Project:	Order No:	Document No:
Margam	2052032	0654733

Calibration of T2s monitoring according to 17. BImSchV. by CFD results

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1. Introduction

T_{2S} is to be determined according to ”Fachliche Erläuterung zur: Bundeseinheitlichen Praxis bei der Überwachung der Verbrennungsbedinungengen an Abfallverbrennungsanlagen nach 17. BImSchV; April 1994”.

The foundation of the T_{2S} determination according to this guideline is a formula based on the temperature in the top of the 1st boiler pass and the steam production. Using these two parameters in a calibrated formula makes it possible to calculate the temperature (T_{2S}) of the flue gas after 2 seconds residence time after the last injection of combustion air.

The formula to be calibrated is as follow:

$T_{2S} = T_{B10} + A + B \times Q_{steam}$

Where:

T_{2S} : Temperature after 2 seconds of residence time after last injection of combustion air.
T_{B10} : 10 minutes average of the plant T_B measurement.
Q_{steam} : Steam flow [kg/s].
A, B : Factors to be determined by calibration.

Computational Fluid Dynamics (CFD) modelling has been carried out on the plant in the design phase of the project. The results from the CFD modelling will be used to set up the T_{2S} formula. The boundary conditions in the CFD modelling were based upon the assumption that the plant was operated in full load operation at least 8000 hours.

Calibration based on the results of the CFD model of the boiler is performed in order to determine the T_{2S} during operation.

A physical verification of the T2s formula can be made when the plant is in operation and all conditions necessary are established.

2. Determination of the temperature after 2s of residence time

For the calibration of the T2s monitoring the temperature has to be known in two levels of the first boiler pass and at two different load situations (high and low load). These temperatures together with the temperatures in the top of the 1st boiler pass and the steam production forms the basis for the determination of the formula. In Figure 1 the furnace and 1st pass of the boiler are shown stating the level of the calibration temperatures.

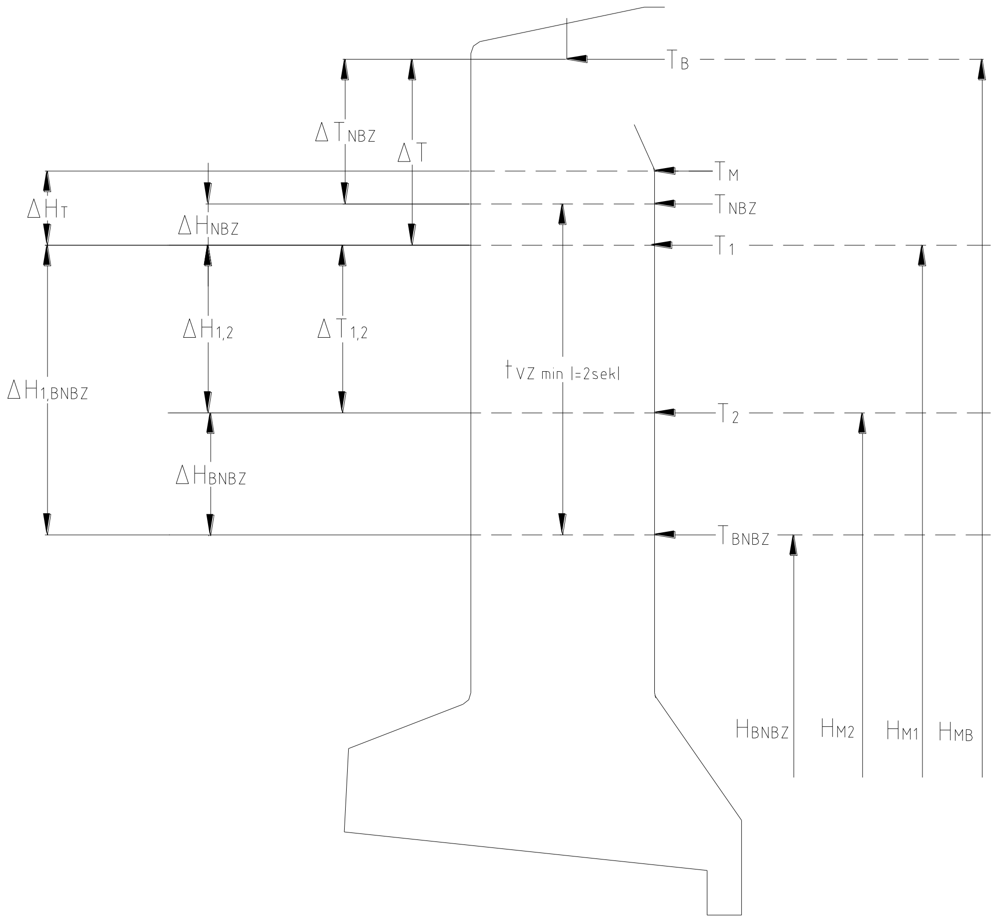

Figure 1. Sketch of furnace and 1st pass of the boiler.

