Karlsruher Institut für Technologie

Determination of the R1-value for an integrated WtE-plant – example Mainz

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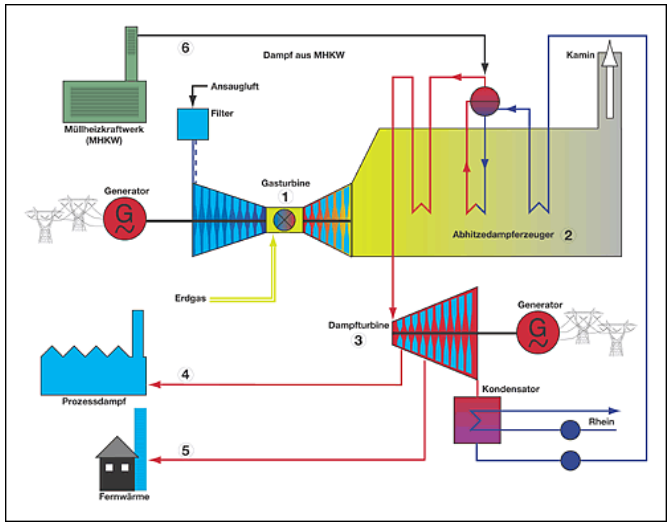
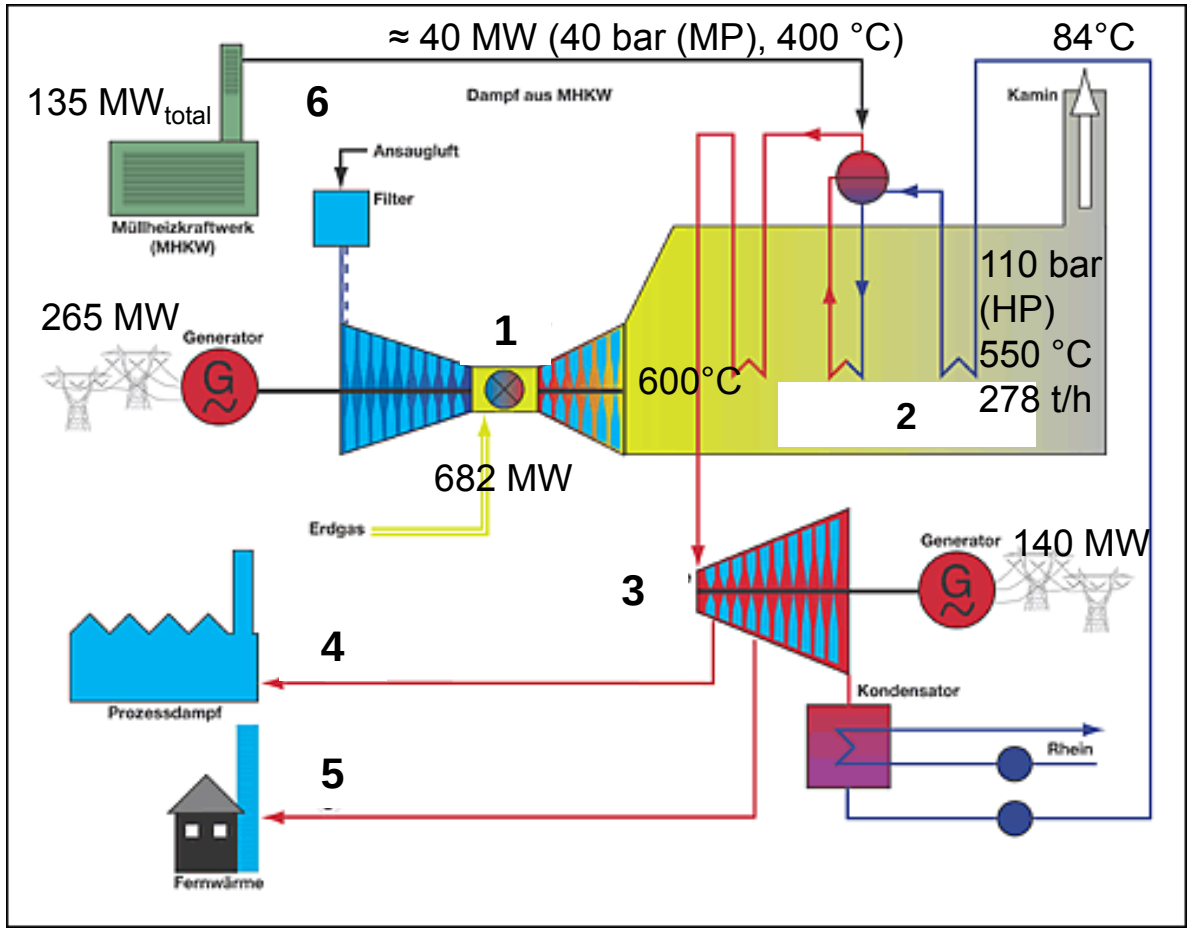


