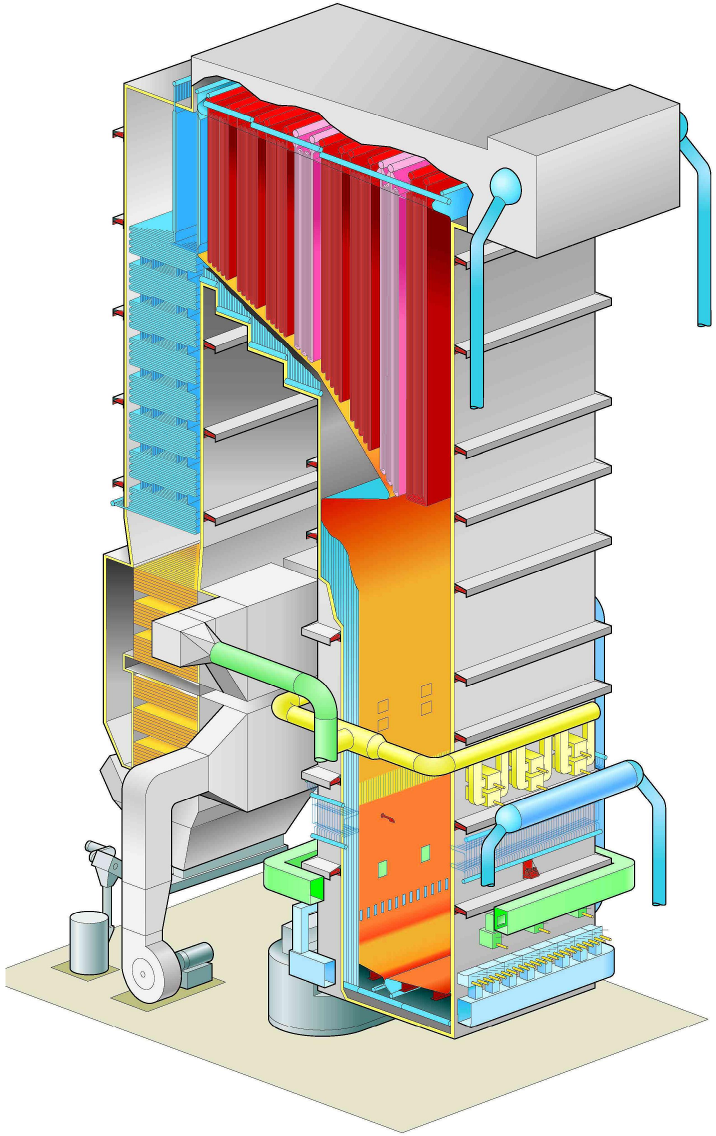
Reheater recovery boiler concept

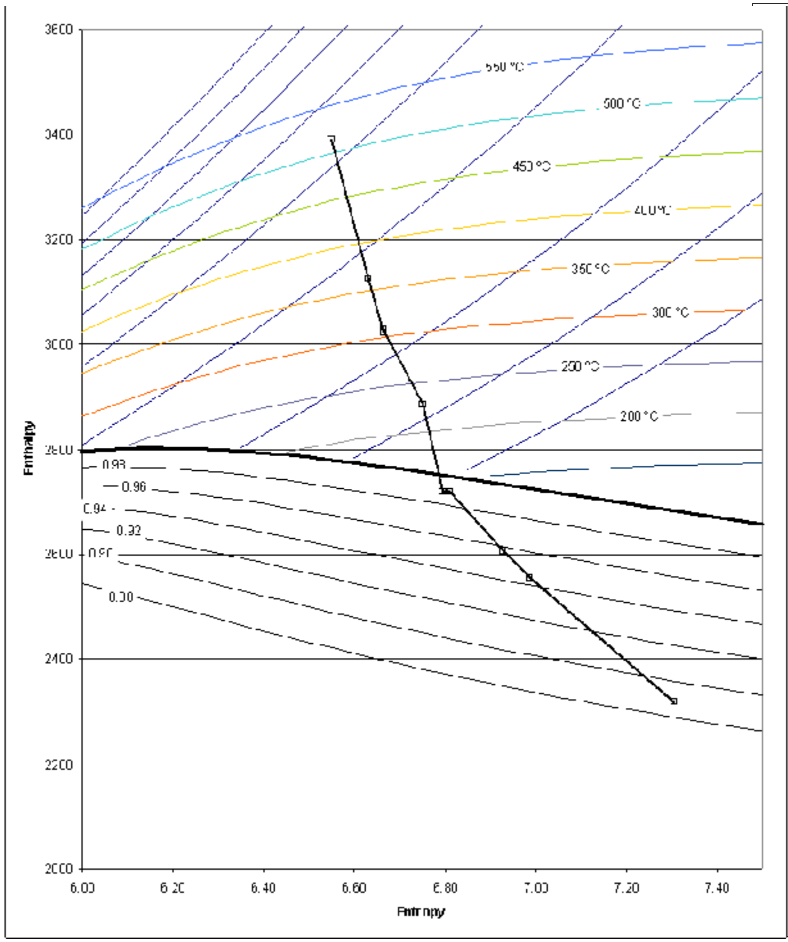
Reheater recovery boiler concept Vendor Babcock & Wilcox, Capacity 4500 t ds/24h, Black liquor ds 85 %

Main steam 130 kg/s 179 bar(a) 510 °C

Reheated steam 62 bar(a) 443 °C.



Case C


550 °C
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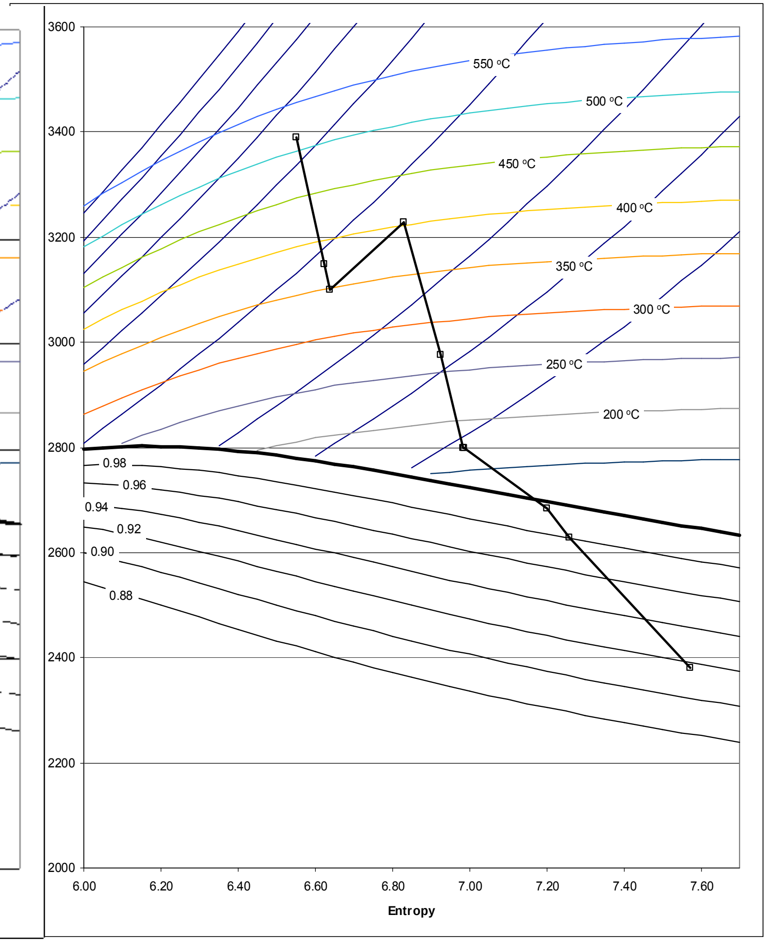
6.60
6.80
7.00
7.20
7.40
Enthalpy
Entropy

Case E


550 °C
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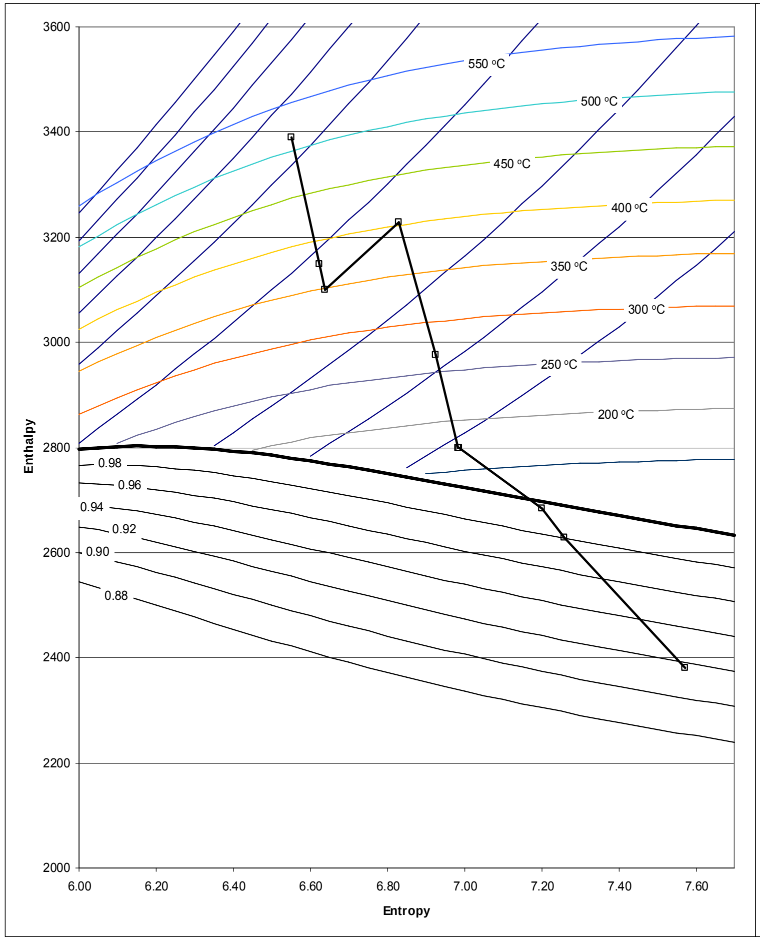
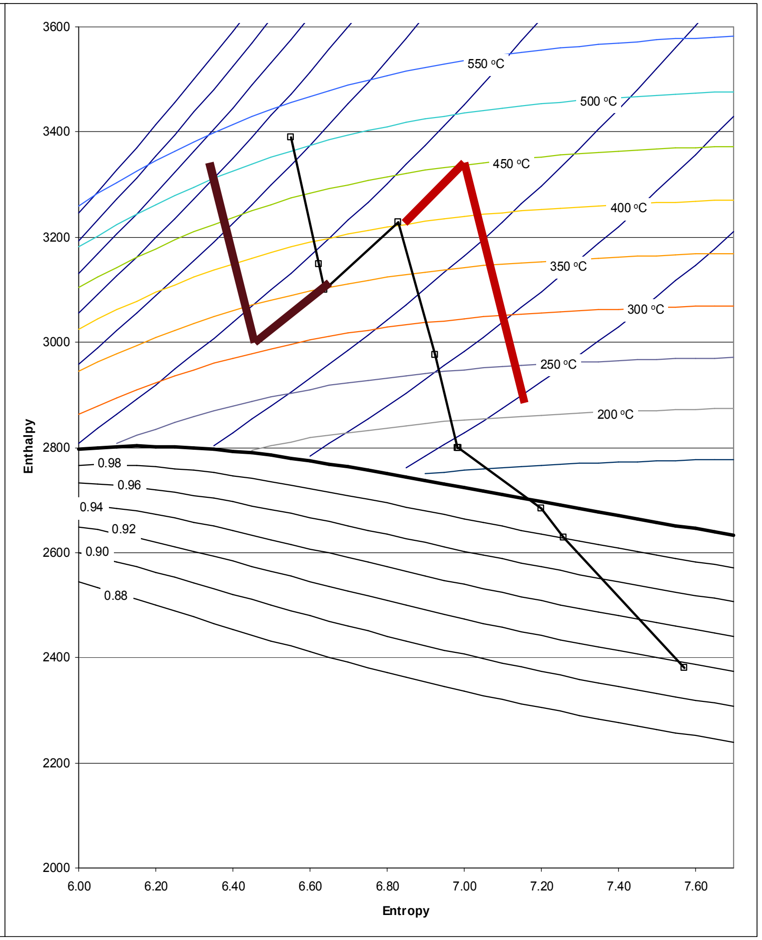
2800
2600
2400
2200
2000
6.00
6.20
6.40
6.60
6.80
7.00
7.20
7.40
7.60
Entropy

Case E



Case E160



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Choise of reheating steam values

	480°C	460°C	440°C	420°C	400°C	380°C	360°C	340°C	320°C
5.4 MPa	182.7	***169.9***	***157.1***	***147.9***	147.9	147.9	147.9	147.9	147.9
	1.000	***1.000***	***1.000***	***0.994***	0.978	0.938	0.920	0.900	0.879
4.4 MPa	202.4	189.3	***176.1***	***162.8***	***147.9***	***147.9***	147.9	147.9	147.9
	1.000	1.000	***1.000***	***1.000***	***1.000***	***0.984***	0.967	0.934	0.914
3.4 MPa	228.2	214.5	200.8	187.0	***173.2***	***159.3***	***147.9***	147.9	147.9
	1.000	1.000	1.000	1.000	***1.000***	***1.000***	***0.995***	0.978	0.960
2.4 MPa	264.8	250.3	235.8	221.2	206.6	192.0	***177.3***	***162.6***	***147.9***
	1.000	1.000	1.000	1.000	1.000	1.000	***1.000***	***1.000***	***0.998***
1.4 MPa	326.8	310.8	294.8	278.7	262.6	246.5	230.4	214.3	198.1
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

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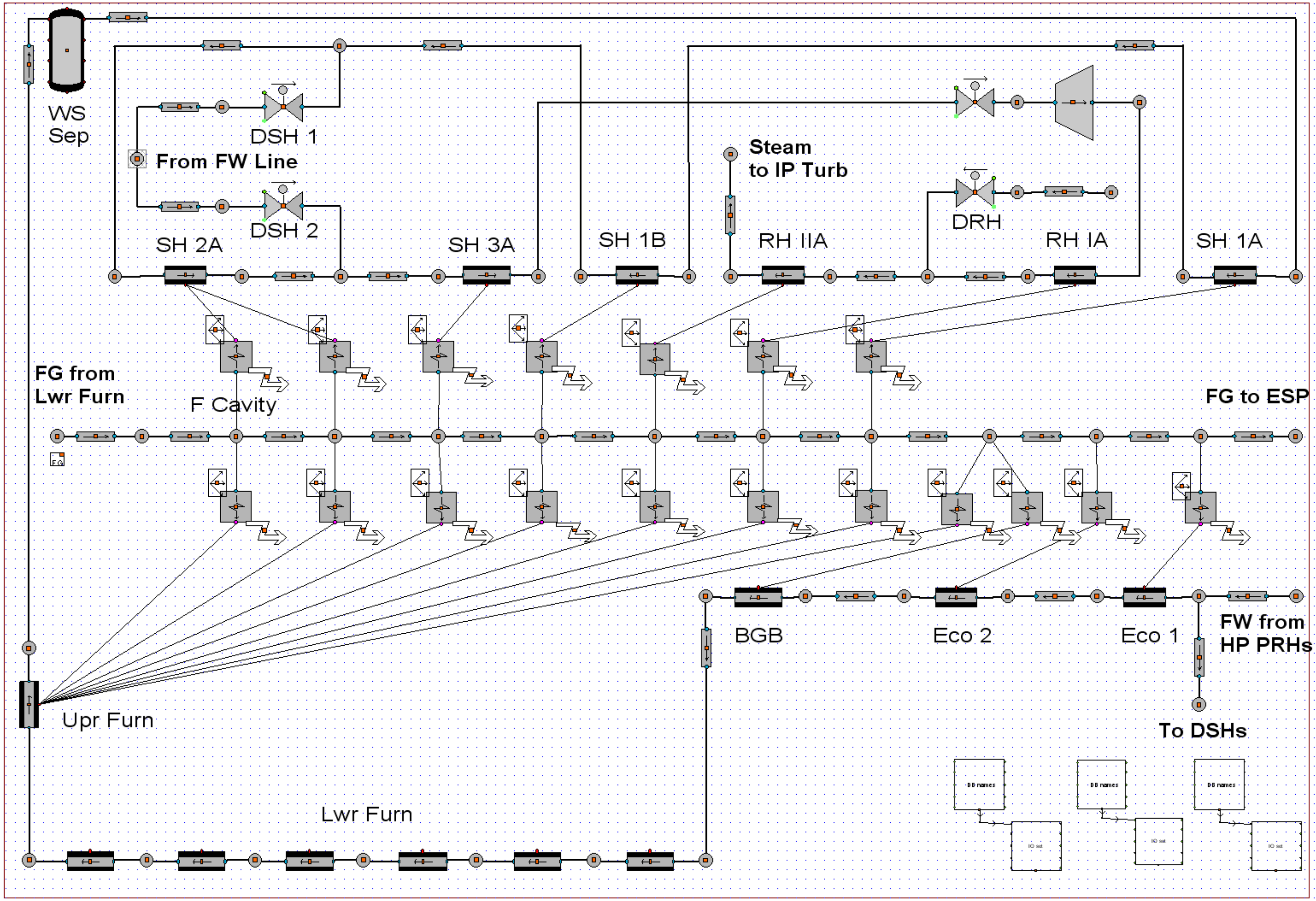
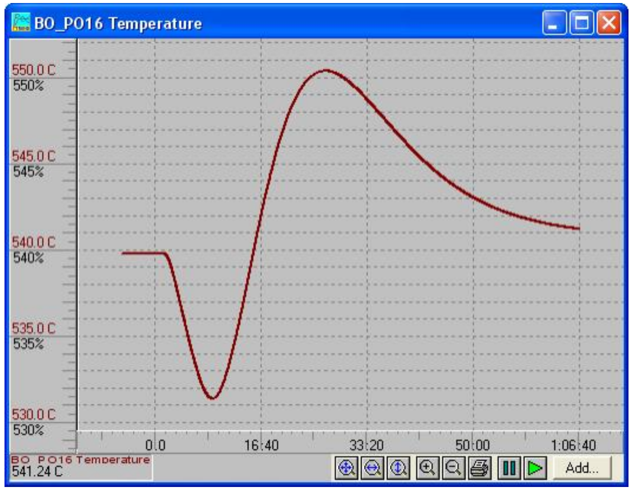
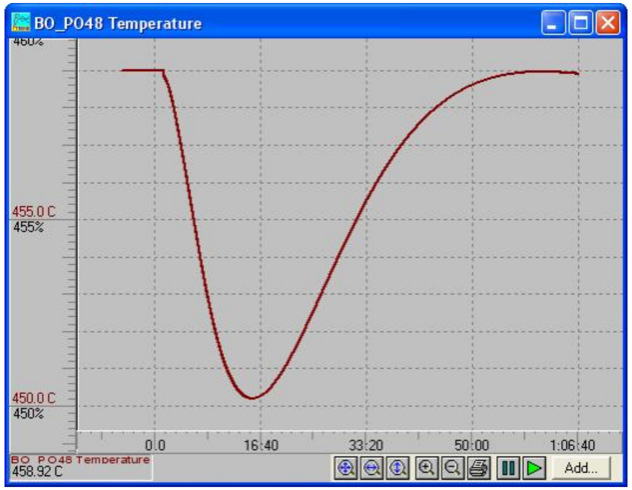
APROS calculations

- Calculations 100 % ja 80 % Tapaus F
- Calculation 100 % -> 80 %


WS
Sep
DSH 1
From FW Line
DSH 2
SH 2A
SH 3A
SH 1B
Steam
to IP Turb
DRH
RH IIA
RH IA
SH 1A
FG from
Lwr Furn
F Cavity
FG to ESP
BGB
Eco 2
Eco 1
FW from
HP PRHs
To DSHs
Upr Furn
Lwr Furn



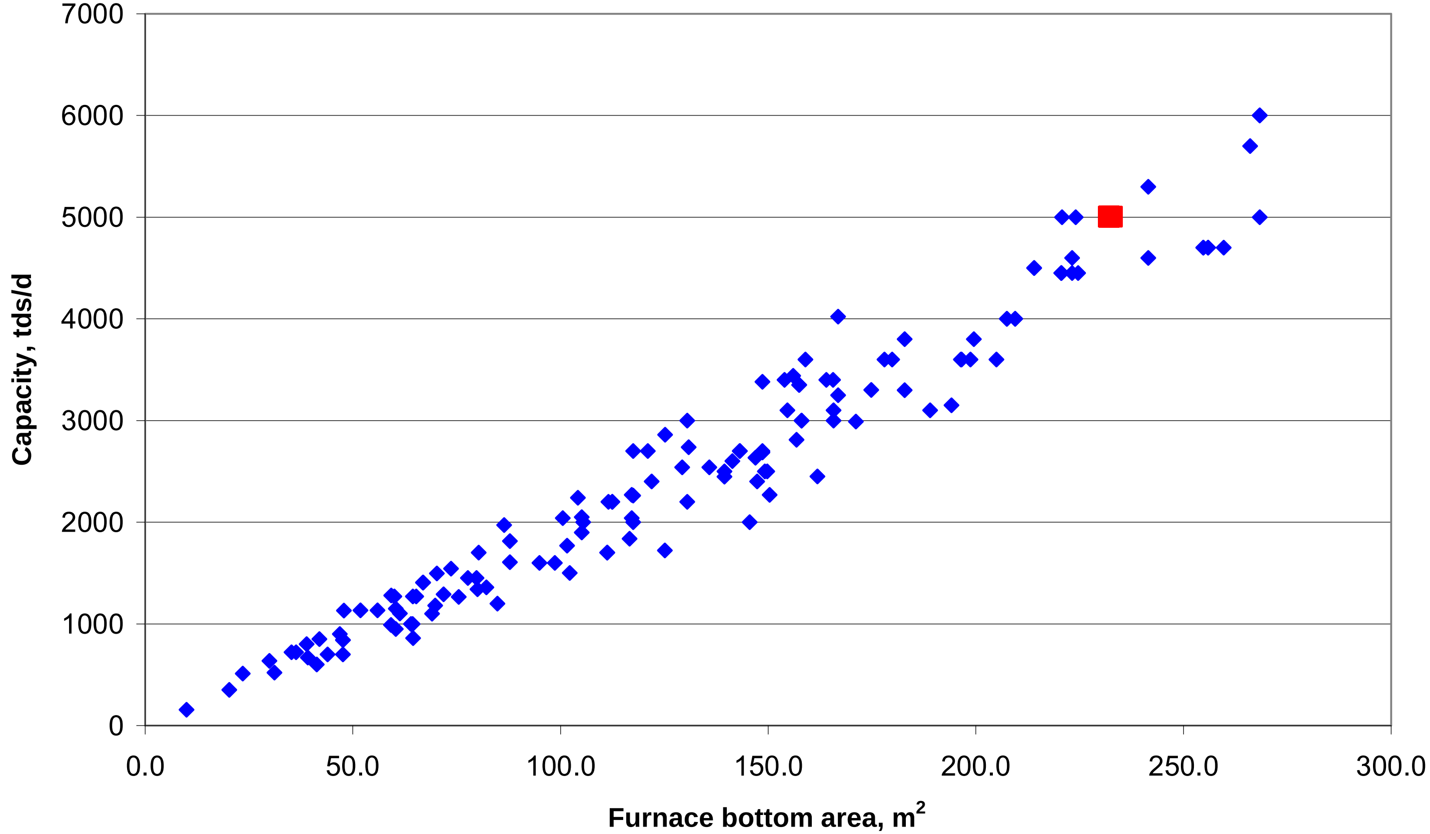


- Main steam temperature
- Reheat steam temperature

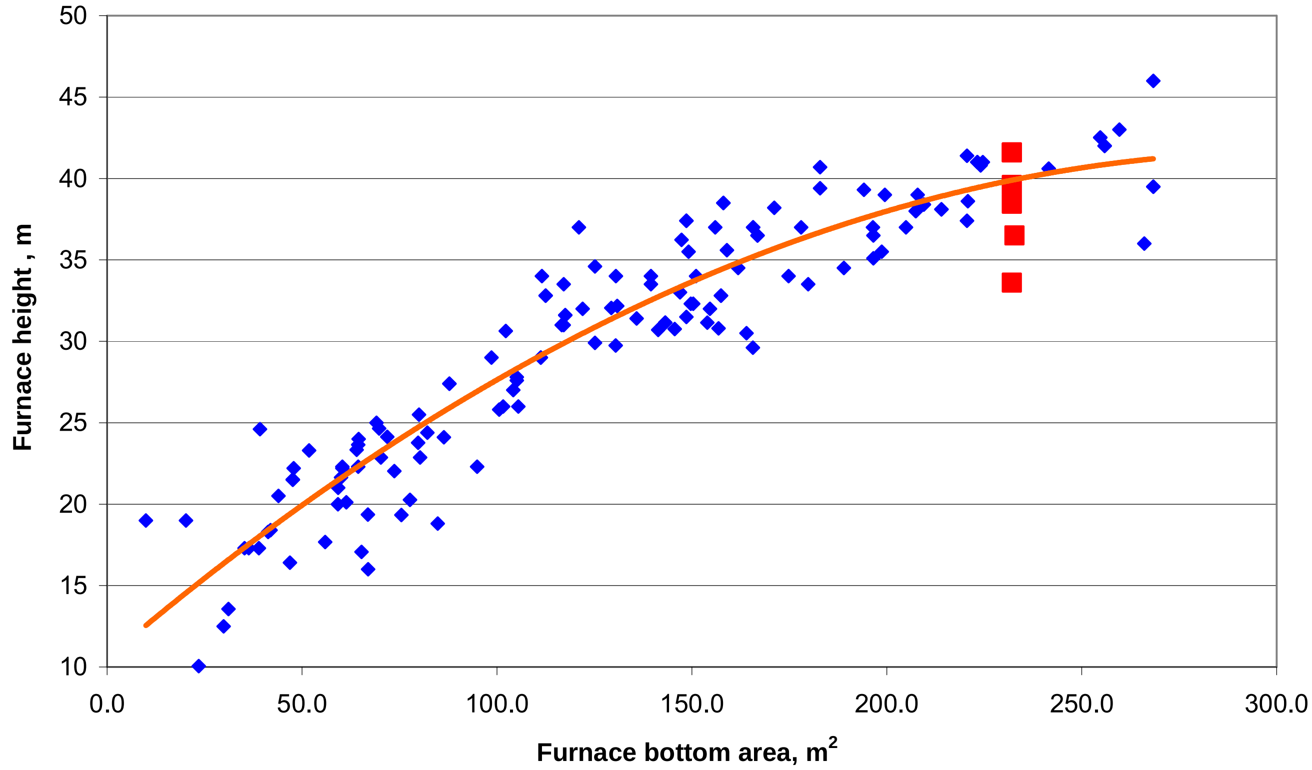
Dimensioning and economy

- Dimensions for each Case
- Prices for each Case
- Economies for each Case

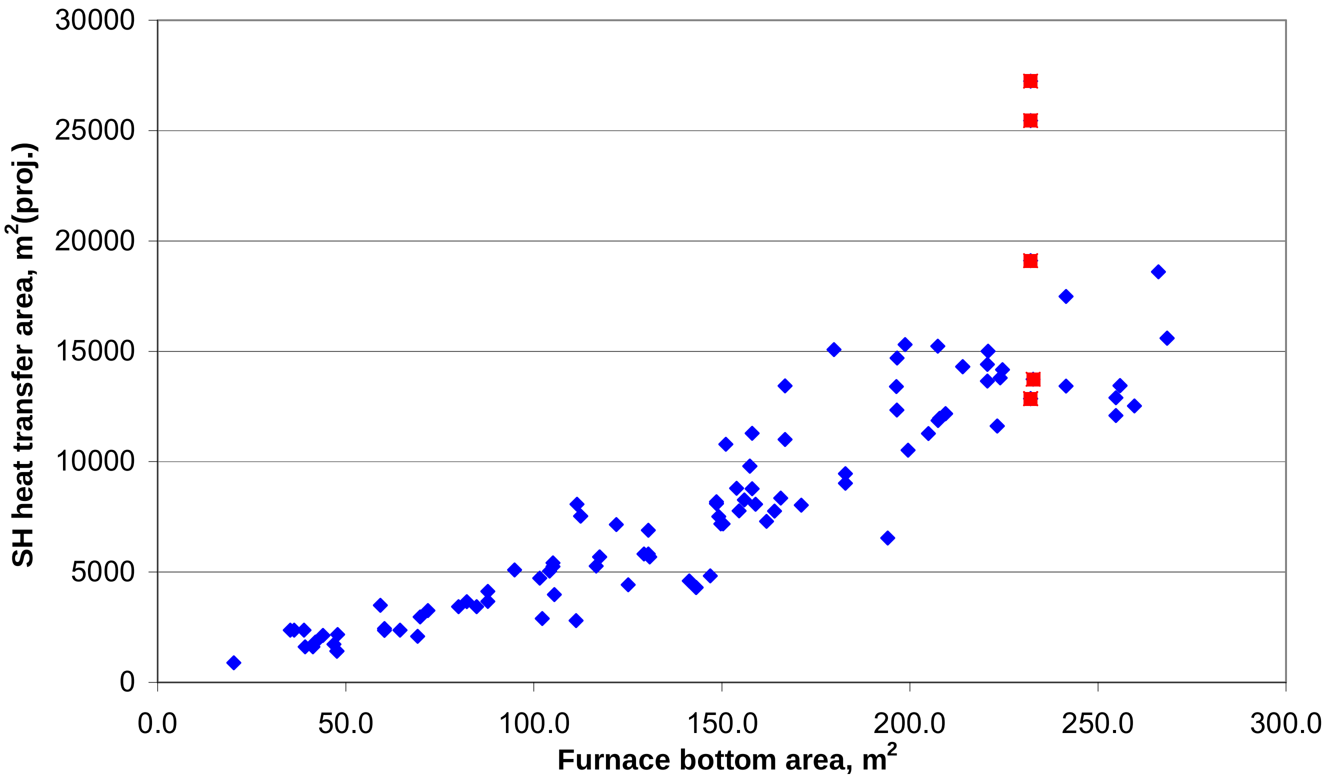
Capacity vs furnace bottom area



Furnace height ve bottom area



Superheater surface vs bottom area



Recovery boiler ht-surfaces

Case		A	B	C	D	E	F
Main steam	bar(a)	94.0	104.0	124.0	164.0	124.0	264.0
Main steam	°C	490.0	505.0	515.0	540.0	515.0	540.0
Design pressure	bar(e)	130	129	148	186	148	289
Furnace area	m^2	233.6	232.1	232.1	232.1	232.1	234.4
Height to nose	m	36.5	41.6	41.6	39.6	38.4	33.6
Boiler height	m	75.5	75.1	78.0	76.0	75.0	72.0
Furnace	m^2	4417	5056	5056	4813	4672	4084
Screen	m^2	0	796	0	796	796	796
Superheater	m^2	16004	12984	15446	19429	20437	23803
Boiler bank	m^2	13600	10262	11982	11982	11982	12786
Eco	m^2	40720	39676	39676	39529	39382	39235
Total surface	m^2	98454	82310	88262	96804	98575	105075
Additional electricity	MW	0.0	4.0	11.2	23.6	12.3	22.9
	%	0.0	6.8	19.3	40.5	21.1	39.4

Recovery boiler weights

Case		**A**	**B**	**C**	**D**	**E**	**F**
Capacity	tds/d	5500	5500	5500	5500	5500	5500
Dry solids	%	82.0	85.0	85.0	85.0	85.0	85.0
Main steam	bar(a)	94.0	104.0	124.0	164.0	124.0	264.0
Main steam	°C	490.0	505.0	515.0	540.0	515.0	540.0
Pressure part weight							
Furnace	tons	1035	1085	1107	1157	1051	843
Screen	tons	0	465	0	588	503	543
Superheater	tons	2254	1463	1827	2490	2417	2569
Boiler bank	tons	813	740	1041	1041	1041	1080
Eco	tons	1845	2080	2080	2072	2063	2057
Total surface	tons	5946	5832	6055	7348	7075	7091
Haning weight	tons	9250	8760	9270	10290	10170	10140

Additional electricity

Case		**A**	**B**	**C**	**D**	**E**	**F**
Capacity	tds/d	5500	5500	5500	5500	5500	5500
Dry solids	%	82.0	85.0	85.0	85.0	85.0	85.0
Main steam	bar(a)	94.0	104.0	124.0	164.0	124.0	264.0
Main steam	°C	490.0	505.0	515.0	540.0	515.0	540.0
Cost							
Cost difference	M€	9.2	0.0	6.5	17.1	24.3	27.0
Electricity diff.	MWe	-4.0	0.0	7.3	19.6	8.3	19.0
Additional MW	k€/MWe	-2310	0	890	875	2921	1422
Additional electricity	€/MWh	-57.8	0.0	22.2	21.9	73.0	35.6

Additional electricity

		case C	sootblow	No HPFW	<Fw T	Air 150	Air 120
Case		**C0**	**C1**	**C2**	**C3**	**C4**	**C5**
Air temperature	°C	190.0	190.0	190.0	190.0	**150.4**	**121.2**
Feedwater	°C	148.0	148.0	148.0	**120.0**	**120.0**	**120.0**
HP FW	°C	200	200	200	200	200	200
HP FW	°C	220	220	**200**	**200**	**200**	**200**
Flue gases	°C	197	197	197	**155**	**155**	**155**
Sootblowing	kg/s	6.0	**6.0**	**6.0**	**6.0**	**6.0**	**6.0**
Steam flow (RB)	kg/s	232.5	228.6	221.0	217.1	213.6	211.1
Change	%	0.0	-1.7	-5.0	-6.6	-8.1	-9.2
Pulp production	MW	88.9	88.9	88.9	88.9	88.9	88.9
Mill	MW	92.4	92.4	92.4	92.4	92.4	92.4
electricity	MW	161.8	160.8	158.4	156.5	154.5	153.6
Sales	MW	69.4	68.3	66.0	64.1	62.0	61.2

Summary

- Additional electricity profitable
- Reheating profitable
- Higher main steam profitable if boilers last
- Assisted circulation profitable, corrosion = ?
- Once-trough profitable, corrosion = ?

APPENDIX IV

LUT:
Once-through and reheater recovery boiler concepts – report for comments 18.11.2009

Lappeenrannan teknillinen yliopisto
Teknillinen tiedekunta, Energiatekniikka

Vakkilainen Esa, Kaikko, Juha, Hamaguchi, Marcelo

Once-through and reheater recovery boiler – concept studies

Final report 18.11.2009

Lappeenranta University of Technology
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Summary

The starting point of this study was increasing kraft pulp mill electricity generation. It has already considerably improved though higher main steam pressure and temperature values.

This research focuses on a new pulp mill with a large recovery boiler at nominal capacity 5500 tds/24h (as fired liquor) which runs at about 200 kg/s steam flow. This study considers both the pulp mill with biomass boiler as well as pulp mill without biomass boiler.

In this study several recovery boiler concepts were compared with the whole pulp mill energy balance being considered. The studied concepts are

A. Natural circulation 82 %, 490 ^{o}C, 9.0 MPa (reference Joutseno)

B. Natural circulation 85 %, 505 ^{o}C, 10.2 MPa (reference Kymi)

C. Natural circulation 85 %, 515 ^{o}C, 12.0 MPa (reference Yonago)

D. Assisted circulation 85 %, 540 ^{o}C, 16.0 MPa (reference SoTu)

E. Natural circulation 85 %, 515/400 ^{o}C, 12.0/3.0 MPa (SkyRec)

F. Once-through 85 %, 540/460 ^{o}C, 26.0/5.4 MPa (SkyRec+)

Steam and electricity generation for each recovery boiler case is shown in Table 9-1. The steam production increases from Case A to Case B because of higher black liquor dry solids and more air preheating. The steam production increases from Case B to Case C because of high pressure preheating. The recovery boiler steam flow starts decreasing as further increases in main steam parameters require more heat.

As can be seen the modern recovery boiler Case C does produce about 20 % more electricity than roughly ten years ago, case A. reheating cases E and E160 seem to give only marginally better electricity production. The only alternative seems to be to increase the main steam temperature to 540 ^{o}C, Cases D and F. The pulping electricity usage is not constant. The main parameter that changes is the recovery boiler feedwater pump power requirement.

Electricity generation does not depend a lot on how the boiler steam side is configured. Reheating and once-through appear only marginally better when considering the recovery boiler electricity generation.

The increase in electricity generation seems very profitable up to case C. This confirms the rationality of design choices that have lead to the present recovery boiler. Case A costs more that it should were it built today. The reason is larger than required superheating surface and smaller than currently used superheater tube size. From cost of additional power, going to SoTu concept of 540 ^{o}C steam seems desirable. Currently the corrosion issues have not yet been solved so in this study we assume that superheaters do not corrode. Reheater boiler concept seems not at all profitable. The additional electricity generation was only marginal. Once-through recovery boiler did produce as much additional electricity than the SoTu concept of 540 ^{o}C steam. The corrosion issues still remain the same.

Yhteenveto

Tutkimuksen lähtökohtana on sellutehtaan sähköenergian kehityksen parantaminen. Sellutehtaan sähköenergiaa ovat parantaneet erilaiset jo käytetyt tavat kuten päähöyryn lämpötilan tai paineen nosto.

Tässä tutkimuksessa on otettu lähtökohdaksi kokonaan uusi sellutehdas, jossa nimelliskooltaan 5500 tka/24h (polttolipeänä) soodakattila ajaa noin 200 kg/s höyrykuormaa. Tarkasteluna on käsitelty sekä soodakattilan että voimakattilan muodostamaa kokonaisuutta samoin kuin pelkästään soodakattilan muodostamaa kokonaisuutta.

TABLE OF CONTENTS

ABBREVIATIONS

CHP	combined heat and power
CNCG	concentrated non condensable gases
DNB	departure from nucleate boiling.
DNCG	diluted non condensable gases
HP	high pressure steam (steam from recovery boiler)
LP	low pressure steam (3.5 - 6 bar)
MCR	maximum continuous rating
MP	medium pressure steam (9.5 – 14 bar)
NBSW	Northern bleached softwood pulp

1 INTRODUCTION

The Finnish Recovery Boiler Committee has undertaken to study the future recovery boiler concepts. The aim is to increase the electricity generating potential and energy efficiency of recovery boilers. This is in line with the Finnish Government's long-term climate and energy strategy and the aims of the European Union and its objectives. This work has been supported by TEKES.

The work consists of once-through recovery boiler concept and study how this might increase the electrical efficiency. Necessary automation and safety changes are to be listed. Final report is a summary of the main tasks.