The legends shown in the above Figure 1 is to be used in the following and are defined in the below Table 1.

Start after last combustion air injection	H_{BNBZ}	1.500	m	
Lowest measurement point boiler 1st pass	H_{ME2}	8.350	m	
Highest measurement point boiler 1st pass	H_{ME1}	14.300	m	
Plant temperature measurement point	H_{MB}	18.300	m	
Cross section area	A	60.288	m²	
Minimum residence time temperature	$T_{M,\ min}$	850	°C	
Minimum residence time	$t_{Vz,min}$	2	s	
Distance from inlet to lowest boiler point	ΔH_{BNBZ} =	6.850	m	(H_{ME2}-H_{BNBZ})
Distance between lowest and highest point	$\Delta H_{1,2}$ =	5.950	m	(H_{ME1}-H_{ME2})
Distance from highest boiler point to inlet	$\Delta H_{1,BNBZ}$ =	12.800	m	(H_{ME1}-H_{BNBZ})

Table 1. Definition of legends in Figure 1.

From the CFD model it is possible to extract flue gas data in any given point within the boiler, temperature among other. Different load situations have been modelled using CFD. In this situation the modelling of the points LP2 and LP5 in the capacity diagram. In each case will the recirculation of flue gases (RECI) be modelled at minimum and maximum flow of 0 Nm^3/H and 47527 Nm3/H, respectively, and it is assumed that the steam production is the same in both of these cases. The capacity diagram is shown in Figure 2.