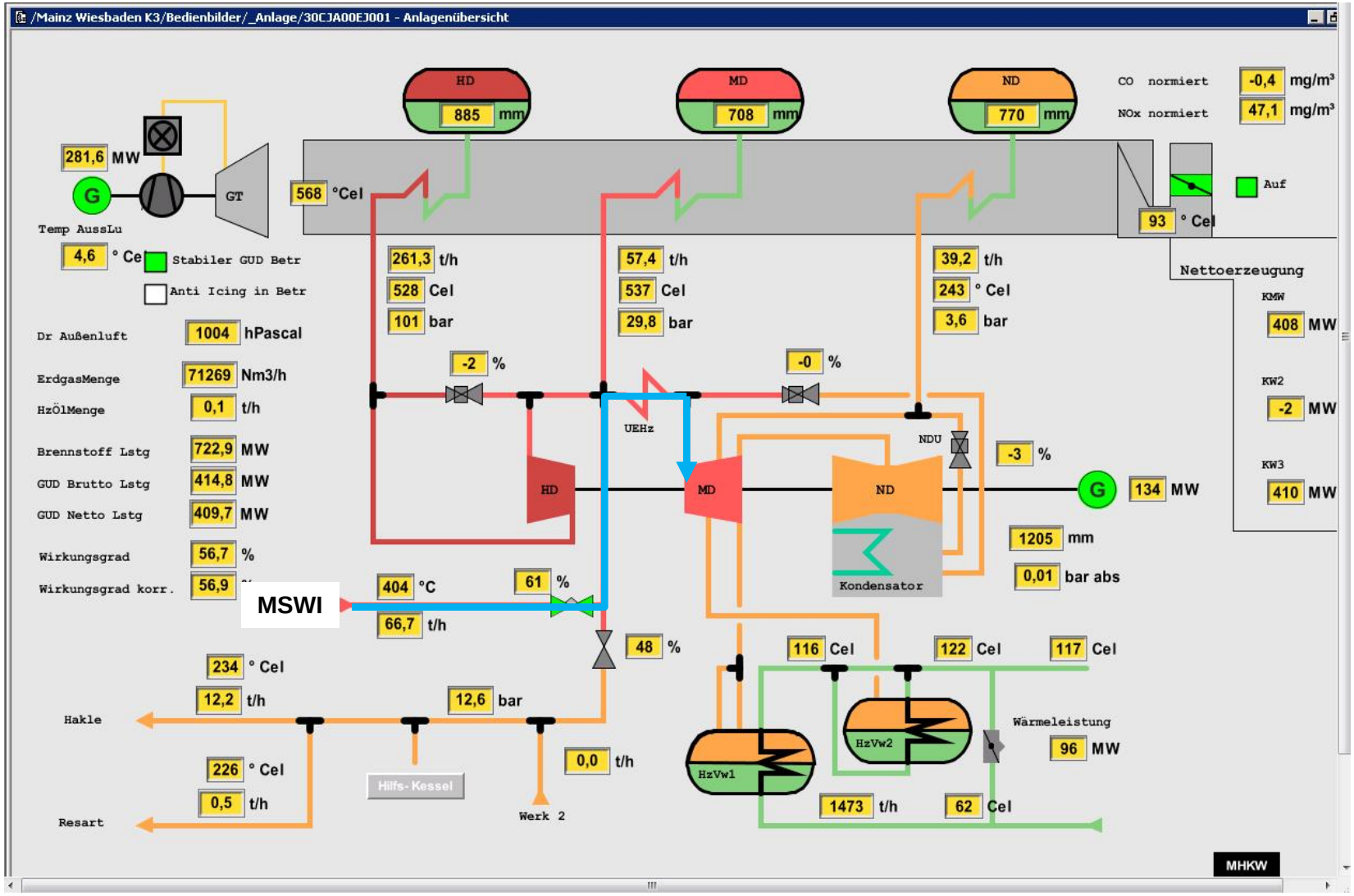
Network of MSWI and Gas Power Plant



1: Gas Turbine
2: Steam Boiler
3: Steam Turbine
4: Process Steam
5: District Heating
6: Steam from MSWI