1. Calculate mass and energy balances to a recovery boiler of about 200 kg_{steam}/s (~5000 tds/d).
2. Place heating surfaces at several typical pressures and temperatures along the flue gas flow
3. Show how water-steam circulation is done
4. Examine 100 % ja 80 % flows with concepts studied with APROS
5. Examine the effect of feedwater preheating
6. Examine the effect of air preheating
7. Look at how placing of reheater affects the recovery boiler

1.1 Comments to targets given 25.6.2009

SKYREC organized a meeting to get comments on different concepts studied. The following comments were received

- Maximum current superheating with long term experience is 515^{o}C
- Calculate once-through boiler with reheater (without reheater does not make sense)
- The need is to calculate new concepts 515^{o}C with reheating
- Choose main steam and reheated steam values so that for LP-steam desuperheating is maximum 30 ^{o}C or minimum 2 % of moisture.
- Study effect of feedwater preheating for Case C include the resizing of superheaters
- Study effect of air preheating for Case C include the resizing of superheaters
- Do mill steam consumption and electricity steam consumption separate to recovery boiler
- Reheater boiler needs more Sootblowing steam
- Sanicro price is ~300 €/m
- Examine low pressure or medium pressure steam production from flue gases

Case C represents the state-of-the-art with respect of electricity generation. It utilizes the maximum main steam temperature that can be considered currently economically 515^{o}C. The mill is producing MP or LP steam from the recovery boiler flue gases 197^{o}C -> 155^{o}C.

To find from literature clear comparisons of current cases e.g. Swedish boilers and Finnish boilers.

The main steam pressure and temperature of concept D needs more thought.

When choosing the main steam values the low pressure steam the maximum moisture allowed for LP steam is 2 % and the maximum attemperating fro Lp steam is 30 ^{o}C.

There is no reason to consider just once-though boiler but to consider once-through reheater boiler.

2 DEVELOPMENT OF RECOVERY BOILER

The pulp and paper industry faces a new era. New environmental expectations have appeared. Cutting down air emissions is not enough. Pulp and paper mills need to maximize their bioenergy potential and minimize their electricity consumption to produce green electricity.

Recovery boilers, which produce bioenergy, are built all over the world. The recovery boiler has developed in the past 70 years. It has culminated with units that are among largest biofuel boilers in the world. For pulp mills the significance of electricity generation from the recovery boiler has been secondary. The most important design criterion for the recovery boiler has been the high availability.

2.1 Main steam temperature

Maximizing electricity generation is driving increases in the main steam pressures and temperatures. The maximum steam temperature can be limited by the ash properties. The first melting curve at the superheater front should be taken into account. Increasing mill closure with high chlorine and potassium decreases the melting temperatures. The overall mill heat balance should be used to optimize the feed water and flue gas temperatures.

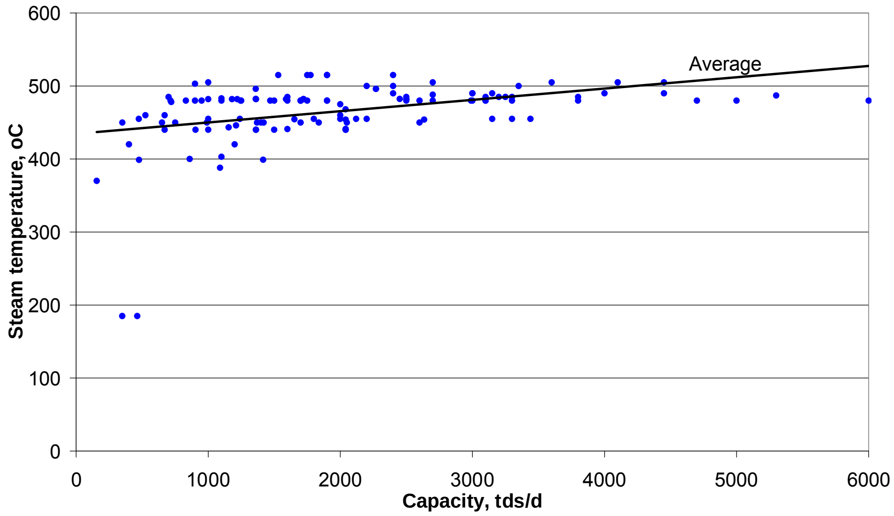

Figure 2-1, Main steam temperature as a function of recovery boiler capacity.

The main steam temperature of recent recovery boilers is shown in Figure 2-1 as a function of MCR capacity of that boiler. The average steam temperature increases with size. Small boilers tend to have lower pressures to reduce specific cost. There are many boilers with main steam parameters higher than 500 ^{o}C. Most of them are in Japan.

2.2 Relationship between main steam values

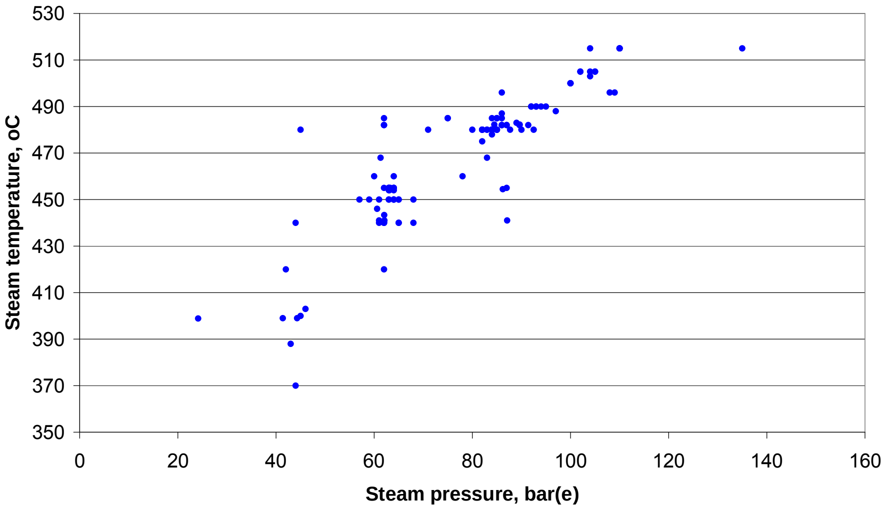

Figure 2-2, Main steam temperature as a function of recovery boiler main steam pressure.

The main steam temperature of recovery boilers is shown in Figure 2-2 with the corresponding main steam pressure. An increase in main steam temperature is usually accompanied with an increase in the main steam pressure. Increasing just either steam pressure or temperature alone has only a minor effect on back pressure electricity generation.

2.3 Black liquor dry solids

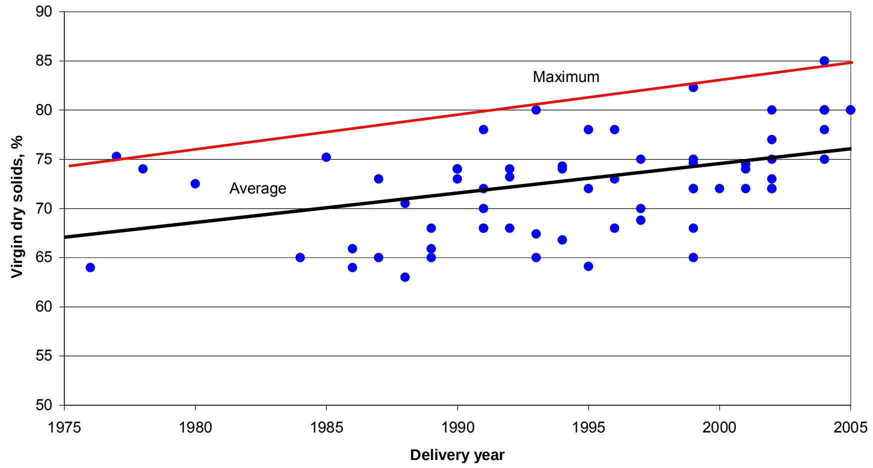

Figure 2-3, Virgin black liquor dry solids as a function of purchase year of the recovery boiler.

Black liquor dry solids has always been limited by the ability of available evaporation technology to handle highly viscous liquor. As technology has evolved so has the final black liquor dry solids. The virgin black liquor dry solids of recovery boilers is shown in Figure 2-3 as a function of purchase year of that boiler.

On average the virgin black liquor dry solids content has increased. This is especially true for latest very large recovery boilers. Design dry solids for the new green field mills and new recovery islands have been either 80 or 85 % dry solids. In Asia and South America 80 % (earlier 75 %) dry solids is in use. In Europe 85 % (earlier 80 %) dry solids is in use.

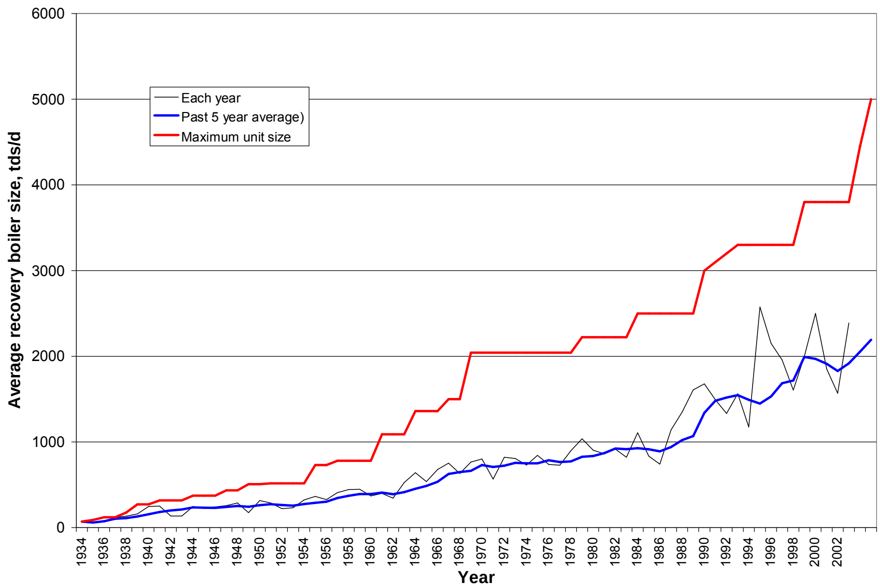

Figure 2-4, Size of the recovery boiler as a function of purchase year.

Recovery boiler size keeps increasing. The recovery boiler size doubles about every 20 years. Boilers with over 200 square meter bottom area are typical for the largest new greenfield mills. The largest recent proposals have been for a 6000 tds/d boiler. Average boiler size has typically been about half of the largest boiler bought.

The recovery boiler is now challenging circulating fluidized bed boilers for the title of largest bio-fuel fired boiler. Recovery boiler furnace size is about the size of the largest natural circulation coal fired boilers. This means that the existing mechanical and commercial limits of furnace size for natural circulation units have now been reached.

3 RECOVERY BOILER CONCEPTS

In the study some of the existing recovery boiler concepts are compared to future recovery boiler concepts. In the meeting 26.6.2009 it was agreed that the studied concepts are

A. Natural circulation 82 %, 490 ^{o}C, 9.0 MPa (reference Joutseno)
B. Natural circulation 85 %, 505 ^{o}C, 10.2 MPa (reference Kymi)
C. Natural circulation 85 %, 515 ^{o}C, 12.0 MPa (reference Yonago)
D. Assisted circulation 85 %, 540 ^{o}C, 16.0 MPa (reference SoTu)
E. Natural circulation 85 %, 515/400 ^{o}C, 12.0/3.0 MPa (SkyRec)
F. Once-through 85 %, 540/460 ^{o}C, 26.0/5.4 MPa (SkyRec+)

3.1 Case A - Modern high efficiency boiler

The modern recovery boiler is of a single drum design, with vertical steam generating bank and wide spaced superheaters. The most marked change was the adoption of single drum construction. The construction of the vertical steam generating bank is similar to the vertical economizer.

The effect of increasing dry solids concentration has had a significant effect on the main operating variables. The steam flow increases with increasing black liquor dry solids content. Increasing closure of the pulp mill means that less heat per unit of black liquor dry solids will be available in the furnace (Clement 1990).

The flue gas heat loss will decrease as the flue gas flow diminishes. Increasing black liquor dry solids is especially helpful since the recovery boiler capacity is often limited by the flue gas flow.

The most marked change in this case was that the mill (market NBSW pulp mill) was able to produce substantial amounts of electricity for sale even when selling all bark to neighbouring mills (Veitola, 2000).

In this concept the benefits of having a condensing tail were first realized. In addition this was one of the first boilers where biosludge with both DNCG and CNCG were burned with high dry solids black liquor (Vakkilainen, 2000)

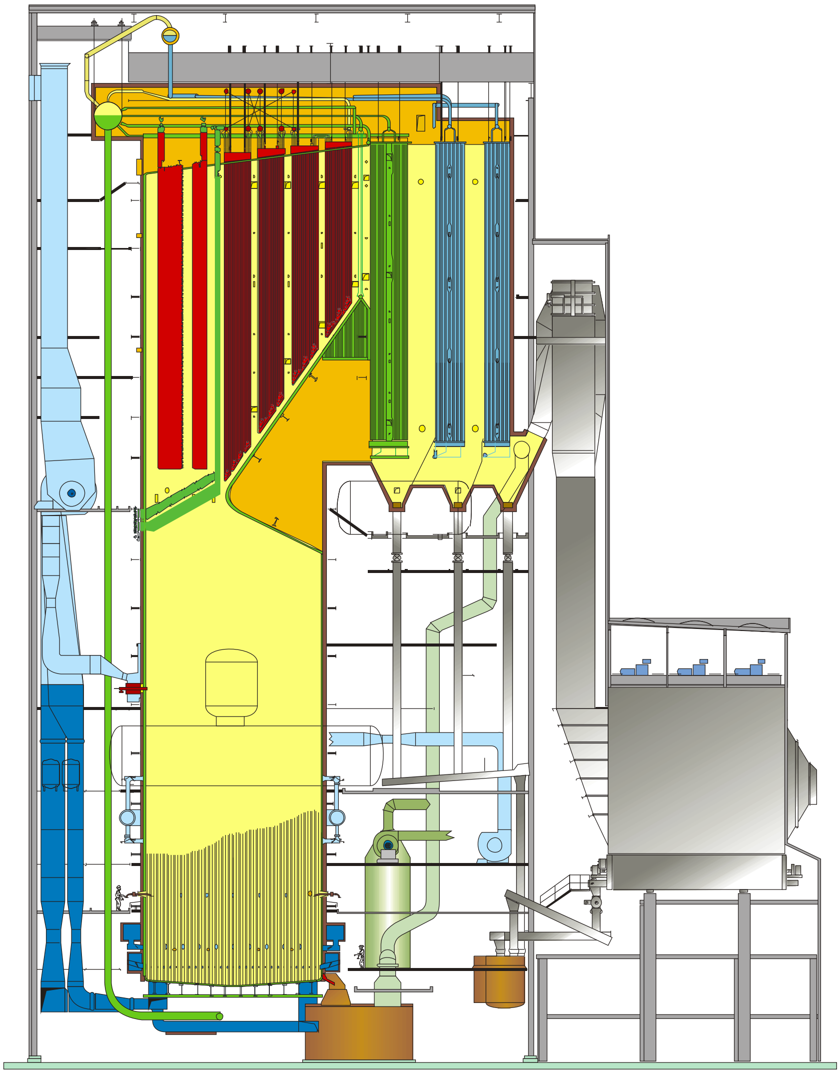

Figure 3-1, Modern recovery boiler, Vendor Andritz Oy, Capacity 3500 t ds/24h, Black liquor ds 82,3 % (80 %) Main steam 130 kg/s 93 bar(a) 490 °C.

3.2 Case B – High efficiency recovery boiler

During recent years the price of electricity has increased and especially the desirability of electricity produced from renewable fuels has risen. This has led to mills adopting strategies to increase the electrical generating efficiency (Raukola et al., 2002, Saviharju and Lehtinen 2005, Westberg 2007).

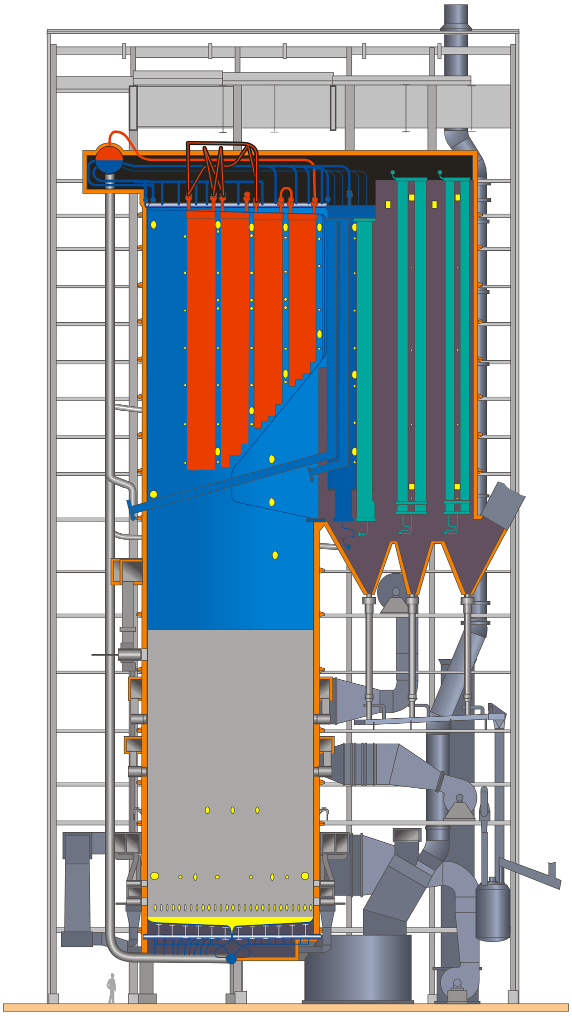

Figure 3-2, High efficiency recovery boiler, Vendor Metso Power Oy, Capacity 3600 t ds/24h, Black liquor ds 85 % (80 %) Main steam 170 kg/s 102 bar(a) 505 °C.

One of the aims of this project was to increase the share of electricity produced with biomass (Tikka, 2008). A special feature of this boiler is usage of 29 bar unregulated steam for sootblowing and high air preheating temperature to 190 °C. The feedwater inlet temperature has been raised ot 148 °C and there is an intermediate HP steam feedwater preheat stage between economizer I and Economizer II. Because of the high superheating temperature the last tubes of tertiary superhaters are of Sanicro 28 (Aikio, 2008)

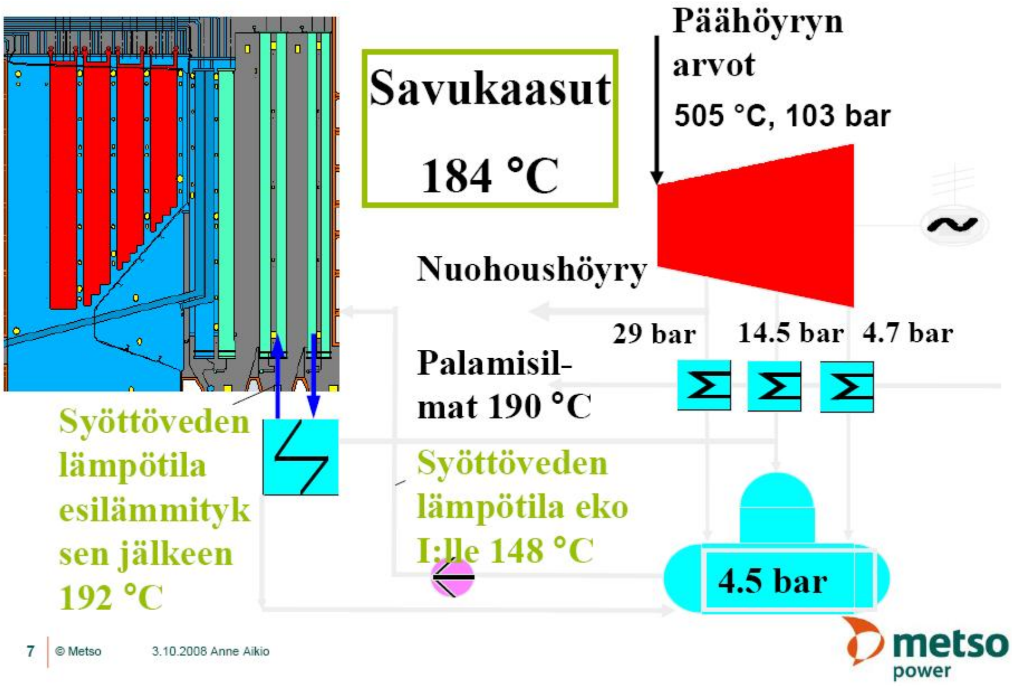

Figure 3-3, Some special features to increase electricity generating efficiency (Aikio, 2008).

3.3 Case C – High pressure and temperature recovery boiler

In 1998 the second generation high pressure and temperature recovery boiler started commercial operation in Japan (Arakawa et al., 2004). Figure 3-4 shows a second-generation high pressure and temperature recovery boilers. The second-generation recovery boiler is of single drum without evaporator design. Furnace outlet water or steam cooled screen tubes are not necessary with new 25%Cr special stainless steel for superheater.

Increasing superheating means that more heat transfer surface needs to be added. The higher main steam outlet temperature requires more heat to be added in the superheating section. Typically the furnace outlet gas temperature has increased. The alternative is to significantly increase superheating surface to decrease boiler bank inlet fluegas temperature. If boiler bank inlet gas temperature is reduced the average temperature difference between flue gas and steam is also decreased. This reduces heat transfer and substantially more superheating surface is needed. Low furnace outlet temperature design has been abandoned because of increased cost. With increasing dry solids content the furnace exit temperature can safely increase without fear of corrosion caused by carryover.

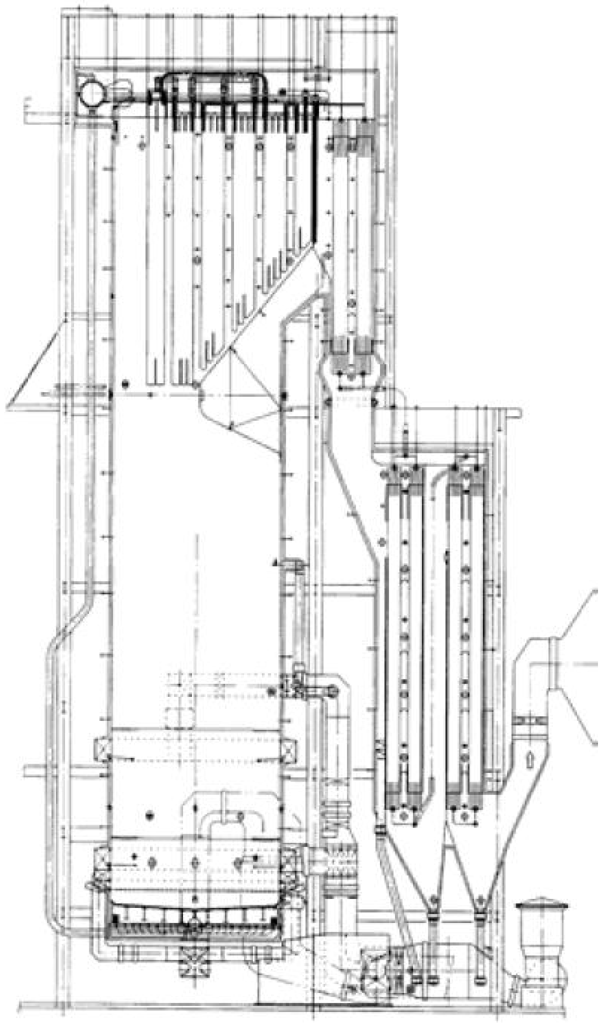

Figure 3-4, High pressure and temperature recovery boiler, Vendor Mitsubishi Heavy Industries, Ltd, Capacity 2500 t ds/24h, Black liquor ds 75 % Main steam 114 kg/s 109 bar(a) 515 °C**.**

3.4 Case D - Assisted circulation recovery boiler concept

Previously the target for higher electricity production has been to further increase temperature and pressure. previously the target concept has been maximum pressure with traditional design (Suomen Soodakattilayhdistys ry., 2007.)

The limit with natural circulation / assisted circulation design was chosen based on literature as 16 MPa (Steam 1992, Steam power engineering 1999). The target steam temperature was chosen as 540 ^{o}C. Concept was however never detailedly studied.

3.5 Case E - Reheater concepts

From steam boiler literature we know that one way to increase electrical generation is applying reheating (Steam, 1992). That is after the steam has expanded partly in a turbine we take it back to the boiler and through another set of heat transfer surfaces called reheating surfaces, where the steam temperature is again raised. Reheating has been practiced in steam boilers for about 100 years.

3.5.1 Case E – High pressure and temperature recovery boiler with reheater concept

Babcock and Wilcox has recently promoted reheating recovery boilers (Hicks et al., 2009). One of the key features is the ability to use old turbine and just add new high pressure set with the new recovery boiler. This typically means rather high reheating pressures.

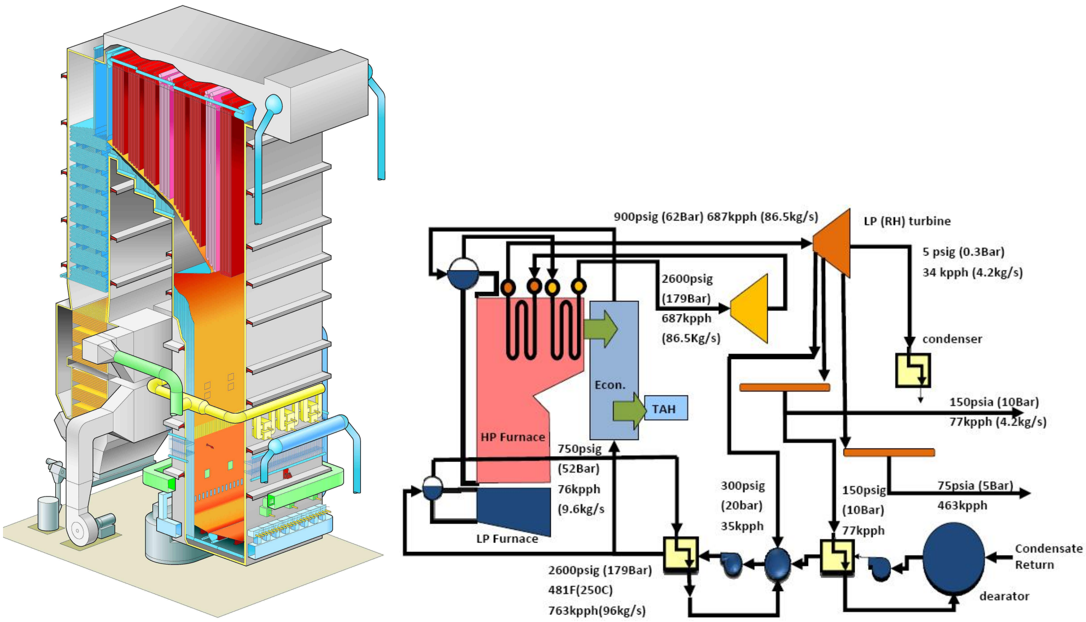

Figure 3-5, Reheater recovery boiler concept Vendor Babcock & Wilcox, Capacity 4500 t ds/24h, Black liquor ds 85 % Main steam 130 kg/s 179 bar(a) 510 °C reheated steam 62 bar(a) 443 °C**.**

One should also note the horizontal tube economizer. Running high dry solids i.e. practically no SO_2 creates non sticky conditions to economizer area.

3.5.2 First choice of reheat temperature

When choosing reheating pressure and temperature the requirement given (Chapter 1.1) was kept in mind. Choose main steam and reheated steam values so that for LP-steam desuperheating is maximum 30 °C or minimum 2 % of moisture. In table 3-1 several different steam values are examined. The starting condition was chosen based on given instructions as 515°C/12 MPa.

Table 3-1 **4.5 bar(a) steam temperature and moisture with different reheats from 515 °C/12 MPa to different pressure and temperature combinations (bold values full fill condition <30 °C desuperheat and < 2 % moisture).**

	480°C	460°C	440°C	420°C	400°C	380°C	360°C	340°C	320°C
5.4 MPa	182.7	***169.9***	***157.1***	***147.9***	147.9	147.9	147.9	147.9	147.9
	1.000	***1.000***	***1.000***	***0.994***	0.978	0.938	0.920	0.900	0.879
4.4 MPa	202.4	189.3	***176.1***	***162.8***	***147.9***	***147.9***	147.9	147.9	147.9
	1.000	1.000	***1.000***	***1.000***	***1.000***	***0.984***	0.967	0.934	0.914
3.4 MPa	228.2	214.5	200.8	187.0	***173.2***	***159.3***	***147.9***	147.9	147.9
	1.000	1.000	1.000	1.000	***1.000***	***1.000***	***0.995***	0.978	0.960
2.4 MPa	264.8	250.3	235.8	221.2	206.6	192.0	***177.3***	***162.6***	***147.9***
	1.000	1.000	1.000	1.000	1.000	1.000	***1.000***	***1.000***	***0.998***
1.4 MPa	326.8	310.8	294.8	278.7	262.6	246.5	230.4	214.3	198.1
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Of the choices the combination of 3.6 MPa out and 3.4 MP in with reheating to 400 °C was chosen. This means that steam to be reheated can be used as sootblowing steam.

3.5.3 Comparison of chosen reheat temperature and pressure

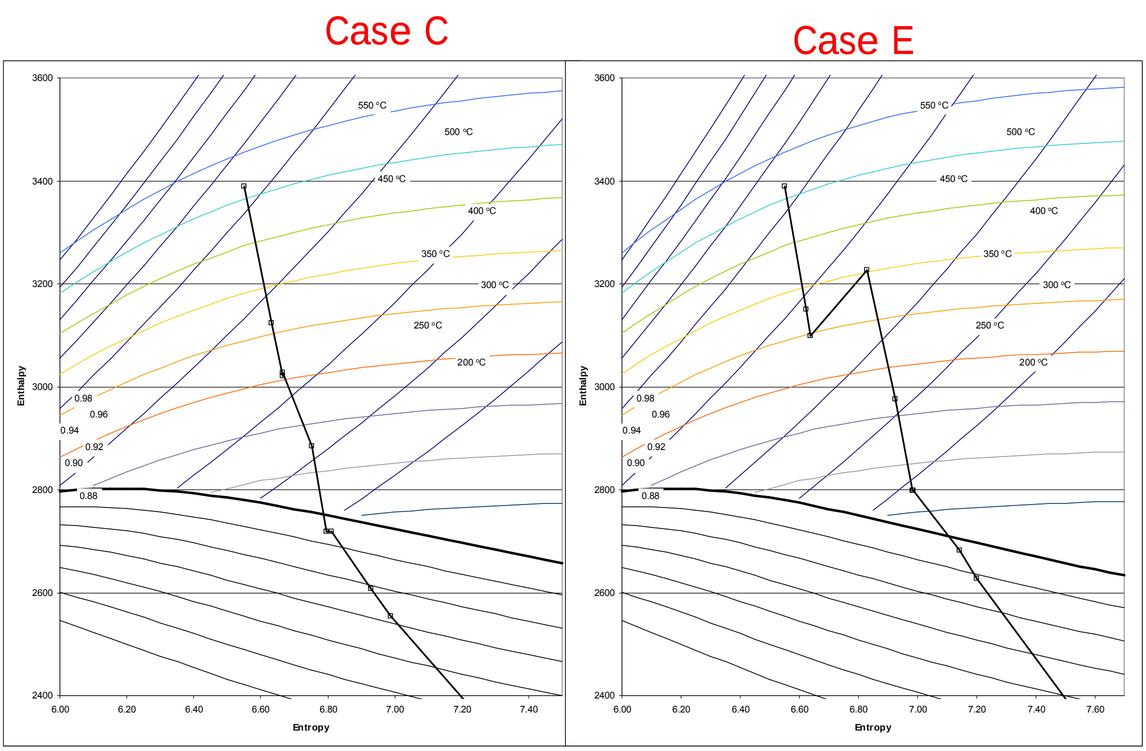

Figure 3-6, Comparison of case C and E

The chosen concept was calculated but the increase in electricity generation remained rather small. Therefore comparison with Case C was done.

Both start expansion at h=3389.2 kJ/kg at 514/118. After expansion to h=3098.9 kJ/kg at 348/34 reheater case E goes back for more heating and traditional case C continues expansion in the turbine. Case C expands to h=2726.1 kJ/kg at 149.5/4.5 while case E expands after reheat from h=3227.3 kJ/kg at 400/32 to h=2799.1 kJ/kg at 173/4.5.

Because 3389.2-2726.1= 663.1 kJ/kg and 3227.3-3098.9 + 3227.3-2799.1= 718.5 kJ/kg with difference of 55.4 kJ/kg the extra electricity from reheat seems large. However, the additional expansion is only 55.4/(3389.2 – 2799.1) if we assume that condensing tail expansion difference remains the same. This means that for each kg of steam expanding through turbine 8.4 % of more electricity is generated.

To generate reheated steam more heat is needed. In case C the heat addition is from 148 ^{o}C = 623.5 kJ/kg to main steam = 3340.4 kJ/kg (=2765.7 kJ/kg). In Case E more heat is added in reheat from 348 ^{o}C = 3098.9 kJ/kg to 400 ^{o}C = 3225.9 kJ/kg. So in Case C the heat addition is 3389.2 - 623.5 = 2765.7 kJ/kg and in Case E this is 2716.9 + (3227.3 - 3098.9) = 2894.1 kJ/kg. So in Case C the heat that produces 1 kg of steam produces only 0.956 kg steam with the same heat addition. The increase in electricity generation is therefore reduced to 0.956*718.5 = 686.6 kJ/kg or 3.4 %. If we take into account that the added sootblowing (+2 kg/s) reduces steam flow through the turbine and reheating causes poorer working of the condensing tail, the net benefit is reduced to almost zero.

3.5.4 Improving reheat from first premise

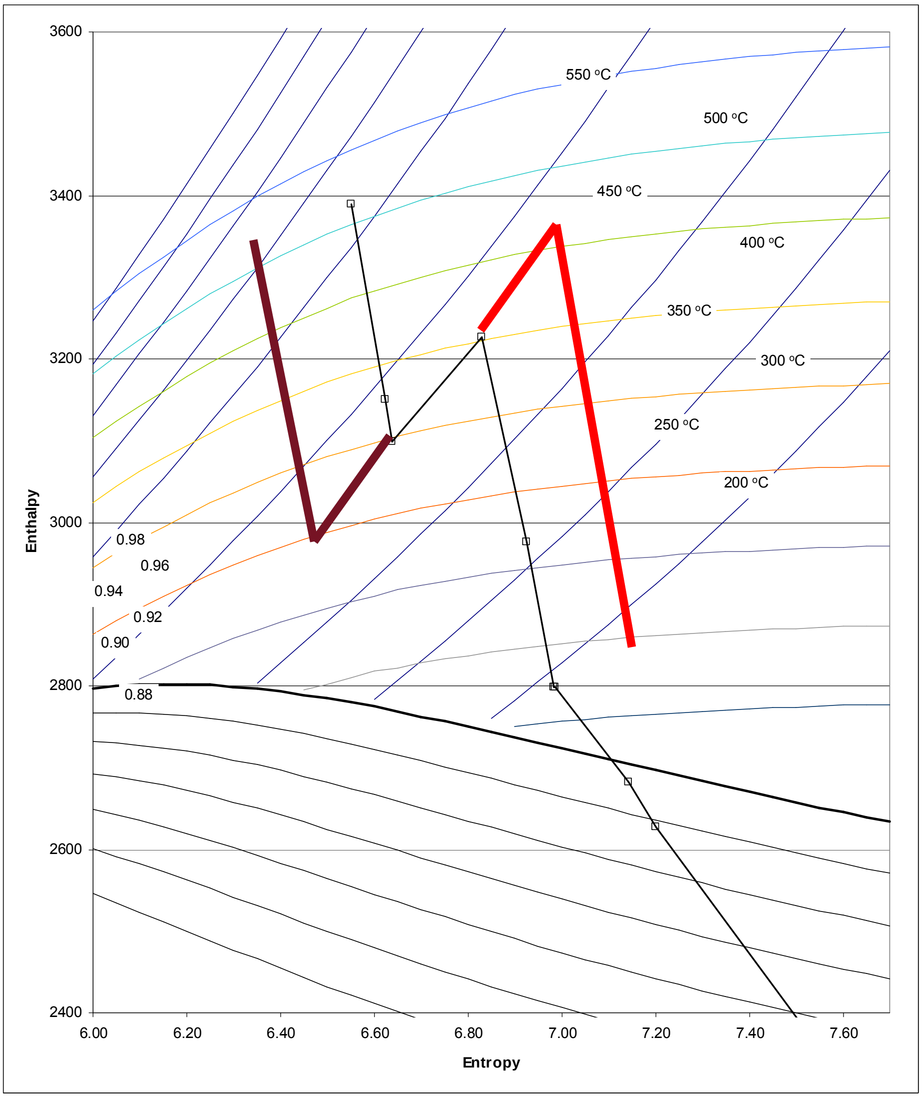

Figure 3-7, Options to improve reheat

One can increase reheating (the bright red line), but then the LP steam gets more and more superheated. A better alternative is to increase main steam pressure to e.g. 160 bar resulting in larger expansion, more heat addition and increased steam generation.

Therefore the alternative Case E with 160 bar furnace was calculated. The drawback is even more reheater surface.

3.6 Case F - Once-through recovery boiler with reheater concept

If we still want to increase the operating pressure we need to change to once-through boiler concept. Once-through boilers have been used since the 1930's and have been the main type for large utility boilers from the 1950's.

To improve cycle efficiency, utility boiler main steam pressures have increased to typically 248 bar. The steam temperatures have long remained conservative i.e. 540 °C, but have recently started to climb close to 600 °C.

Utility boilers use typically multiple feedwater heaters and have regenerative air heaters where flue gas heats air. These features add significantly to steam generation efficiency. To make comparison valid no additional heaters have been used for Case F. To choose main parameters again a comparison for end expansion conditions has been done, Table 3-2.

Table 3-2 4.5 bar(a) steam temperature and moisture with different reheats from 540 °C/26 MPa to different pressure and temperature combinations (bold values fullfill condition <30 °C desuperheat and < 2 % moisture).

	520°C	**500°C**	**480°C**	**460°C**	**440°C**	**420°C**	**400°C**	**380°C**	**360°C**
5.4 MPa	208.2	195.4	182.7	***169.9***	***157.1***	***147.9***	147.9	147.9	147.9
	1.000	1.000	1.000	***1.000***	***1.000***	***0.994***	0.978	0.938	0.920
4.4 MPa	228.7	215.6	202.4	189.3	***176.1***	***162.8***	***147.9***	***147.9***	147.9
	1.000	1.000	1.000	1.000	***1.000***	***1.000***	***1.000***	***0.984***	0.967
3.4 MPa	255.5	241.8	228.2	214.5	200.8	187.0	***173.2***	***159.3***	***147.9***
	1.000	1.000	1.000	1.000	1.000	1.000	***1.000***	***1.000***	***0.995***
2.4 MPa	293.8	279.3	264.8	250.3	235.8	221.2	206.6	192.0	***177.3***
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	***1.000***
1.4 MPa	358.9	342.9	326.8	310.8	294.8	278.7	262.6	246.5	230.4
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Of the choices the combination of 5.6 MPa out and 5.4 MP in with reheating to 460 °C was chosen. This means that the reheat lines remain smaller than with lower pressures. If a higher temperature was chosen (e.g. 540 °C) then the expansion would be quite dry at around 5 bar.