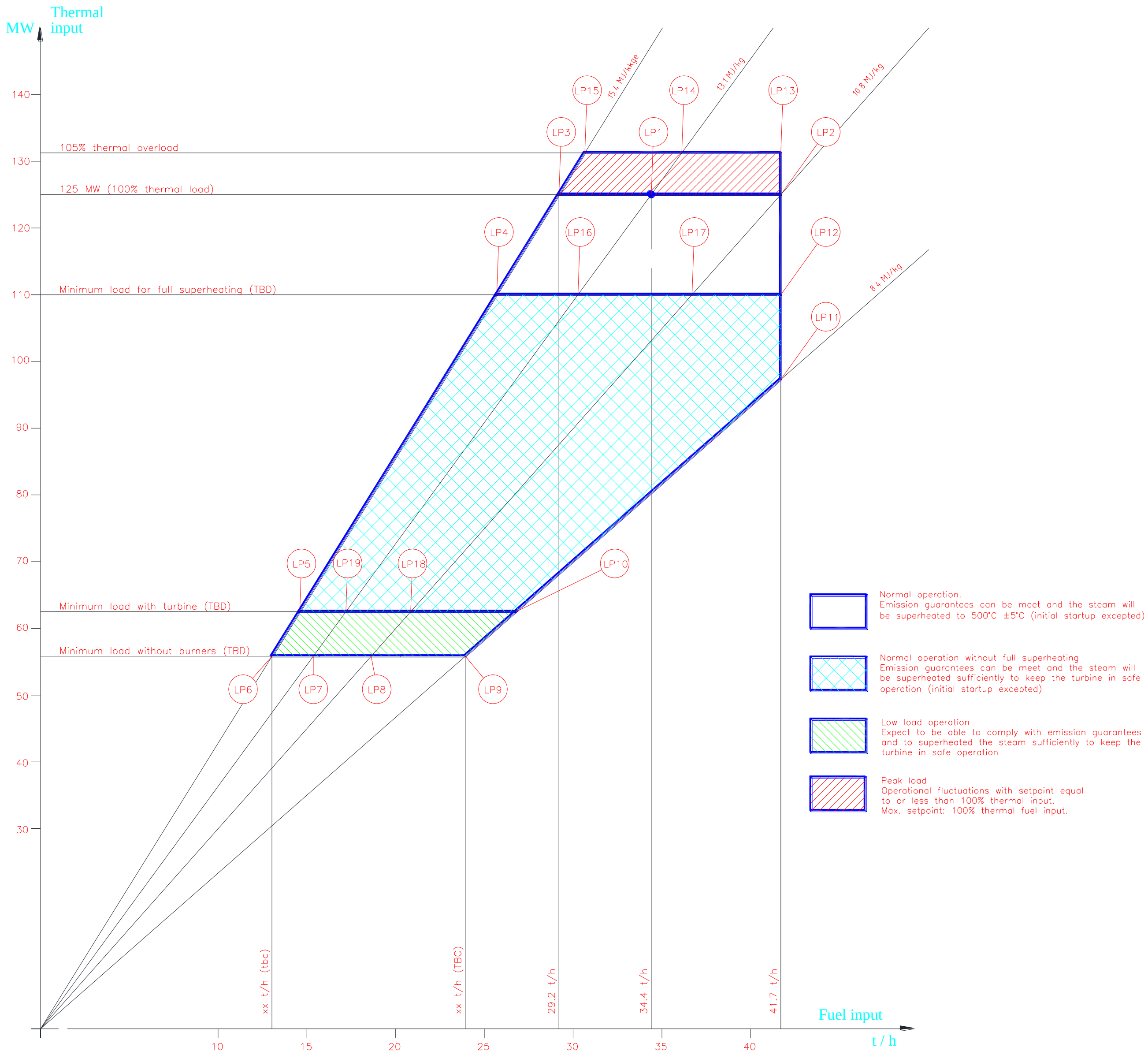

Figure 2. Capacity diagram of the boiler (MDoc: 0576620), Margam.

According to the guideline the grid for the calibration must have 24 points at each plane.

Temperatures were extracted from the results of the CFD model in the 24 points as shown in Figure 3

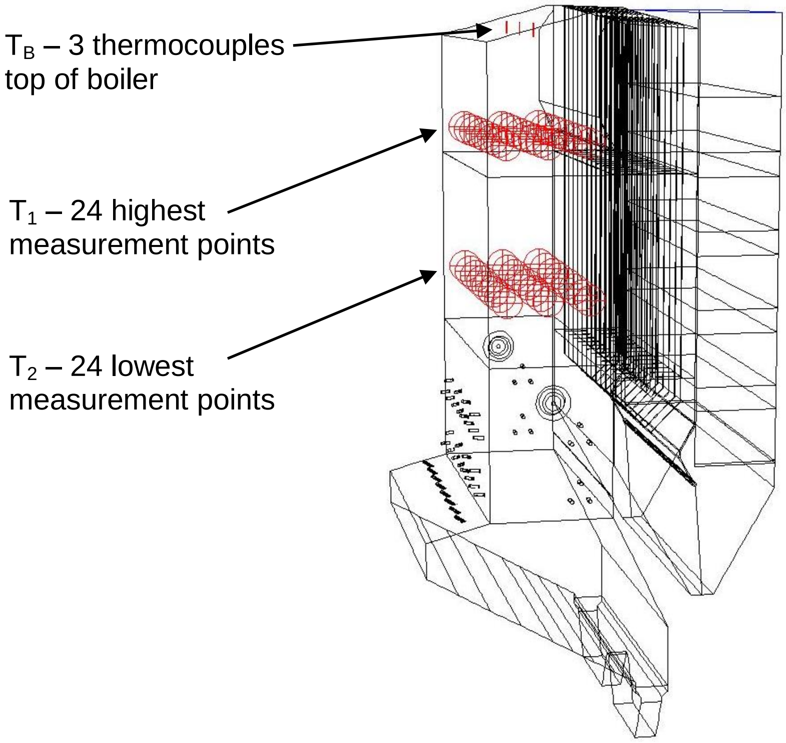

Figure 3. Sketch showing the points where temperatures were extracted from the CFD model.

2.1 Minimum recirculation of flue gases

In Table 2 the temperatures extracted from the results of the CFD model in load case LP2 is shown and in Table 3 the temperatures extracted from the results of the CFD model in load case LP5 is shown at recirculation of flue gases (RECI) flow of 0 Nm3/h.