$\eta_{el} \approx 56\ \%$

Steam connection



MSWI

Delivery consortium

Consortium leader MARTIN GMBH

MARTIN GMBH für Umwelt- und Energietechnik · BABCOCK BORSIG POWER ENVIRONMENT · WALTER · BAU · AG vereinigt mit DYWIDAG

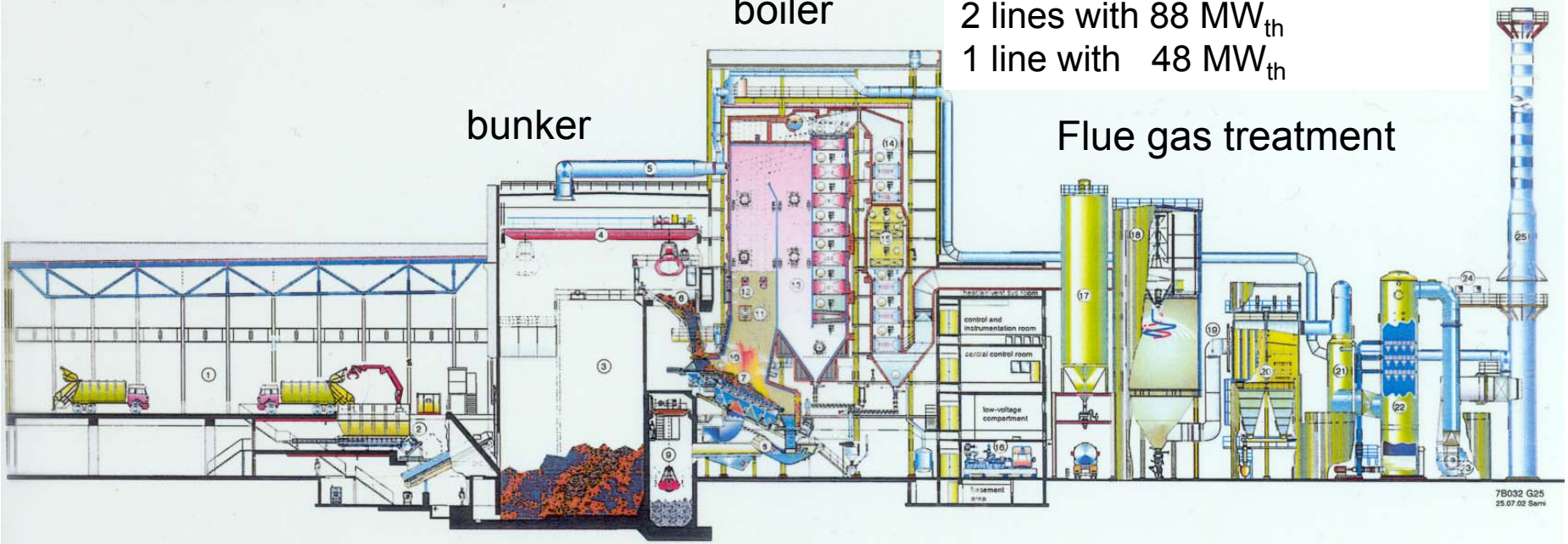
WASTE-TO-ENERGY FACILIT

Total capacity: 350,000 Mg p.y.
Availability: 8,200 hours
2 lines with 88 MW_{th}
1 line with 48 MW_{th}

boiler

bunker

Flue gas treatment



MARTIN® GRATE

Runs	=	3
Number of steps	=	13
Run width	=	1875 mm
Grate width	=	5945 mm

TECHNICAL DATA

Waste throughput	=	2x16,2	Mg/h
at a waste heating value	=	9815	k J/kg
Gross heat release	=	2x44,0	MW
Superheated steam pressure	=	43,3	bar
Superheated steam temperature	=	400	°C
Flue gas temperature	=	190-230	°C

LEGEND

1 Tipping hall
2 Facility for crushing bulky waste
3 Refuse pit
4 Waste crane
5 Suction facility in refuse pit
6 Feed hopper
7 Reverse-acting grate and furnace
8 Discharger
9 Bottom ash bunker with ash-handling cra
10 Overfire air and injection system for thin sludge
11 Auxiliary and start-up burners
12 SNCR NOx reduction
13 Steam generator
14 Soot blowers
15 Slip catalytic converter
16 Turbine/generator unit for in-plant requirements
17 Dust silo
18 Spray absorber
19 Injection of adsorbent agent
20 Fabric filter
21 Pre-scrubber
22 Scrubber
23 Induced draught fan
24 Analysis container
25 Chimney

R1 – criteria (I)

Plant has to comply with at least one criteria of BAT according BREF WI:

- Exported total energy > 1.9 MWh/Mg waste or[1]
- 0.4 to 0.65 MWh gross electricity/Mg waste with additional exported steam, based on a LCV of 10.4 MJ/kg[2]
- At least the production of electricity should cover the own consumption[3].