4 WATER AND STEAM CIRCULATION

For a boiler to operate properly the steam water circulation must be designed for large variations of load, manageable temperature differences in parallel tubes and low possibility of tube inside erosion.

The main areas in steam-water side circulation design are choosing the right type of circulation, dimensioning downcomers and risers, dimensioning of superheater and dimensioning boiler banks.

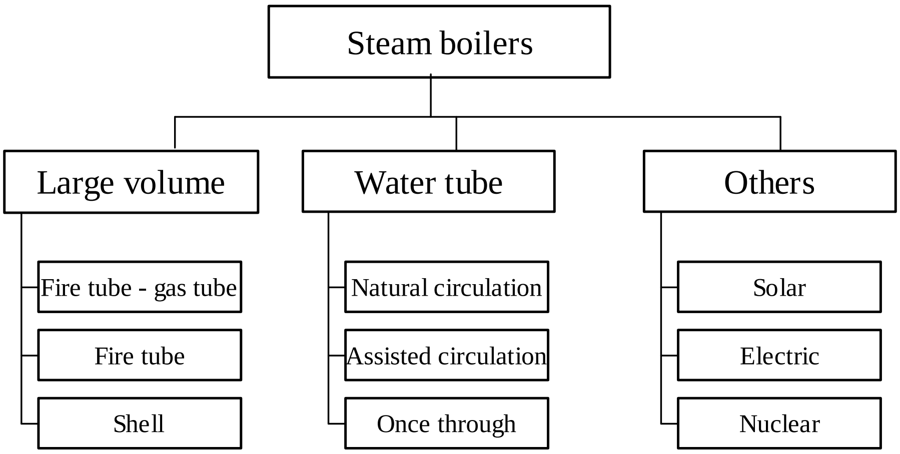

Figure 4-1, Classification of steam water side

There are two main groups of steam water circulation, Figure 4-1. The first group is the large volume boilers. In them the heating evaporates steam inside a large volume of water. For example a teakettle could be considered a large volume type.

Second group is the boilers where boiling occurs inside a tube filled initially with water. For example the coffee maker operates on this principle. Most of the large modern boilers belong to this group. In addition there is a group that could be called others of miscellaneous. They have features from both of these two groups. Many of the nuclear plant steam circuits as well as solar power circuits belong to this mixed group. All groups, in spite of the design are governed by the same laws.

4.1 Large volume boilers

Large volume boilers are usually fire tube boilers. Because of design they are limited by steam production (capacity) and operating pressure. The basic design has remained the same since the Scottish marine boilers of 1800.

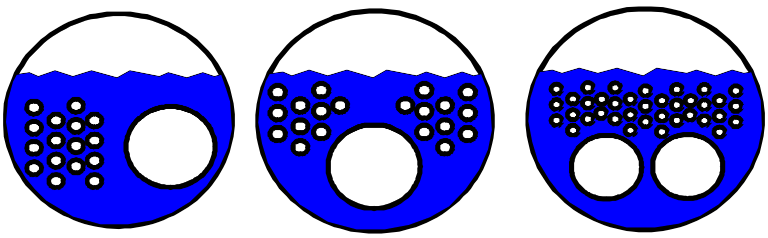

Figure 4-2, Firetube – gas tube boiler designs (Effenberger, 2000).

In large volume boilers water circulates downwards at the edges of the boilers, Figure 4-2. Steam bubbles rise, creating upward flow in the centerline of the boilers. Same mode of operation can be seen by watching a pot of water boiler on a stove.

4.2 Natural circulation boiler

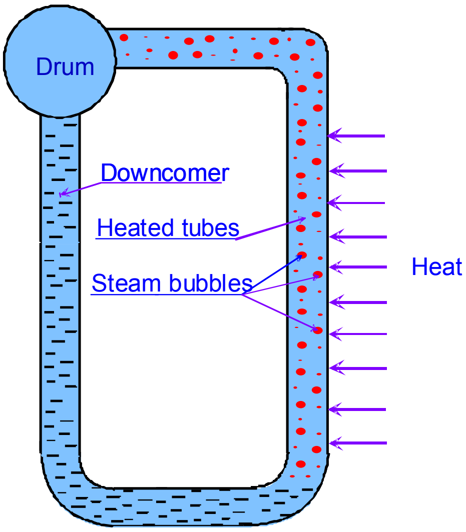

Figure 4-3, Principle of natural circulation.

Natural circulation is based on the density differences. The same principle can be seen in e.g. room in a cold winter day. Heated air rises on the wall where room is heated and subsequently cooled more dense air falls downwards on the opposite wall.

Natural circulation is caused by the density difference between saturated water and heated water partially filled with steam bubbles. In a natural circulation unit water tubes are connected to a loop, Figure 4-3. Heat is applied to one leg called raiser tubes, where water steam mixture flows upward. Denser saturated water flows downward in unheated leg called downcomer. Natural circulation means that the steam water movement in the evaporative tubes is achieved without use of external prime energy and mechanical means.

Driving force is static head difference between water in downcomers and steam/water mixture in furnace tubes.

$$\Delta P_{losses} = (\rho_{water} - \rho_{mixture})gh \qquad 4\text{-}1$$

where

ΔP_{losses} is the flow losses in the circulation

ρ_{water} is the density of the water in the downcomers

$\rho_{mixture}$ is the density of the water steam mixture in the heated section

h height of the circulation

Pressure increase decreases driving force. Natural circulation design is affected by several design factors. If we increase furnace height the driving head increases. We must try to avoid steam in downcomers. Efficient steam separators reduce the fraction of steam inside the drum. Inserting feedwater to drum at subsaturated state cools down and collapses remaining bubbles. Minimize axial flow inside drum helps creating equal flow in all parts of boilers. Natural circulation is also improved by higher heat flux in lower part of the tubes.

4.3 Assisted circulation

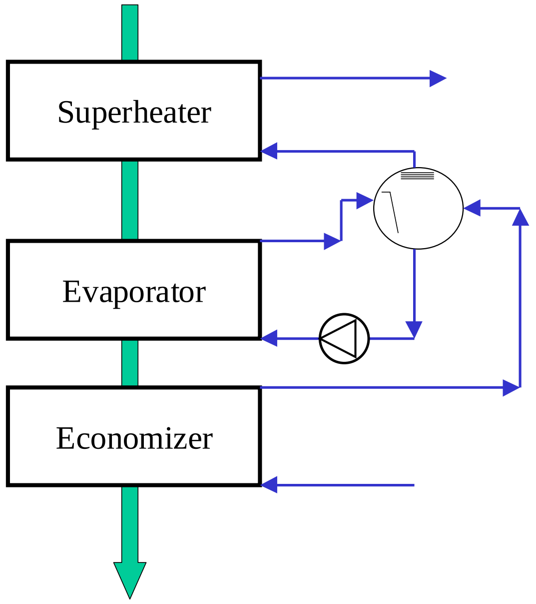

Figure 4-4, Assisted circulation in a HRSG.

Assisted circulation is typical in HRSG boilers and high pressure units. Water from the drum is pumped through evaporative surfaces. Synonyms for assisted circulation are forced circulation and controlled circulation.

4.3.1 Controlled circulation

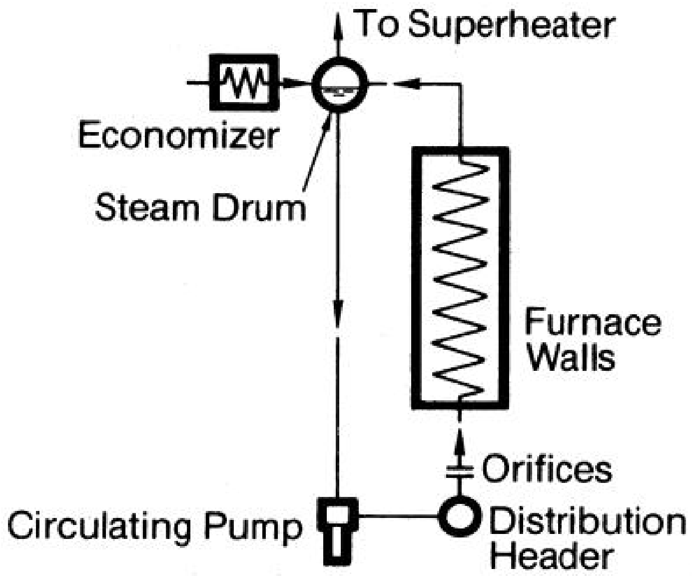

Figure 4-5, Controlled circulation (Combustion, 1991).

In controlled circulation a pump assists flow. Flow is regulated by orifices. This ensures even flow in all wall tubes. Controlled circulation is a trademark of ABB.

4.3.2 La Mont boiler

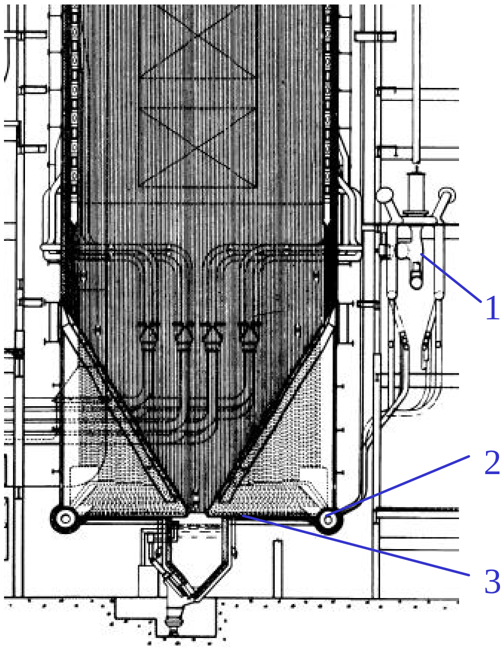

Figure 4-6, La Mont boiler, 1 - HP circulating pump, 2 - header with orifices, 3 - individual wall tubes (Ledinegg, 1966).

The most famous assisted circulation type is the La Mont boiler. The name comes from one manufacturer of these boilers. In La Mont boilers the drum pressure was usually below 19.0 MPa. The main advantage is that the designer can quite freely choose the tube pattern. Water flow through the tubes is controlled by appropriate sized orifices.

Circulation ratio in la Mont boilers is from 4 to 10. Pressure loss in a circuit was usually from 0.1 to 0.3 MPa.

4.4 Once-through boiler

In once-through boiler the water flows continuously through the boiler coming as 100 % steam at the main steam outlet. The circulation does not limit the pressure so boiler can be built at very high pressures. As positive circulation is kept up with the pressure difference the pressure loss through the boiler tends to be large. High pressure loss means high own power demand.

Feedwater purity must be very high as any contaminant tends to stay at the boiler walls. The feedwater must have about the same purity than the steam. The steam purity is dictated by the turbine requirements. Starting and shutting the boiler is problematic.

Because of pumps the mass flow densities in once through boilers are high, Table 4-1.

Table 4-1, Mass flow densities.

Surface	Mass flow density
	kg/m^{2}s
Convective superheater	1000
Furnace tubes	2000-3000
Economizer	600

The furnace tube arrangement is difficult. In natural and assisted circulation the furnace could be made of straight tubes of same temperature. Once-through boilers employ various tube patterns to cover the furnace walls. Based on the type of these circuits the once through boilers are divided into Sultzer Monotube boilers, Benson boilers and Ramzin boilers.

4.4.1 Sultzer Monotube boiler

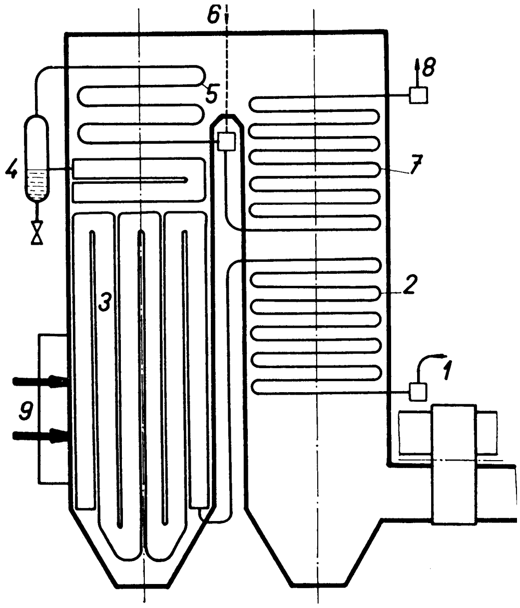

Figure 4-7, Sultzer Monotube circulation, 1 – feedwater inlet, 2-economizing surface, 3-furnace tubes, 4-bottle, 5-superheating surface, 6-desuperheating spray, 7-superheating, 8-main steam out (Doležal, 1967).

One of the first successful once through boilers was the Sultzer Monotube boiler. Its trademark is the use of a bottle, where remaining water droplets are separated from the steam. The flow in the furnace uses u-shaped tube bundles.

4.4.2 Benson-boiler

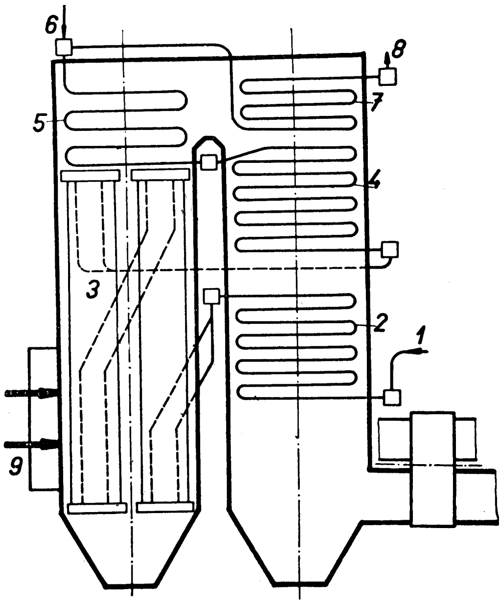

Figure 4-8, Benson boiler circulation, 1 – feedwater inlet, 2-economizing surface, 3-furnace tubes, 4-backpass surface, 5-superheating surface, 6-desuperheating spray, 7-superheating, 8-main steam out (Doležal, 1967).

A competitor to the Sultzer design the Benson boiler had a very similar tube pattern. Very rarely was the bottle or similar device used in a Benson boiler. To facilitate design Benson boiler uses straight heated up flowing parts and unheated down flow parts. In Benson boiler there is no definite point where the evaporation ends and the superheating begins, when operated under the critical pressure.

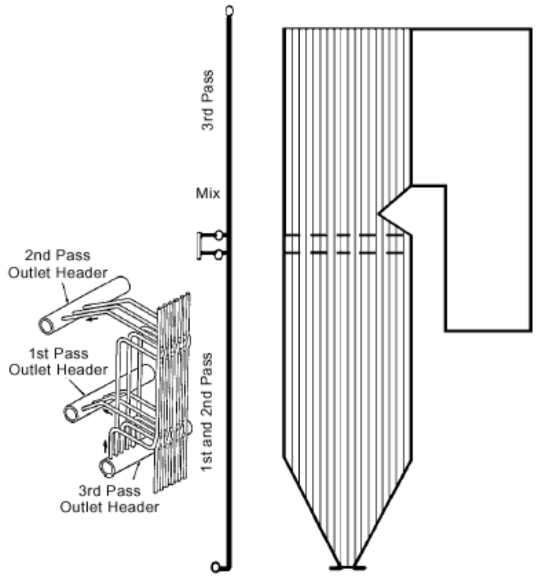

Figure 4-9, Dividing wall passes to segments (Smith, 1998).

Dividing each pass to several segments helps to maintain low temperature differences between adjacent tubes. Heat flux to tubes can vary because of localized fouling and tube placement.

4.4.3 Ramzin-boiler

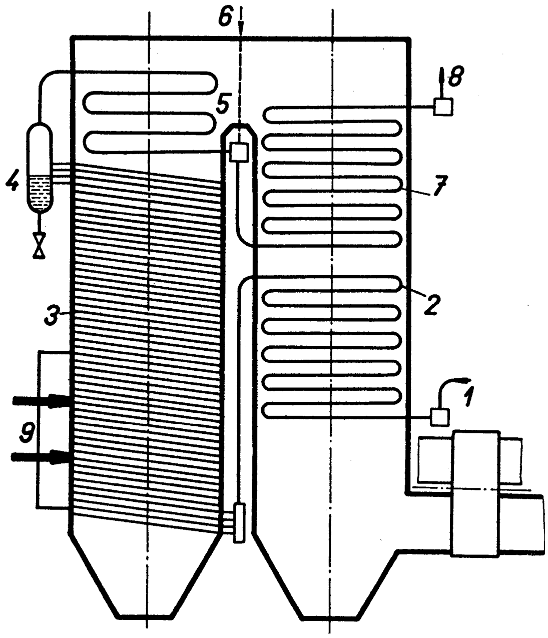

Figure 4-10, Ramzin circulation, 1 – feedwater inlet, 2-economizing surface, 3-furnace tubes, 4-bottle, 5-superheating surface, 6-desuperheating spray, 7-superheating, 8-main steam out (Doležal, 1967).

Ramzin boiler was developed in the Russia. It uses much the same operating principles that the Sultzer monotube boiler. The main distinctive feature of Ramzin boiler is that the tubes circle the furnace. It is expensive to manufacture. Separation (4) similar to Sultzer design, was added later. The main use of Ramzin boilers has been in former eastern block.

4.4.4 Tube selection for once through boiler

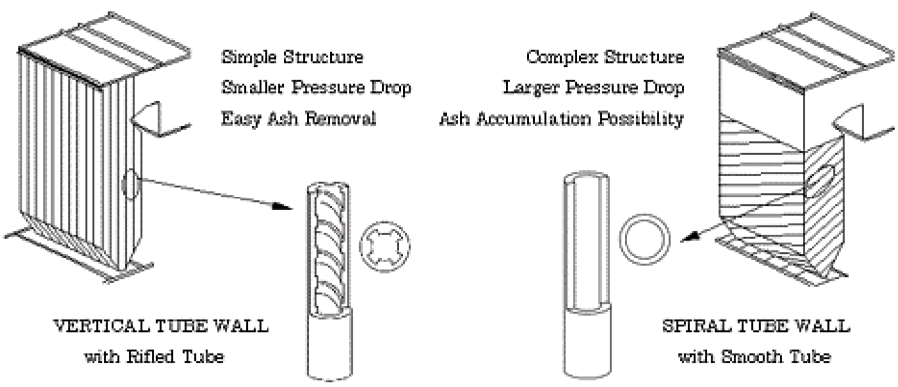

Figure 4-11, Selection of tubes for once through boilers (Mitsubishi Heavy Industries Ltd, 2001).

In once trough boilers the evaporation is brought to completion. Therefore parts of the tubes must be operated at very high vapor contents. This kind of operation stresses some tubes when water sometimes is separated from the tube walls and sometimes not. One helpful way is to make parts of the tubes from rifled or internally finned tubes. Water steam solution is brought into rotative motion and heavier water tends to stay longer at the tube walls.

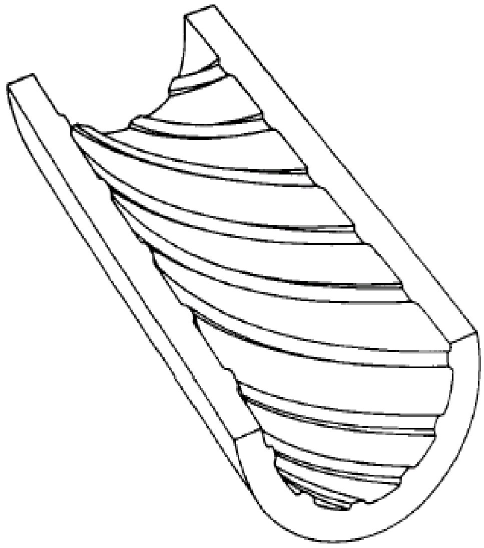

Figure 4-12, Typical internally spirally finned tube.

Spirally finned tube increases wall wetting, decreases the possibility of DNB and is more expensive than straight tube.

4.4.5 Combined circulation

Combined circulation is a trademark of former Combustion Engineering, now part of Ahlstom Power. Target in combined circulation is to improve ‘once-through’ in low loads. Includes pump for partial load operation. When low loads are run a part of the stam water solution can be recirculated to drum and pumped again through the boiler.

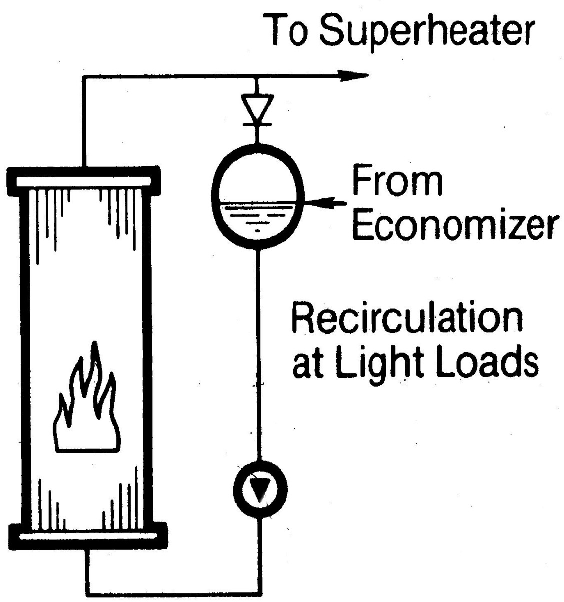

Figure 4-13, Combined circulation (Singer, 1981).

Headers were earlier of various shapes. Even square cross section was used. Nowadays only tubular headers are used.

4.4.6 Departure from nucleate boiling

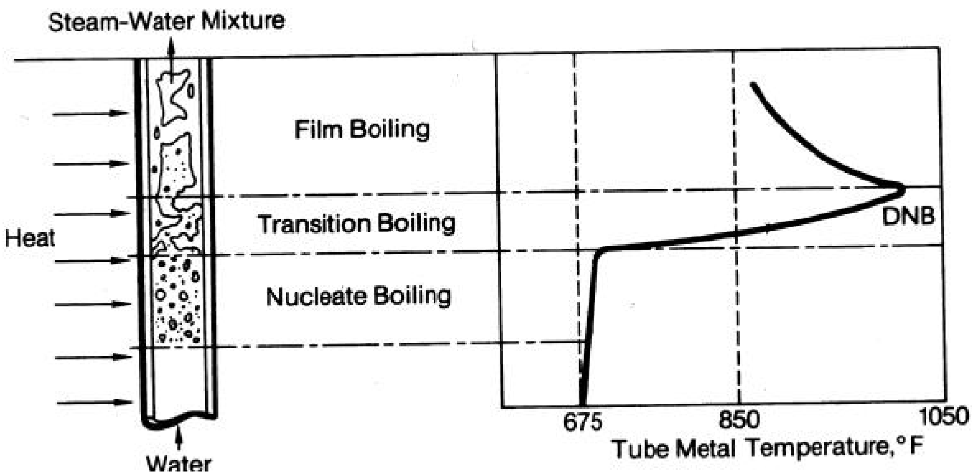

Figure 4-14, Departure from nucleate boiling.

The biggest design consern for once-through design is that DNB must be avoided. Furnace heat transfer must be arranged so that the furnace tube temperatures keep relatively constant even at partial load.

5 MILL BALANCES

Every recovery boiler case was considered in a mill setting. Two alternatives were used. The first is typical new mill with biomass boiler. The second was the same mill but with no additional boilers i.e. bark etc. are sold. This was done for not to confuse the electricity generating values with possible biomass boiler specific extra electricity generation.

5.1 Mill base dimensioning

Target annual production, t/a	1100000
Softwood, ADt/a	480000
Hardwood, ADt/a	620000
Target operating days, d	350
Required average production, ADt/24h	3143
Mill debarking	
Additional wood for combustion, m^3sub/a	500000

This mill corresponds to a new large mill at northern latitudes. The size was chosen large. The economical possibilities for extra electricity generation are better with large boilers.

5.2 Mill department sizing

Woodroom, m^3_{sub}/d	34300
Digester, ADt/d	3680
Oxygendel., ADt/d	3680
Screening, ADt/d	3680
Pulp washing, ADt/d	3680
Bleaching, ADt/d	3490
Pulpdryer, ADt/d	3490
Evaporation, t H_2O/h	1140
Recovery boiler, tDS/d	5300
Causticizing, m^3WL/d	20956
Lime kiln, t lime/d	1080
CNCG-handling, m^3/h	2300
DNCG-handling, m^3/s	40
Power boiler, kg/s	90
Turbogenerators	Case

The mill department sizing was done using LUT based mill balance program MILLFLOW.

5.3 Mill steam and electricity balances

Mill main balances were calculated to find out how changing the recovery boiler main steam parameters affect the kraft mill balances especially the recovery boiler electricity generation. The main balances were calculated using MILLFLOW excel spreadsheet as basis for balances.

When calculating the main balances the departmental steam usages correspond to needs for each case. So for each case the full mill steam and electricity balances are satisfied. The fiberline operation remains essentially unchanged as the mill production is kept constant. Recovery boiler preheating and pumping needs change from case to case. In addition in case A the evaporation is to lower solids. Main balance summary for recovery boiler is seen in Table 5-1.

Table 5-1 Recovery boiler operating values for each case.

		Joutseno	Kymi	Yonago	SoTu	SkyRec	SkyRec+	SkyRec
Case		**A**	**B**	**C**	**D**	**E**	**F**	**E160**
Capacity	tds/d	5500	5500	5500	5500	5500	5500	5500
capacity (virgin)	tds/d	5005	5005	5005	5005	5005	5005	5005
Dry solids	%	82.0	85.0	85.0	85.0	85.0	85.0	85.0
HHV	MJ/kgds	13.00	13.00	13.00	13.00	13.00	13.00	13.00
LHV	MJ/kgds	12.28	12.28	12.28	12.28	12.28	12.28	12.28
O2 in dry flue gas	%	2.8	2.8	2.8	2.8	2.8	2.8	2.8
Primary air percentage	%	23.0	22.0	22.0	22.0	22.0	22.0	22.0
Primary air temp.	°C	150.0	190.0	190.0	190.0	190.0	190.0	190.0
Secondary air percentage	%	50.0	54.0	54.0	54.0	54.0	54.0	54.0
Secondary air temp.	°C	120.0	190.0	190.0	190.0	190.0	190.0	190.0
Tertiary air percentage	%	27.0	12.0	12.0	12.0	12.0	12.0	12.0
Tertiary air temp.	°C	30.0	190.0	190.0	190.0	190.0	190.0	190.0
Quartenary air percent.	%	0.0	12.0	12.0	12.0	12.0	12.0	12.0
Quartenary air temp.	°C	30.0	190.0	190.0	190.0	190.0	190.0	190.0
Total air temperature	°C	102.6	190.0	190.0	190.0	190.0	190.0	190.0
Main steam pressure RB	bar(a)	94.0	104.0	124.0	164.0	124.0	264.0	164.0
Main steam temp. RB	°C	490.0	505.0	515.0	540.0	515.0	540.0	515.0
Main steam pressure PB	bar(a)	94.0	104.0	124.0	164.0	124.0	124.0	102.0
Main steam temp. PB	°C	490.0	505.0	515.0	540.0	515.0	515.0	505.0
Feedwater pressure	bar(a)	110.0	121.0	146.0	182.0	146.0	290.0	290.0
Feedwater temp.	°C	120.0	148.0	148.0	148.0	148.0	148.0	148.0
Reheater inlet pressure	bar(a)					36	56	36
Reheater inlet temp.	°C					348	337	310
Reheater outlet pressure	bar(a)					34	54	34
Reheater outlet temp.	°C					400	460	400
HP FW preheater inlet	°C	200	200	200	200	200	200	200
HP FWpreheater outlet	°C	200	200	220	220	220	220	220
Flue gas temp. (eco out)	°C	155	197	197	197	197	197	197
Flue gas temp. (to stack)	°C		155	155	155	155	155	155
Sootblowing	kg/s	6.0	6.0	6.0	6.0	8.0	8.0	8.0

The main balances were calculated using MILLFLOW excel spreadsheet as basis for balances. The mill condensing tail flow was set to balance the steam balance. The example pulp mill has condensing tail in its turbine. Most of the older pulp mills do not have a condensing tail, but run only backpressure operation. It should be noted that in the example mill there is no bark boiler. Recovery boiler is the sole steam producer in the mill. The bark is sold to outside of the mill.

In all cases the pulp mil produces more electricity than it consumes. This is because the mill is modern and thus energy efficient i.e. it has steam surplus. The second reason for high electricity generation is high steam parameters. The third reason is extra electricity generation done with condensing tail in the steam turbine.

Table 5-2 Main balance values for each case, power boiler in operation.

		Joutseno	Kymi	Yonago	SoTu	SkyRec	SkyRec+	SkyRec
Case		**A**	**B**	**C**	**D**	**E**	**F**	**E160**
Capacity	tds/d	5500	5500	5500	5500	5500	5500	5500
capacity (virgin)	tds/d	5005	5005	5005	5005	5005	5005	5005
Dry solids	%	82.0	85.0	85.0	85.0	85.0	85.0	85.0
Main steam pressure RB	bar(a)	94.0	104.0	124.0	164.0	124.0	264.0	164.0
Main steam temp. RB	°C	490.0	505.0	515.0	540.0	515.0	540.0	515.0
Main steam pressure PB	bar(a)	94.0	104.0	124.0	164.0	124.0	124.0	102.0
Main steam temp. PB	°C	490.0	505.0	515.0	540.0	515.0	515.0	505.0
Feedwater pressure	bar(a)	110.0	121.0	146.0	182.0	146.0	290.0	290.0
Feedwater temp.	°C	120.0	148.0	148.0	148.0	148.0	148.0	148.0
Reheater inlet pressure	bar(a)					36	56	36
Reheater inlet temp.	°C					348	337	310
Reheater outlet pressure	bar(a)					34	54	34
Reheater outlet temp.	°C					400	460	400
Sootblowing	kg/s	6.0	6.0	6.0	6.0	8.0	8.0	8.0
Steam flow RB	kg/s	215.0	226.4	232.5	232.0	224.0	218.5	220.8
Change in steam flow	%	0.0	5.3	8.1	7.9	4.1	1.6	2.7
Pulping usage total	MW	87.6	88.1	88.9	90.2	88.2	93.2	90.0
Mill total usage	MW	95.5	96.1	96.9	98.2	96.2	101.2	98.0
Electricity production	MW	234.4	239.5	249.8	262.9	250.1	263.4	251.1
Surplus electricity	MW	138.9	143.3	153.0	164.7	153.8	162.2	153.1
Efficiency to electricity	%	23.2	23.1	24.1	25.4	24.1	25.4	24.2
Change in electricty	MW	0.0	4.4	14.0	25.8	14.9	23.2	14.1
	%	0.0	3.2	10.1	18.5	10.7	16.7	10.2

We note that the steam production increases from Case A to Case B because of higher black liquor dry solids and more air preheating. The steam production increases from Case B to Case C because of high pressure preheating. The recovery boiler steam flow starts decreasing as further increases in main steam parameters require more heat.

The pulping electricity usage is not constant. The main parameter that changes is the recovery boiler feedwater pump power requirement, Table 5-3.

Table 5-3 Recovery boiler own power usage for each case.

		Joutseno	Kymi	Yonago	SoTu	SkyRec	SkyRec+	SkyRec
Case		**A**	**B**	**C**	**D**	**E**	**F**	**E160**
Air fan power	kW	2275	2296	2296	2296	2296	2296	2296
Flue gas fan power	kW	2570	2534	2534	2534	2534	2534	2534
Feedwater pumping power	kW	3055	3556	4347	5719	4187	8606	5443
Other power	kW	1500	1500	1500	1500	1500	1500	1500
Total power	kW	9401	9886	10677	12049	10518	14937	11773

Table 5-4 Main balance values for each case, no power boiler in operation.

		Joutseno	Kymi	Yonago	SoTu	SkyRec	SkyRec+	SkyRec
Case		**A**	**B**	**C**	**D**	**E**	**F**	**E160**
Capacity	tds/d	5500	5500	5500	5500	5500	5500	5500
capacity (virgin)	tds/d	5005	5005	5005	5005	5005	5005	5005
Dry solids	%	82.0	85.0	85.0	85.0	85.0	85.0	85.0
Main steam pressure RB	bar(a)	94.0	104.0	124.0	164.0	124.0	264.0	164.0
Main steam temp. RB	°C	490.0	505.0	515.0	540.0	515.0	540.0	515.0
Main steam pressure PB	bar(a)	91.0	104.0	124.0	164.0	124.0	124.0	102.0
Main steam temp. PB	°C	490.0	505.0	515.0	540.0	515.0	515.0	505.0
Feedwater pressure	bar(a)	110.0	121.0	146.0	182.0	146.0	290.0	290.0
Feedwater temp.	°C	120.0	148.0	148.0	148.0	148.0	148.0	148.0
Reheater inlet pressure	bar(a)					36	56	36
Reheater inlet temp.	°C					348	337	310
Reheater outlet pressure	bar(a)					34	54	34
Reheater outlet temp.	°C					400	460	400
Sootblowing	kg/s	6.00	6.00	6.00	6.00	8.00	8.00	8.00
Steam flow RB	kg/s	215.0	226.4	233.6	232.0	224.0	218.5	224.0
Change in steam flow	%	0.0	5.3	8.6	7.9	4.1	1.6	4.1
Pulping usage total	MW	87.6	88.1	88.9	90.2	88.2	93.2	90.0
Mill total usage	MW	91.1	91.7	92.4	93.8	91.8	96.8	93.6
Electricity production	MW	149.3	153.9	161.8	175.6	162.3	177.9	167.0
Surplus electricity	MW	58.2	62.2	69.4	81.7	70.5	81.1	73.4
Efficiency to electricity	%	20.4	20.4	21.4	23.2	21.5	23.5	22.7
Change in electricty	MW	0.0	4.0	11.2	23.6	12.3	22.9	15.2
	%	0.0	6.8	19.3	40.5	21.1	39.4	26.2

As can be seen the modern recovery boiler Case C does produce about 20 % more electricity than roughly ten years ago, case A. reheating cases E and E160 seem to give only marginally better electricity production. The only alternative seems to be to increase the main steam temperature to 540 ^{o}C, Cases D and F.

Electricity generation does not depend a lot on how the boiler steam side is configured. Reheating and once through appear only marginally better when considering the recovery boiler electricity generation.

6 BOILER DIMENSIONING

All described cases have been dimensioned. The dimensioning is based on typical recovery boiler dimensioning. The studied cases were

A. Natural circulation 82 %, 490 ^{o}C, 9.0 MPa (reference Joutseno)

B. Natural circulation 85 %, 505 ^{o}C, 10.2 MPa (reference Kymi)

C. Natural circulation 85 %, 515 ^{o}C, 12.0 MPa (reference Yonago)

D. Assisted circulation 85 %, 540 ^{o}C, 16.0 MPa (SoTu)

E. Natural circulation 85 %, 515/400 ^{o}C, 12.0/3.4 MPa (SkyRec) *Reheating*

F. Once-through 85 %, 540/460 ^{o}C, 26.0/5.4 MPa (Skyrec+) *Reheating*

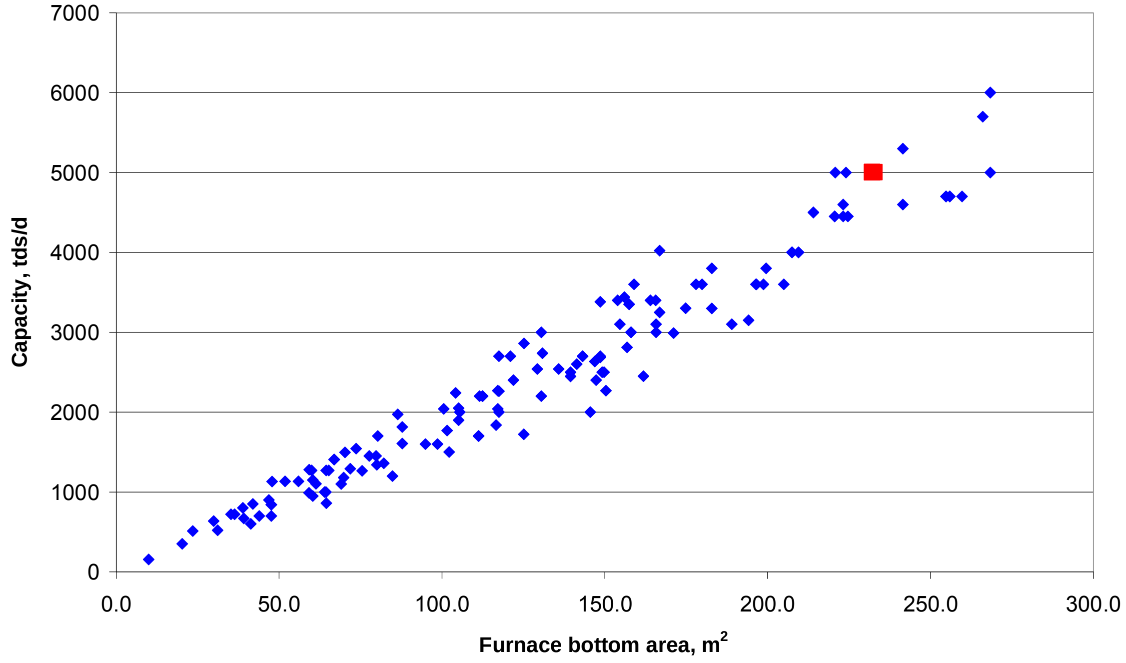

Figure 6-1, Boiler bottom area vs capacity, red squares indicate cases A-F.

Each boiler was dimensioned similar to commercial recovery boilers using recovery boiler specific dimensioning. The furnace bottom area size was kept constant, but furnace height varied, Figure 6-2. As can be seen the reheater cases E and F have rather low furnaces and thus high furnace nose temperatures. If we try to use traditional furnace nose temperatures the superheater surface area required quickly becomes much too large. Choise of variable furnace nose temperature meant that boiler bank entrance section temperature was kept reasonably unchanged.

Because of equal boiler bank entrance section temperature the boiler bank and economizer area comes up similar.