Lowest boiler points (2)				
Position	*x1*	*x2*	*x3*	
z1	1164	1133	1112	**T_2= 1174**
z2	1190	1119	1116	
z3	1213	1139	1121	
z4	1217	1205	1161	
z5	1216	1196	1190	
z6	1217	1175	1176	
z7	1211	1162	1195	
z8	1201	1179	1174	
Highest boiler points (1)				
Position	*x1*	*x2*	*x3*	
z1	1103	1083	1056	**T_1= 1097**
z2	1112	1061	1050	
z3	1125	1068	1056	
z4	1134	1108	1097	
z2	1130	1099	1113	
z3	1125	1089	1100	
z4	1123	1095	1087	
z5	1119	1112	1091	
Point B				
Position	*1*	*2*	*3*	
	989	981	977	**T_B= 982**

Table 2. Temperatures [°C] extracted from the CFD model in load case LP2 at RECI flow of 0 Nm3/h.

Lowest boiler points (2)				
Position	*x1*	*x2*	*x3*	
z1	833	835	831	**T_2= 940**
z2	837	847	843	
z3	854	849	843	
z4	926	885	852	
z5	1028	1042	1007	
z6	1067	1022	1053	
z7	1077	1017	995	
z8	1031	1009	986	
Highest boiler points (1)				
Position	*x1*	*x2*	*x3*	
z1	852	844	850	**T_1= 905**
z2	894	888	895	
z3	917	902	915	
z4	933	879	917	
z5	935	872	900	
z6	937	891	899	
z7	949	917	902	
z8	964	953	913	
Point B				
Position	*1*	*2*	*3*	
	794	786	794	**T_B= 791**

Table 3. Temperatures [°C] extracted from the CFD model in load case LP5 at RECI flow of 0 Nm3/h.

Flue gas flow and steam production is needed for the determination of the calibrated formula. These data has been extracted from the H&M balance. In *Table 4* the values are listed for the two load situations.

Load situation		LP2	LP5
Flue gas flow (V_{FN})	[Nm^3/h]	194092	77514
Steam production (Q_{steam})	[kg/s]	44.315	19.738

Table 4. Flue gas flow and steam production.

Using the above data the residence time above 850°C after the last injection of combustion air can be determined as follows:

			LP2	LP5
$\Delta T_{1.2}$	$= T_2 - T_1$	[°C]	76.9	35.4
ΔT	$= T_1 - T_B$	[°C]	114.8	113.8
$\Delta T_{1.2}/\Delta H_{1.2}$		[°C/m]	12.9	5.9
T_{BNBZ}	$= T_2 + (\Delta T_{1.2}/\Delta H_{1.2}) \times \Delta H_{BNBZ}$	[°C]	1262.8	981.1
T_{mean}	$= (T_{BNBZ} + T_{M.\ min})/2$	[°C]	1056.4	915.6
V_{FR}	$= (V_{FN}/3600) \times (T_{mean} + 273.15)/273.15$	[m³/s]	262.4	93.7
ΔH_T	$= (T_1 - T_{M.\ min})\Delta H_{1.2} / \Delta T_{1.2}$	[m]	19.1	9.2
t_{Vz}	$= A(\Delta H_{1.BNBZ} + \Delta H_T)/V_{FR}$	[s]	7.3	14.2

The residence time (t_{Vz}) is in both maximum and minimum load above the demanded 2 seconds.

The next step is to determine the temperature and location of 2 seconds of residence time and determine the minimum acceptable temperature in the top of the 1st boiler pass ($T_{B.minimum}$). This is done as follows:

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			LP2	LP5
ΔH_{NBZ}	$= (tVZMin * VFR)/A - \Delta H_{1.BNBZ}$	[m]	-4.1	-9.7
T_{NBZ}	$= T_1 - (\Delta T_{1.2}/\Delta H_{1.2})x\ \Delta H_{NBZ}$	[°C]	1150.2	962.6
ΔT_{NBZ}	$= T_{NBZ} - T_B$	[°C]	167.8	171.5
$T_{B.minimum}$	$= T_{M.\ min} - \Delta T_{NBZ}$	[°C]	682.2	678.5

Below is summarised the results needed to define the formula that can calculate the temperature after 2 seconds of residence time after the last injection of combustion air (T_{2S}).