1: not fulfilled (1.42 MWh/Mg waste)
2: 0.46 MWh gross electricity/Mg waste
3: complies with

R1 – criteria (II)

Annex II of 2008/98/EC

A MSWI recovers waste, if

$$R1 = \frac{E_p - E_f - E_i}{0{,}97 \cdot (E_w + E_f)}$$

> 0.60 for plants, which were approved before 1/1/2009

> 0.65 for plants, which were approved after 31/12/2008

Equation is only valid for MSWI,
SRF-power plants always recovers energy from waste
Hazardous waste incinerators always dispose the waste

$E_{production}$: Total used energy [GJ/a]: $E_p = 2.6 \cdot P_{el} + 1.1 \cdot Q_{use}$

- Steam for soot blowers, about 3.5% of produced high pressure steam
- Produced steam for third users minus return (steam or condensates)
- Produced electricity for third users
- Internal used electricity
- Internal used steam minus return (steam or condensates)
- Start-up and shut down processes are only R1- relevant, if steam is produced for utilization

R1 – criteria (III)

E_{fossil}: externally fuel for steam generation
(natural gas, light oil) [GJ/a]

$E_{imported}$: externally supplied energy
(no waste or natural gas etc., but power) [GJ/a]

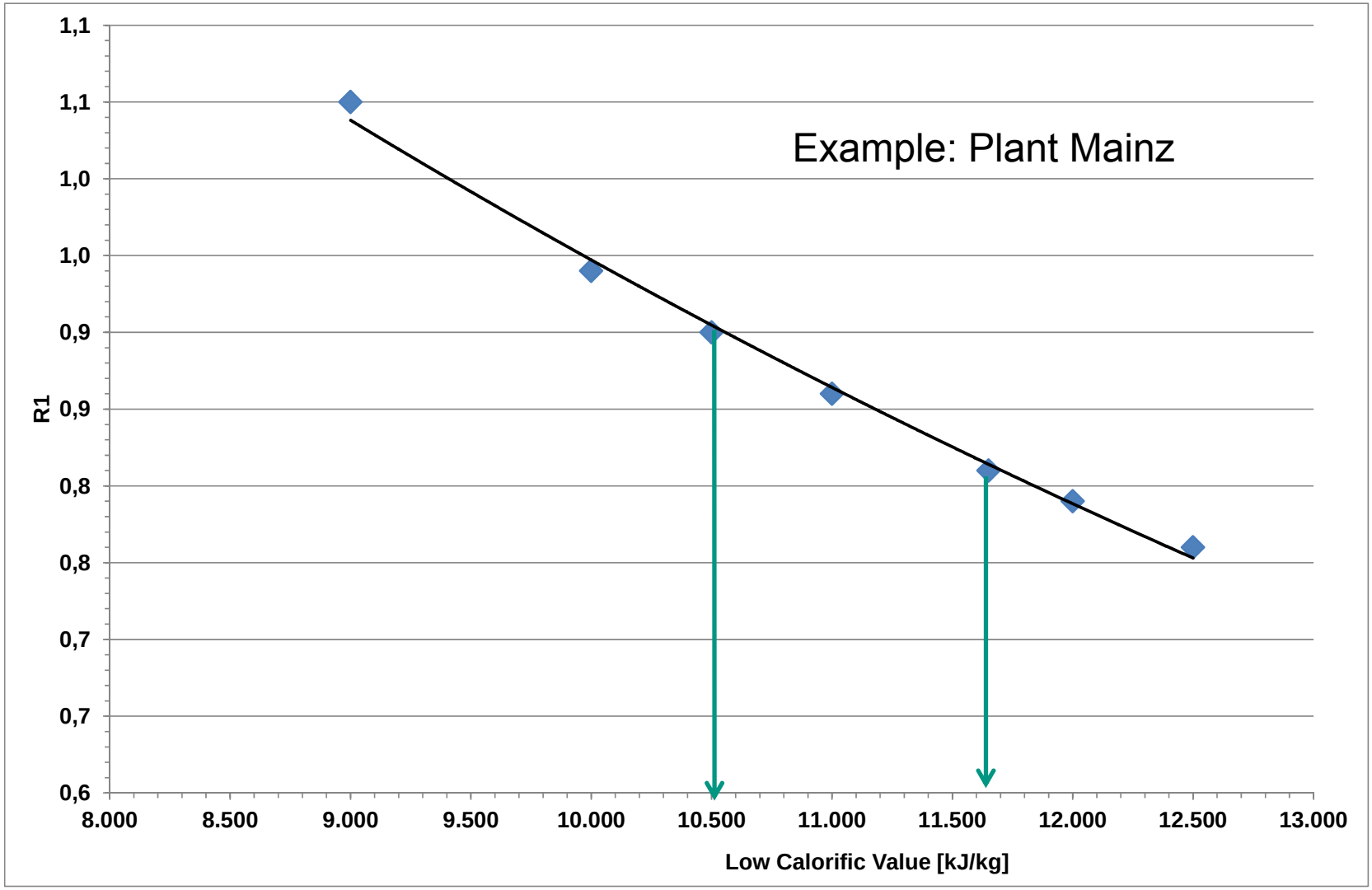
E_{waste}: enthalpy of the waste [GJ/a]
Factor 0.97 takes into account all heat losses