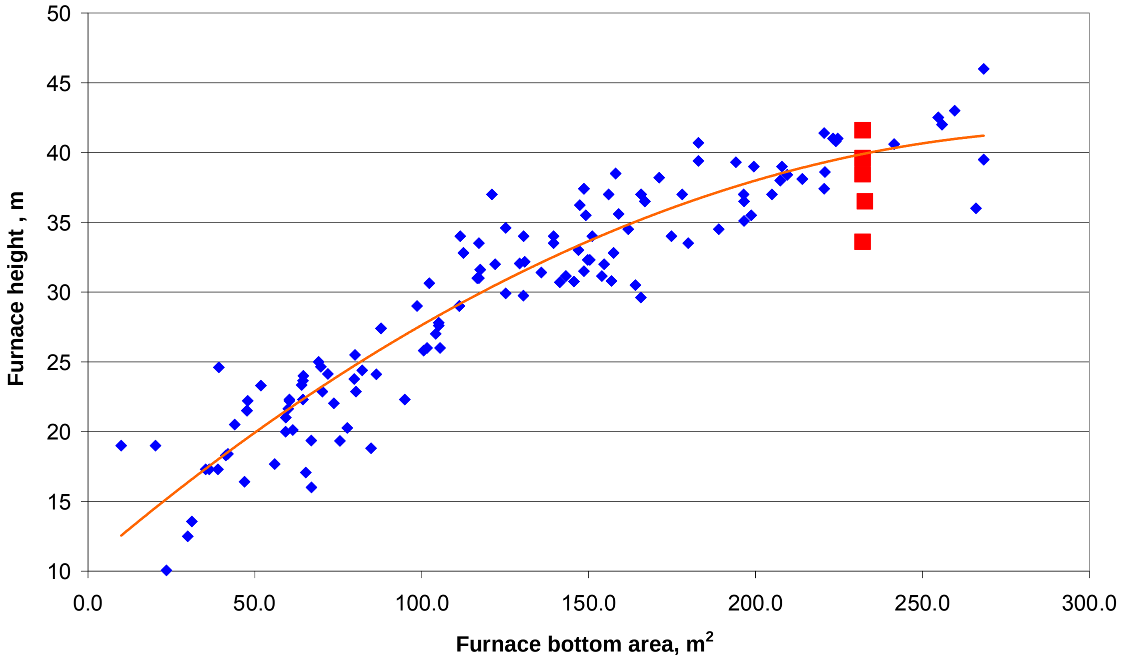

Figure 6-2, Boiler bottom area vs furnace height, red squares indicate cases A-F.

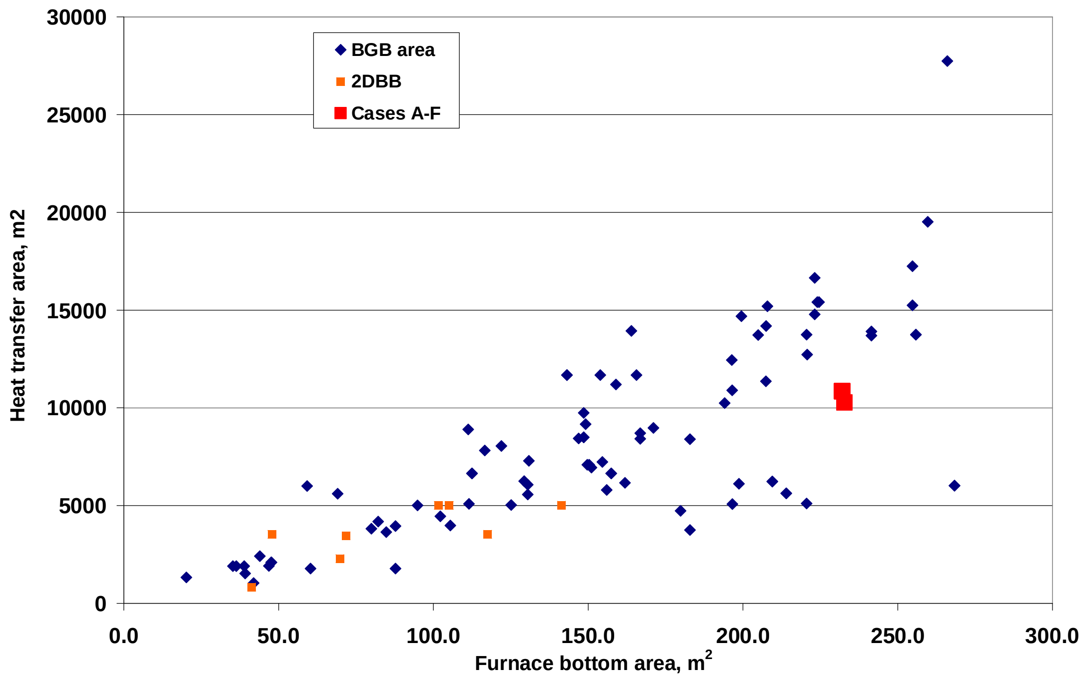

Figure 6-3, Boiler bottom area vs boiler bank area, red squares indicate cases A-F.

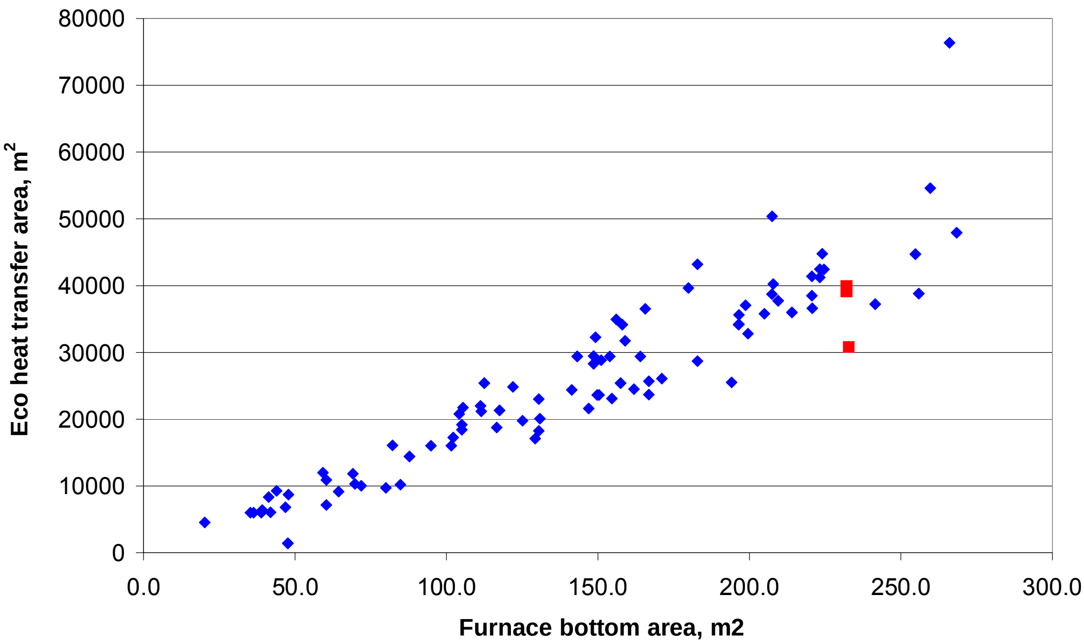

Figure 6-4, Boiler bottom area vs economizer area, red squares indicate cases A-F.

The superheater and reheater area between different cases varied quite much.

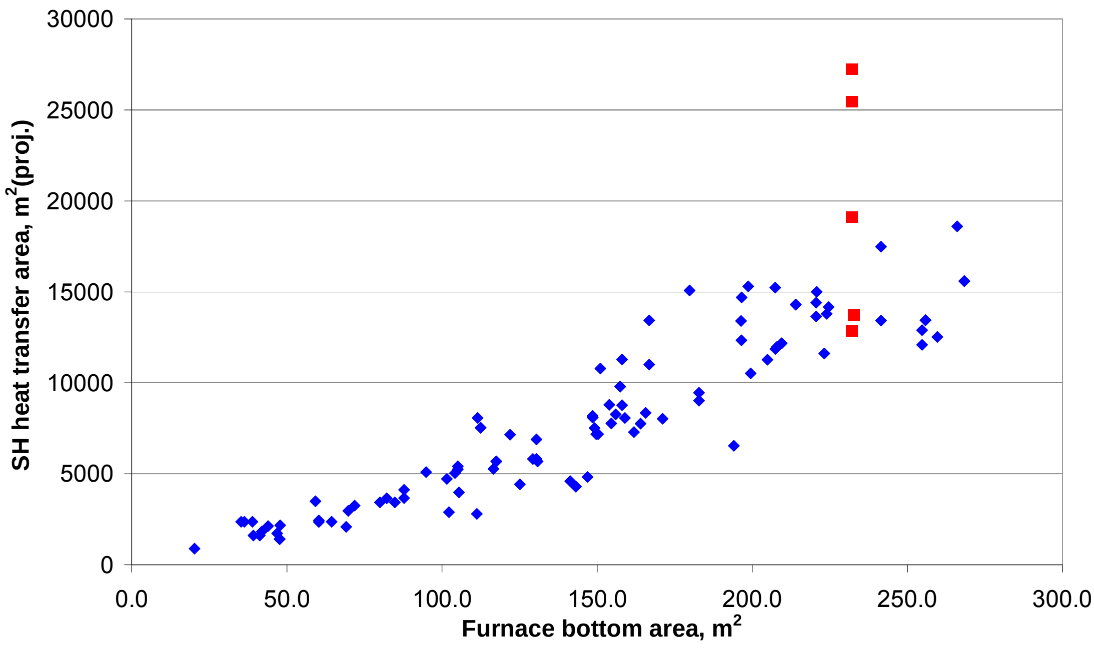

Figure 6-5, Boiler bottom area vs sum of superheater and reheater area, red squares indicate cases A-F.

Each case dimensioning is discussed in more detail.

6.1 Case A - Modern high efficiency boiler

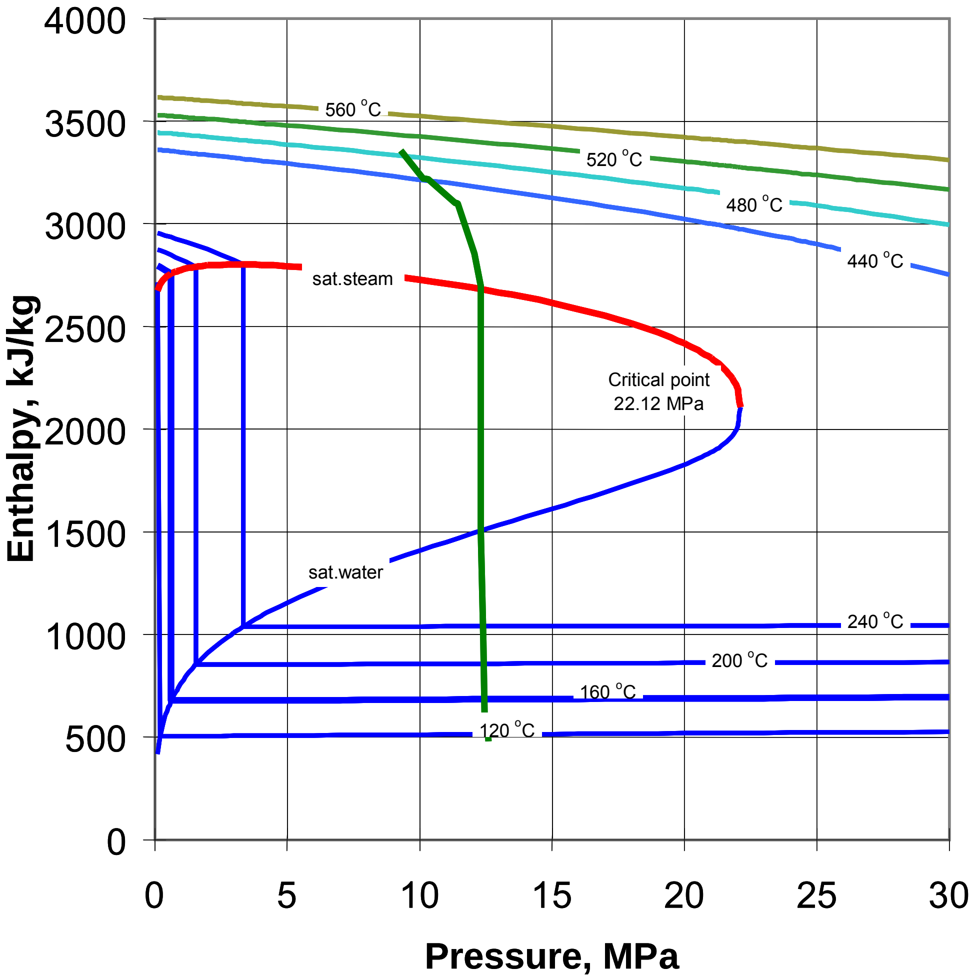

Figure 6-6, Modern recovery boiler in p-h-diagram, 215.0 kg/s, 9.0 MPa, 490 °C.

The heat addition diagram for Case A is presented as figure 6-1. As is typical the biggest pressure drop is in the superheaters.

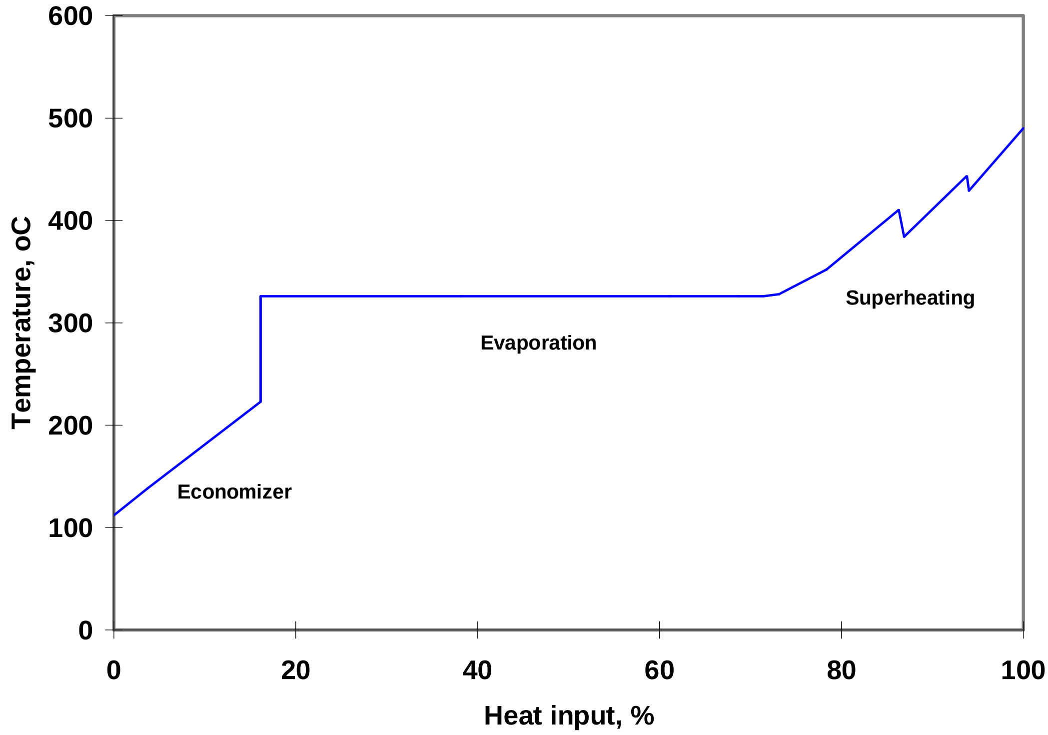

Figure 6-7, Modern recovery boiler in Φ-t-diagram, 215.0 kg/s, 9.0 MPa, 490 °C.

The heat-steam/waterside temperature diagram for Case A is presented as figure 6-2. The evaporation is overdimensioned as is typical and economizers are underdimensioned. This is because sizing boiler bank an economizers roughly of equal height gives savings in boiler house volume. The main dimensions for Case A are shown in Table 6-1.

Table 6-1 Main dimensions of modern recovery boiler, Case A.

Surface	**unit**	
Furnace area	m^2	232.8
Furnace height	m	36.5
Total boiler height	m	70.5
Furnace area	m^2	4417
Screen area	m^2	
Superheater area	m^2	16880
Superheater area (proj)	m^2	13731
Boiler bank area	m^2	10274
Economizer area	m^2	30855
Total area	m^2	

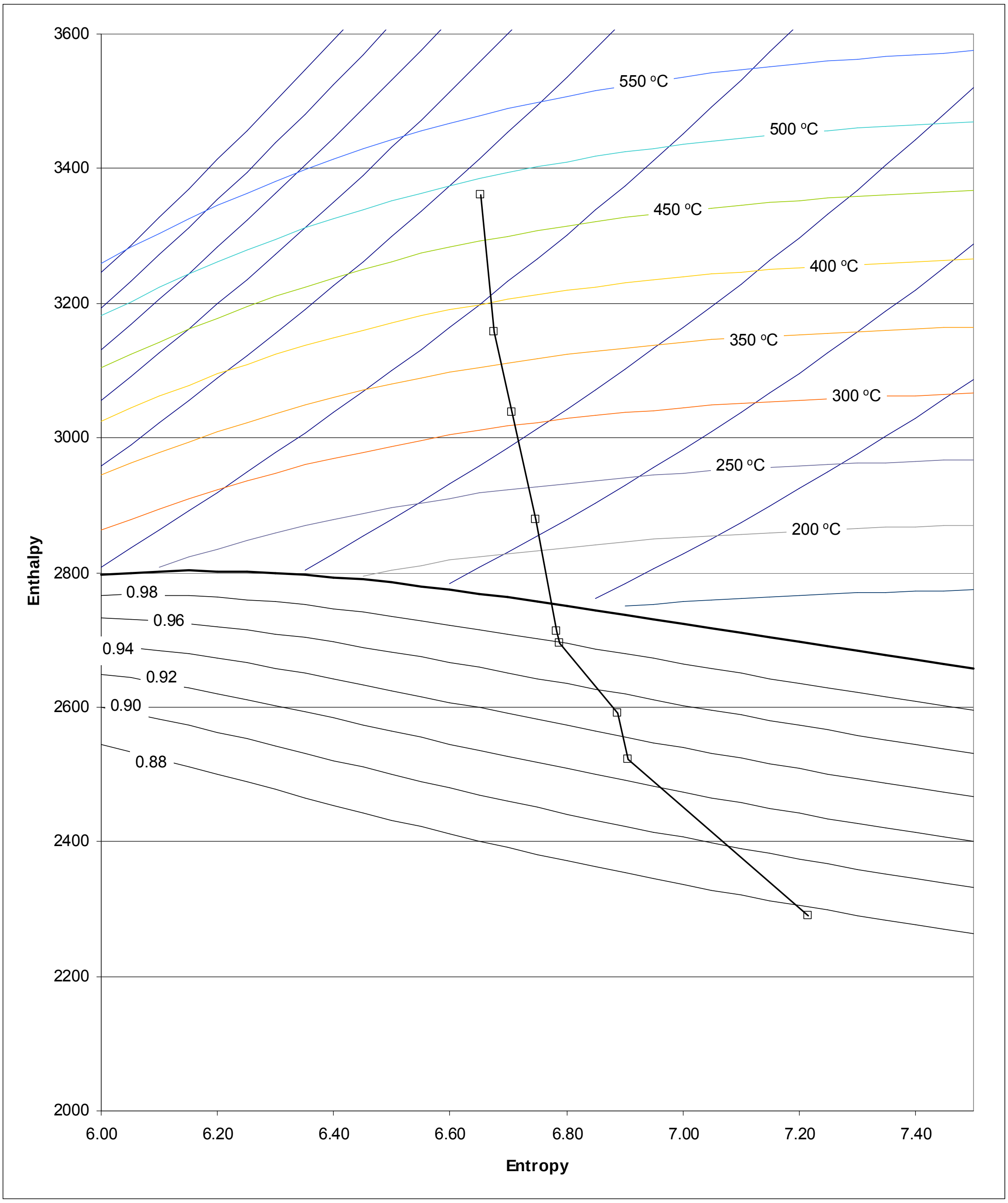

Figure 6-8, Modern recovery boiler turbine expansion in h-s-diagram, 215 kg/s, 9.0 MPa, 490 °C.

As seen in the figure 6-3 the turbine expansion tends to go to wet steam at about 5 bar(g) so this option requires higher low pressure steam values than others. In addition the turbine condenser end is at moisture which exceeds 12 %. Normally this would require special turbine design to be feasible.

If the turbine isentropic efficiency is lowered or turbine condenser end pressure is increased the turbine can be brought to more normal design conditions.

6.2 Case B – High efficiency recovery boiler

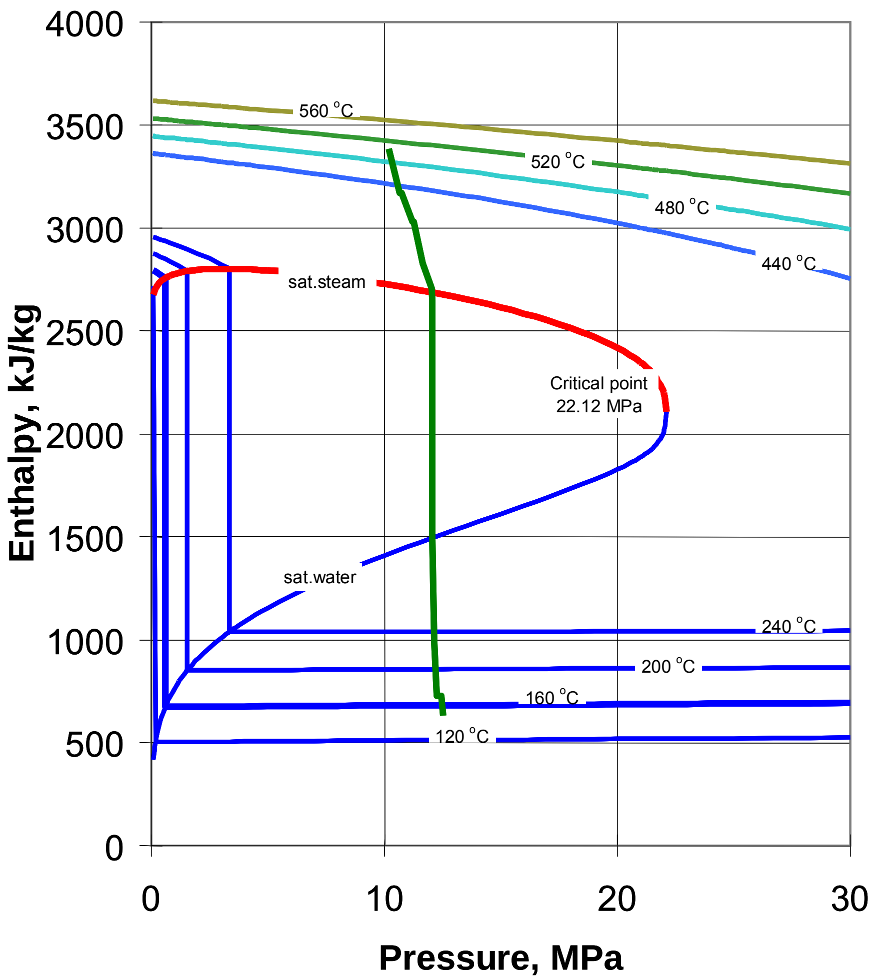

Figure 6-9, High efficiency recovery boiler in p-h-diagram, 226.4 kg/s, 10.2 MPa, 505 °C.

The heat addition diagram for Case B is presented as figure 6-4. This diagram does not markedly differ form the one for Case A. As can be seen the preheating of feedwater takes a fairly large portion of the heat flow.

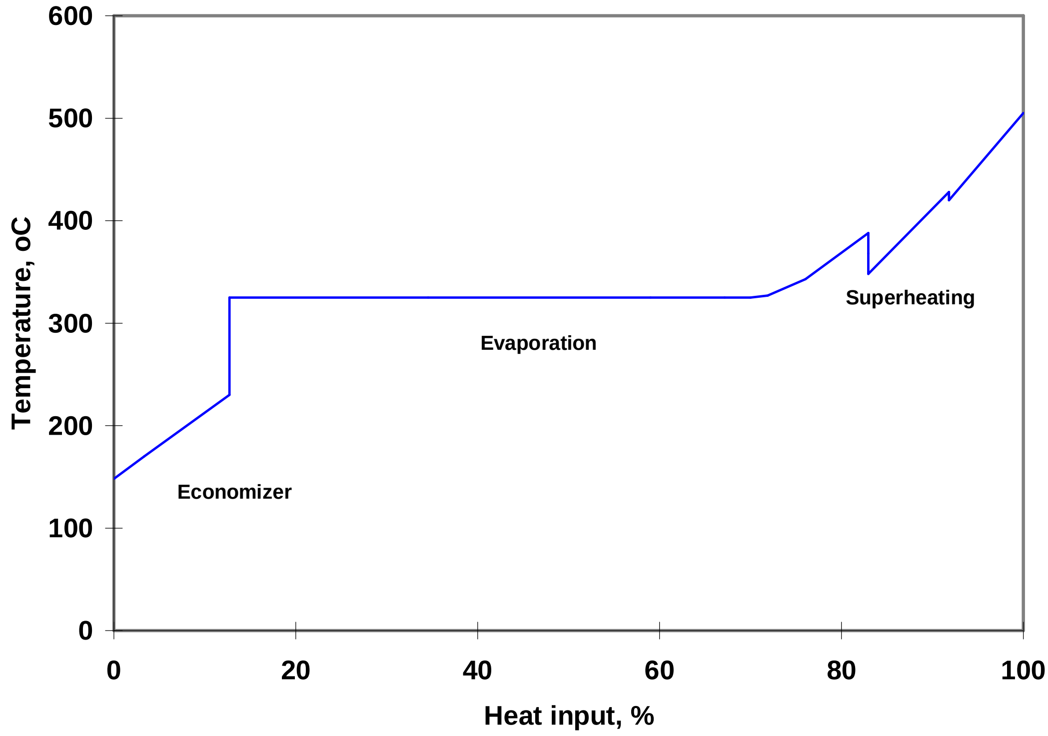

Figure 6-10, High efficiency recovery boiler in Φ-t-diagram, 226.4 kg/s, 10.2 MPa, 505 °C.

The heat-steam/waterside temperature diagram for Case B is presented as figure 6-5. The diagram is fairly similar to case A. The main dimensions for Case B are shown in Table 6-2.

Table 6-2 **Main dimensions of high efficiency recovery boiler, Case B.**

Surface	**unit**	
Furnace area	m^2	232.1
Furnace height	m	41.6
Total boiler height	m	75.1
Furnace area	m^2	5056
Screen area	m^2	
Superheater area	m^2	13536
Superheater area (proj)	m^2	12851
Boiler bank area	m^2	10852
Economizer area	m^2	39972
Total area	m^2	

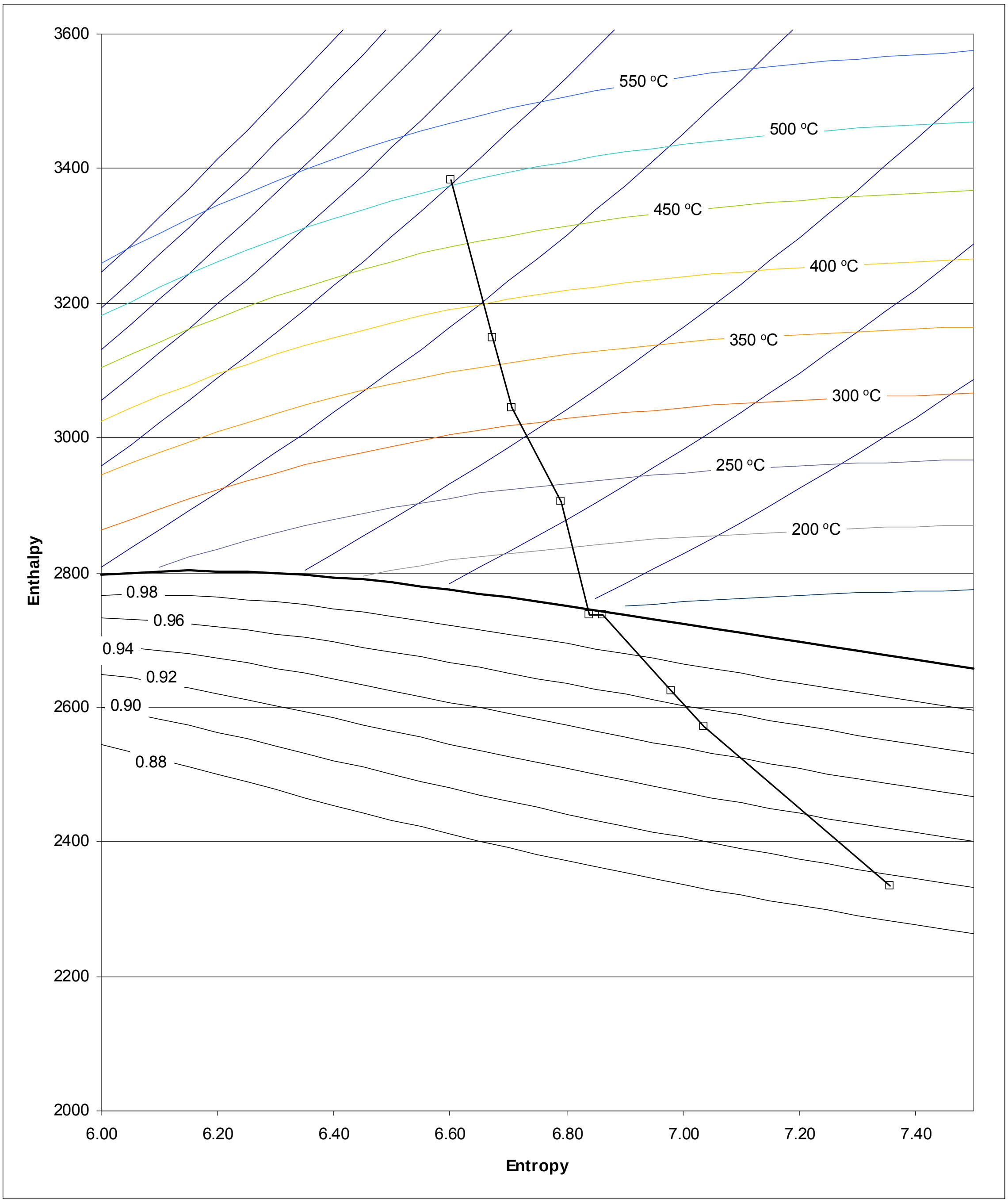

Figure 6-11, High efficiency recovery boiler turbine expansion in h-s-diagram, 226.4 kg/s, 10.2 MPa, 505 °C.

The high efficiency boiler turbine expansion seems to fit better the chosen LP pressure 3.5 bar(g). The end moisture is somewhat over 10 % which is still possible, but requires better materials for the last rows of turbine blades.

6.3 Case C – High pressure and temperature recovery boiler

The heat addition diagram for Case C is presented as figure 6-7. As is typical the biggest pressure drop is in the superheaters.

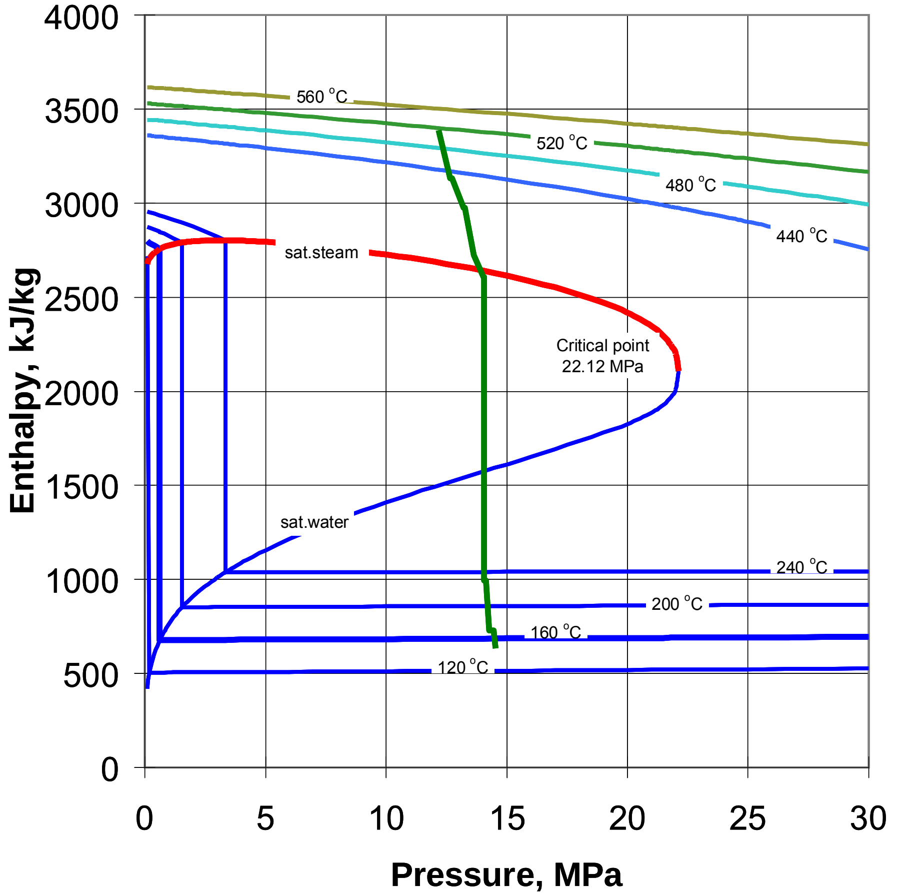

Figure 6-12, High pressure and temperature recovery boiler in p-h-diagram, 232.5 kg/s, 12.0 MPa, 520 °C.

There are not big changes in heat transfer surface placement nor in their sizing, therefore the p-h-diagram is fairly similar to cases A and B. As the pressure increases the portion of heat to evaporation decreases and the portion of heat to both superheating and preheating increases. This is the reason why different constructions from traditional are used in the boiler bank. Because the entrance to boiler bank has been kept fairly close to traditional values then the furnace inlet temperature has increases.

In the Φ-t-diagram one notices that the economizer outlet temperature starts to be fairly low compared to the evaporation temperature.

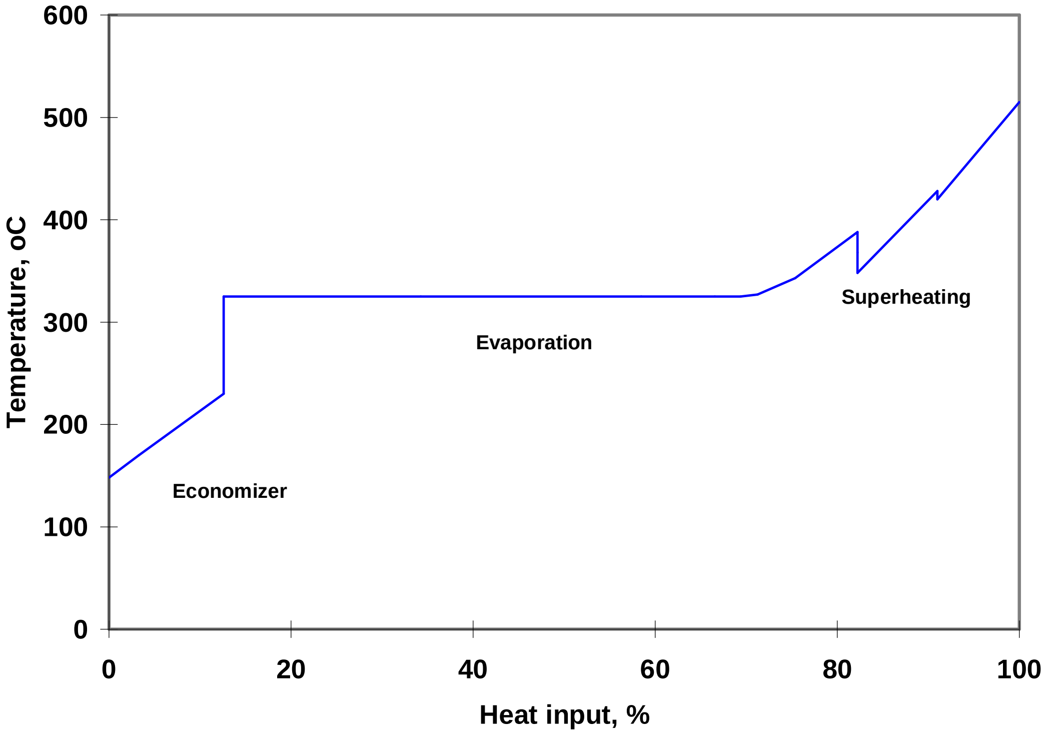

Figure 6-13, High pressure and temperature recovery boiler in Φ-t-diagram, 232.5 kg/s, 12.0 MPa, 520 °C.

Table 6-3 **Main dimensions of high pressure and temperature recovery boiler, Case C.**

Surface	**unit**	
Furnace area	m^2	232.8
Furnace height	m	41.6
Total boiler height	m	78
Furnace area	m^2	5056
Screen area	m^2	
Superheater area	m^2	13536
Superheater area (proj)	m^2	12851
Boiler bank area	m^2	10852
Economizer area	m^2	39849
Total area	m^2	

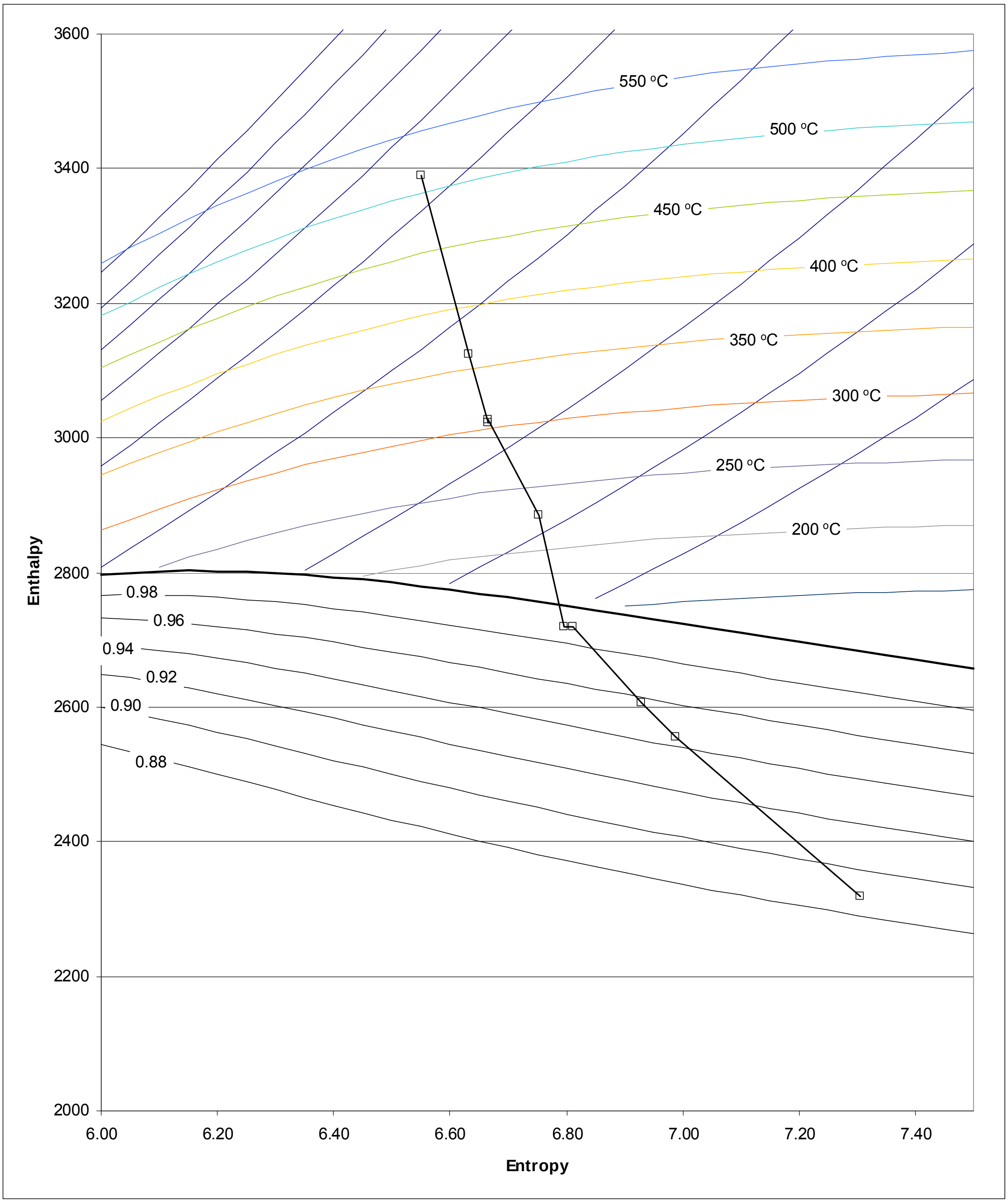

Figure 6-14, High pressure and temperature recovery boiler turbine expansion in h-s-diagram, 232.5 kg/s, 12.0 MPa, 520 °C.

