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Theory of reheating

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Why reheating did not pay off?

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- Finnish Recovery boiler committee looked at reheating recovery boilers but reheating did not seem to make much difference.
- Rehating Case E produced only a bit more electricity than the best traditional Case C

Concepts studied

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A. Natural circulation 82 %, 490 °C, 9.0 MPa (Joutseno)

B. Natural circulation 85 %, 505 °C, 10.2 MPa (Kymi)

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

Future boiler concept

D. Assisted circulation 85 %, 540 °C, 16.0 MPa (SoTu)

Reheat boilers

E. Natural circulation 85 %, 515/515 °C, 12.0/3.0 MPa (SkyRec)

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

Case		A	B	C	D	E	
Capacity	tds/d	5500	5500	5500	5500	5500	
capacity (virgin)	tds/d	5005	5005	5005	5005	5005	
Dry solids	%	82.0	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)

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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

Electricity generation (No PB)

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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 electricity

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Case		A	B	C	D	E	F
Air-fans	kW	2275	2296	2296	2296	2296	2296
FG-fans	kW	2570	2534	2534	2534	2534	2534
FW-pump	kW	3055	3556	4347	5719	4187	8606
Other	kW	1500	1500	1500	1500	1500	1500
Total	kW	9401	9886	10677	12049	10518	14937

Boiler process – Case C

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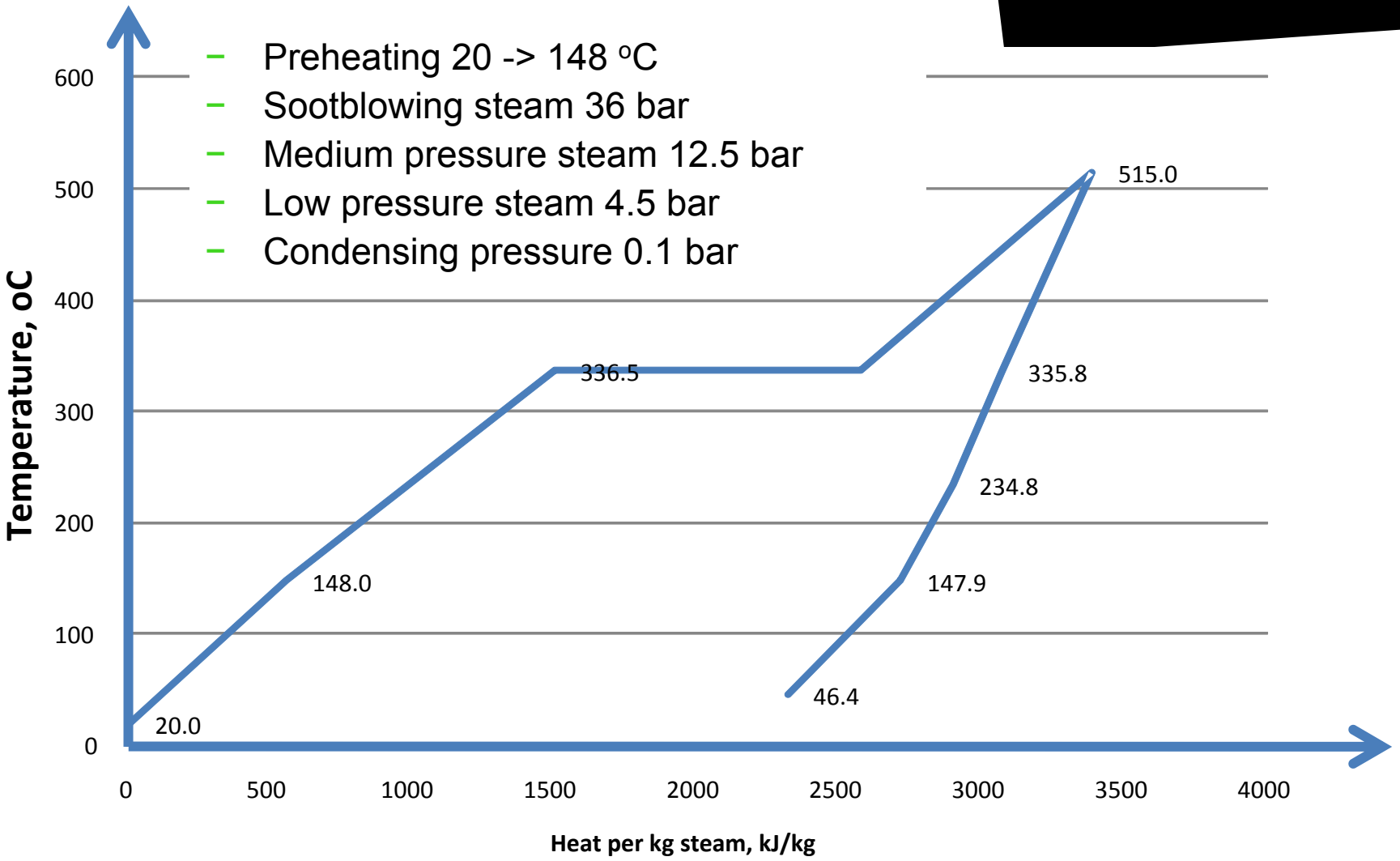
- Preheating 20 -> 148 °C
- Sootblowing steam 36 bar
- Medium pressure steam 12.5 bar
- Low pressure steam 4.5 bar
- Condensing pressure 0.1 bar