- To be determined:
  - LCV of waste and
  - boiler efficiency

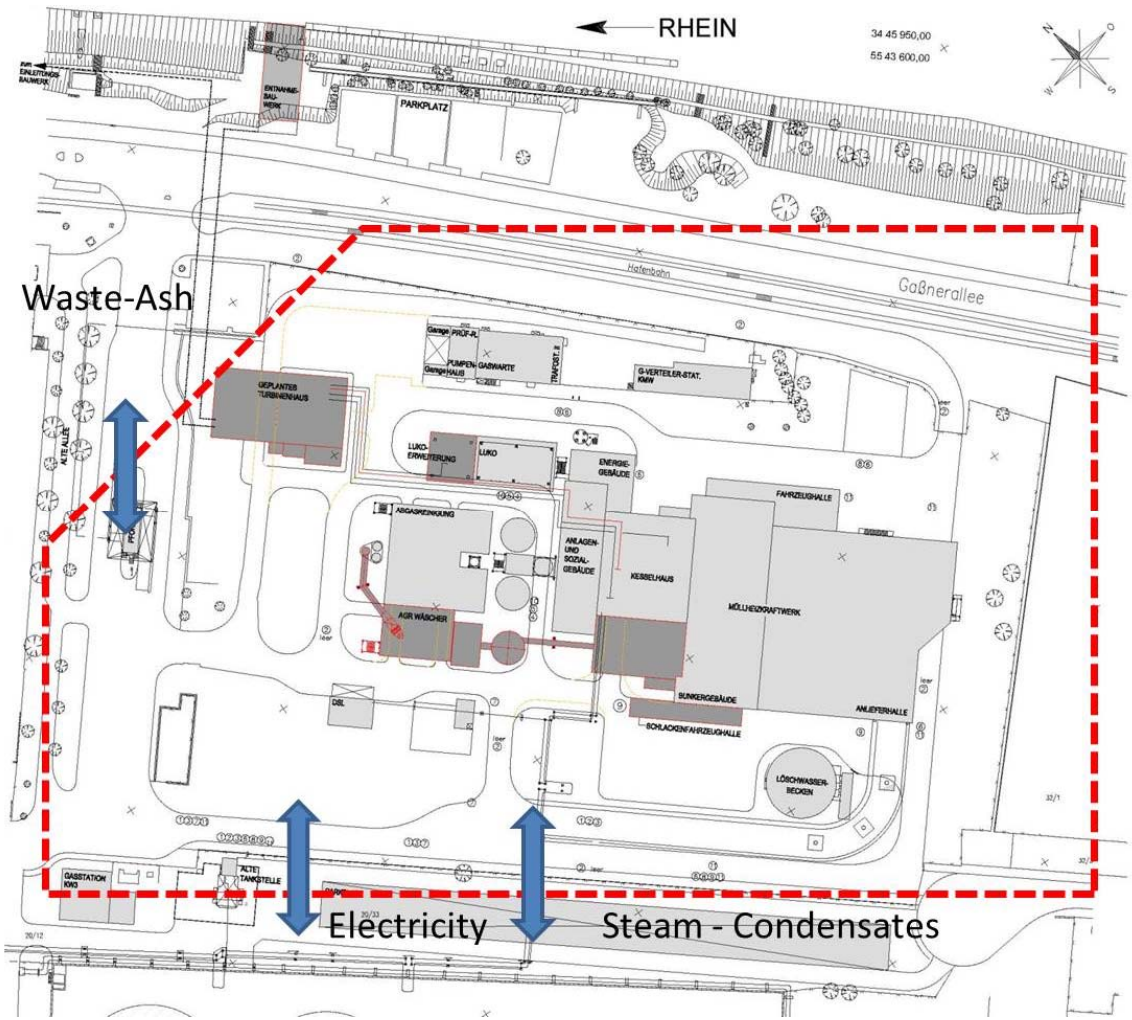
$$\eta_{Boiler} = \frac{H_{Steam} - H_{Feedwater}}{E_w + E_f + H_{PA+SA}}$$