6.4 Case D - Assisted circulation recovery boiler concept

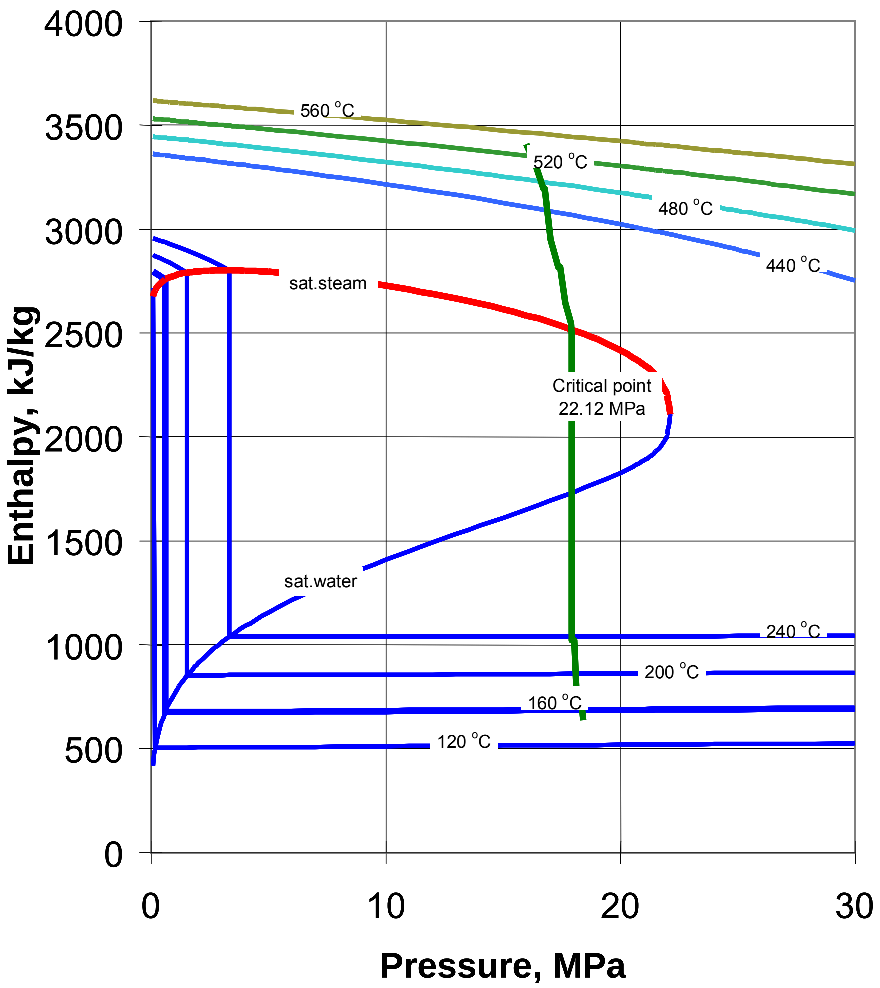

Figure 6-15, Assisted circulation recovery boiler in p-h-diagram, 232.0 kg/s, 16.0 MPa, 540 °C.

Table 6-4 Main dimensions of assisted circulation recovery boiler, case D.

Surface	unit	
Furnace area	m^2	232.1
Furnace height	m	39.6
Total boiler height	m	75
Furnace area	m^2	5082
Screen area	m^2	
Superheater area	m^2	20255
Superheater area (proj)	m^2	19014
Boiler bank area	m^2	10852
Economizer area	m^2	39765
Total area	m^2	

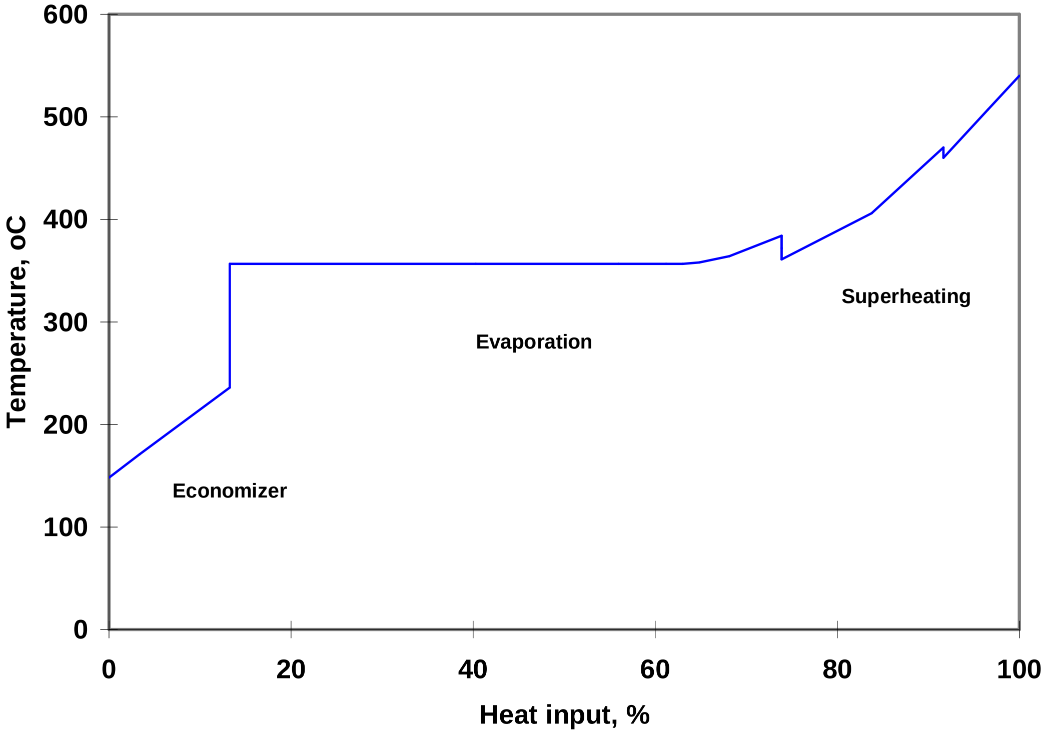

Figure 6-16, Assisted circulation recovery boiler in Φ-t-diagram, 232.0 kg/s, 16.0 MPa, 540 °C.

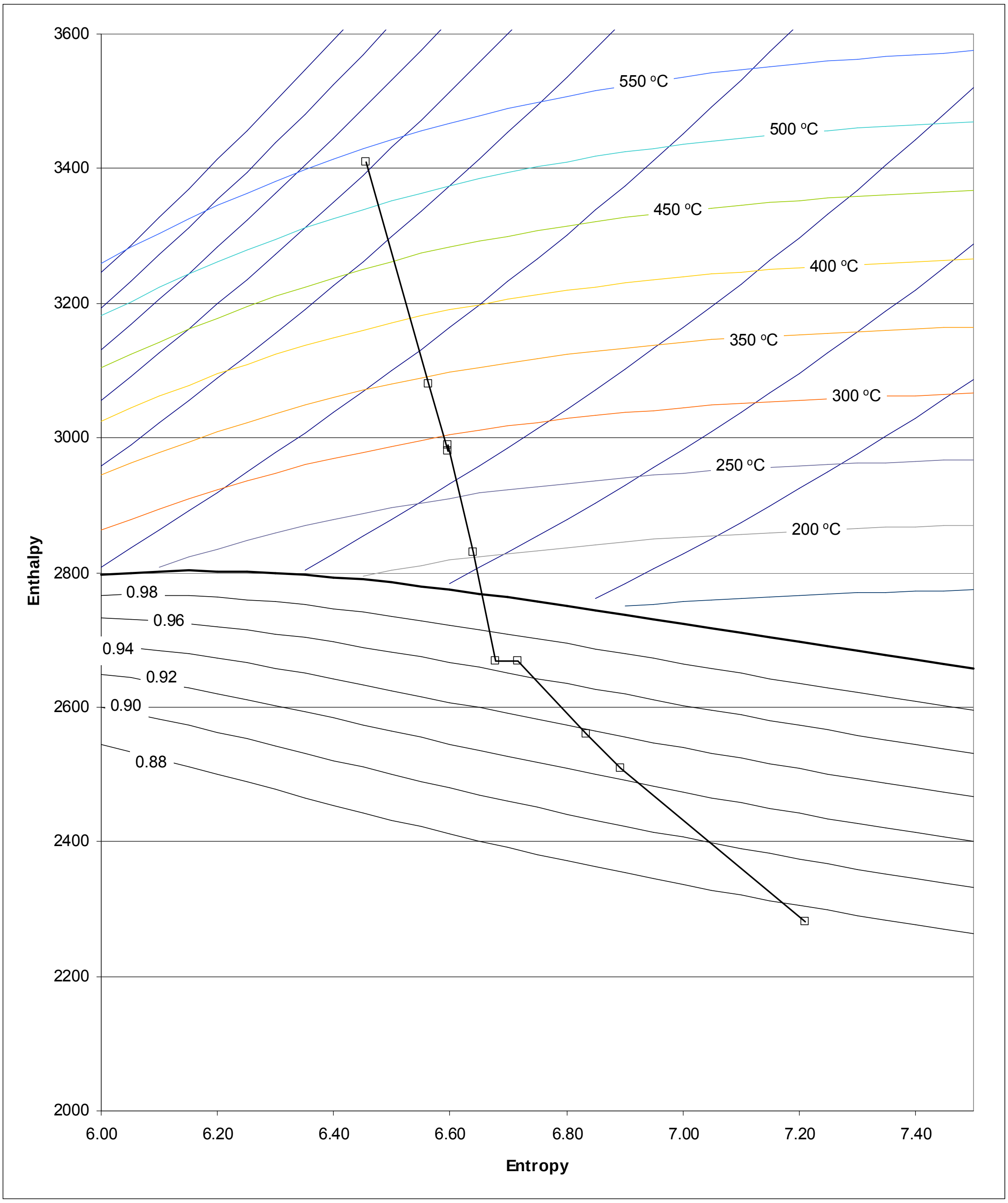

Figure 6-17, Assisted circulation recovery boiler turbine expansion in h-s-diagram, 232.0 kg/s, 16.0 MPa, 540 °C.

6.5 Case E – High pressure and temperature recovery boiler with reheat concept

This boiler equals the boiler of Case C but with reheating applied

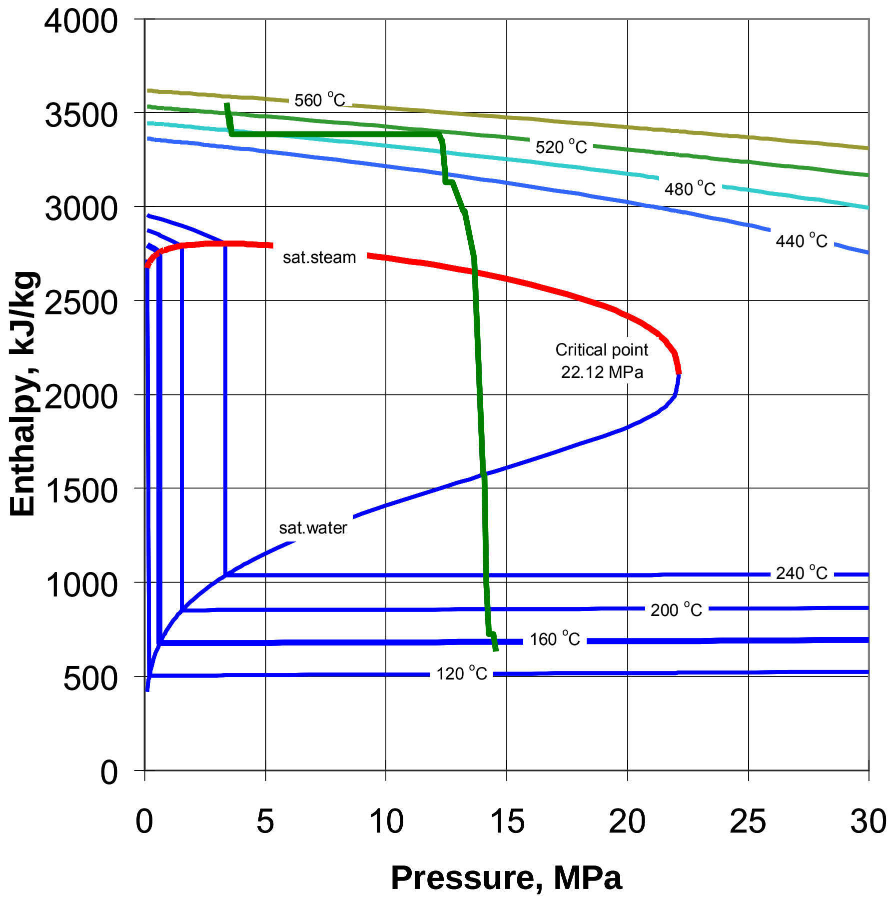

Figure 6-18, High pressure and temperature recovery boiler with reheat in p-h-diagram, 224.0 kg/s, 12.0/3.4 MPa, 515/400 °C.

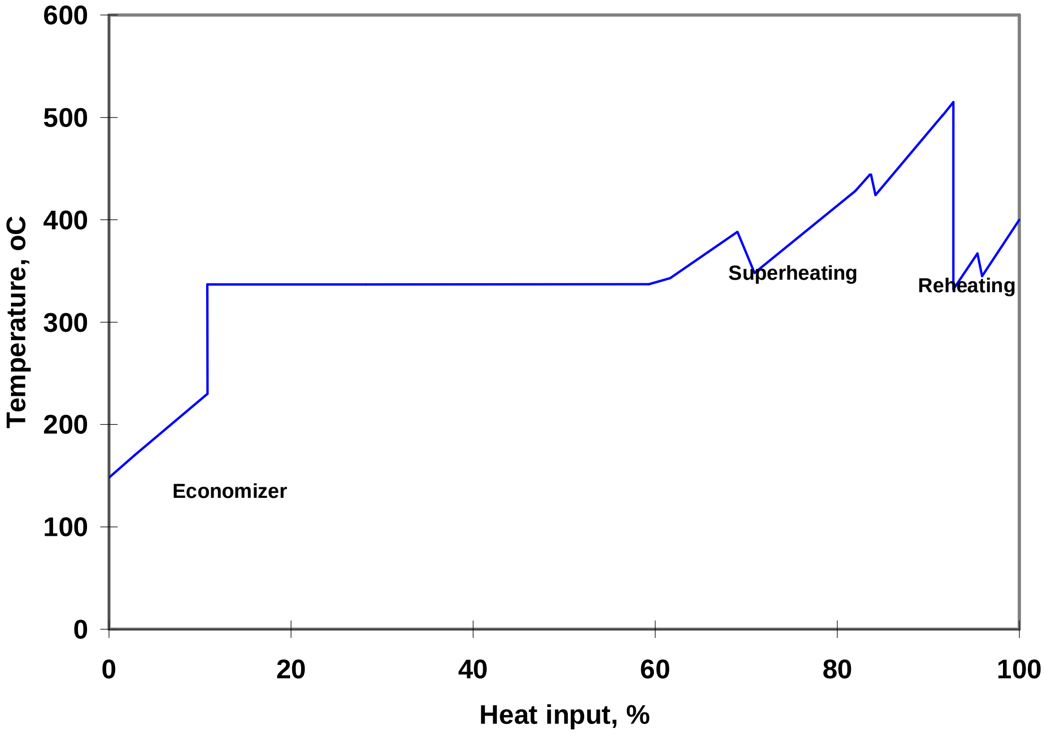

Figure 6-19, High pressure and temperature recovery boiler with reheat in Φ-t-diagram, 224.0 kg/s, 12.0/3.4 MPa, 515/400 ^{o}C.

Table 6-5 **Main dimensions of high pressure and temperature recovery boiler with reheat, case E.**

Surface	**unit**	
Furnace area	m^2	232.1
Furnace height	m	38.4
Total boiler height	m	75
Furnace area	m^2	4473
Screen area	m^2	
Superheater area	m^2	20255
Superheater area (proj)	m^2	25451
Boiler bank area	m^2	10852
Economizer area	m^2	39975
Total area	m^2	

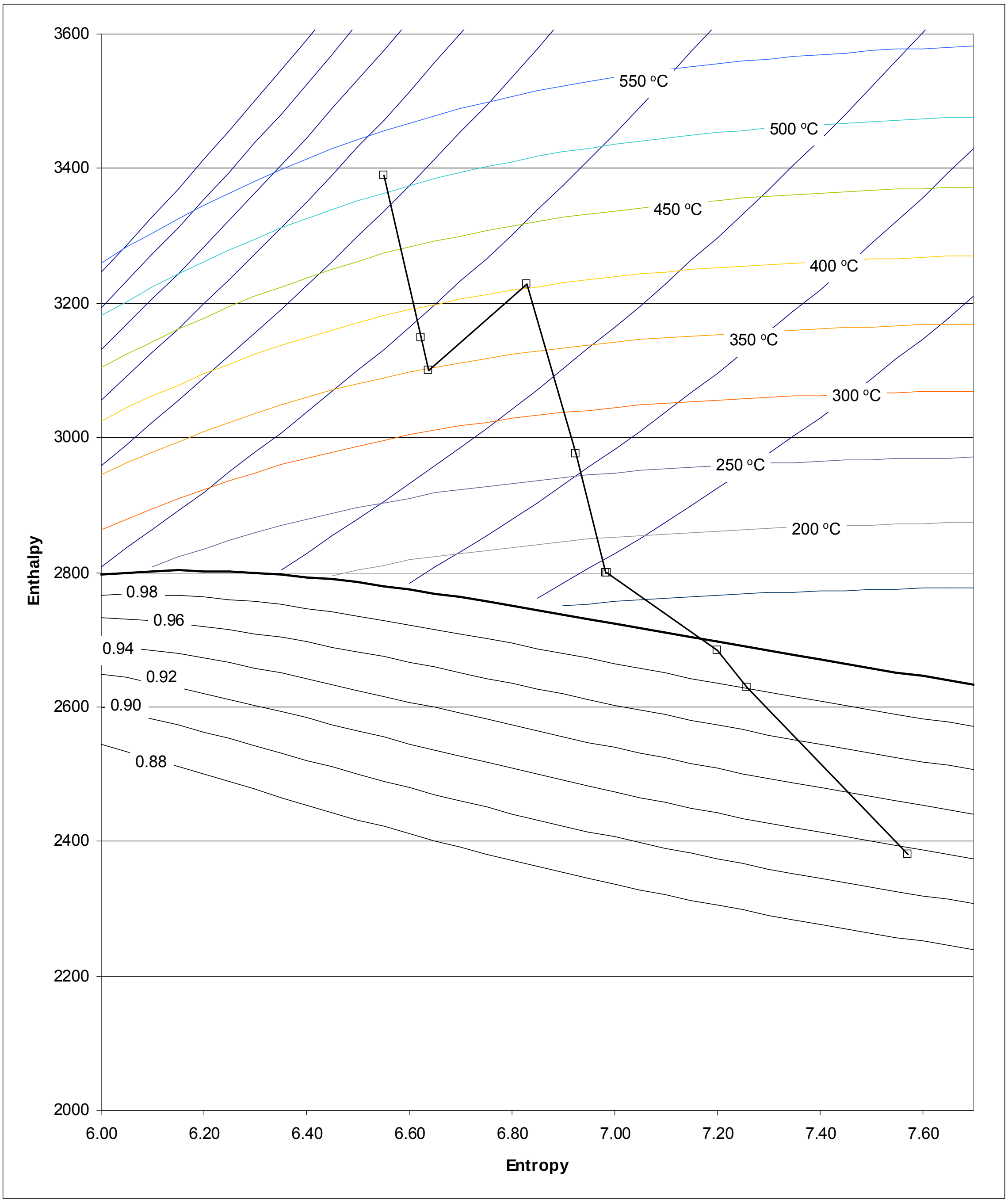

Figure 6-20, High pressure and temperature recovery boiler with reheat in h-s-diagram, 224.0 kg/s, 12.0/3.4 MPa, 515/400 °C.

6.6 Case F – Once-through recovery boiler with reheat concept

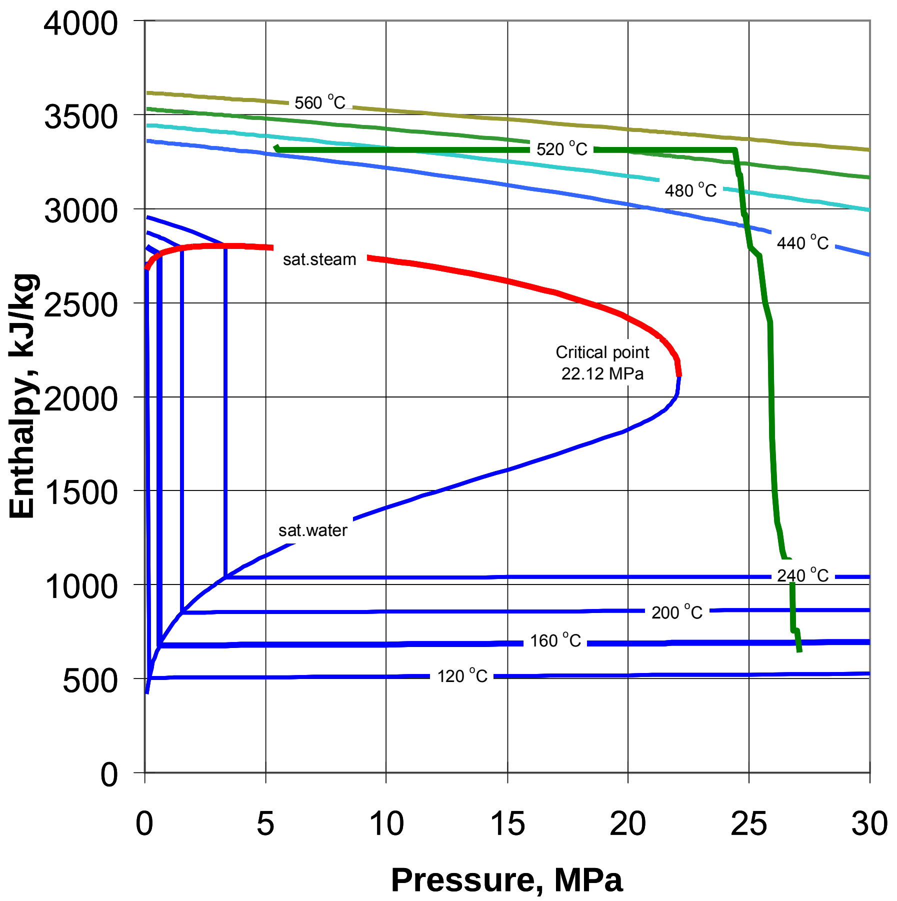

Figure 6-21, Once-through recovery boiler with reheat in p-h-diagram, 218.5 kg/s, 24.0/5.4 MPa, 540/460 °C.

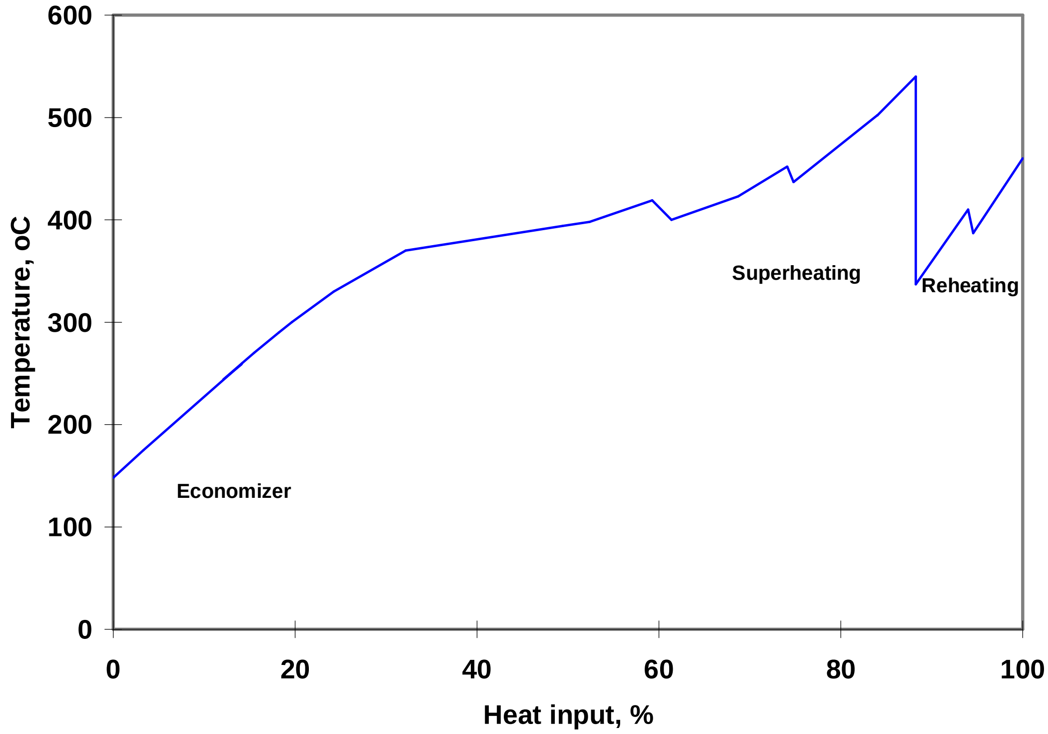

Figure 6-22, Once-through recovery boiler with reheat in Φ-t-diagram, 218.5 kg/s, 24.0/5.4 MPa, 540/460 °C.

Table 6-6 **Main dimensions of once-through recovery boiler with reheat, Case F.**

Surface	**unit**	
Furnace area	m^2	234.4
Furnace height	m	33.6
Total boiler height	m	72.0
Furnace area	m^2	4084
Screen area	m^2	796
Superheater area	m^2	24372
Superheater area (proj)	m^2	23803
Boiler bank area	m^2	12786
Economizer area	m^2	39235
Total area	m^2	105075

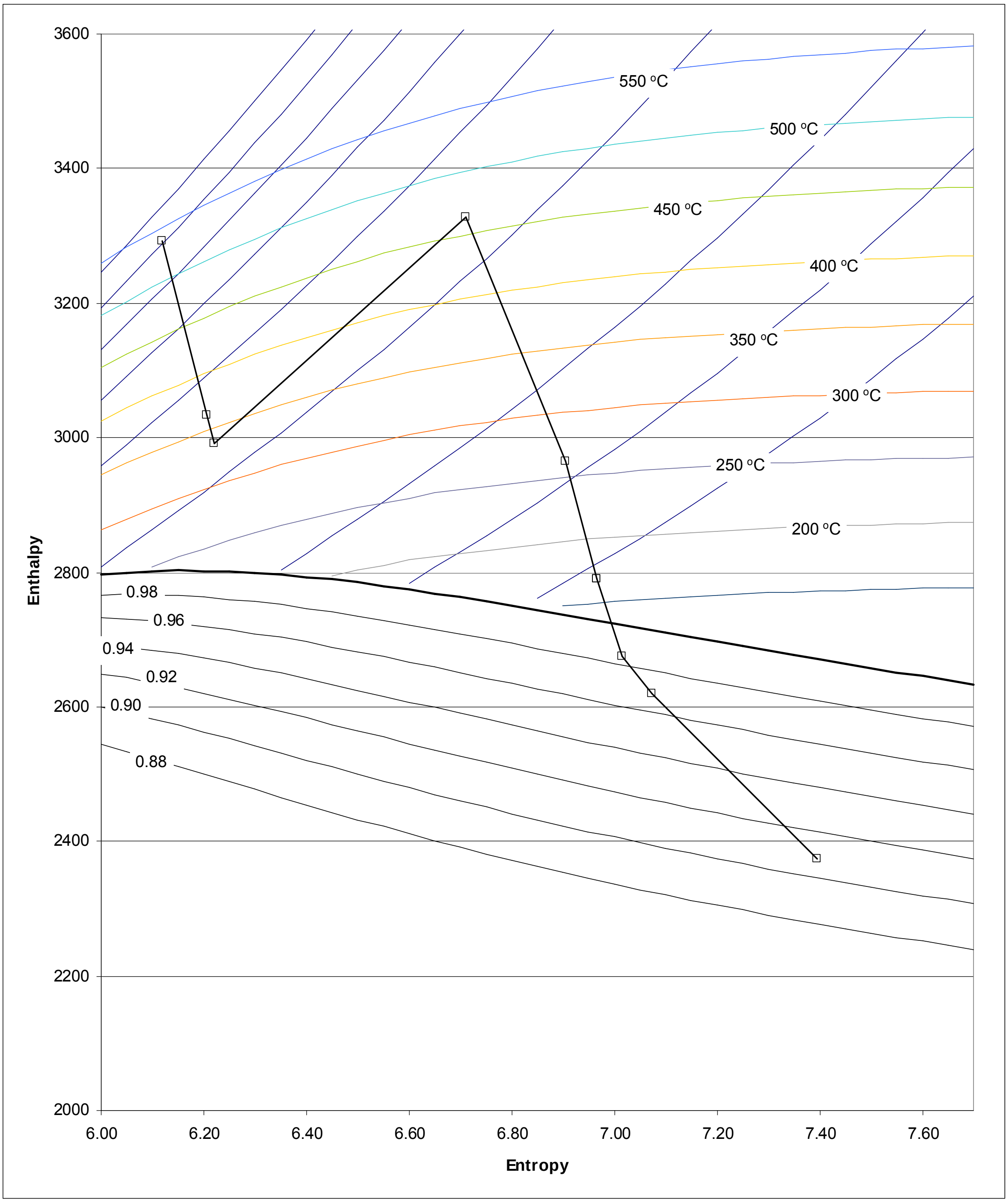

Figure 6-23, Once-through recovery boiler with reheat in h-s-diagram, 218.5 kg/s, 24.0/5.4 MPa, 540/460 °C.

6.7 Boiler size comparison

Recovery boiler pressure part weights for different options are shown in Table 6-7.

Table 6-7 Main size values for each case.

		Joutseno	Kymi	Yonago	SoTu	SkyRec	SkyRec+
Case		**A**	**B**	**C**	**D**	**E**	**F**
Capacity	tds/d	5500	5500	5500	5500	5500	5500
capacity (virgin)	tds/d	5005	5005	5005	5005	5005	5005
Dry solids	%	82.0	85.0	85.0	85.0	85.0	85.0
Main steam pressure RB	bar(a)	94.0	104.0	124.0	164.0	124.0	264.0
Main steam temp. RB	°C	490.0	505.0	515.0	540.0	515.0	540.0
General data							
Design pressure	bar(e)	130	129	148	186	148	289
Areas							
Furnace area	m2	233.6	232.1	232.1	232.1	232.1	234.4
Furnace height	m	36.5	41.6	41.6	39.6	38.4	33.6
Total boiler height	m	75.5	75.1	78.0	76.0	75.0	72.0
Furnace area	m2	4417	5056	5056	4813	4672	4084
Screen area	m2	0	796	0	796	796	796
Superheater area	m2	23712	13536	16102	20255	21306	24372
Superheater area (proj)	m2	16004	12984	15446	19429	20437	23803
Boiler bank area	m2	13600	10262	11982	11982	11982	12786
Economizer area	m2	40720	39676	39676	39529	39382	39235
Total area	m2	98454	82310	88262	96804	98575	105075
Pressure part weight							
Furnace panels weight	tons	1035	1085	1107	1157	1051	843
Screen weight	tons	0	465	0	588	503	543
Superheater weight	tons	2254	1463	1827	2490	2417	2569
Boiler bank weight	tons	813	740	1041	1041	1041	1080
Economizer weight	tons	1845	2080	2080	2072	2063	2057
Total weight	tons	5946	5832	6055	7348	7075	7091
Total hanging weight	tons	9250	8760	9270	10290	10170	10140
Cost							
Cost difference	M€	9.2	0.0	6.5	17.1	24.3	27.0
Electricity difference	MWe	-4.0	0.0	7.3	19.6	8.3	19.0
Cost for additional	k€/MWe	-2310	0	890	875	2921	1422
Price of extra power	€/MWh	-57.8	0.0	22.2	21.9	73.0	35.6

The increase in electricity generation seems very profitable up to case C. This confirms the rationality of design choices that have lead to the present recovery boiler. Case A costs more that it should were it built today. The reason is larger than required superheating surface and smaller than currently used superheater tube size. From cost of additional power, going to SoTu concept of 540 ^{o}C steam seems desirable. Currently the corrosion issues have not yet been solved so in this study we assume that superheaters do not corrode. Reheater boiler concept seems not at all profitable. The additional electricity generation was only marginal. Once-through recovery boiler did produce as much additional electricity than the SoTu concept of 540 ^{o}C steam. The corrosion issues still remain the same.

7 APROS-STUDIES

The Advanced Process Simulation Environment (APROS) provides tools, solution algorithms and mode libraries for fullscale modelling and simulation of dynamic processes, such as combustion power plants. The model libraries have been comprehensively validated against real physical process experiments. The modular and hierarchical approach of APROS allows unique flexibility of process analysis at various conceptual levels.

APROS allows the inclusion of the user's own models in the calculation as well as easy connection to external models, automation systems or control room equipment. A large process model can be divided into several flowsheet diagrams. This can be done both in a hierarchical and a horizontal way. At any time, the complete model information can be saved into a model snapshot file containing the full model configuration and its momentary state data at the time instant. Similarly, at any time, the user can backtrack to a snapshot once saved in the past.

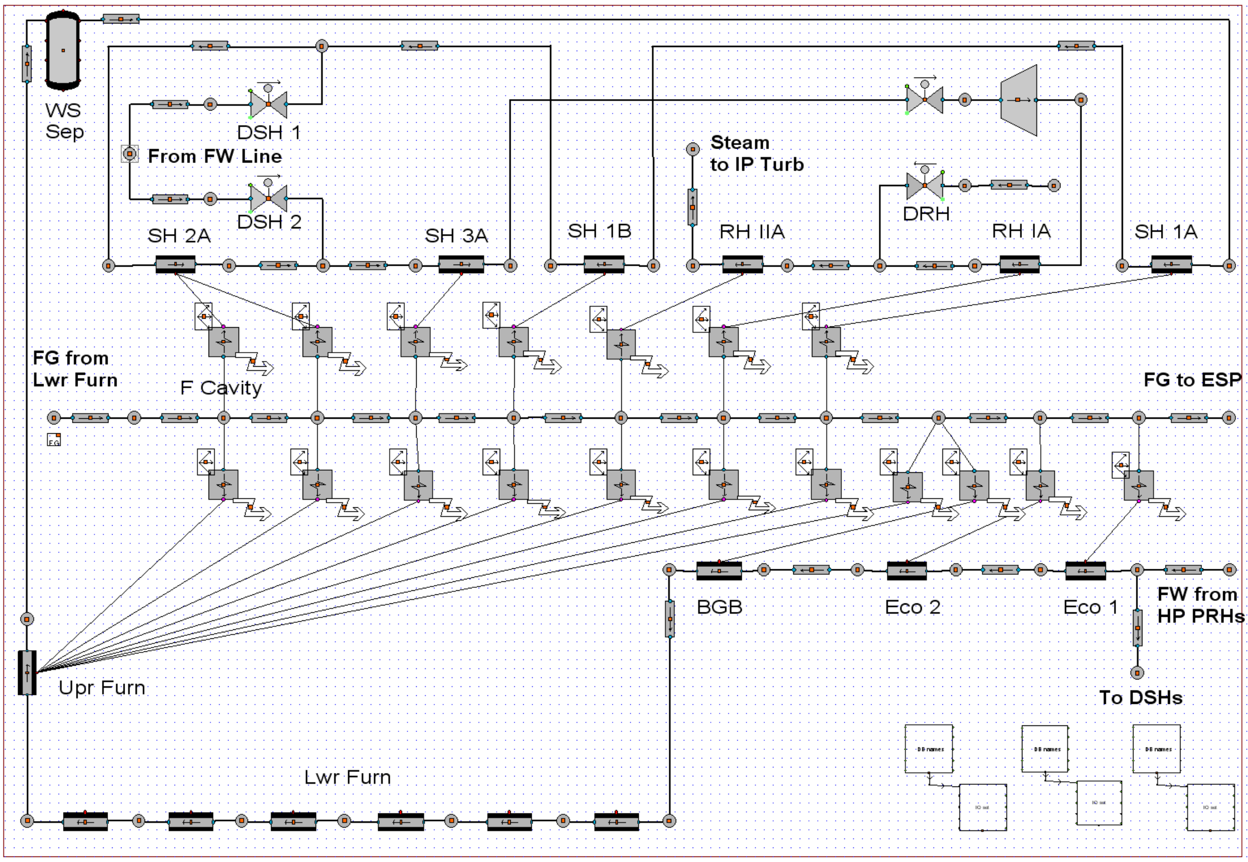

Figure 7-1, Once-through recovery boiler with reheat APROS model, 218.5 kg/s, 24.0/5.4 MPa, 540/460 ^oC.

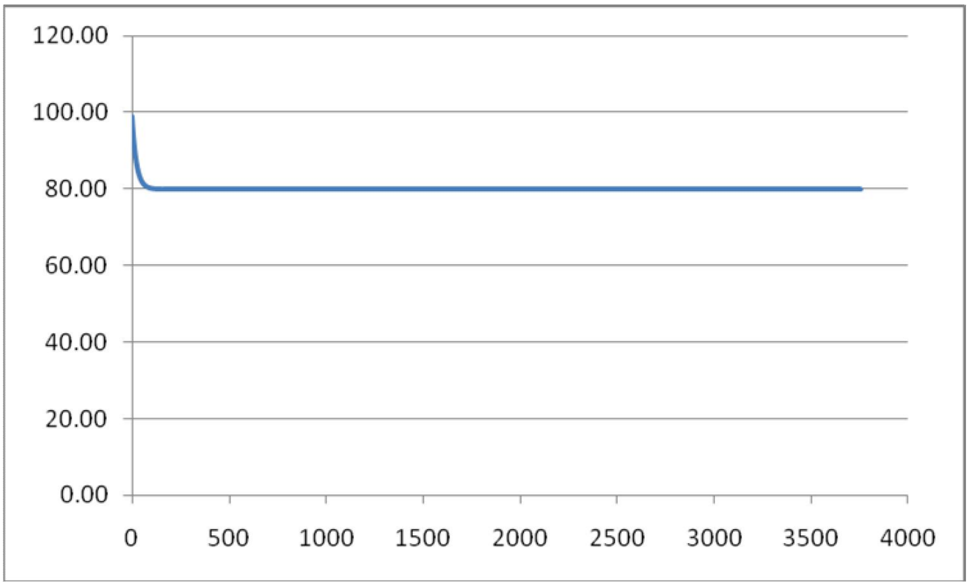

Figure 7-2, Change in firing rate in once-through recovery boiler with reheat.