Turbine – Case C

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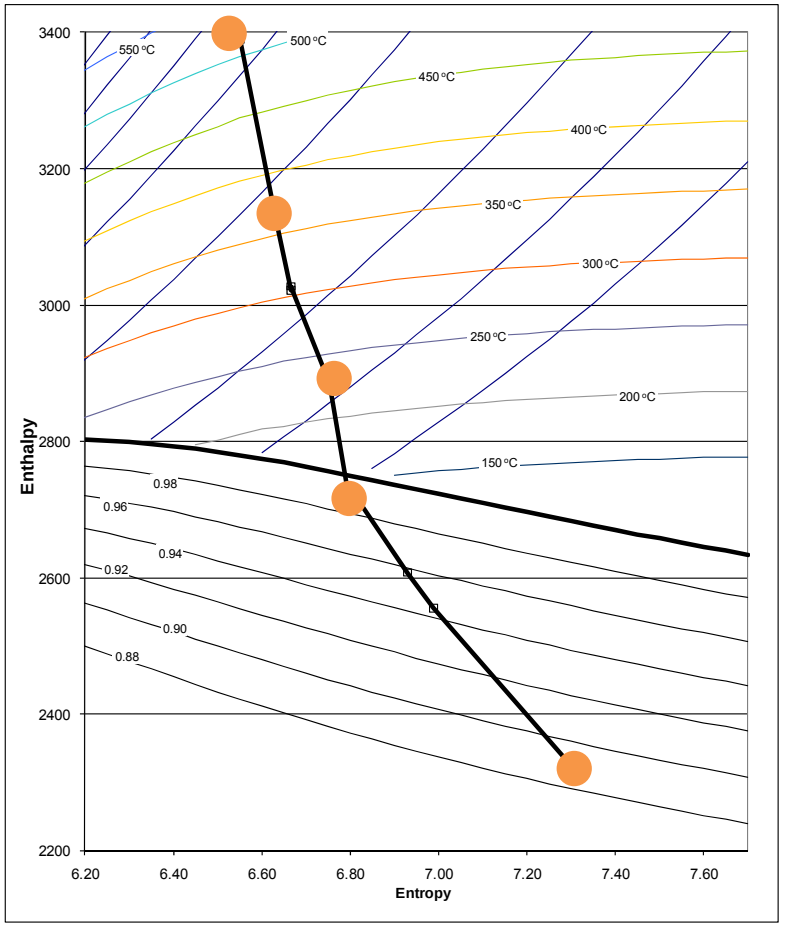
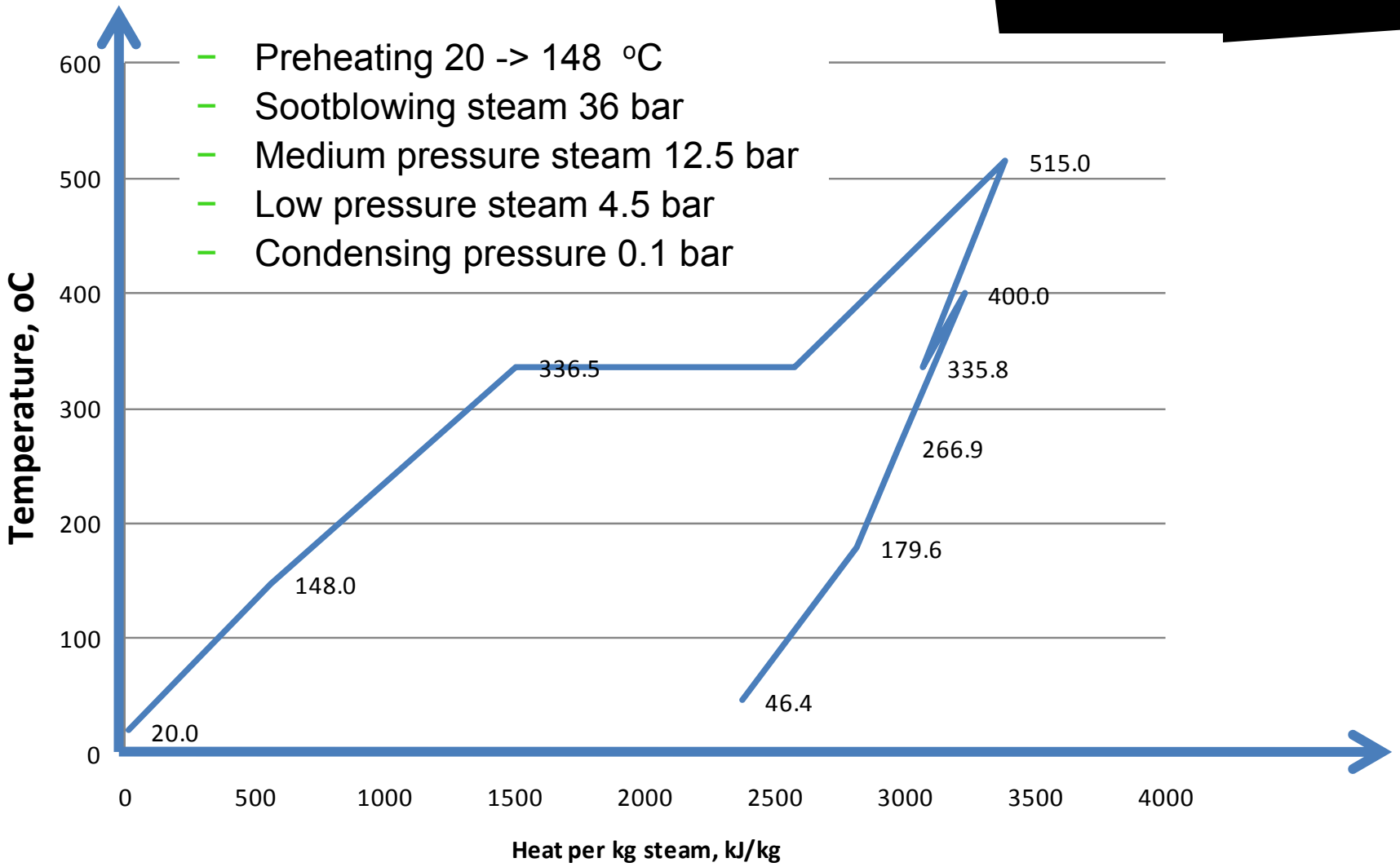
Flue gas gives heat
3384.5-562.5 = 2822.0 kJ/kg
Sootblowing steam 36 bar
3384.5-3069.2 = 315.3 kJ/kg 11.2 %
Medium pressure steam 12.5 bar
3384.5-2897.8 = 486.7 17.2 %
Low pressure steam 4.5 bar
3384.5-2714.9 = 669.6 23.7 %
Condenser 0.1 bar
3384.5-2319.4 = 1065.1 37.7 %