$H_{PA+SA} \approx 3.5\%$ of E_w (result of acceptance test from MARTIN GmbH 2005)
(is in the range of R1 guidance with 5%)

R1 criteria

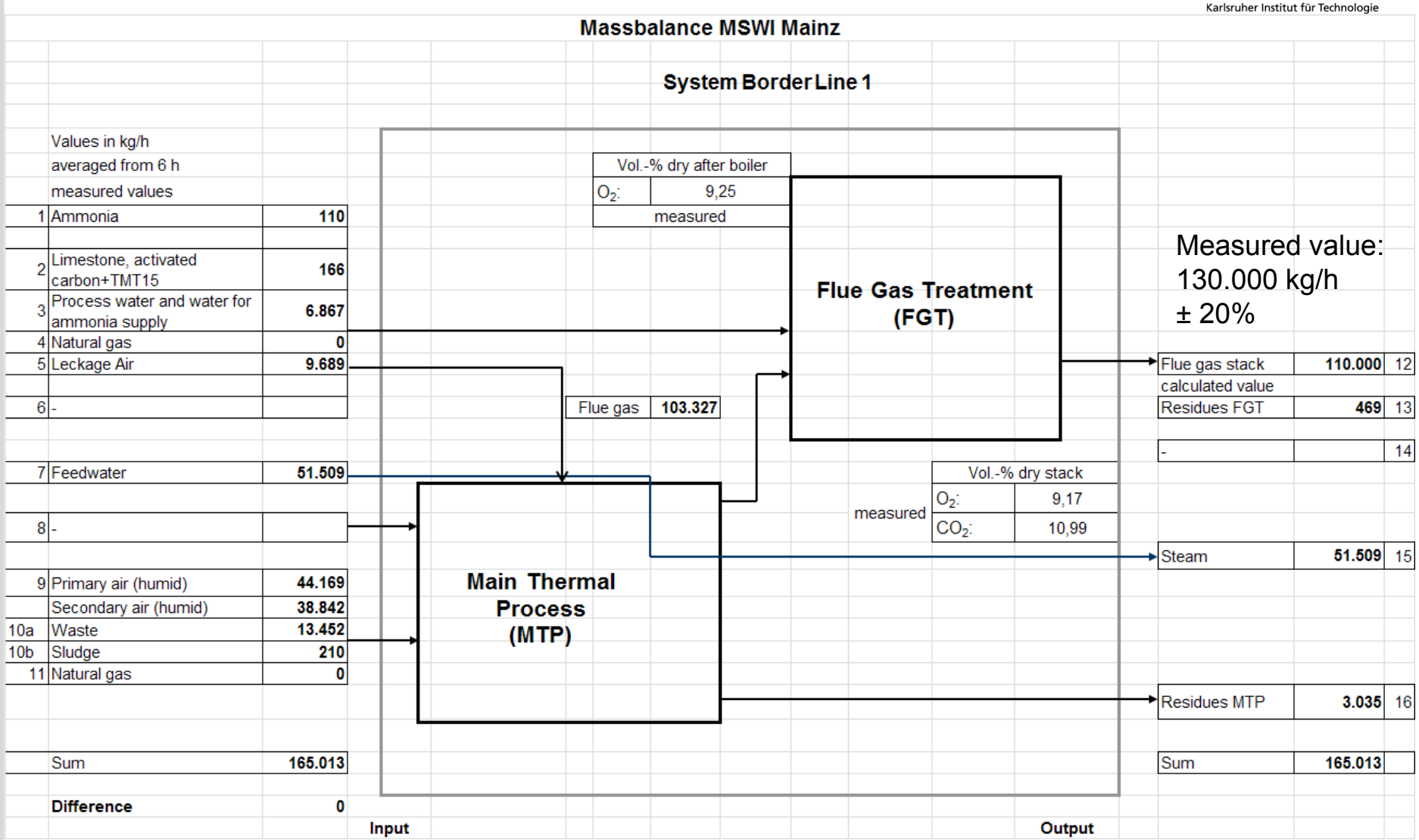

Example: Plant Mainz
R1
1,1
1,1
1,0
1,0
0,9
0,9
0,8
0,8
0,7
0,7
0,6
8.000
8.500
9.000
9.500
10.000
10.500
11.000
11.500
12.000
12.500
13.000
Low Calorific Value [kJ/kg]