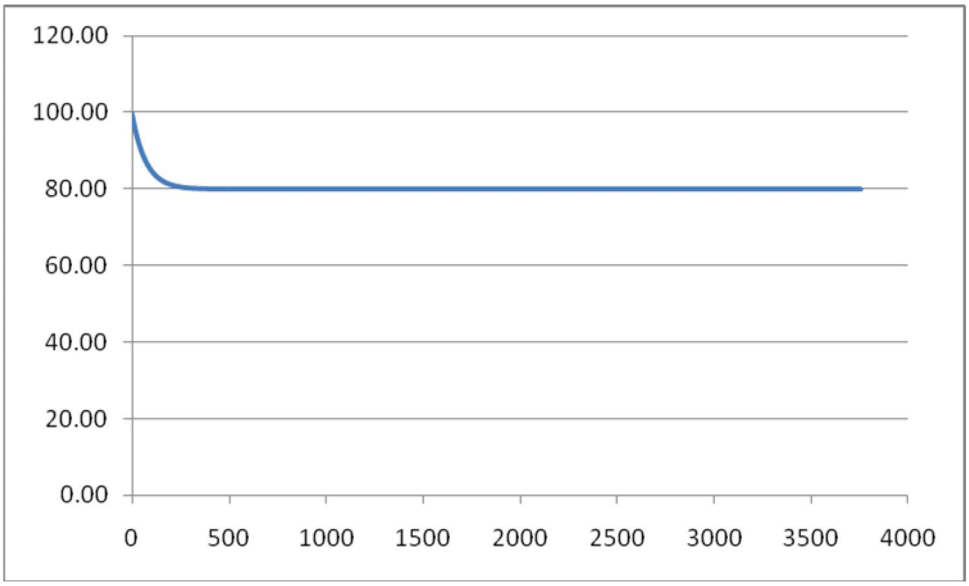

Figure 7-3, Desired change in steam flow in once-through recovery boiler with reheat.

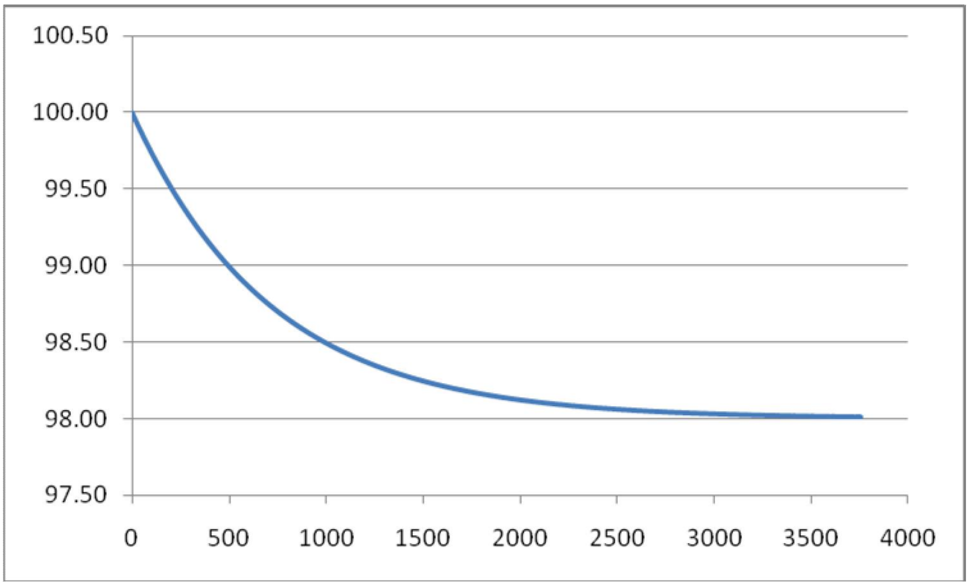

Figure 7-4, Desired change in steam temperature in once-through recovery boiler with reheat.

8 PREHEATER CONCEPTS

One of the most successful ways to increase electricity generation form recovery boilers hah been the implementation of different preheating schemes (Raukola et al., 2002).

The preheating schemes have been selected based on typical practice.

8.1 Air preheater concepts

It is important to heat air. In Case C5 the air on average is preheated only to 121.2 ^{o}C. This was typical to so called cold tertiary air systems. Cold tertiary was used to increase the mixing of air to flue gases in the furnace.

In Case C4 the air on average is preheated already to 150.4 ^{o}C. This was typical after newer air systems became wider spread. In Case C3 the air on average preheated to 190 ^{o}C. This is the case for modern high electricity boilers (Aikio, 2009).

8.2 Water preheater concepts

In cases C5 – C3 the feedwater was preheated to 120 ^{o}C. Flue gas temperature is then 155 ^{o}C. In Case C2 the feedwater is preheated to 148 ^{o}C before the economizers. This means that flue gas exit temperature increases to 198 ^{o}C. The flue gas is cooled down in air heater so the temperature to stack remains constant.

In case C1 the feedwater is additionally preheated between economizers from 200 to 220 ^{o}C. This high pressure preheater concept is patented.

8.3 Sootblowing concepts

In cases C5 – C1 the sootblowing was taken from inside the recovery boiler. In Case C0 the Sootblowing is taken from turbine so some expansion in turbine occurs which increases the electricity generation.

8.4 Electricty generation changes

Electricity generation in cases C5 – C0 is shown in the Table 8-1.

Table 8-1 Main values and electricity generation for additional cases.

Case		As case C **C0**	inside SB **C1**	No FW prh **C2**	Low FW **C3**	Air 150 **C4**	Air 120 **C5**
Capacity	tds/d	5500	5500	5500	5500	5500	5500
capacity (virgin)	tds/d	5005	5005	5005	5005	5005	5005
Dry solids	%	85.0	85.0	85.0	85.0	85.0	85.0
ds (virgin)	%	83.8	83.8	83.8	83.8	83.8	83.8
recycle ash	%	9.0	9.0	9.0	9.0	9.0	9.0
HHV	MJ/kgds	13.00	13.00	13.00	13.00	13.00	13.00
HHV (virgin)	MJ/kgds	14.29	14.29	14.29	14.29	14.29	14.29
LHV	MJ/kgds	12.28	12.28	12.28	12.28	12.28	12.28
LHV (virgin)	MJ/kgds	13.49	13.49	13.49	13.49	13.49	13.49
O2 in dry flue gas	%	2.8	2.8	2.8	2.8	2.8	2.8
Primary air	%	22.0	22.0	22.0	22.0	22.0	22.0
Primary air temp	°C	190.0	190.0	190.0	190.0	**160.0**	**150.0**
Secondary air	%	54.0	54.0	54.0	54.0	54.0	54.0
Secondary air temp	°C	190.0	190.0	190.0	190.0	**160.0**	**150.0**
Tertiary air percentage	%	12.0	12.0	12.0	12.0	12.0	12.0
Tertiary air temp	°C	190.0	190.0	190.0	190.0	**120.0**	**30.0**
Quartenary air	%	12.0	12.0	12.0	12.0	12.0	12.0
Quartenary air temp	°C	190.0	190.0	190.0	190.0	**120.0**	**30.0**
Total air percentage	%	100.0	100.0	100.0	100.0	100.0	100.0
Total air temperature	°C	190.0	190.0	190.0	190.0	150.4	121.2
Reduction	%	96.00	96.00	96.00	96.00	96.00	96.00
Main steam pressure RB	bar(a)	124.0	124.0	124.0	124.0	124.0	124.0
Main steam temp RB	°C	515.0	505.0	515.0	515.0	515.0	515.0
Feedwater pressure	bar(a)	146.0	146.0	146.0	146.0	146.0	146.0
Feedwater temperature	°C	148.0	148.0	148.0	**120.0**	**120.0**	**120.0**
HP FWpreh inlet temp	°C	200	200	200	200	200	200
HP FWpreh outlet temp	°C	220	220	**200**	**200**	**200**	**200**
Flue gas temp (eco out)	°C	197	197	197	**155**	**155**	**155**
Flue gas temp (to stack)	°C	155	155	155	155	155	155
Sootblowing	kg/s	6.0	**6.0**	**6.0**	**6.0**	**6.0**	**6.0**
Steam flow	kg/s	232.5	228.6	221.0	217.1	213.6	211.1
Change in steam flow	%	0.0	-1.7	-5.0	-6.6	-8.1	-9.2
Pulping usage total	MW	88.9	88.9	88.9	88.9	88.9	88.9
Mill total usage	MW	92.4	92.4	92.4	92.4	92.4	92.4
Electricity production	MW	161.8	160.8	158.4	156.5	154.5	153.6
Surplus electricity	MW	69.4	68.3	66.0	64.1	62.0	61.2

9 CONCLUSIONS

In this study several recovery boiler concepts were compared with the whole pulp mill energy balance being considered. The studied concepts are

G. Natural circulation 82 %, 490 ^oC, 9.0 MPa (reference Joutseno)

H. Natural circulation 85 %, 505 ^oC, 10.2 MPa (reference Kymi)

I. Natural circulation 85 %, 515 ^oC, 12.0 MPa (reference Yonago)

J. Assisted circulation 85 %, 540 ^oC, 16.0 MPa (reference SoTu)

K. Natural circulation 85 %, 515/400 ^oC, 12.0/3.0 MPa (SkyRec)

L. Once-through 85 %, 540/460 ^oC, 26.0/5.4 MPa (SkyRec+)

Steam and electricity generation for each recovery boiler case is shown in Table 9-1. The steam production increases from Case A to Case B because of higher black liquor dry solids and more air preheating. The steam production increases from Case B to Case C because of high pressure preheating. The recovery boiler steam flow starts decreasing as further increases in main steam parameters require more heat.

Table 9-1 Steam and electricity generation for each case.

		Joutseno	Kymi	Yonago	SoTu	SkyRec	SkyRec+	SkyRec
Case		**A**	**B**	**C**	**D**	**E**	**F**	**E160**
Capacity	tds/d	5500	5500	5500	5500	5500	5500	5500
capacity (virgin)	tds/d	5005	5005	5005	5005	5005	5005	5005
Dry solids	%	82.0	85.0	85.0	85.0	85.0	85.0	85.0
Main steam pressure RB	bar(a)	94.0	104.0	124.0	164.0	124.0	264.0	164.0
Main steam temp. RB	°C	490.0	505.0	515.0	540.0	515.0	540.0	515.0
Steam generation								
Steam flow RB	kg/s	215.0	226.4	233.6	232.0	224.0	218.5	224.0
Change in steam flow	%	0.0	5.3	8.6	7.9	4.1	1.6	4.1
Electricity								
Pulping usage total	MW	87.6	88.1	88.9	90.2	88.2	93.2	90.0
Mill total usage	MW	91.1	91.7	92.4	93.8	91.8	96.8	93.6
Electricity production	MW	149.3	153.9	161.8	175.6	162.3	177.9	167.0
Surplus electricity	MW	58.2	62.2	69.4	81.7	70.5	81.1	73.4
Efficiency to electricity	%	20.4	20.4	21.4	23.2	21.5	23.5	22.7
Change in electricty	MW	0.0	4.0	11.2	23.6	12.3	22.9	15.2
	%	0.0	6.8	19.3	40.5	21.1	39.4	26.2

As can be seen the modern recovery boiler Case C does produce about 20 % more electricity than roughly ten years ago, case A. reheating cases E and E160 seem to give only marginally better electricity production. The only alternative seems to be to increase the main steam temperature to 540 ^oC, Cases D and F. The pulping electricity usage is not constant. The main parameter that changes is the recovery boiler feedwater pump power requirement.

Electricity generation does not depend a lot on how the boiler steam side is configured. Reheating and once-through appear only marginally better when considering the recovery boiler electricity generation.

Table 9-2 Cost difference and price of extra power for each case.

		Joutseno	Kymi	Yonago	SoTu	SkyRec	SkyRec+
Case		**A**	**B**	**C**	**D**	**E**	**F**
Capacity	tds/d	5500	5500	5500	5500	5500	5500
capacity (virgin)	tds/d	5005	5005	5005	5005	5005	5005
Dry solids	%	82.0	85.0	85.0	85.0	85.0	85.0
Main steam pressure RB	bar(a)	94.0	104.0	124.0	164.0	124.0	264.0
Main steam temp. RB	°C	490.0	505.0	515.0	540.0	515.0	540.0
Cost							
Cost difference	M€	9.2	0.0	6.5	17.1	24.3	27.0
Electricity difference	MWe	-4.0	0.0	7.3	19.6	8.3	19.0
Cost for additional	k€/MWe	-2310	0	890	875	2921	1422
Price of extra power	€/MWh	-57.8	0.0	22.2	21.9	73.0	35.6

The increase in electricity generation seems very profitable up to case C. This confirms the rationality of design choices that have lead to the present recovery boiler. Case A costs more that it should were it built today. The reason is larger than required superheating surface and smaller than currently used superheater tube size. From cost of additional power, going to SoTu concept of 540 ^{o}C steam seems desirable. Currently the corrosion issues have not yet been solved so in this study we assume that superheaters do not corrode. Reheater boiler concept seems not at all profitable. The additional electricity generation was only marginal. Once-through recovery boiler did produce as much additional electricity than the SoTu concept of 540 ^{o}C steam. The corrosion issues still remain the same.

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APPENDICES

APPENDIX I

APPENDIX II

APPENDIX V

Åbo Akademi:
Corrosion behavior of four steels under reducing conditions – test results and preliminary conclusions

PROCESS CHEMISTRY CENTRE

ÅBO AKADEMI UNIVERSITY

Skyrec

December 16th 2009

SUOMEN SOODAKATTILAYHDISTYS
FINNISH RECOVERY BOILER COMMITTEE

Skyrec - project

1. High temperature behavior of steels under alkali sulfates and chlorides containing synthetic ashes in reducing atmosphere

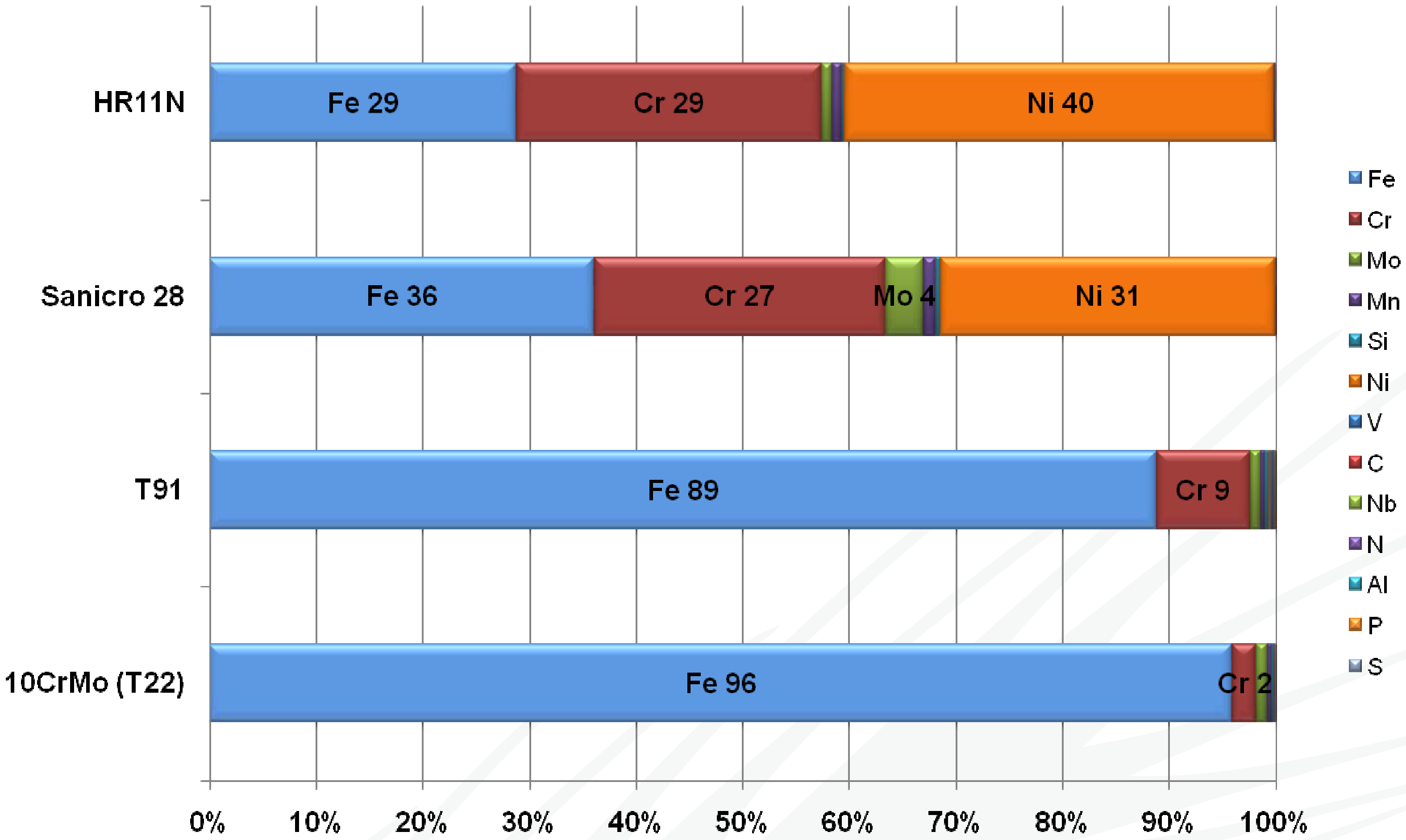
Temperatures: 450ºC, 500ºC, 550ºC, 600ºC

Salts:
- Salt 5 - Na_2SO_4
- Salt 8 - Na_2SO_4 + K_2SO_4 + NaCl + KCl
- Salt 9 - Na_2SO_4 + NaCl
- Salt 10 - Na_2SO_4 + K_2SO_4 + KCl

Steels:
10CrMo9-10
T91
S28
HR11N

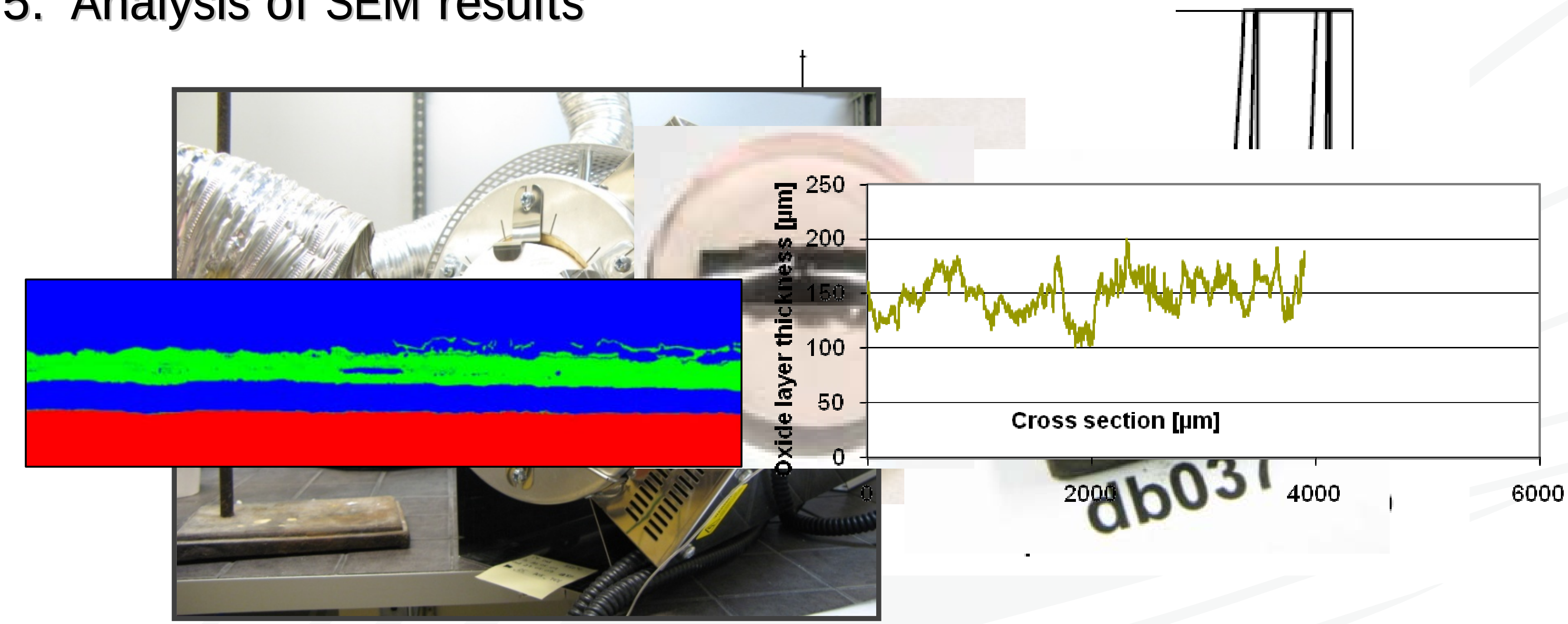
Atmosphere: reducing (5% CO + 95% N_2 – 2 l/min)

Skyrec - tested steels composition

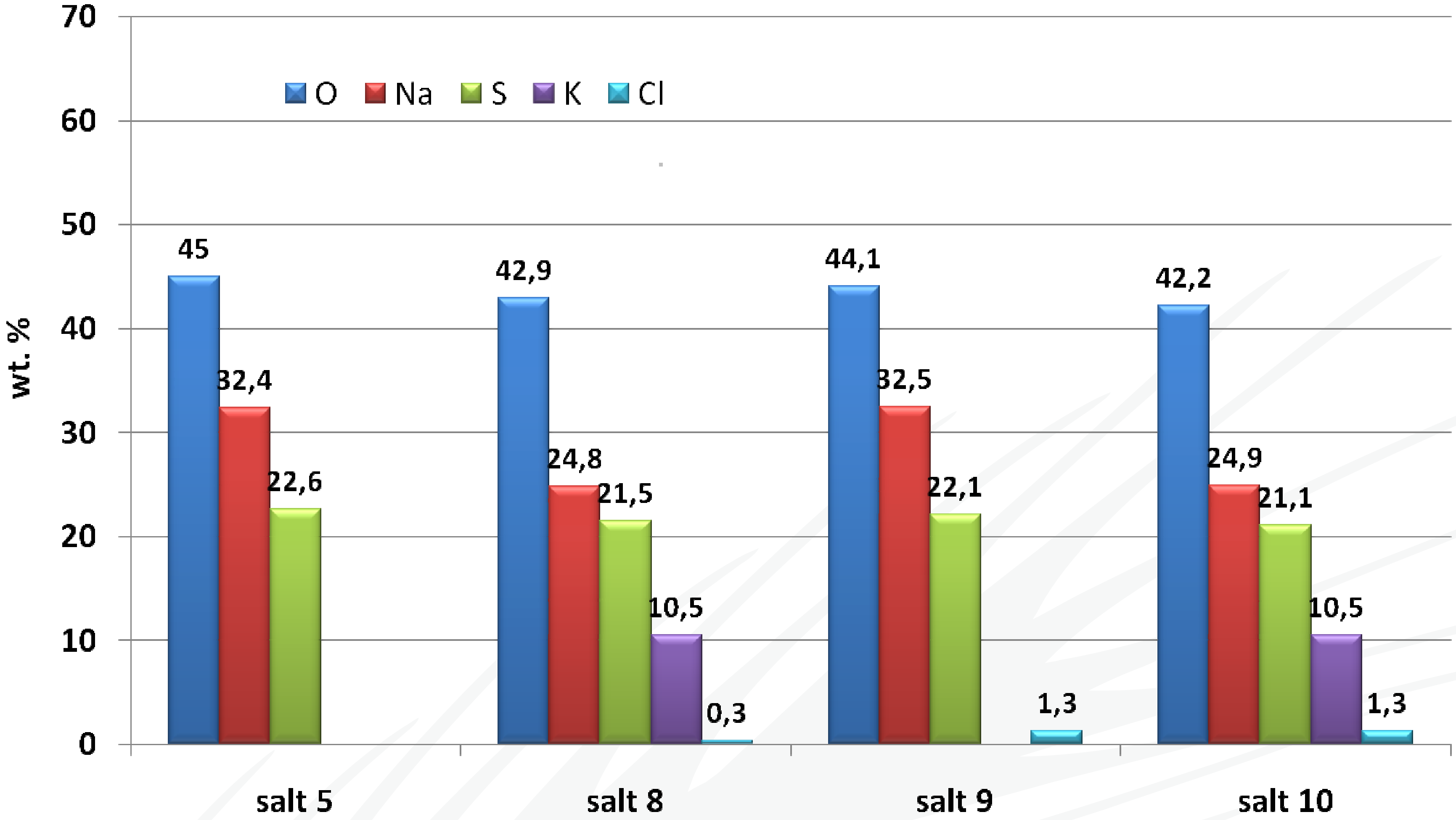


Laboratory method for HT corrosion tests

1. Preparation of salts
2. Preparation of steel samples for the experiment
3. Tube furnace tests
4. Preparation of samples for SEM/EDXA
5. Analysis of SEM results



Skyrec – synthetic ashes composition



Skyrec - corrosion test matrix - Na_2SO_4

	Salt	Steel	Temp	Corrosion products thickness
1	Na_2SO_4	**10CrMo**	450	
2	Na_2SO_4	**T91**	450	
3	Na_2SO_4	**Sanicro 28**	450	
4	Na_2SO_4	**HR11N**	450	
5	Na_2SO_4	**10CrMo**	450	
6	Na_2SO_4	**10CrMo**	500	
7	Na_2SO_4	**T91**	500	
8	Na_2SO_4	**Sanicro 28**	500	
9	Na_2SO_4	**HR11N**	500	
10	Na_2SO_4	**T91**	500	
11	Na_2SO_4	**10CrMo**	550	
12	Na_2SO_4	**T91**	550	
13	Na_2SO_4	**Sanicro 28**	550	
14	Na_2SO_4	**HR11N**	550	
15	Na_2SO_4	**Sanicro 28**	550	
16	Na_2SO_4	**10CrMo**	600	**24**
17	Na_2SO_4	**T91**	600	**6**
18	Na_2SO_4	**Sanicro 28**	600	
19	Na_2SO_4	**HR11N**	600	**2**
20	Na_2SO_4	**HR11N**	600	

Salt 5 characteristic:

$T_0 = 884^oC$

No Cl^-

No K^+

Skyrec - corrosion test matrix - Na_2SO_4+NaCl

	Salt	Steel	Temp	Corr prod. thickness
41	Na_2SO_4+NaCl	**10CrMo**	450	
42	Na_2SO_4+NaCl	**T91**	450	**1**
43	Na_2SO_4+NaCl	**Sanicro 28**	450	
44	Na_2SO_4+NaCl	**HR11N**	450	
45	Na_2SO_4+NaCl	**10CrMo**	450	**3**
46	Na_2SO_4+NaCl	**10CrMo**	500	**2**
47	Na_2SO_4+NaCl	**T91**	500	
48	Na_2SO_4+NaCl	**Sanicro 28**	500	
49	Na_2SO_4+NaCl	**HR11N**	500	
50	Na_2SO_4+NaCl	**T91**	500	
51	Na_2SO_4+NaCl	**10CrMo**	550	**13**
52	Na_2SO_4+NaCl	**T91**	550	
53	Na_2SO_4+NaCl	**Sanicro 28**	550	
54	Na_2SO_4+NaCl	**HR11N**	550	
55	Na_2SO_4+NaCl	**Sanicro 28**	550	
56	Na_2SO_4+NaCl	**10CrMo**	600	
57	Na_2SO_4+NaCl	**T91**	600	
58	Na_2SO_4+NaCl	**Sanicro 28**	600	
59	Na_2SO_4+NaCl	**HR11N**	600	**62**
60	Na_2SO_4+NaCl	**HR11N**	600	

Salt 9 characteristic:

T_0 = 621°C

1.3 wt% of Cl^-

No K^+

Skyrec - corrosion test matrix -

$Na_2SO_4+NaCl+K_2SO_4+KCl$

	Salt	Steel	Temp	Corr prod. thickness
21	$Na_2SO_4+K_2SO_4+NaCl+KCl$	**10CrMo**	450	**11**
22	$Na_2SO_4+K_2SO_4+NaCl+KCl$	**T91**	450	**9**
23	$Na_2SO_4+K_2SO_4+NaCl+KCl$	**Sanicro 28**	450	
24	$Na_2SO_4+K_2SO_4+NaCl+KCl$	**HR11N**	450	
25	$Na_2SO_4+K_2SO_4+NaCl+KCl$	**10CrMo**	450	**3**
26	$Na_2SO_4+K_2SO_4+NaCl+KCl$	**10CrMo**	500	**3**
27	$Na_2SO_4+K_2SO_4+NaCl+KCl$	**T91**	500	
28	$Na_2SO_4+K_2SO_4+NaCl+KCl$	**Sanicro 28**	500	
29	$Na_2SO_4+K_2SO_4+NaCl+KCl$	**HR11N**	500	
30	$Na_2SO_4+K_2SO_4+NaCl+KCl$	**T91**	500	
31	$Na_2SO_4+K_2SO_4+NaCl+KCl$	**10CrMo**	550	
32	$Na_2SO_4+K_2SO_4+NaCl+KCl$	**T91**	550	
33	$Na_2SO_4+K_2SO_4+NaCl+KCl$	**Sanicro 28**	550	
34	$Na_2SO_4+K_2SO_4+NaCl+KCl$	**HR11N**	550	
35	$Na_2SO_4+K_2SO_4+NaCl+KCl$	**Sanicro 28**	550	
36	$Na_2SO_4+K_2SO_4+NaCl+KCl$	**10CrMo**	600	**334**
37	$Na_2SO_4+K_2SO_4+NaCl+KCl$	**T91**	600	
38	$Na_2SO_4+K_2SO_4+NaCl+KCl$	**Sanicro 28**	600	
39	$Na_2SO_4+K_2SO_4+NaCl+KCl$	**HR11N**	600	
40	$Na_2SO_4+K_2SO_4+NaCl+KCl$	**HR11N**	600	

Salt 8 characteristic:

T_0 = 526°C

0.3 wt% of Cl^-

10.5 wt% of K^+

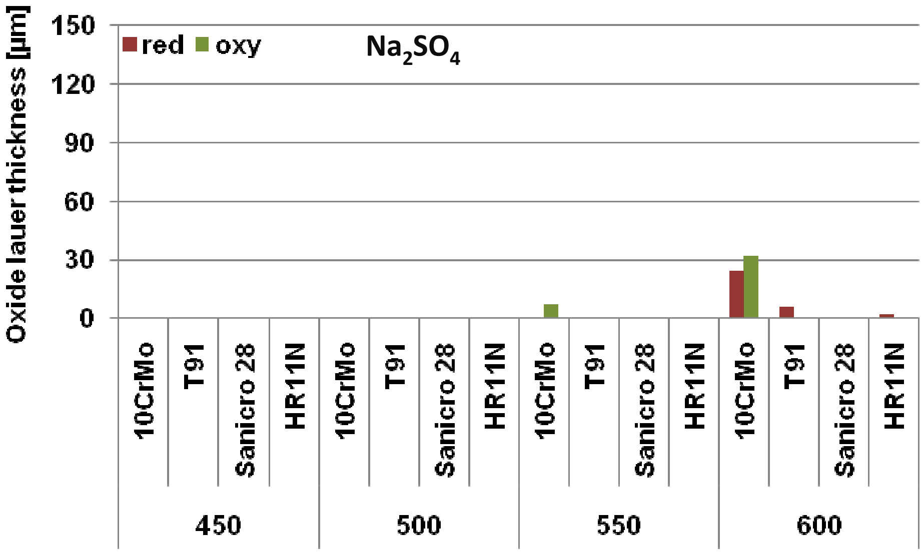
Skyrec - corrosion test matrix - Na_2SO_4+KCl+K_2SO_4

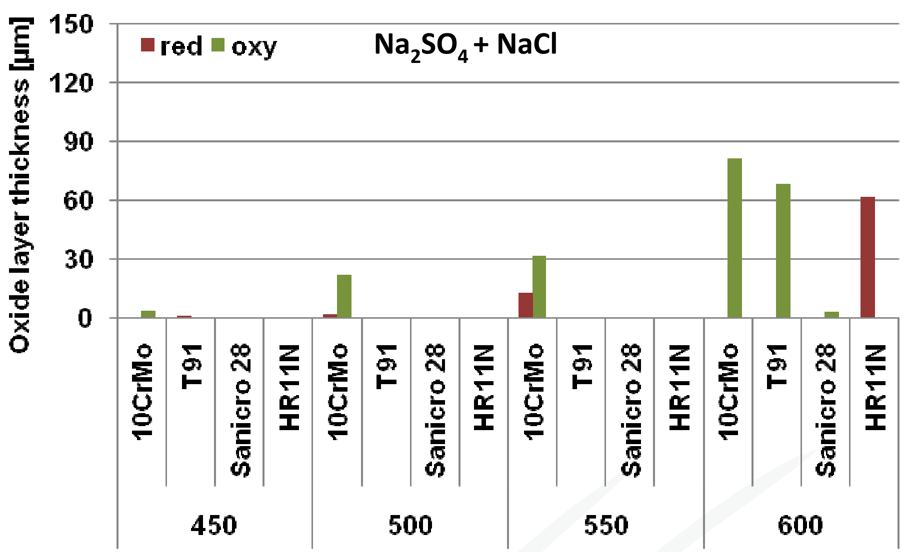
	Salt	Steel	Temp	Corr prod. thickness
61	$Na_2SO_4+K_2SO_4+KCl$	**10CrMo**	450	
62	$Na_2SO_4+K_2SO_4+KCl$	**T91**	450	
63	$Na_2SO_4+K_2SO_4+KCl$	**Sanicro 28**	450	
64	$Na_2SO_4+K_2SO_4+KCl$	**HR11N**	450	
65	$Na_2SO_4+K_2SO_4+KCl$	**10CrMo**	450	
66	$Na_2SO_4+K_2SO_4+KCl$	**10CrMo**	500	
67	$Na_2SO_4+K_2SO_4+KCl$	**T91**	500	
68	$Na_2SO_4+K_2SO_4+KCl$	**Sanicro 28**	500	
69	$Na_2SO_4+K_2SO_4+KCl$	**HR11N**	500	
70	$Na_2SO_4+K_2SO_4+KCl$	**T91**	500	
71	$Na_2SO_4+K_2SO_4+KCl$	**10CrMo**	550	**2**
72	$Na_2SO_4+K_2SO_4+KCl$	**T91**	550	**2**
73	$Na_2SO_4+K_2SO_4+KCl$	**Sanicro 28**	550	**2**
74	$Na_2SO_4+K_2SO_4+KCl$	**HR11N**	550	**2**
75	$Na_2SO_4+K_2SO_4+KCl$	**Sanicro 28**	550	**2**
76	$Na_2SO_4+K_2SO_4+KCl$	**10CrMo**	600	**306**
77	$Na_2SO_4+K_2SO_4+KCl$	**T91**	600	**54**
78	$Na_2SO_4+K_2SO_4+KCl$	**Sanicro 28**	600	**53**
79	$Na_2SO_4+K_2SO_4+KCl$	**HR11N**	600	**76**
80	$Na_2SO_4+K_2SO_4+KCl$	**HR11N**	600	**24**

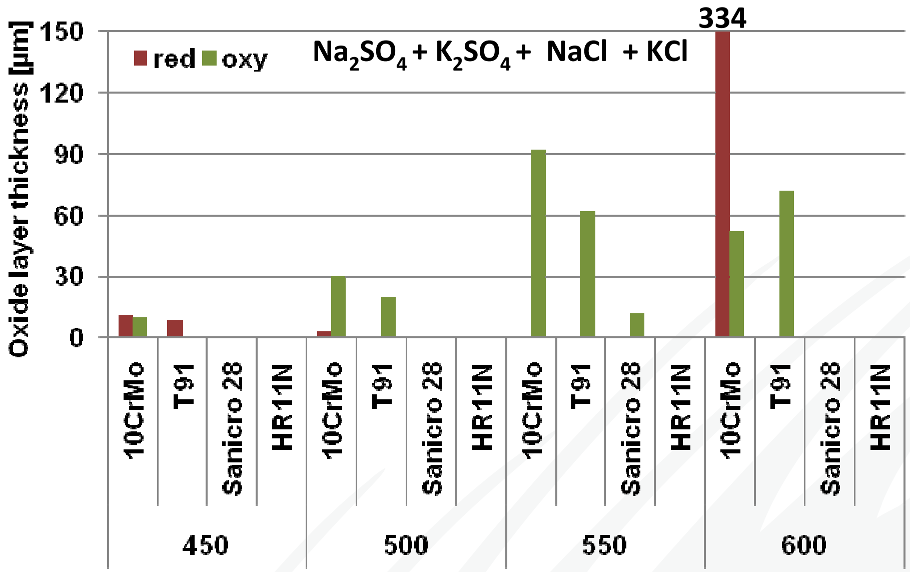
← {Oxide layer + internal attack} thickness

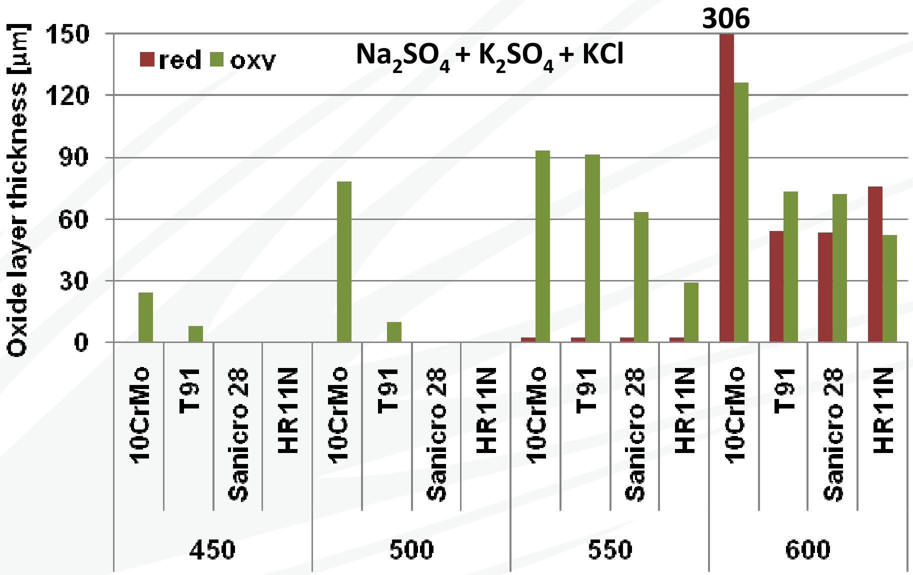
Salt 10 characteristic:
T_0 = 522°C
1.3 wt% of Cl^-
10.5 wt% of K^+