Boiler process – Case E

- Preheating 20 -> 148 °C
- Sootblowing steam 36 bar
- Medium pressure steam 12.5 bar
- Low pressure steam 4.5 bar
- Condensing pressure 0.1 bar



Turbine – Case E

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Flue gas gives heat

3384.5-562.5+3225.9-3099.1 = 2948.7kJ/kg

Sootblowing steam 36 bar

3384.5-3069.2 = 315.3 11.2 %

Medium pressure steam 12.5 bar

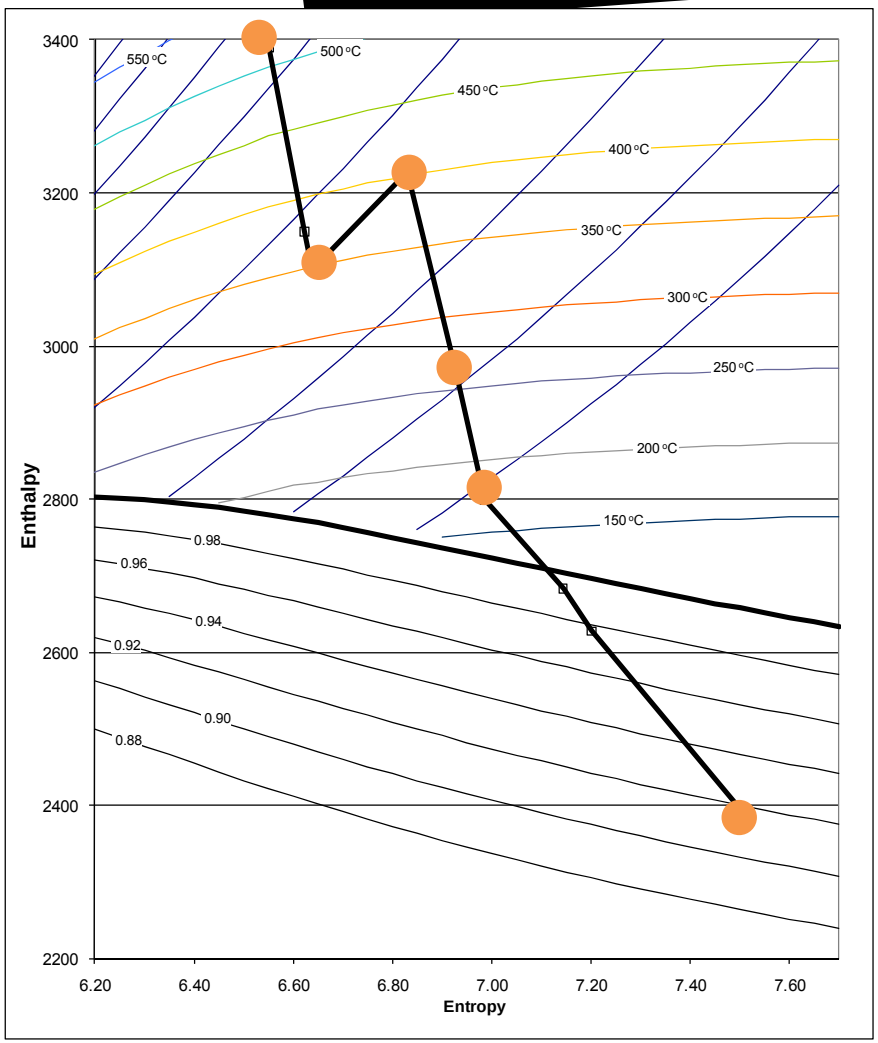
315.3+3225.9-2972.1 = 569.0 19.1 %

Low pressure steam 4.5 bar

315.3+3225.9-2714.9 = 727.4 27.7 %

Condenser 0.1 bar

315.3+3225.9-2319.4 = 1168.2 41.0 %



Comparison if power plant

In a power plant all steam expands in Case E and in Case C

Direct:

- Flue gas gives heat 3384.5- 562.5 = 2822.0 kJ/kg
- Electricity Condenser 0.1 bar 3384.5-2319.4 = 1065.1 kJ/kg
- If steam 233.5 kg/s then 233.5*1065.1 = 248.7 MW

Reheating:

- Flue gas gives heat 3384.5-562.5+3225.9-3099.1
  = 2948.7 kJ/kg
- Electricity Condenser 0.1 bar = 1168.2 kJ/kg
- If steam 221.8 kg/s* then 221.8*1168.2 = 259.1 MW (+4.2 %)

*Less steam because Reheating

Comparison – condensing tail

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Flue gas gives same amount of heat in Case E and Case C.

Most of the steam expands to intermediate pressures only.

Excess steam expands to condensing pressure.

	Steam		Energy		Electricity	
Expansion	Reheat	Direct	Reheat	Direct	Reheat	Direct
	kg/s	kg/s	kJ/kg	kJ/kg	MW	MW
124-36	221.8	233.5	315.3	315.3	69.9	73.6
36-12.5	207.9	219.6	253.7	171.4	52.8	37.6
12.5-4.5	173.9	185.6	158.4	182.9	27.5	34.0
4.5-0.1	25.6	**37.3**	440.8	395.5	11.3	14.8
					161.5	**160.0**