Plausibility Check (I)



- Data acquisition
  - Delivery contracts (heat, electricity)
  - Basic calibration documents
  - Access to measurement devices
  - Access to process control data
  - Data from Technical Supervisory Association
- Plant inspection

Plausibility Check (II)



Leckage air: purge air natural gas burner and other sources

Plausibility Check (III)

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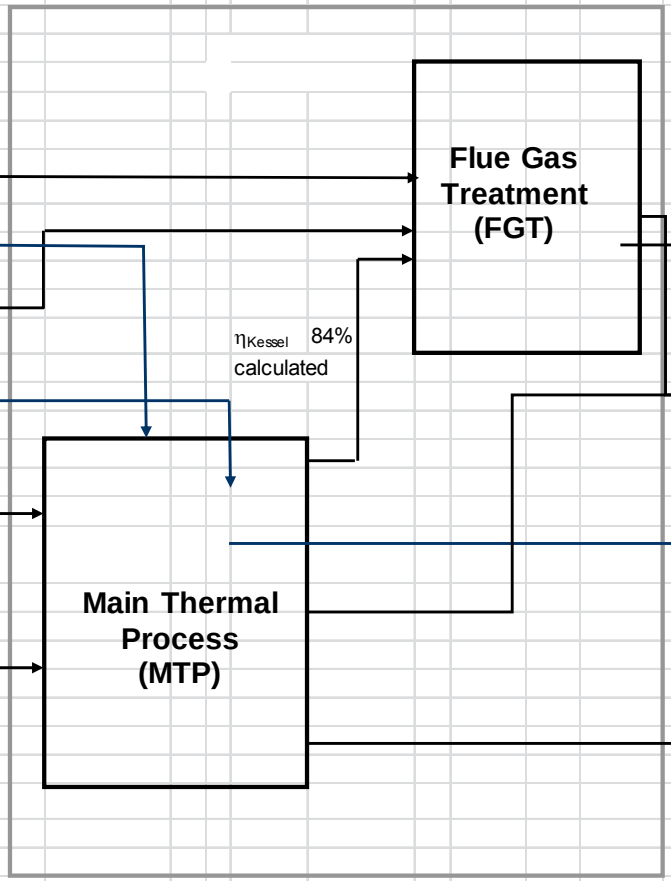
Energy Balance for MSWI Mainz

System border for Line 1

Values in kW

1	Ammonia	2
2	Limestone, activated carbon+TMT15	1
3	Process water and water for ammonia supply	239
4	Natural gas	0
5	Leckage Air	54
6	electricity ID fan	123
7	Feedwater	7.871
	Enthalpy condensator	550
	Pressure [bar]	62
	and temperature [°C]:	130
8	electricity PA and SA fan	112
9	Primary Air	1.305
	Secondary Air	518
10a	Waste*	39.436
10b	Sludge with 10 % DM**	-33
11	Natural gas	0
	* with LCV [kJ/kg]	10.532
	** with LCV [kJ/kg]	-650
	Sum	49.628

Input



Output

Flue gas stack	2.173	12
flue gas temperature	63	
Residues FGT	7	13
heat losses	496	14
Losses % of total enthalpy from acceptance tests	1	
Steam	46.362	15
Enthalpy	3.240	
Pressure [bar]	43	
and temperature [°C]:	415	
Residues MTP	590	16
with TOC [%]	2	
data from operator		
Sum	49.628	

LCV waste acc. data of operator: 11.650 kJ/kg; deviation about 10%

Plausibility Check (IV)

$$\eta_{Boiler} = 1 - \frac{\vartheta_{ECO2}}{\vartheta_{adiabat}}$$ measured value available

$$\vartheta_{adiabat} = \frac{\lambda_{\text{boiler}} \cdot l_{\min} \cdot c_{p,A} \cdot (\vartheta_A - \vartheta_0) + c_{p,w} \cdot (\vartheta_w - \vartheta_0) + LCV_w - \zeta_{Ash} \cdot c_{p,Ash} \cdot (\vartheta_{Ash} - \vartheta_0)}{1 + \lambda_{\text{boiler}} \cdot l_{\min} \cdot c_{p,adiabat} \cdot (\vartheta_{adiabat})}$$

$$\lambda_{boiler} = \frac{21}{21 - \psi_{O_2, ECO2}} \qquad l_{\min} = \frac{LCV_w\ [kJ/kg]}{3133}$$