Skyrec – reducing vs ambient atmosphere



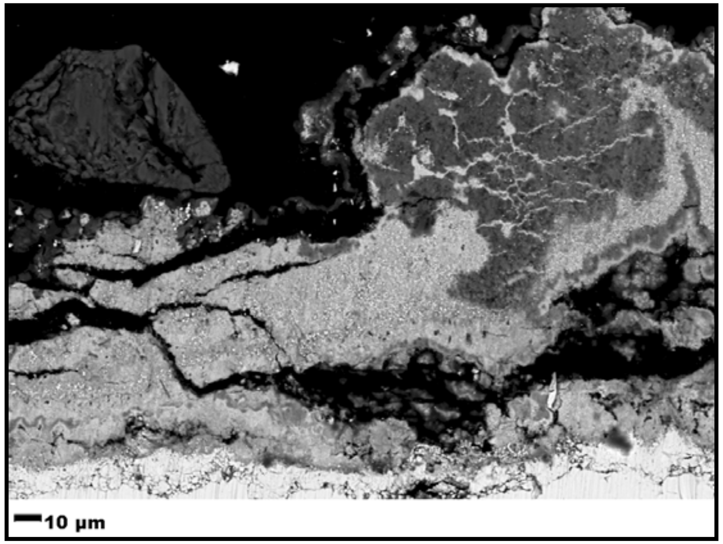


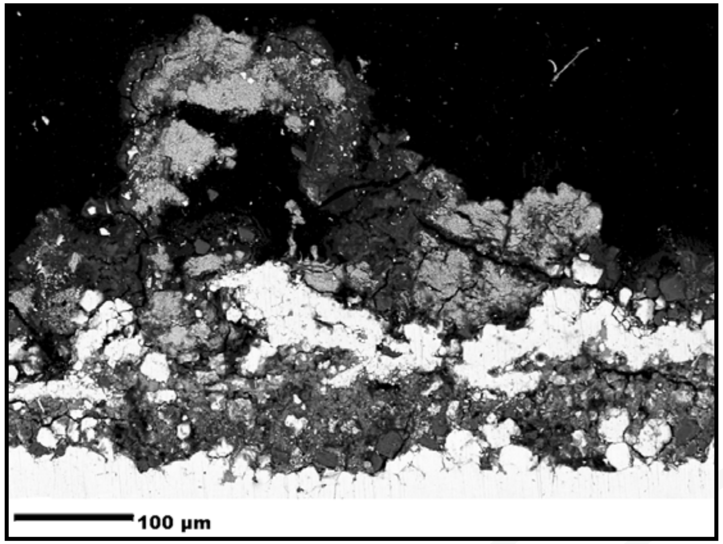




Skyrec – results 10CrMo, 600^{o}C

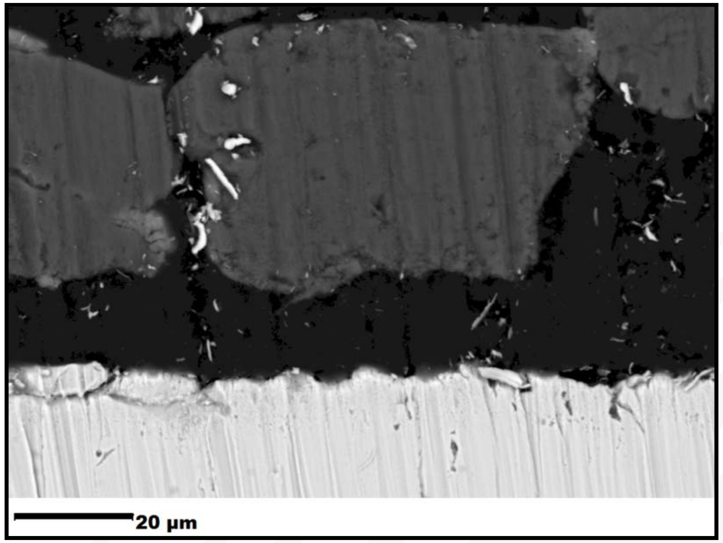
T_0 = 884^{o}C
No Cl
No K
Salt 5
24 µm

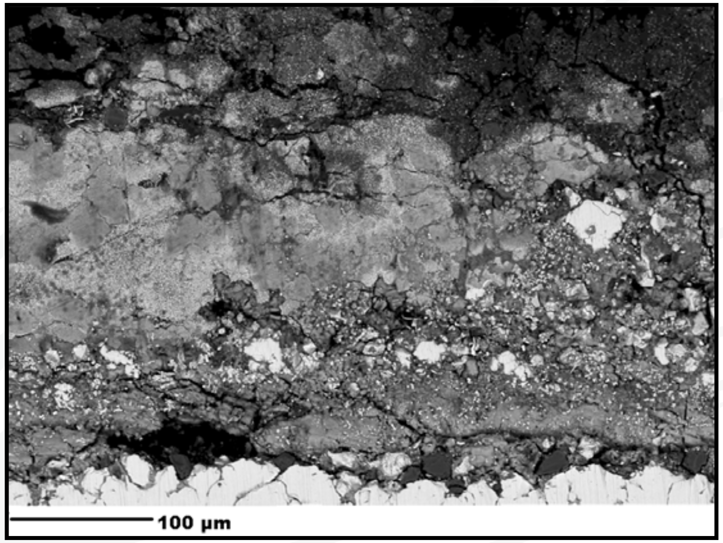




T_0 = 526^{o}C
0.3 mol% of Cl
13mol% of K
Salt 8
334 µm

T_0 = 621^{o}C
1.7 mol% of Cl
No K
Salt 9
0 µm

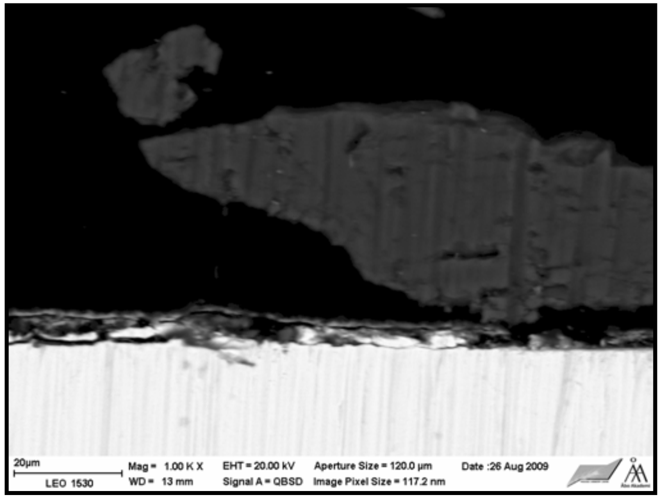


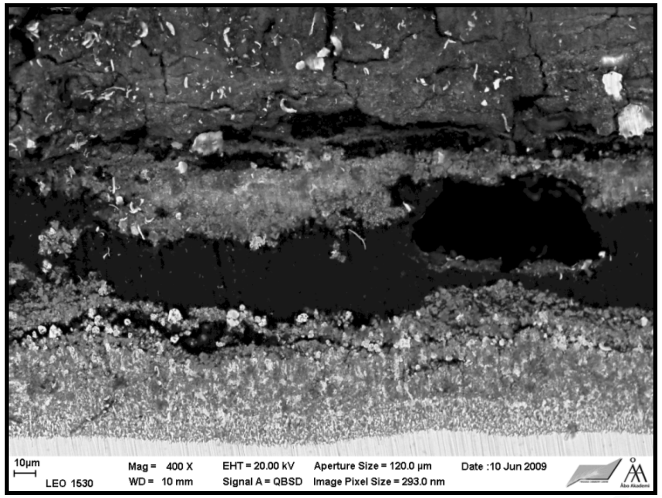


T_0 = 522^{o}C
1.7 mol% of Cl
13mol% of K
Salt 10
306 µm

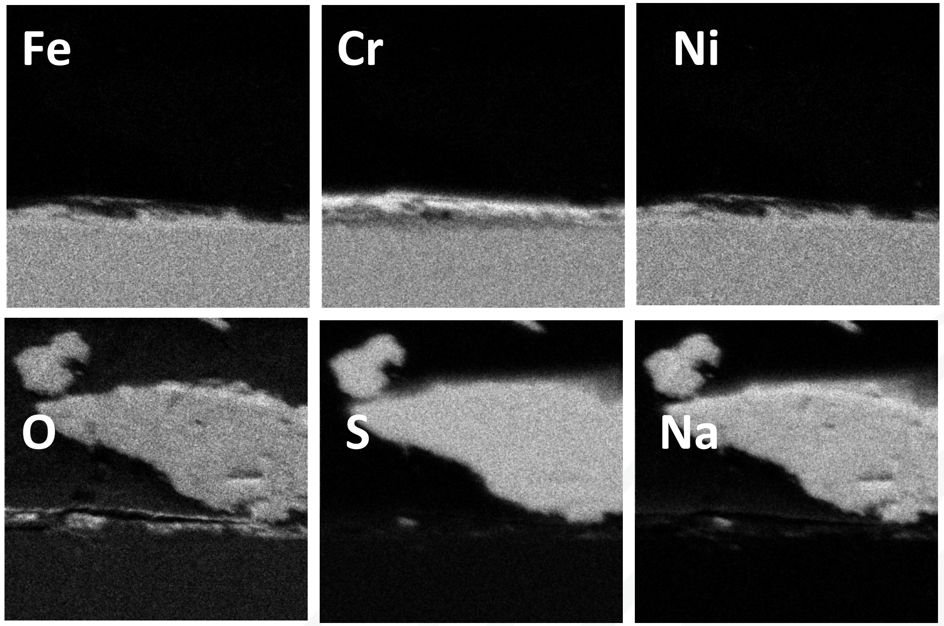
Skyrec – results, 600°C

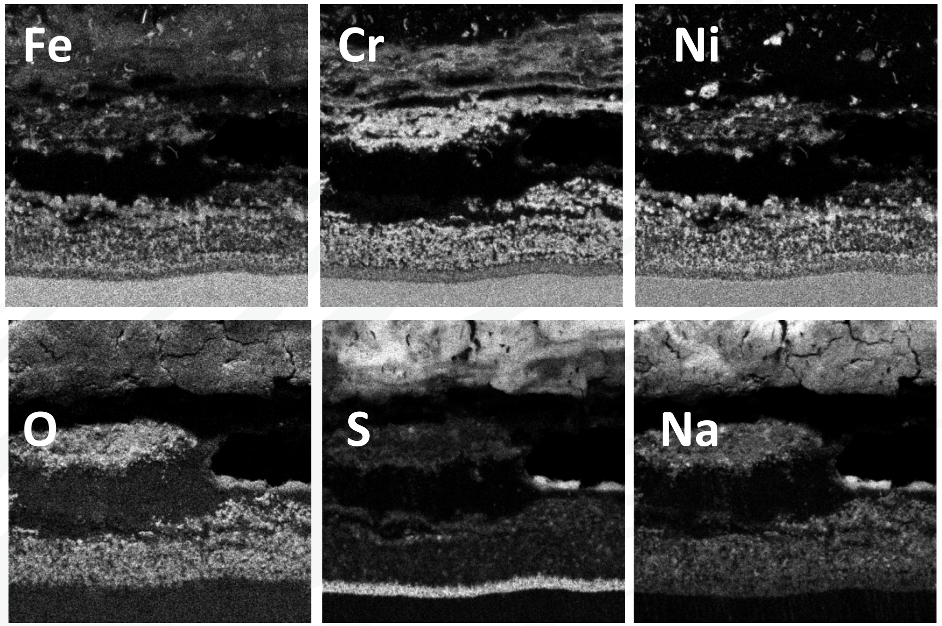
HR11N, red
Na_2SO_4
Salt 5
2 µm





HR11N, red
Na_2SO_4 +
NaCl
Salt 9
62 µm

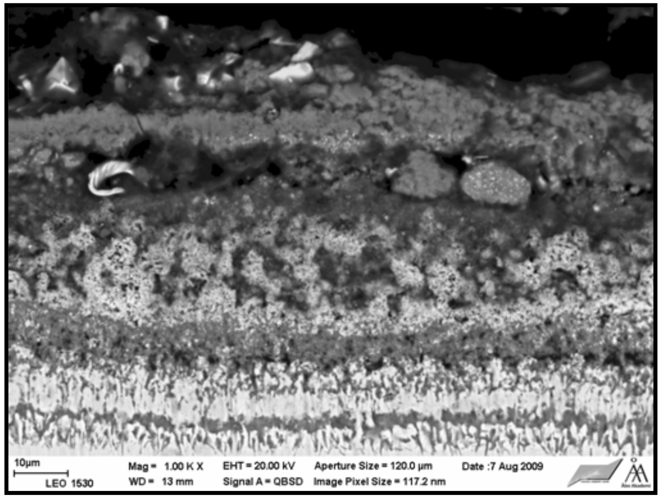


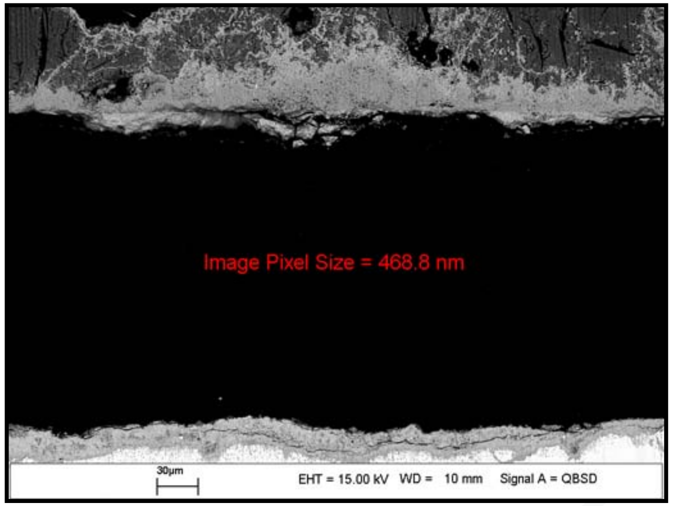


Skyrec – results, 600°C

S28, red
Na_2SO_4 +
K_2SO_4 + KCl
Salt 10

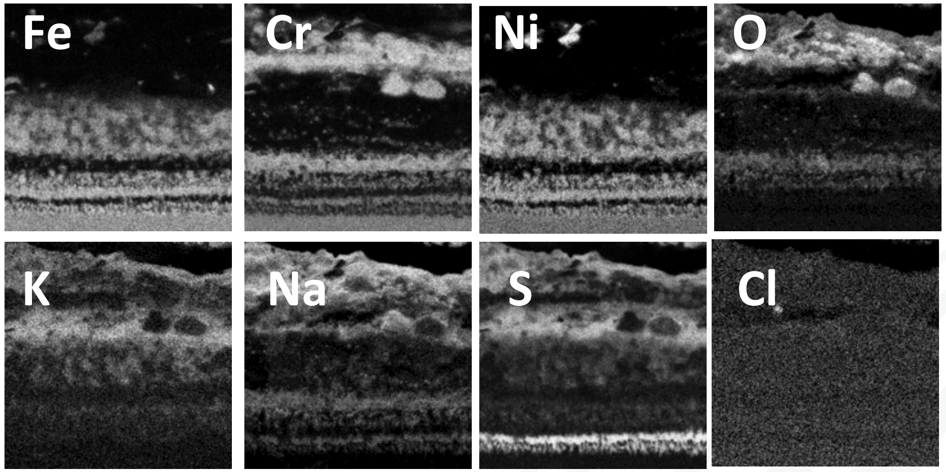
53 µm

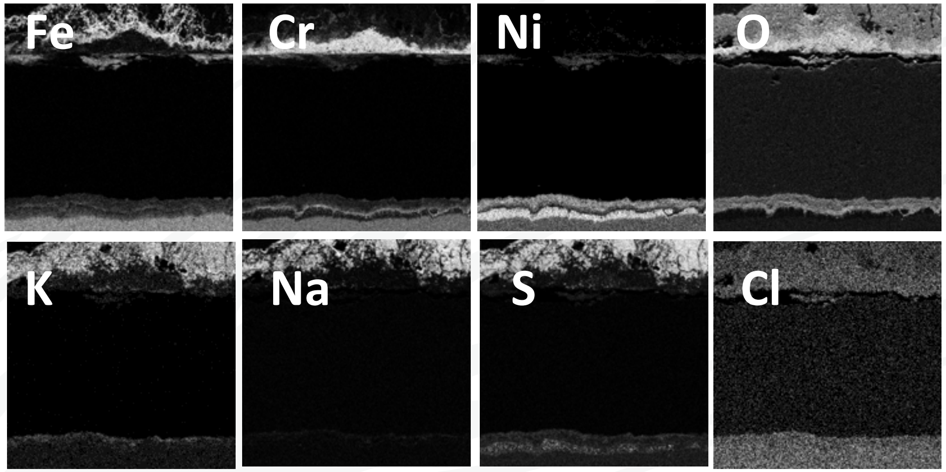




S28, ambient
Na_2SO_4 +
K_2SO_4 + KCl
Salt 10

72 µm

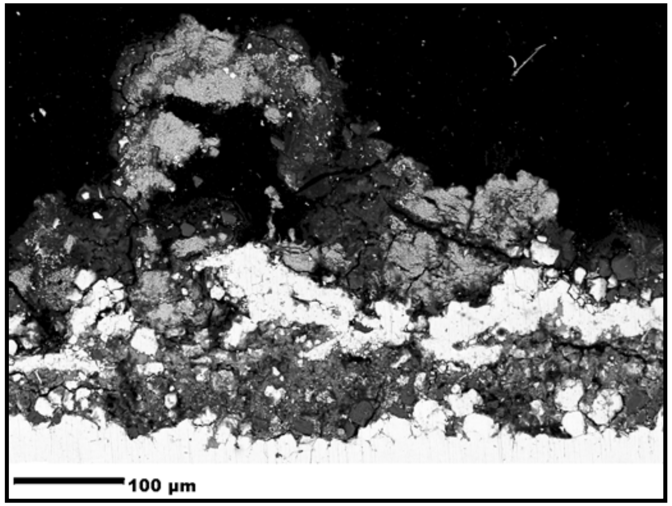


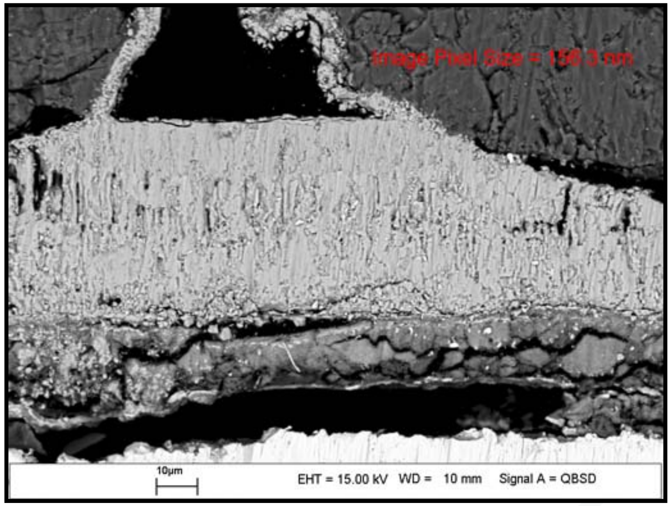


Skyrec – results, 600°C

10CrMo, red
Na_2SO_4+K_2SO_4
+NaCl + KCl
Salt 8

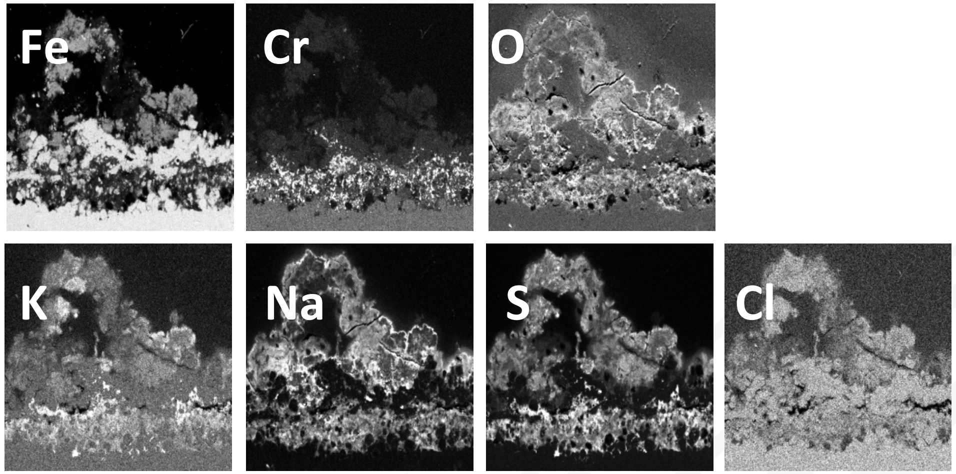
334 µm

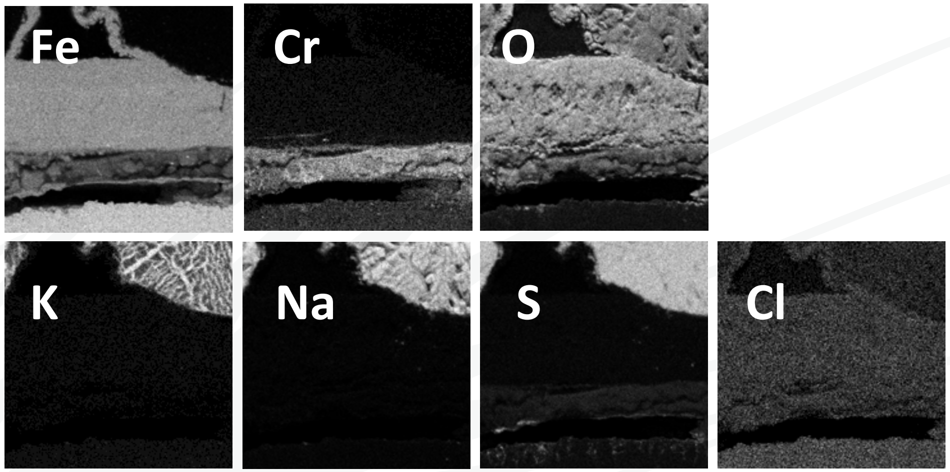




10CrMo,
ambient
Na_2SO_4+K_2SO_4
+NaCl + KCl
Salt 8

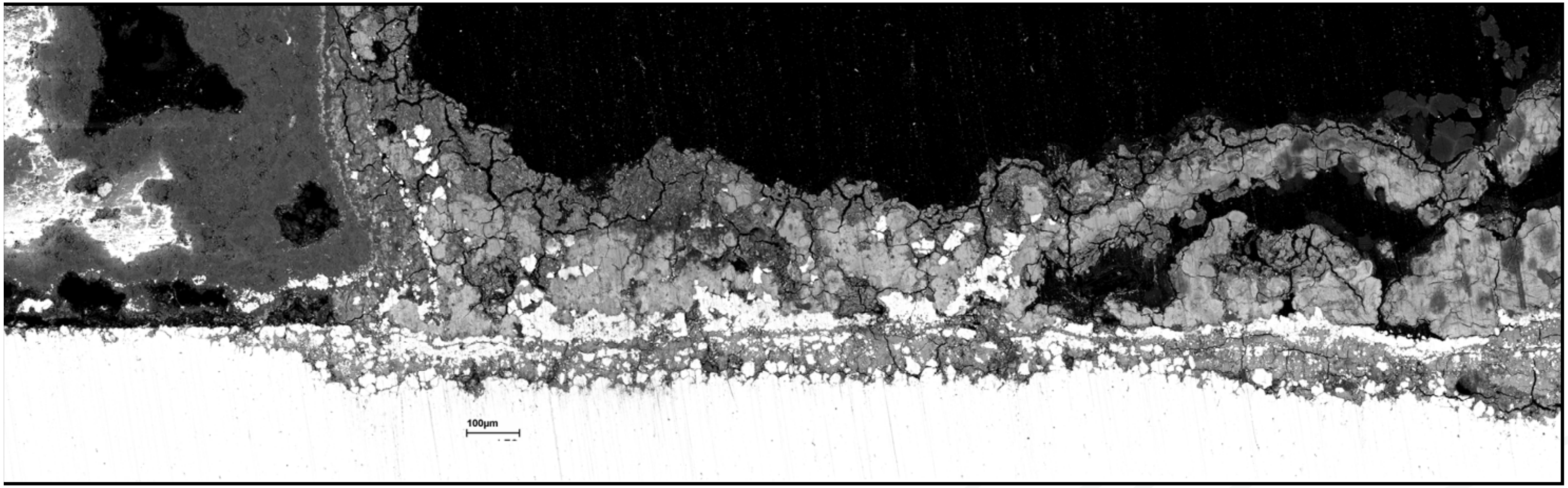
52 µm

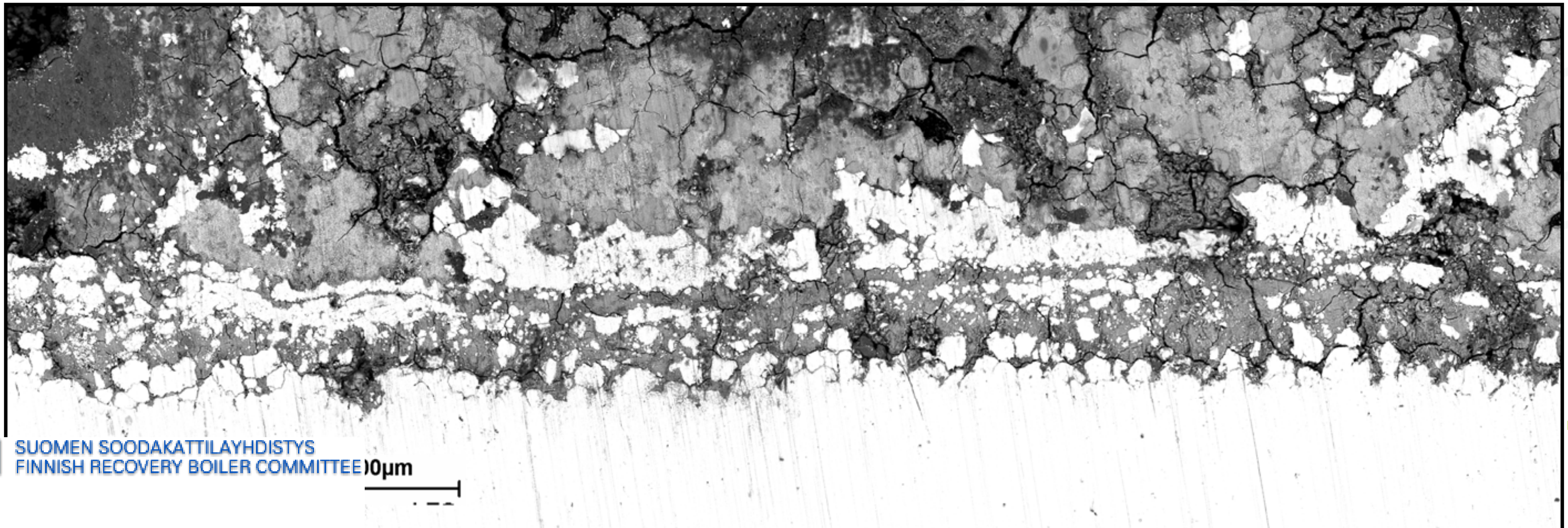




Skyrec – results

10CrMo at 600°C with salt 8 attacked by the grain boundary corrosion





Skyrec – preliminary conclusions

- Ambient atmosphere seems to be more harmful than reducing under tested temperature and salts

- K containing salts show more detrimental effect
– especially ≥ 500ºC for low grade steels, ≥ 550ºC for all steels - at ambient conditions
– ≥ 550ºC for all steels - at reducing conditions
(T_0 of the K containing salts slightly above 500ºC)

- In reducing conditions and high temperature:
– Low grade steels are destroyed mainly by grain boundary corrosion
– Austenitic steels undergo heavy Cr leaching

- *Sulfur* often found on the corrosion front, deep in the pores

- Reducing conditions induce mainly internal attack of the steel*
- In ambient conditions growth of the oxide layer is promoted*

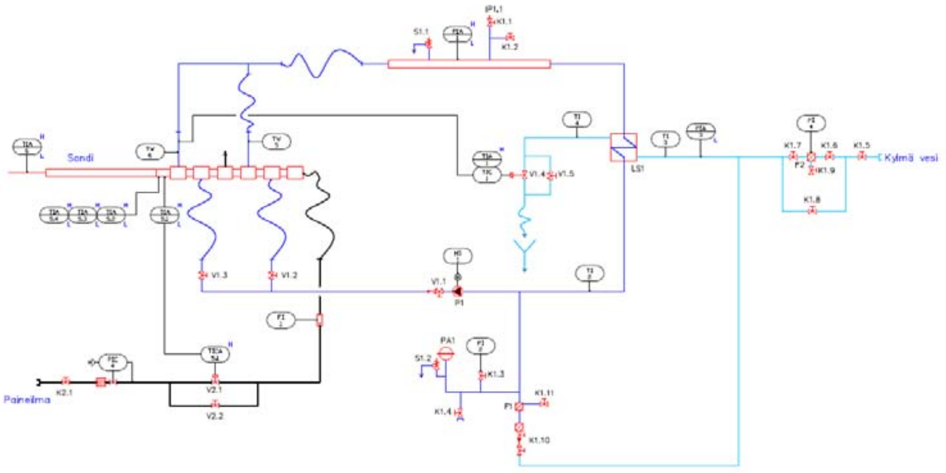
* Under tested temperatures and salts

Skyrec – To be done

- Final reporting (date to be decided)
- Corroded samples will be reported in a printed version of the report
- All the results (SEM/EDX) will be delivered on the CD

APPENDIX VI

VTT:
Mill tests of superheater materials – status report 26.11



Tulistinputkimateriaalien korroosiotutkimus soodakattilalla

Tilaaja: Suomen Soodakattilayhdistys ry

Tilaaja

Suomen Soodakattilayhdistys ry

Yhteyshenkilö VTT:ssä

MARKKU ORJALA, Customer Manager
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Jyväskylä, FINLAND
Tel. +358 20 722 2534
Mobile +358 400 341 474
Fax +358 20 722 2720
Email markku.orjala@vtt.fi

Työn sisältö

Tutkimuksessa kartoitetaan kuuden materiaalin kuumakorroosioriskit soodakattilan tulistinalueella kahdella eri kattilalla tai kahdessa eri lämpötilassa tilaajan osoittamissa paikoissa. Tutkimuksessa selvitetään tulistinalueelle kertyvien kerrostumien koostumusta, tutkitaan eri tulistinmateriaalien kestävyyttä. Materiaalien altistusaika on n. 1000 tuntia. Kerrostumien muodostumisen monitorointiin ja tulistinmateriaalien kestävyyden arviointiin käytetään VTT:llä kehitettyjä sondeja.

Tilannekatsaus 25.11.09

- Joutsenon laitoksella huoltoseisokki viikolla 48
- Laitokselle on toimitettu tiedot sondien vaatimuksista (yhteet, vesi, ilma, sähkö yms.)
- Sondien kunnostustoimenpiteet loppusuoralla
- Sondin jäähdytysratkaisun suunniteltu (kts. tämän raportin kannen kuva) ja komponenttien hankinta ovat käynnissä. Kokoaminen/rakentaminen käynnistyy täysimääräisesti komponenttien saavuttua. Tavoiteaikataulu joulukuu.
- Kaikki testattavat holkkimateriaalit on hankittu ja näytekappaleiden valmistus menossa
- Mittausten aloittaminen ensi vuoden alussa (tavoiteaikataulu tammikuu)

JAKELU Tilaaja
VTT / projektiryhmä

APPENDIX VII

Oulun yliopisto:
Ceramic structural materials – accepted proposal

TARJOUS TUTKIMUKSEN SUORITTAMISESTA

Tarjoamme tulenkestävien soodakattimateriaalien tutkimuksen suorittamista alla mainituin ehdoin.

1 Tarjouksen tekijä

Oulun yliopisto, prosessimetallurgian laboratorio.

2 Tarjouksen kohde ja suoritusaika

On liitteellä 1.

3 Maksuehdot

Tutkimus laskutetaan sopimushintaan 15 000 € ALV 0 % ilman mikrorakenne tutkimusta. Maksu suoritetaan kertasuorituksena loppuraportoinnin jälkeen.

4 Muut ehdot

Tarjous on voimassa 2 kuukautta tarjouskirjeen päiväyksestä.

Mikäli tarjous tulee hyväksytyksi, sopimukseen sovelletaan Oulun yliopiston tilaajarahoitteisen tutkimuksen yleisiä sopimusehtoja (Liite 2).

5 Tutkimuksen tekijää koskevat tiedot

Vastuullinen johtaja :Professori Jouko Härkki
Sähköposti: jouko.harkki@oulu.fi
Puhelin: 040-5215655

Yhteyshenkilö: Laboratorioinsinööri Riku Mattila
Sähköposti: riku.mattila@oulu.fi
Puhelin: 040-7301094
Osoite: Prosessimetallurgian laboratorio
Erkki Koiso-Kanttilan katu, ovi V2
90570 Oulu

Allekirjoitus
Oulun yliopisto 30/11 2009

Jouko Härkki
____
Tutkimuksen vastuullinen johtaja

KOKEELLINEN VERTAILEVA TUTKIMUS TULENKESTÄVISTÄ MASSOISTA SOODAKATTILASSA

1 TAUSTAA

Oulun yliopiston prosessi- ja ympäristötekniikan osaston prosessimetallurgian laboratoriossa tutkittiin syksyllä 2005 soodakattilan tulenkestäviä materiaaleja. Tutkimuksen tilaajana oli Suomen Soodakattilayhdistys ry. [1]

Kokeellisessa osassa testattiin osittain spinelliin pohjautuvaa materiaalia altistamalla se soodakattilan sulalle Stora Enson Oulun tehtaalla. Vertailukohteena käytettiin nykyisin käytössä olevaa samottista materiaalia. Spinelliä sisältäneet koekappaleet kestivät soodakattilan olosuhteita paremmin kuin nykyisin käytetystä materiaalista valmistettu kappale. Spinelliä sisältävän materiaalin lisäksi jatkotutkimuksiin suositeltiin myös ZrO_2-pohjaista materiaalia sekä forsteriitin ja ceriumoksidin soveltuvuuden arviointia.

2 TUTKIMUSSUUNNITELMA

Testit on tarkoitus suorittaa Stora Enson Oulun tehtaiden soodakattilassa ajon aikana. Suoritusajaksi on kaavailtu vuoden 2009 loppua ja 2010 alkua.

2.1 Materiaalit

Tutkittaviksi materiaaleiksi on valittu seuraavat:

- Vertailu materiaali (Hassle ja MagnesiaRautatiili tehtaalta)
- Spinelliä muodostavaa massaa (Betker tai vastaava)
- Valmista spinelliä sisältävää massaa
- ZrO2 kaupallista massaa (Zircoa-Cast™ Castable Refractory, 0872-8D)
- CeO2 pohjainen massa tai pinnoite
- Forsteriitti pohjainen massa
- Tiivis aloksimassa (tehtaalla bloki).

2.2 Koekappeleiden valmistus

Koekappaleet valmistetaan massanvalmistajien ohjeiden mukaisesti.

Tulenkestävistä massoista valmistetaan noin 100-150mm pitkä neliöprofiilinen tanko jonka sivu on noin 50mm. Koekappale kiinnitetään teräs tankoon ”tikkariksi”.

Massat kuivataan 110°C valun ja sidoksen muodostuksen jälkeen. Sen jälkeen poltetaan tiilen valmistus lämpötilaa vastaavaksi.

Tikkarit ladotaan asennuspaketiksi, jossa on pahvin mentävä rako tikkareiden välillä. Pakettia ylläpitää teräksinen kehikko, jonka toiseen aukkoon tikkarien teräsvahvikkeet kiinnittyvät ja jossa on ulosvetoa ja asennusta varten tanko kehikossa. Raot tilkitään tulenkestävällä villalla.

Kehikon tekee Oulun yliopisto yhteistyössä tehtaan kanssa.

2.3 Kokeiden suorittaminen

Tikkareita mahtuu 250mm x 100mm ruiskutusaukkoon noin kolmesta viiteen kappaletta kerrallaan, jotka asetetaan kehikossa sisään. Vähintään yksi ”tikkareista” on vertailumateriaalia. Mitataan upotussyvyys ja erillisellä termoelementillä lämpötila.

Toimitaan samoin seuraavien materiaalien kanssa.

Koekappaleita pidetään kattilassa 1 – 2 vko.

Testin läpikäyneet koekappaleet merkitään, kuvataan ja säilötään jatkotutkimusta varten.

3-5 kpl parhaiten menestyneitä valitaan materiaaleiksi pitempiaikaaseen kokeeseen joka valmistellaan ja toteutetaan edellä mainutulla tavalla.

2.4 Koekappaleiden analysointi

Koekappaleet mitataan sekä kuvataan ennen ja jälkeen kokeen. Tästä saa jo käsityksen mikä vertailtavista materiaaleista on paras. 3- 5 kpl valitaan pitempiaikaiseen testiin joista maihdollisesti tutkitaan mikrorakenne.

Mikrorakenteen tutkiminen on oma projektinsa.
Näytteen valmistus vedetön 100
Valomikroskopointi 0,5h 150
Hiilipäällystys 25
SEM/EDS 1h 450
Raportointi 1 h 300
Mikrorakenne yhteensä 1025 euroa/näyte

2.5 Aikataulu

Koekappaleen muottien 6-10 kpl valmisteluaika vähintään 2 päivää.
Kehikoiden 2kpl valmisteluaika 2 päivää.
Koekappaleen teko 1 kpl/päivä joten muotteja tarvitaan useita 6 kpl muotteja homma hoituu nopeammin noin 1 päivässä.
Koekappaleiden poltto 1 päivä 6 kpl kerralla.
Kappaleiden kuvaus ja kasaaminen kehikkoon 1 päivä.
Yhteensä minimi valmisteluaika kahdelle testikehikolle koekappaleineen on noin 2+2+1+1+1= 7 päivää

Kappaleiden purku, kulumien mittaus, valokuvaus ja nopea raportti 1 vko.
Seuraavan erän teko pitempaikaiseen kokeeseen vähintään 5 päivää.
Raportointi havainnoista ja suositukset jatkosta 1 vko.

Yhteensä tehollista työaikaa arvoidaan kuluvan noin 4 vko.

2.6 Lähteet

Hannu Makkonen ja Riku Mattila. Soodakattilan keraamiset rakenteet. 2005. Luottamuksellinen.

3 KUSTANNUKSET

Tehokasta työaikaa kuluu arviolta noin 4 viikkoa. Tähän sisältyy kuitenkin jonkin verran päällekkäistä työaikaa yliopiston pajan, laboratorioinsinöörin ja tutkijan välillä. Laskutus on siis noin viiden viikon verran. Koemateriaalien hankinta ja valmistukseen kuluu jonkin verran rahaa samoin matkoihin jne. Arvio muihin kuluihin on noin 1800 euroa. Kokonaiskustannus on 15000 euroa alv0% ilman mikrorakennetutkimusta.