*Because of back pressure only small flow to CT

Boiler process – Case 515/515

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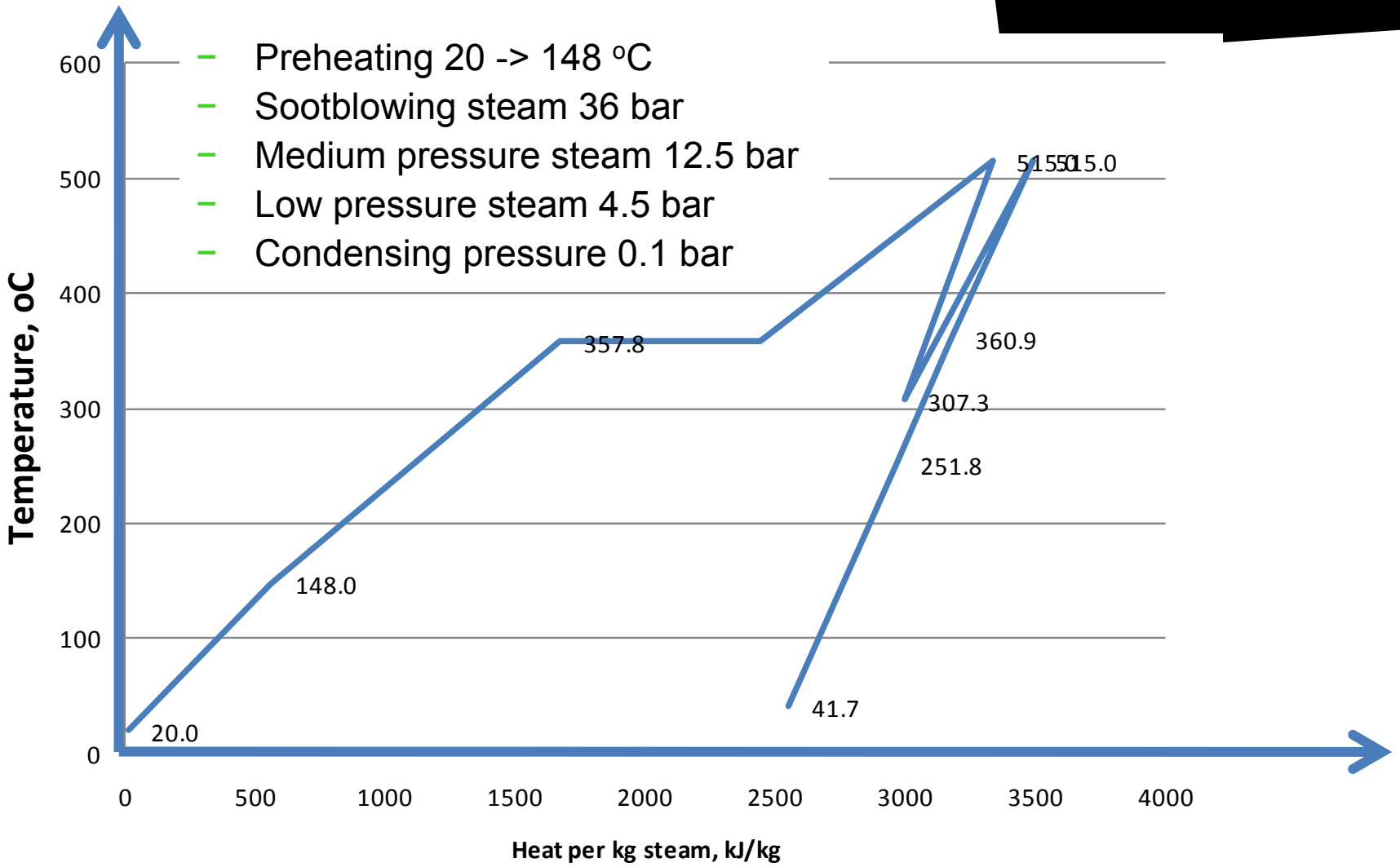
- Preheating 20 -> 148 °C
- Sootblowing steam 36 bar
- Medium pressure steam 12.5 bar
- Low pressure steam 4.5 bar
- Condensing pressure 0.1 bar