λ_{boiler}	1.79
$l_{\min}$	3.4 kgA/kgW
LCV_w	10.5 MJ/kg
ϑ_A	104 °C
ϑ_{Ash}	40°C
$\vartheta_{adiabat}$	1,355 °C
ϑ_{ECO2}	209 °C

$$\eta_{Boiler} = 83.9\%$$

Very good accordance with data from acceptance tests with 84.2% for Line 1 and 84.6% for Line 2!

Calculation of R1 for Mainz

			Year	2011	
No	Type of energy	Unit	Amount [Mg]	LCV [kJ/kg]	**Energy E_x [MWh]**
1.1	Amount of incinerated waste (without 1.2)		353.504	10.500	1.031.053
1.2	Sludge with 10 wt.% dry matter		5.505	-650	-994
1	**E_w: Energy input into the system by wastes**	**MWh**			**1.030.059**
2.1	$E_{f\ 1}$: Amount of Natural gas for start up and keeping the minimum temperature of 850 °C		45	43.000	535
2	**Σ E_f: Energy input with imported energy with steam production**	**MWh**			**535**
3.1	$E_{i\ 1}$: Amount of Natural gas for start up andshut down without steam production		113	43.000	1.353
3.2	$E_{i\ 2}$: imported electricity (multiplied with factor of 2.6)	MWh			578
3.3.	$E_{i\ 3}$: imported steam from gas power plant 3 (multiplied with factor 1.1)	MWh			0
3	**Σ E_i: Energy input with imported energy without steam production**	**MWh**			**1.931**
4.1	$E_{p\ el\ internal\ used}$: produced and internal used electricity for combustion process	MWh			36.920
4.2	$E_{p\ el\ exported}$: exported electricity for third users	MWh			131.108
4	**Σ $E_{p\ el\ internal\ used}$ + $E_{p\ el\ exported}$**	**MWh**			**168.028**
5.1	$E_{p\ heat\ exp.\ 1}$: exported steam for third users (gas power plant 3) with return of condensates	MWh			376.151
5.2	$E_{p\ heat\ exp.\ 2}$: exported steam for third users' district heating fron LP grid with return of condensates	MWh			5.589
5	**Σ $E_{p\ heat\ exp.}$ = $E_{p\ heat\ exp.\ 1}$ + $E_{p\ heat\ exp.\ 2}$**	**MWh**			**381.739**
6.1	$E_{p\ heat\ internal\ used\ 1}$: Internal use of steam without influence on steam production in the waste heat boiler with return of condensates[1]				
6.2	$E_{p\ heat\ internal\ used\ 2}$: Steam for sootblowing without return	MWh			40.397
6.3	$E_{p\ heat\ internal\ used\ 3}$: Steam for heating purposes etc.				
6	**Σ $E_{p\ heat\ internal\ used}$ = $E_{p\ heat\ internal\ used\ 1}$ + $E_{p\ heat\ internal\ used\ 2}$ + $E_{p\ heat\ internal\ used\ 3}$**	**MWh**			**40.397**
	E_p = 2,6* (Σ $E_{p\ el\ internal\ used}$ + Σ $E_{p\ el\ exported}$) + 1,1* (Σ $E_{p\ heat\ internal\ used}$ + Σ $E_{p\ heat\ exported}$)	**MWh**			**901.223**
	$R_1 = (E_p - (E_f + E_i)) / (0,97 * (E_w + E_f))$				
	R_1 =	[-]			**0,90**
	[1]: Guidance R1-equation in Annex II of RL 2008/98/EG, p. 13				

Summary / Outlook

$$E_{w,simplified} = \frac{\frac{H_{Steam} - H_{FW}}{\eta_{boiler}} - E_f}{1 + x_{PA}}$$

with

η_{boiler} 0.84

x_{PA} 0.035 part of enthalpy of PA + SA from E_w

Deviation of $E_{w,simplified}$ to exact value of E_w: 6.7 %

Considering of only net produced electricity in E_p (delete 4.1) reduces R1 from 0.9 to 0.8!

Thank you for your attention!