APPENDIX VIII

Teollisuuden Vesi Oy,
TOC-removal methods and applicability for recovery boiler make-up water treatment (in Finnish)- status report

Tilauksenne 16A0913/S88

TOC-poistomenetelmät ja niiden soveltuvuus soodakattiloiden lisäveden valmistukseen

Väliraportti

Teollisuuden Vedeltä on tilattu kirjallisuusselvitys TOC-poistomenetelmistä sekä selvitys ioninvaihtomassojen toiminnasta orgaanisten aineiden poistoon. Työt on aloitettu tarjouksen mukaisesti syyskuun alussa ja ne ovat edenneet suunnitelmien mukaan.

Kirjallisuusosassa tuodaan esille eri TOC-poistoon soveltuvat menetelmät (nanosuodatus, käänteisosmoosi, aktiivihiilisuodatus ja erilaiset UV-tekniikat mukaan lukien AOP-Advanced Oxidation Process) ja niiden tehokkuus. Investointikustannuksista annetaan arvio.

Ioninvaihtomassojen toimintaa selvitetään kirjallisuusosan lisäksi myös laboratorio-olosuhteissa niin, että sekä Rauman Botnian että Stora Enson Kotkan laitoksilta on hankittu näytteet anionivaihtomassoista. Massoille on tehty/tehdään seuraavat kokeet:

- TOC-likaantuminen (mg/g hartsia)
- Kokonaiskapasiteetti ja vahva kapasiteetti
- TOC-kapasiteetti ja elvyttyminen

Näiden kokeiden lisäksi molemmilta laitoksilta on lähetetty vesinäytteet laboratorioon Saksaan luonnon orgaanisen aineen jakautumisen määrittämiseksi vedenkäsittelyprosessin eri vaiheista mm.:

- liuennut hiili, DOC
- biopolymeerit (polysakkaridit, proteiinit)
- neutraalit orgaaniset aineet (alkoholit, aldehydit, ketonit)
- orgaaniset hapot

Työn alustavat tulokset esitellään 10.12.09 ns. projektipalaverissa Kotkan, Rauman ja Pietarsaaren käyttöhenkilökunnan kesken. Varsinaiseen jakeluun kommentteja varten raportti tutkimustuloksineen ja liitteineen toimitetaan viimeistään 9.1.2009.

Teollisuuden Vesi Oy
Y-tunnus1855496-8
www.teollisuudenvesi.fi
info@teollisuudenvesi.fi

Hyllyväntie 6-8
04600 MÄNTSÄLÄ
gsm 040 503 1258

APPENDIX IX
Oulun Yliopisto,
Reduction of TOC from recovery boiler make-up water – status report

Soodakattilalaitoksen lisäveden orgaanisen aineen (TOC) vähentäminen

20.11.2009
Tero Luukkonen

Mitä tähän mennessä tehty

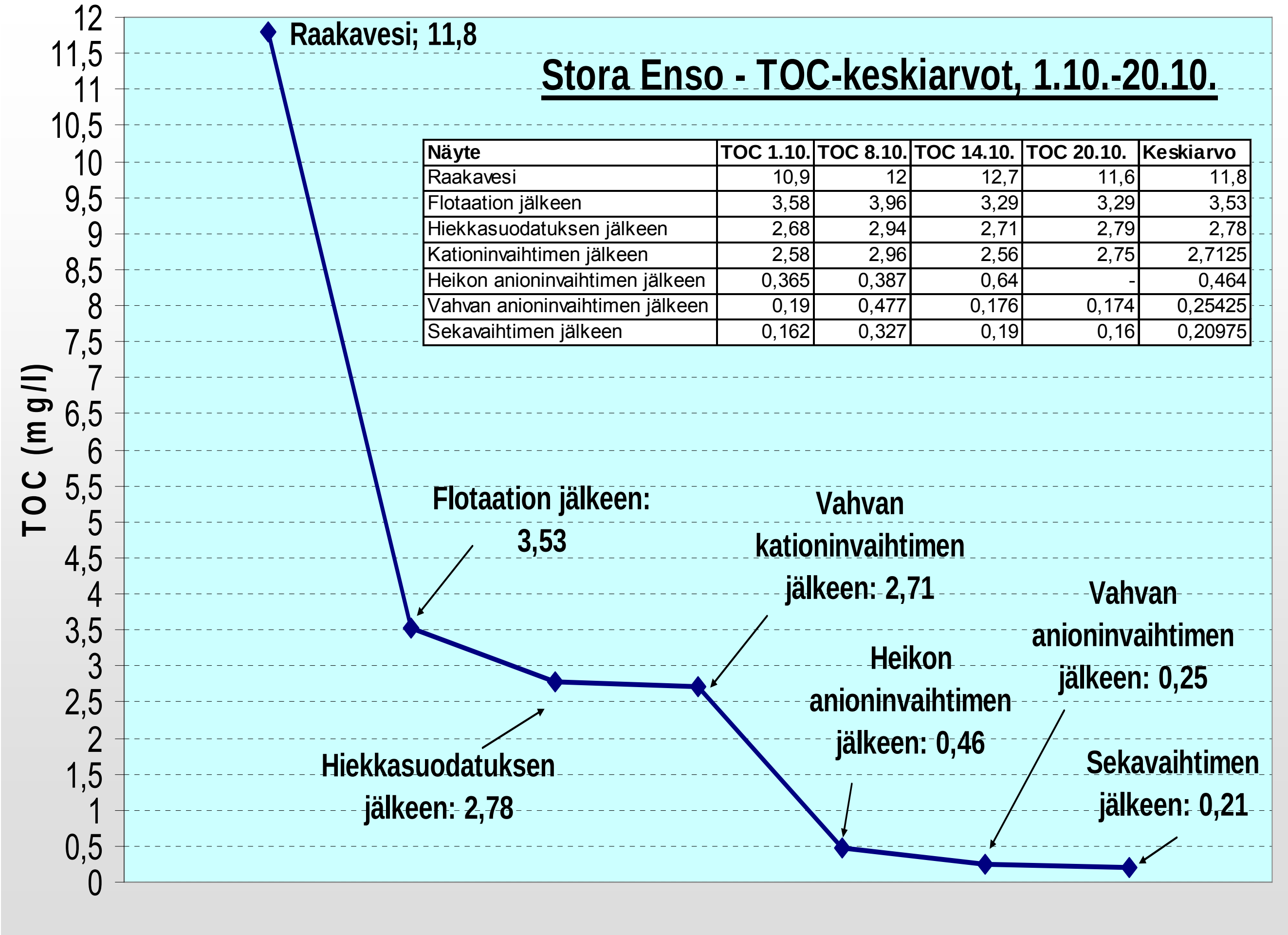
- TOC-mittaussarjat (4 kpl) tutkittavilta laitoksilta (Stora Enso, Kemira, Oulun vesi)
- Ioninvaihdon ajovaiheen vaikutus TOC-poistumaan
- Oulun veden valmistaman talousveden käyttö raakavetenä
- Mittaussarjat Veitsiluodon vedenpuhdistamolta sekä Kurkelanrannasta (Oulun veden toinen laitos)

TOC-mittaussarjojen tuloksia

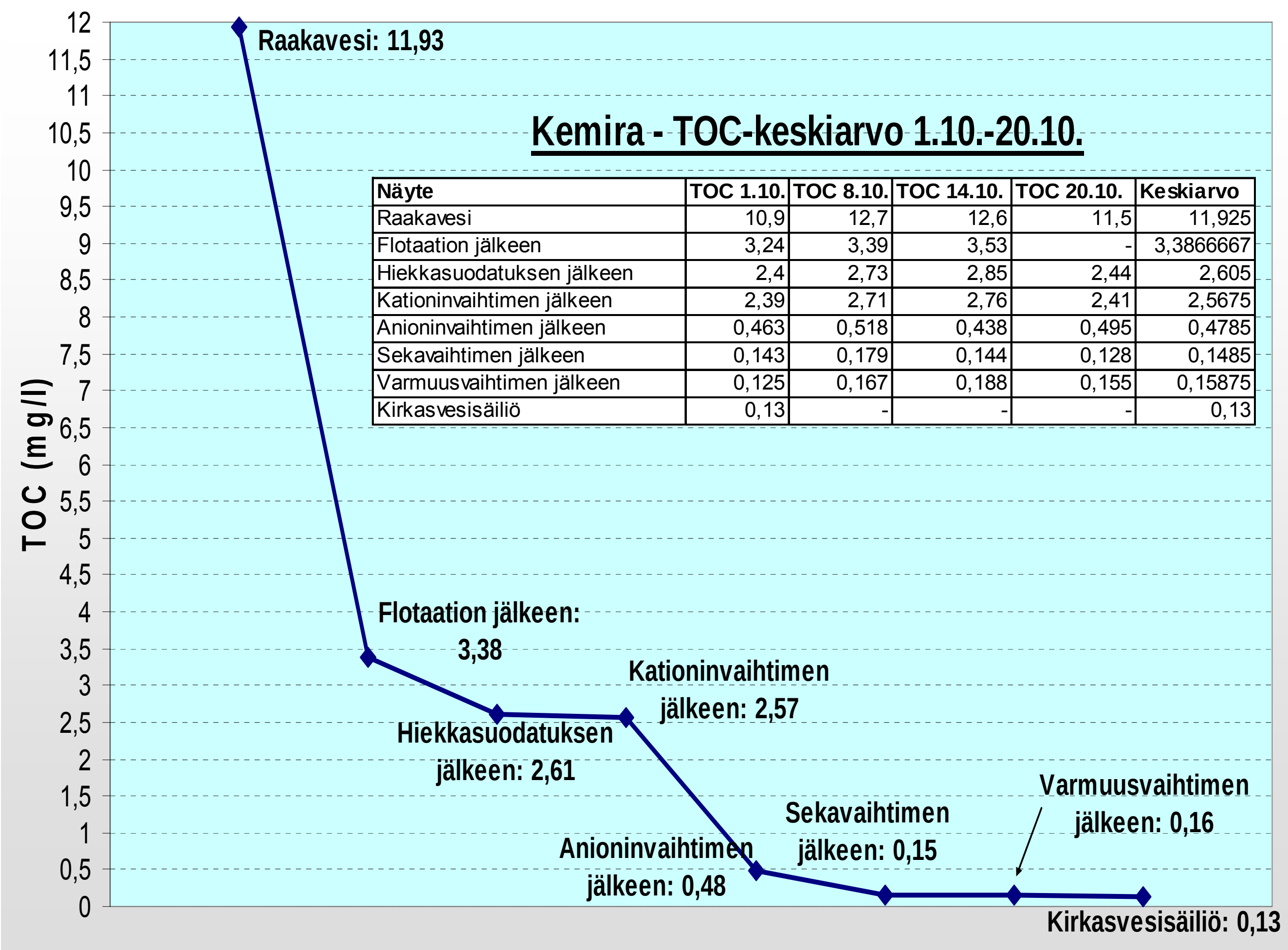
Näyte	**Stora Enso (keskiarvo) /ppm**	**Kemira (keskiarvo) /ppm**
Raakavesi	11,70	11,75
Flotaation jälkeen	3,41	3,47
Hiekkasuodatuksen jälkeen	2,62	2,57
Kationinvaihtimen jälkeen	2,40	2,28
Heikon anioninvaihtimen jälkeen	0,46	-
Vahvan anioninvaihtimen jälkeen	0,22	0,46
Sekavaihtimen jälkeen	0,19	0,24
Varmuusvaihtimen jälkeen	-	0,20

TOC-mittaussarjojen tuloksia

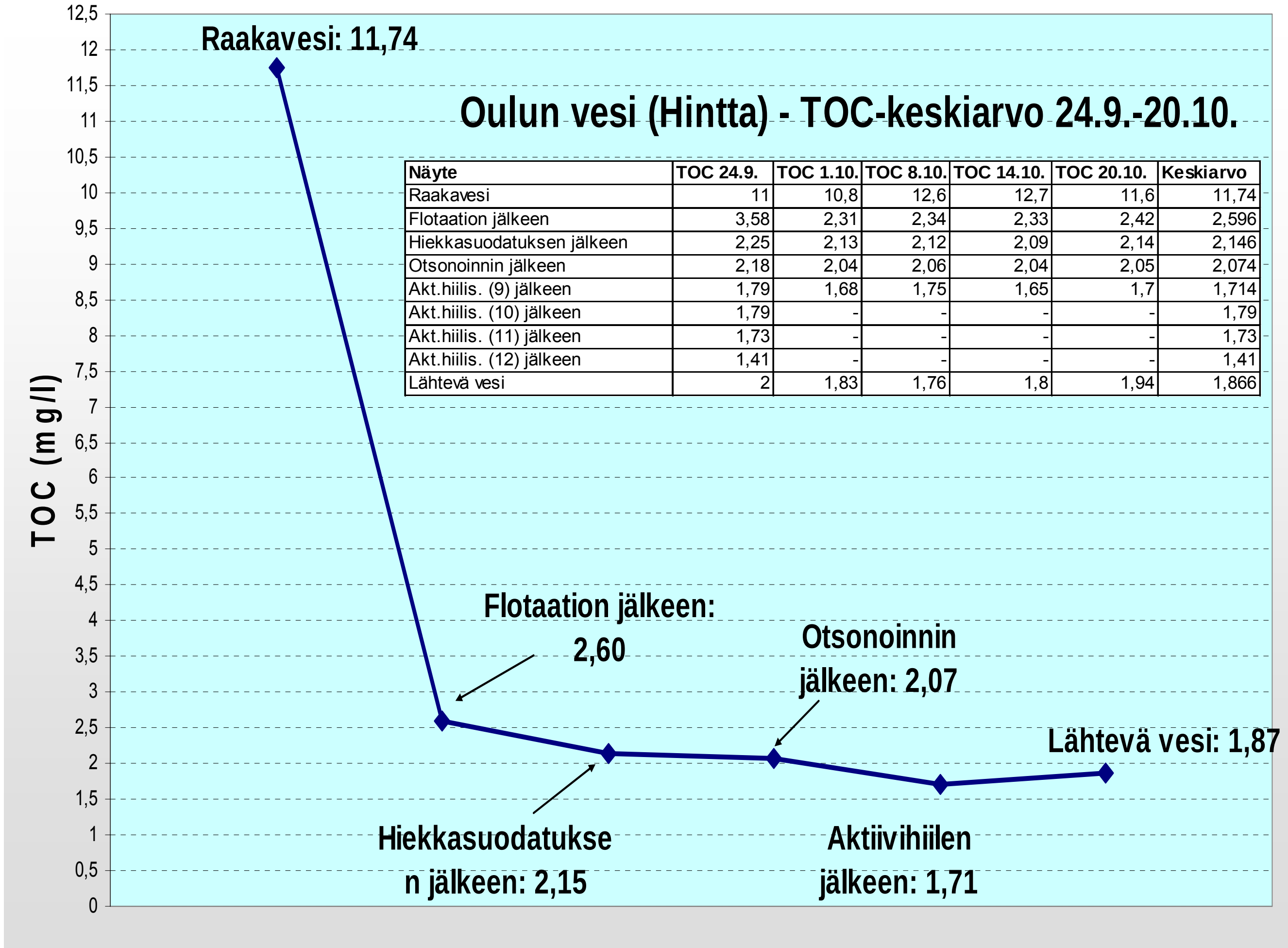
Näyte	**Oulun vesi (Hintan laitos), keskiarvo /ppm**
Raakavesi	11,67
Flotaation jälkeen	2,51
Hiekkasuodatuksen jälkeen	2,14
Otsonoinnin jälkeen	2,06
Akt.hiilis. (9) jälkeen	1,70
Akt.hiilis. (10) jälkeen	1,79
Akt.hiilis. (11) jälkeen	1,73
Akt.hiilis. (12) jälkeen	1,41
Lähtevä vesi	1,90



Näyte	TOC 1.10.	TOC 8.10.	TOC 14.10.	TOC 20.10.	Keskiarvo
Raakavesi	10,9	12	12,7	11,6	11,8
Flotaation jälkeen	3,58	3,96	3,29	3,29	3,53
Hiekkasuodatuksen jälkeen	2,68	2,94	2,71	2,79	2,78
Kationinvaihtimen jälkeen	2,58	2,96	2,56	2,75	2,7125
Heikon anioninvaihtimen jälkeen	0,365	0,387	0,64	-	0,464
Vahvan anioninvaihtimen jälkeen	0,19	0,477	0,176	0,174	0,25425
Sekavaihtimen jälkeen	0,162	0,327	0,19	0,16	0,20975



Näyte	TOC 1.10.	TOC 8.10.	TOC 14.10.	TOC 20.10.	Keskiarvo
Raakavesi	10,9	12,7	12,6	11,5	11,925
Flotaation jälkeen	3,24	3,39	3,53	-	3,3866667
Hiekkasuodatuksen jälkeen	2,4	2,73	2,85	2,44	2,605
Kationinvaihtimen jälkeen	2,39	2,71	2,76	2,41	2,5675
Anioninvaihtimen jälkeen	0,463	0,518	0,438	0,495	0,4785
Sekavaihtimen jälkeen	0,143	0,179	0,144	0,128	0,1485
Varmuusvaihtimen jälkeen	0,125	0,167	0,188	0,155	0,15875
Kirkasvesisäiliö	0,13	-	-	-	0,13



Näyte	TOC 24.9.	TOC 1.10.	TOC 8.10.	TOC 14.10.	TOC 20.10.	Keskiarvo
Raakavesi	11	10,8	12,6	12,7	11,6	11,74
Flotaation jälkeen	3,58	2,31	2,34	2,33	2,42	2,596
Hiekkasuodatuksen jälkeen	2,25	2,13	2,12	2,09	2,14	2,146
Otsonoinnin jälkeen	2,18	2,04	2,06	2,04	2,05	2,074
Akt.hiilis. (9) jälkeen	1,79	1,68	1,75	1,65	1,7	1,714
Akt.hiilis. (10) jälkeen	1,79	-	-	-	-	1,79
Akt.hiilis. (11) jälkeen	1,73	-	-	-	-	1,73
Akt.hiilis. (12) jälkeen	1,41	-	-	-	-	1,41
Lähtevä vesi	2	1,83	1,76	1,8	1,94	1,866

Veitsiluodon TOC-tulokset

Näyte	TOC 20.10. (ppm)
Raakavesi	9,58
Ennen humussuodinta	2,68
Humussuotimen jälkeen	0,912
Kationinvaihtimen jälkeen	0,834
Anioninvaihtimen jälkeen	0,186
Sandwich-suotimen jälkeen	0,204

Kurkelanrannan TOC-tulokset

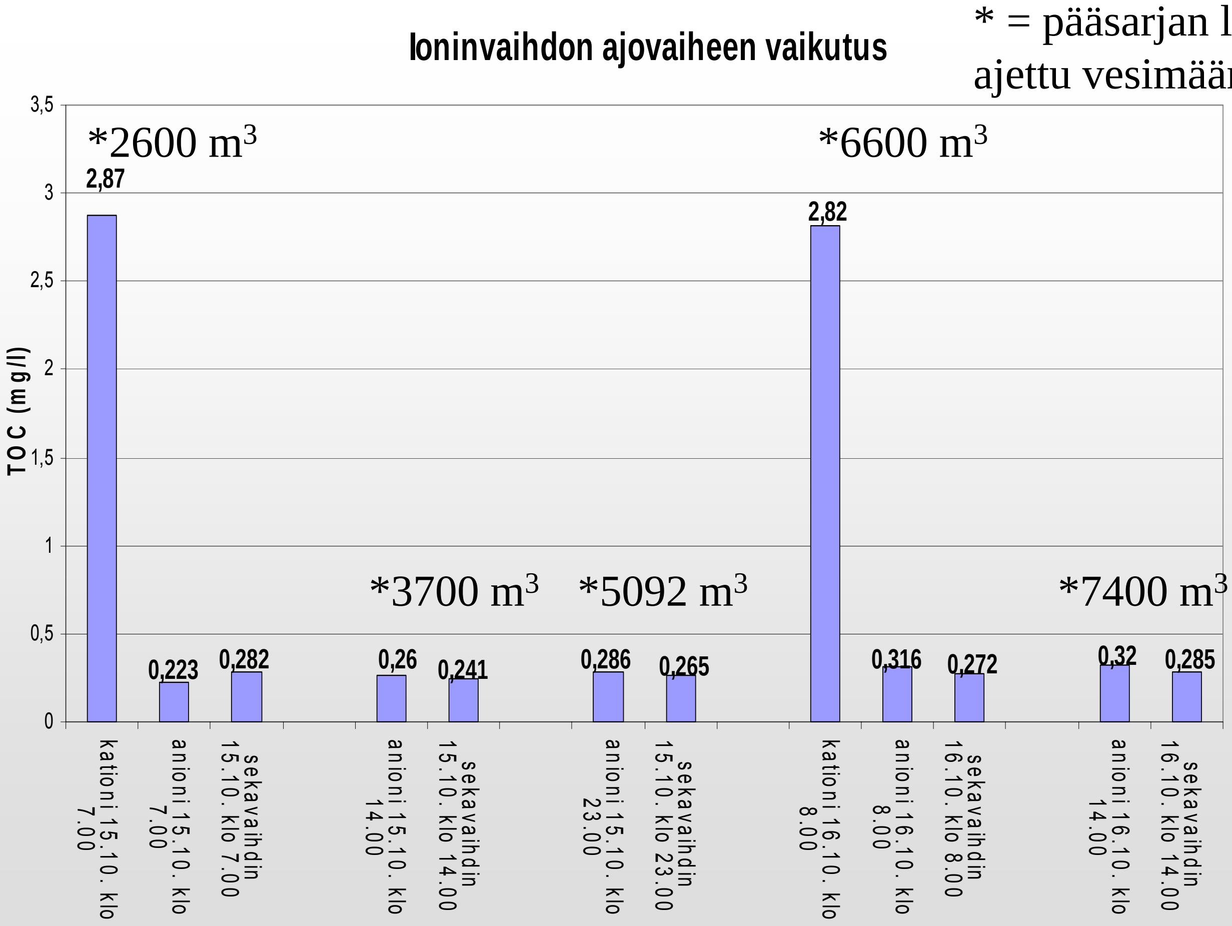
Näyte	TOC 14.10. (ppm)
Flotaation jälkeen	2,42
Hiekkasuodatuksen jälkeen	2,12
Otsonoinnin jälkeen	2,03
Biologisen akt.hiilis. Jälkeen	1,78
Akt.hiilis. jälkeen	1,6
UV:n jälkeen	1,6

- UV (aallonpituus 254 nm) ei vaikuta TOC-lukemaan

”Kaupunginvesi” raakavetenä Stora Ensolla

Näyte	TOC-keskiarvo 1.10.-20.10.	Kaupunginvesi raakavetenä 14.10.
Kationille menevä	2,78 ppm	2,31 ppm
Kationinvaihtimen jälkeen	2,71 ppm	1,73 ppm
Anioninvaihtimen jälkeen	0,254 ppm	0,253 ppm
Sekavaihtimen jälkeen	0,210 ppm	0,190 ppm

* = pääsarjan läpi ajettu vesimäärä



Aktiivihiilikokeet

- Oulun veden aktiivihiili pesty
- Käyttö mekaanisesti (adsorptio) vai biologisesti?
- Aktiivihiilen käyttökode?

Mitä seuraavaksi

- Aktiivihiilikokeet
- UV-kokeet (pelkkä UV ja sopivan hapettimen kanssa)
- Flokkauskokeet (käytetään rautakoagulanttia)

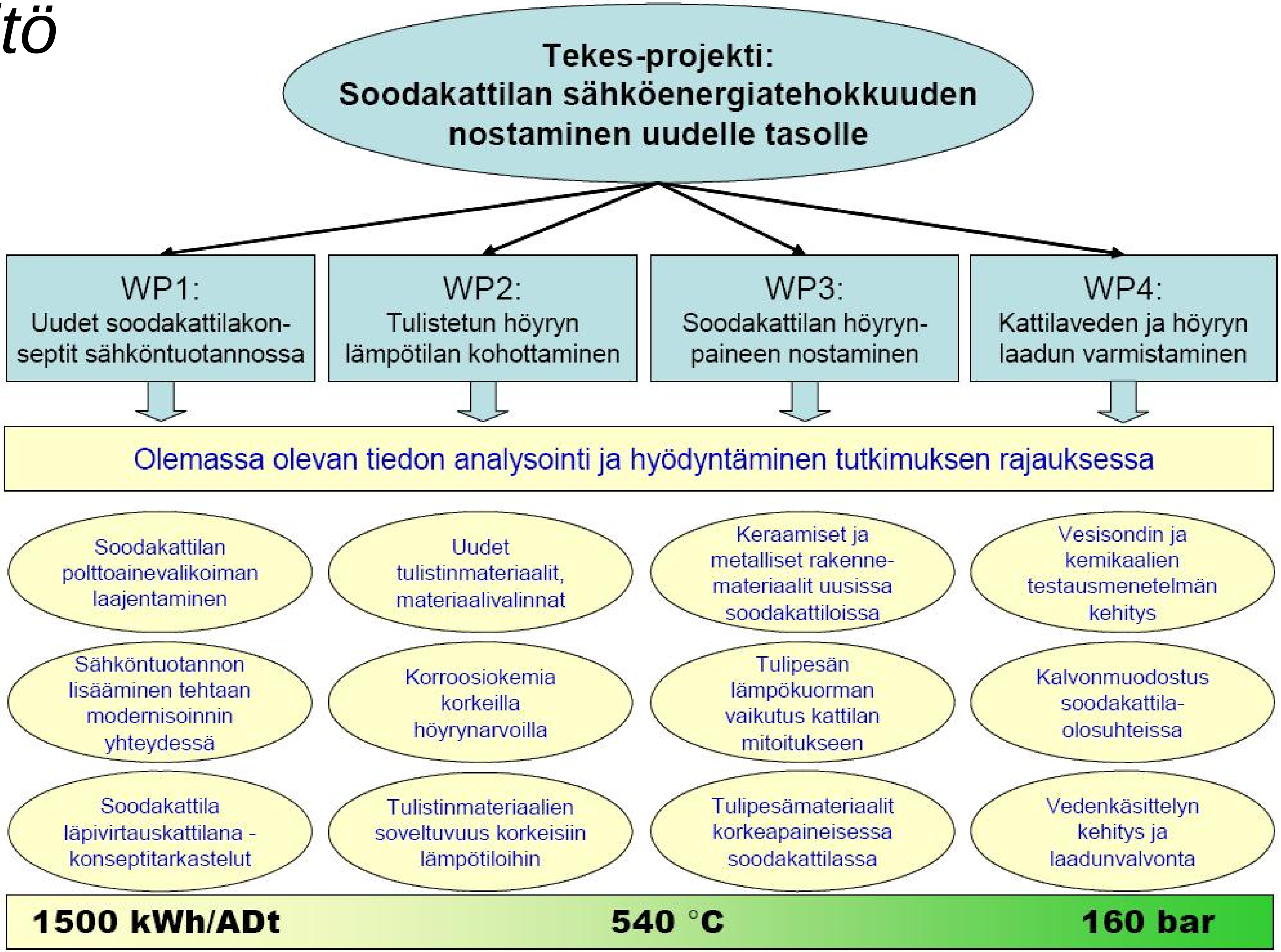
Aktiivihiilikokeiden koe-järjestely: viipymä pyritään saamaan samaksi kuin Oulun vedellä

APPENDIX X
Esa Vakkilainen, Project Coordinator,
To Be Done – presentation

SKYREC
To be done
1.1.2008-30.6.2010

Esa Vakkilainen

Sisältö


Tekes-projekti:
Soodakattilan sähköenergiatehokkuuden nostaminen uudelle tasolle
WP1:
Uudet soodakattilakon-septit sähköntuotannossa
WP2:
Tulistetun höyryn lämpötilan kohottaminen
WP3:
Soodakattilan höyryn-paineen nostaminen
WP4:
Kattilaveden ja höyryn laadun varmistaminen
Olemassa olevan tiedon analysointi ja hyödyntäminen tutkimuksen rajauksessa
Soodakattilan polttoainevalikoiman laajentaminen
Uudet tulistinmateriaalit, materiaalivalinnat
Keraamiset ja metalliset rakenne-materiaalit uusissa soodakattiloissa
Vesisondin ja kemikaalien testausmenetelmän kehitys
Sähköntuotannon lisääminen tehtaan modernisoinnin yhteydessä
Korroosiokemia korkeilla höyrynarvoilla
Tulipesän lämpökuorman vaikutus kattilan mitoitukseen
Kalvonmuodostus soodakattila-olosuhteissa
Soodakattila läpivirtauskattilana - konseptitarkastelut
Tulistinmateriaalien soveltuvuus korkeisiin lämpötiloihin
Tulipesämateriaalit korkeapaineisessa soodakattilassa
Vedenkäsittelyn kehitys ja laadunvalvonta
1500 kWh/ADt
540 °C
160 bar

Missing items from work plan – WP1

  - *Selvitetään mahdollisuudet ja keinot soodakattiloiden rakennusasteen nostamiseen sellutehtaan modernisoinnin yhteydessä. Esiselvityksessä kartoitetaan kaikki mahdollisuudet olemassa olevan soodakattilan rakennusasteen nostamiseksi tehtaan modernisoinnin yhteydessä.*
  - 4.1.2
- Need to ask for quotes for this part of the work during 2009

Missing items from work plan – WP2

- *Lisäksi laaditaan materiaali-suositus nykyisin käytössä olevien ja tulevaisuuden soodakattiloiden tulistimien materiaalivalinnan helpottamiseksi.*
- 4.2

- Need to start working on material selection recommendations during spring 2010

Missing items from work plan – WP3

- *Tulipesän lämpökuorma mitataan sekä lipeäruiskuaukkotasolla että tulipesän alaosassa. Mittauksissa käytettävä sondi asennetaan lipeäruiskuaukkoihin ja tulipesäkamera-aukkoihin. Mittauksia tehdään samoissa kattiloissa (vähintään 2 kattilassa), joissa tehdään myös tulipesämateriaalien kenttäkokeet. Mittauksen kesto on 1 – 2 viikkoa/mittaus. Mittaukset pyritään tekemään kattilan toimiessa täydellä kuormalla.*
- 4.3.2

- Does Boildec measurements cover this? Separate measurements? If, then need to start working on this ASAP

Missing items from work plan – WP4

- *Osaprojektissa laaditaan suositus vesienkäsittelystä, sekä suositus vesi- ja lauhdejärjestelmistä tarvittavine valvontakohteineen. Lisäksi päivitetään käytössä olevat vedenlaatusuositukset kattamaan nykyiset, käytössä olevat soodakattilat ja myös tulevaisuuden korkeapaineiset soodakattilat*.

- Need to start working on water quality and water treatment recommendations during spring 2010
- There is an existing Boildec offer, others also possible

International co-operation

- Co-operation and co-reporting with Sodahuskommittén *Förutsättningar för framtidens sodapanna (3FS)* needed
- Co-operation and co-reporting with ORNL and Paprican needed

Extend end from 30.6.2010

APPENDIX XI
Åbo Akademi,
Co-firing of black liquor and biomass – laboratory combustion tests, phase 2 - proposal

SKY-REC Co-combustion of mixed fuels –Phase 2

28 September 2009

Objective. The proposed work for phase 2 will build on the promising results of the first study of the combustion of mixtures of black liquor with either bark, wood, peat or biosludge. This phase 2 work will focus on bark and wood and will provided data to help answer the following questions:

1. At what addition level does the mixture burn more like bark/wood than black liquor?
2. What is the fate of nitrogen in bark - does the char have more cyanate?
3. What is the impact of bark moisture and combustion temperature?
4. What are the burning characteristics of reduced lignin black liquor with the addition of bark?

Proposed Work. The following pieces are proposed based on the above four questions:

1. At what addition level does the mixture burn more like bark/wood than black liquor?
   Droplet combustion tests (1100 °C, 3% O_2) with 100% bark/wood; mixtures: 50/50 BL/bark or wood on a dry solids basis and then one other ratio either higher or lower than 50/50 depending on those results. These tests would use the same “dry” bark/wood we have used thus far.
2. What is the fate of nitrogen in bark - does the char have more cyanate?
   Pyrolysis (100% N_2) + char gasification experiments (13% CO_2/87% N_2) with BL and one BL + bark mixture.
3. What is the impact of bark moisture and combustion temperature?
   a. Droplet combustion tests (1100 °C, 3% O_2) with wet bark/wood only and a mixtures of BL + bark and BL+ wood at one addition level each. The bark and wood for these experiments would be at approximately 50% moisture.
   b. Droplet combustion tests (900 °C, 3% O_2) with BL and 1 mixture level of BL + bark/wood each.
4. What are the burning characteristics of reduced lignin black liquor with the addition of bark?
   Droplet combustion tests at 1100 °C, 3 % O_2 with lignin reduced black liquor (at one removal level) and lignin reduced black liquor with bark added to replace the energy loss of the lignin.

Cost. The total cost of this project will be **16.000 €** not including VAT.

APPENDIX XII
LUT:
Pulp mill optimal steam pressure levels - proposal

LAPPEENRANTA
UNIVERSITY OF TECHNOLOGY

TARJOUS

Sellutehtaan höyrytasojen optimaaliset paineet

Soodakattilayhdistys ry

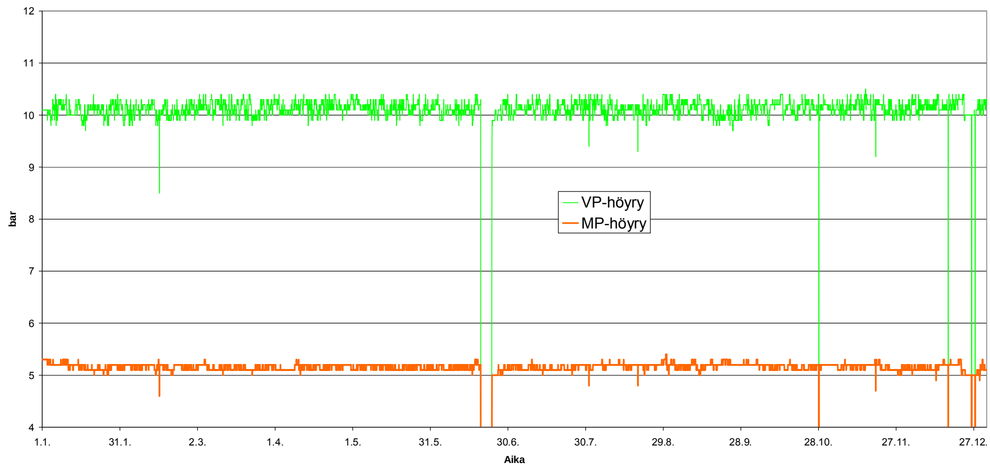
16.12.2009

Lappeenrannan Teknillinen Yliopisto
Professori Esa Vakkilainen.

1 JOHDANTO

Suomen Soodakattilayhdistys (tilaaja) on halukas selvittämään miten sellutehtaan höyrynpainetasot vaikuttavat tehtaiden talouteen.

Sellutehtaan matalapaineen ja välipaineiden painetasoissa on vaihtelua eri tehtailla. Painetasojen nostoa vaativia prosesseja ovat mm. paperikoneet, haihduttamo, valkaisimo ja kuivauskone.



Sellutehtaan painetason valinnat perustuvat melko vanhoihin valintoihin. Painetasojen valintaan ei ole juurikaan kiinnitetty huomiota 70-luvun jälkeen. Matalapainehöyryn paineen ja välipainehöyryn paineen arvot vaikuttavat sellutehtaan sähköntuotantoon. Matalampi paine merkitsee enemmän sähköä. Toisaalta matalampi paine merkitsee isompia höyrylinjoja ja vastaavasti isompia investointikustannuksia. Samoin esimerkiksi sellun kuivauksen investointi (kapasiteetti) riippuu valitusta vastapaineesta.

Painetasoja olisi hyvä tutkia toisaalta lähtökohtana uusi tehdas ja toisaalta miten taloudellista optimia olisi hyvä lähestyä suomalaisella integroidulla ja integroimattomalla tehtaalla.

2 TAVOITTEET

Projektissa tehdään diplomityö, jossa tarkastellaan sellutehtaan painetasojen valintaa.

Työssä selvitetään erityisesti seuraavia seikkoja.

Vaihe 1.

Kerätään Soodakattilayhdistyksen kanssa Suomen tehtaiden tyypilliset nykyisin käytössä olevat painetasot. Kaivetaan esille syyt miksi nykyiset painetasot on valittu. Listataan syitä miksi nyt ajetaan ylempää/alempaa tasoa kuin aiemmin.

Vaihe 2.

Laaditaan uuden n. 600 000 ADt/a modernin sekä perinteisen Suomeen sopivan sellutehtaan vuosikeskiarvotaseet ja arvioidaan eri painetasoille investointien kustannuserot. Tarkastellaan eri sähkön hintojen vaikutusta valittavaan painetasoon. Toistetaan laskenta siinä tapauksessa että ei ole kuorikattilaa. Toistetaan laskenta siinä tapauksessa että kysymyksessä onkin hienopaperi/sellutehdas integraatti.

Vaihe 3.

Selvitetään mahdollisuudet ja keinot soodakattiloiden rakennusasteen nostamiseen sellutehtaan modernisoinnin yhteydessä. Kartoitetaan kaikki mahdollisuudet olemassa olevan soodakattilan rakennusasteen nostamiseksi tehtaan modernisoinnin yhteydessä.

Mikäli Soodakattilayhdistys järjestää mittauksia, joita voidaan tutkimuksessa hyödyntää, niin niiden ja mallittamisen välinen tarkastelu kuuluu mukaan.

3 RAPORTOINTI JA AIKATAULU

3.1 Raportti

Työn loppuraportti kirjoitetaan englanniksi, mutta työstä raportoidaan suomeksi. Työstä raportoidaan sen kestäessä Suomen Soodakattilayhdistykselle sen haluamalla tavalla lipeätyöryhmän ohjauksessa. Työstä tehdään myös yhteenveto suomeksi.

3.2 Aikataulu

Loppuraportti luovutetaan tilaajalle hyväksymistä varten 8 (kahdeksan) kuukautta tilauksesta.

4 RESURSSIT JA YHTEISTYÖ MUIDEN KANSSA

Projektin organisaatio

Projektin vastuullinen johtaja: Esa Vakkilainen. (LTY/Professori)

Pääasiallinen tutkija: Tekn yo. N.N. (DI-työ)

Tämän projektin työ ja tulokset tukevat Soodakattilayhdistyksen tavoitetta soodakattilan sähköntuotannon lisäämiseksi.

5 KUSTANNUSARVIO JA RAHOITUSSUUNNITELMA

Projektin kokonaiskustannus on € 16 000 + ALV. Tämä sisältää palkat, matkat ja muut tutkimusmenot. Mikäli Soodakattilayhdistys edellyttää pitkäaikaisia paikallaoloja tehtailla nämä laskutetaan erikseen valtion matkustussäännön mukaisesti. Projektin raportin painatuksesta vastaa Soodakattilayhdistys.

Kokonaiskustannuksista maksaa Soodakattilayhdistys € 8 000,- + ALV tilauksen yhteydessä ja € 8 000,- + ALV loppuraportin tultua hyväksytyksi. Maksuaika 30 päivää.