			LP2	LP5
Steam production	Q_{steam}	[kg/s]	44.315	19.738
ΔT_{NBZ}	$= T_{NBZ} - T_B$	[°C]	167.8	171.5

Defining ΔT_{NBZ} as a linear function of the steam production ΔT_{NBZ} is determined as follows:

$\Delta T_{NBZ} = A + B \text{ x } Q_{steam} = 174.44 - 0.1503 \text{ x } Q_{steam}$

The formula for T_{2S} or T_{KalB} can then be defined as:

$T_{2S} = T_{KalB} = T_{B10} + \Delta T_{NBZ} = T_{B10} + 174.44 - 0.1503 \text{ x } Q_{steam}$

Where:

T_{2S} : Temperature after 2 seconds of residence time after last injection of combustion air.
T_{KalB} : Equals T_{2S}
T_{B10} : 10 minutes average of the plant T_B measurement.
Q_{steam} : Steam flow [ks/s]

2.2 Maximum recirculation of flue gases

In Table 5 the temperatures extracted from the results of the CFD model in load case LP2 is shown and in Table 6 the temperatures extracted from the results of the CFD model in load case LP5 is shown at recirculation of flue gases (RECI) flow of 47527 Nm3/h.

Lowest boiler points (2)				
Position	*x1*	*x2*	*x3*	
z1	1064	1054	980	**T_2= 1059**
z2	1080	1080	1011	
z3	1058	1099	1037	
z4	1041	1062	1051	
z5	1041	1105	1044	
z6	1063	1124	1041	
z7	1085	1101	1031	
z8	1064	1071	1033	
Highest boiler points (1)				
Position	*x1*	*x2*	*x3*	
z1	1001	1004	990	**T_1= 988**
z2	1007	1003	989	
z3	1007	989	980	
z4	1009	978	964	
z2	1003	992	972	
z3	986	977	970	
z4	984	976	982	
z5	983	989	986	
Point B				
Position	*1*	*2*	*3*	
	886	881	871	**T_B= 879**

Table 5. Temperatures [°C] extracted from the CFD model in load case LP2 at RECI flow of 47527 Nm3/h.

Lowest boiler points (2)				
Position	*x1*	*x2*	*x3*	
z1	808	788	731	**T_2= 807**
z2	862	810	775	
z3	870	797	782	
z4	873	825	792	
z5	836	817	794	
z6	857	785	773	
z7	857	799	767	
z8	820	808	738	
Highest boiler points (1)				
Position	*x1*	*x2*	*x3*	
z1	771	772	766	**T_1= 753**
z2	758	744	764	
z3	757	749	757	
z4	760	745	736	
z5	757	735	734	
z6	752	726	742	
z7	757	733	753	
z8	769	765	764	
Point B				
Position	*1*	*2*	*3*	
	677	679	665	**T_B= 674**

Table 6. Temperatures [°C] extracted from the CFD model in load case LP5 at RECI flow of 47527 Nm3/h.

Flue gas flow and steam production is needed for the determination of the calibrated formula. These data has been extracted from the H&M balance. In *Table 4* the values are listed for the two load situations.

Load situation		LP2	LP5
Flue gas flow (V_{FN})	[Nm^3/h]	241619	125041
Steam production (Q_{steam})	[kg/s]	44.315	19.738

Table 7. Flue gas flow and steam production.

Using the above data the residence time above 850°C after the last injection of combustion air can be determined as follows:

			LP2	LP5
$\Delta T_{1.2}$	$= T_2 - T_1$	[°C]	70.9	54.1
ΔT	$= T_1 - T_B$	[°C]	109.0	78.9
$\Delta T_{1.2}/\Delta H_{1.2}$		[°C/m]	11.9	9.1
T_{BNBZ}	$= T_2 + (\Delta T_{1.2}/\Delta H_{1.2}) \times \Delta H_{BNBZ}$	[°C]	1140.7	869.1
T_{mean}	$= (T_{BNBZ} + T_{M.\,min})/2$	[°C]	995.4	859.5
V_{FR}	$= (V_{FN}/3600) \times (T_{mean} + 273.15)/273.15$	[m³/s]	311.7	144.0
ΔH_T	$= (T_1 - T_{M.\,min})\Delta H_{1.2} / \Delta T_{1.2}$	[m]	11.6	-10.7
t_{Vz}	$= A(\Delta H_{1.BNBZ} + \Delta H_T)/V_{FR}$	[s]	4.7	0.9

The next step is to determine the temperature and location of 2 seconds of residence time and determine the minimum acceptable temperature in the top of the 1st boiler pass ($T_{B.minimum}$). This is done as follows:

			LP2	LP5
ΔH_{NBZ}	= (tVZMin * VFR)/A – $\Delta H_{1.BNBZ}$	[m]	-2.5	-8.0
T_{NBZ}	$= T_1 - (\Delta T_{1.2}/\Delta H_{1.2}) \times \Delta H_{NBZ}$	[°C]	1017.6	825.7
ΔT_{NBZ}	$= T_{NBZ} - T_B$	[°C]	138.3	151.8
$T_{B.minimum}$	$= T_{M.\,min} - \Delta T_{NBZ}$	[°C]	711.7	698.2

Below is summarised the results needed to define the formula that can calculate the temperature after 2 seconds of residence time after the last injection of combustion air (T_{2S}).

			LP2	LP5
Steam production	Q_{steam}	[kg/s]	44.315	19.738
ΔT_{NBZ}	$= T_{NBZ} - T_B$	[°C]	138.3	151.8

Defining ΔT_{NBZ} as a linear function of the steam production ΔT_{NBZ} is determined as follows:

$$\Delta T_{NBZ} = A + B \times Q_{steam} = 162.70 - 0.5499 \times Q_{steam}$$

The formula for T_{2S} or T_{KalB} can then be defined as:

$$T_{2S} = T_{KalB} = T_{B10} + \Delta T_{NBZ} = T_{B10} + 162.70 - 0.5499 \times Q_{steam}$$

Where:
T_{2S} : Temperature after 2 seconds of residence time after last injection of combustion air.
T_{KalB} : Equals T_{2S}
T_{B10} : 10 minutes average of the plant T_B measurement.
Q_{steam} : Steam flow [ks/s]

2.3 The temperature after 2s of residence time adjusted by the flow of recirculation of flue gases

From section 2.1 Minimum recirculation of flue gases and 2.2 Maximum recirculation of flue gases it the formula for determining the temperature after 2 seconds of residence time after last injection of combustion air at a fixed amount of recirculation of flue gas formulated.

The purpose of this section is to reformulate the equations to one that includes the variable amount of recirculation of flue gas (RECI). For a fix amount of RECI the formula is:

RECI = 0 Nm^3/h → ΔT_{NBZ} = 174.44 – 0.1503 x Q_{steam}

RECI = 47527 Nm^3/h → ΔT_{NBZ} = 162.70 – 0.5499 x Q_{steam}

Assuming that there is linearity between the minimum and maximum steam production at constant RECI flow can the combined formula for T_{NBZ} then be defined as:

$$\Delta T_{NBZ} = A + B * Q_{steam} = \frac{706200 - RECI}{706200} * 174.4 - \frac{17880 + RECI}{17880} * 0.1503 * Q_{steam}$$

The formula for T_{2S} or T_{KalB} can then be defined as:

$$T_{2S} = T_{KalB} = T_{B10} + \Delta T_{NBZ} = T_{B10} + \frac{706200 - RECI}{706200} * 174.4 - \frac{17880 + RECI}{17880} * 0.1503 * Q_{steam}$$

Where:

T_{2S} : Temperature after 2 seconds of residence time after last injection of combustion air.
T_{KalB} : Equals T_{2S}
T_{B10} : 10 minutes average of the plant T_B measurement.
Q_{steam} : Steam flow [ks/s]
RECI : Amount of recirculation of flue gas [Nm^3/h]

3. Conclusion

A formula has been determined based on the CFD model of the boiler and the formulation is done according to ”Fachliche Erläuterung zur: Bundeseinheitlichen Praxis bei der Überwachung der Verbrennungsbedinungengen an Abfallverbrennungsanlagen nach 17. BImSchV; April 1994”.

The formula looks as follows:

$$T_{2S} = T_{KalB} = T_{B10} + \Delta T_{NBZ} = T_{B10} + \frac{706200 - RECI}{706200} * 174.4 - \frac{17880 + RECI}{17880} * 0.1503 * Q_{steam}$$

Where:

T_{2S} : Temperature after 2 seconds of residence time after last injection of combustion air.
T_{KalB} : Equals T_{2S}
T_{B10} : 10 minutes average of the plant T_B measurement.
Q_{steam} : Steam flow [ks/s]
RECI : Amount of recirculation of flue gas [Nm^3/h]

The environmental regulations demand is that T_{2S} is higher than 850°C. The calculations show that T_{2S} at both high (100%) and low (45%) load is above the demanded 850°C.