Turbine – Case 515/515

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Flue gas gives heat

3384.5-562.5+3485.4-2995.4 = 3260.4 kJ/kg

Sootblowing steam 36 bar

3384.5-2995.4 = 340.0 12.3 %

Medium pressure steam 12.5 bar

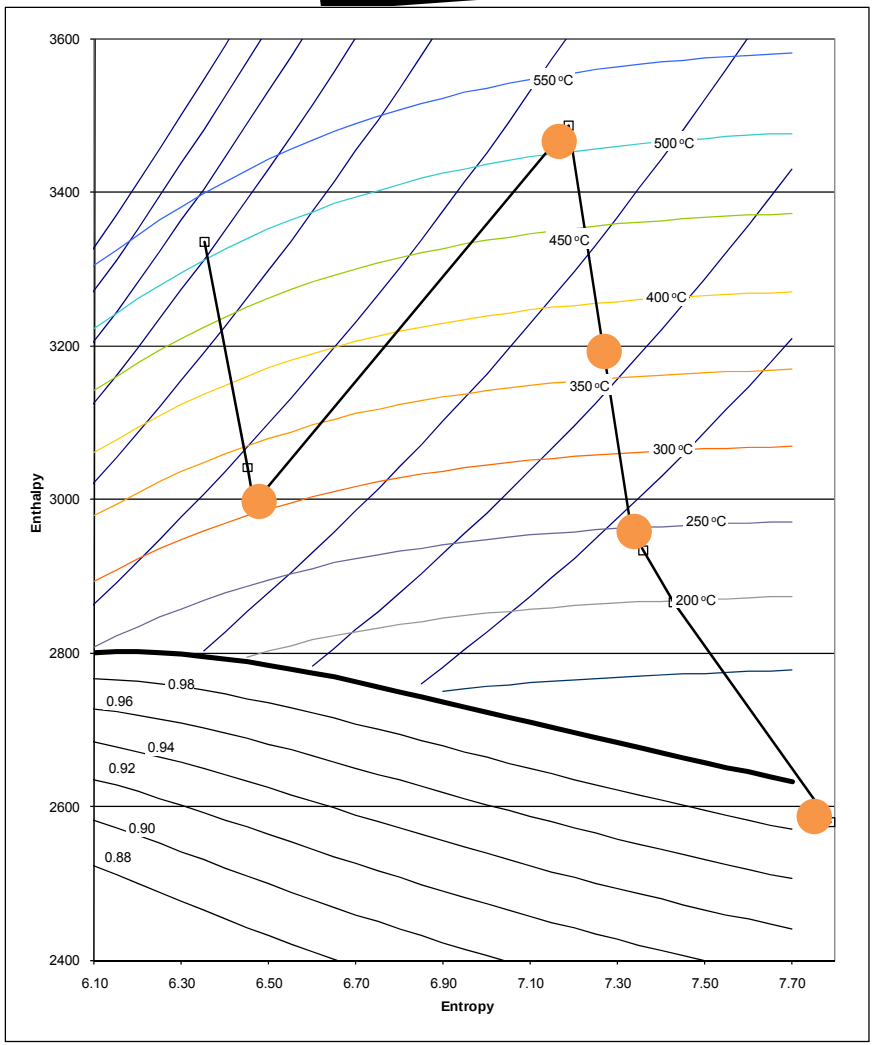
340.0+3485.4-3177.0 = 648.4 30.3 %

Low pressure steam 4.5 bar

340.0+3485.4-2966.5 = 858.9 36.8 %

Condenser 0.1 bar

340.0+3485.4-2552.3 = 1273.1 49.5 %



Comparison – 515/515 CT

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Flue gas gives same amount of heat in Case C and Case 515/515.
Most of the steam expands to intermediate pressures only.
Excess steam expands to condensing pressure.

	Steam		Energy		Electricity	
Expansion	515/515	Direct	515/515	Direct	515/515	Direct
	kg/s	kg/s	kJ/kg	kJ/kg	MW	MW
164(124)-36	202.1	233.5	340.0	315.3	68.7	73.6
36-12.5	188.2	219.6	308.4	171.4	58.1	37.6
12.5-4.5	158.2	185.6	210.5	182.9	33.3	34.0
4.5-0.1	11.2	**37.3**	414.2	395.5	4.6	14.8
					164.7	**160.0**

*Because of back pressure only small flow to CT

Comparison – 515/515 integrate

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Flue gas gives same amount of heat in Case 515/515 and Case C.
Most of the steam expands to intermediate pressures only.
Large difference in production if integrated mill.

	Steam		Energy		Electricity	
Expansion	515/515	Direct	515/515	Direct	515/515	Direct
	kg/s	kg/s	kJ/kg	kJ/kg	MW	MW
164(124)-36	202.1	233.5	340.0	315.3	68.7	73.6
36-12.5	188.2	219.6	308.4	171.4	58.1	37.6
12.5-4.5	158.2	185.6	210.5	182.9	33.3	34.0
4.5-0.1	0	**0**	414.2	395.5	0	0
					160.1	**145.2**

*Because of back pressure only small flow to CT

Summary

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- Reheating process has significantly better efficiency than traditional process
- This difference is lost with back pressure mill with condensing tail
- Thermodynamically it would be better to have expansion points close to saturated temperature e.g. in Case 515/515 electricity is lost as low pressure steam is close to 250 ^{o}C.
- Reheating were significantly better if integrated mill.
- Integrated option with reheat gives large surplus electricity production.
- Because produced electricity is away from steam requires integrated mill more auxiliary boiler steam so also this increases electricity .