Project no.:
019809

Project acronym:
NextGenBioWaste

Project title:
Innovative demonstrations for the next generation of biomass and waste combustion plants for energy recovery and renewable electricity production

Instrument: Integrated project

Thematic priority: 6.1.3.1.4

Start date of project: 2006-02-24

Duration: 4 years

D 2.2.4

Evaluation of two different modern control technologies (models based control versus model predictive control)

Revision [draft]

Due date of deliverable: yyyy-mm-dd
Actual submission date: yyyy-mm-dd

Organisation name of lead contractor for this deliverable: TNO

Project co-funded by the European Commission within the Sixth Framework Programme (2002-2006)		
Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential , only for members of the consortium (including the Commission Services)	

Deliverable number:	D 2.2.4
Deliverable name:	Evaluation of two different modern control technologies (model based control versus model predictive control)
Work package:	WP 2.2 Process Control – Demonstration
Lead contractor:	Peter Paul van het Veen

Status of deliverable		
Action	**By**	**Date** (yyyy-mm-dd)
Submitted (Author(s))		
Verified (WP-leader)		
Approved (SP-leader)		

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Abstract

The combustion of heterogeneous fuel, as waste or biomass, needs a high-sophisticated combustion control system (CCS) than homogeneous fuels. In general there are four different combustion control philosophies. GKS had chosen the Advanced-PID system which delivers extremely good results. Nevertheless sometimes the heterogeneity of the fuel is so extreme, that other measures are necessary to avoid loss in efficiency and increase in emission. To avoid these a chemical-physical model was connected to the CCS (Advanced-PID-MBC). This connection via OPC runs stable and reliable between the CCS and the model computer. The calculated data were also transferred to the DCS via OPC. All these connections work good to all times.

The data from the model had been integrated into the CCS and delivers additional information to run the control system better. Referring to an example the mode of operation is explained. It can be seen, that the information of the bed about an extremely increased bed height delivers the right data to the CCS. There this information was used by reducing the influence of the heterogeneous waste to reduce bed height and avoiding negative outcome.

An alternative to the MBC system was realized at GKS as a model predictive control (MPC) system. This had been described in detail in deliverable D2.1.1.

As a result it can be stated, that the Advanced-PID-MBC system runs extremely good compared with on the one hands side other control systems and on the other hands side the MPC system.

All in all the MBC system is most promising and can be optimised and developed to a commercial add-on for CCS of any kind.

Version history (not to be used if Track version is used in eRoom).
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Date	Version	Author(s)	Comments
2009-02-23		Ragnar Warnecke	DRAFT

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1 INTRODUCTION

In former times waste was a source of illness and pestilence. Incineration is the appropriate measure for on the one hands side inertisation of waste to a non-dangerous, hygienic matter and on the other hand minimising its volume. Waste incineration under controlled conditions in a technical plant is part of the waste handling for more than one hundred years now and seems to be the appropriate technique for the future.
While the combustion of more or less homogenous fossil energy material (i.e. gas, oil, lignite, coal) is investigated extensively in the last decades, the understanding of the combustion process for strongly heterogeneous materials as waste, RDF, biomass etc. is rudimental.

In the plants with heterogeneous fuel a lot of problems can occur: These can be for example the stability of the combustion itself, the release of corrosive species and of deposit causing particles. To manage these problems one boundary condition is to run the combustion stable, to get defined conditions. A stable combustion needs a good combustion control system. In deliverable D2.2.3 an overview over the different systems was given in detail (see Figure 1.1).

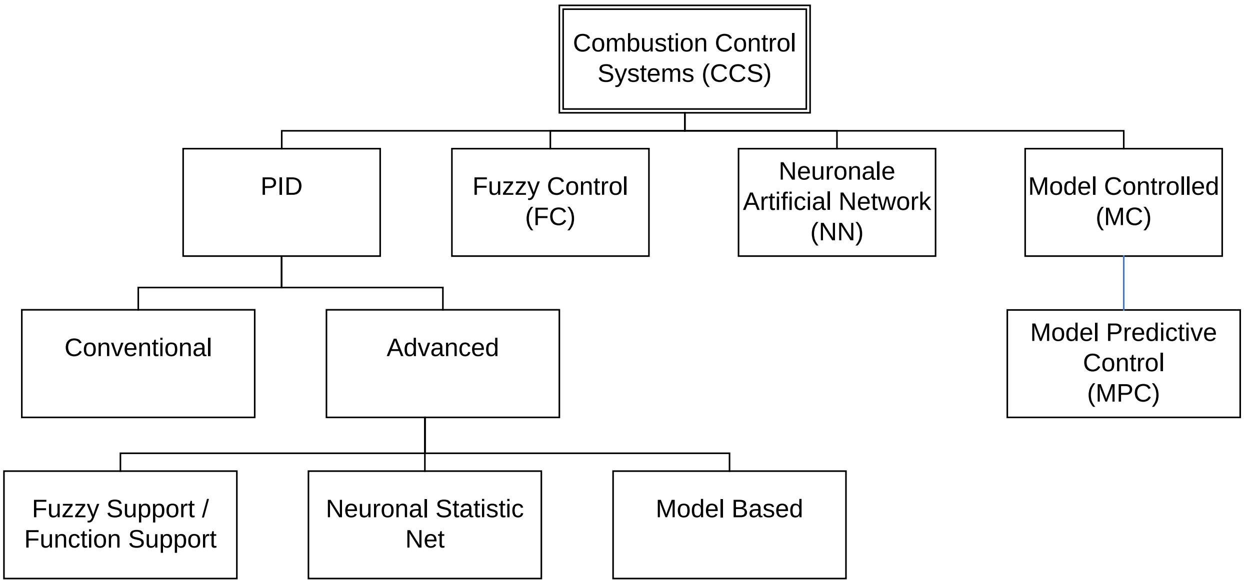


Figure 1.1: Overview combustion control systems

At GKS an Advanced PID controller (A-PID) is implemented with “Function Support” (Function Support is addition of linear or non linear functions to influence specific manipulable variables). The disadvantage of the common controllers is, that they are not really able to foresee the reaction of the system (here: the waste combustion). This is caused be the not known properties of the fuel. The waste can vary widely in the heating value and in the composition. Additionally a high amount of partially incinerated waste is on the grate as a source of energy release and the “source energy” is varying very much depending on the combustion progress and the waste properties. That means that the measured variables can not give enough information about the system so that the combustion control is in a way a “blind flight”. The aim should be to get the information about the disturbance variables heating value, source energy etc. No specific online measurements are in sight in the future, so that another way of getting information is to make a model of the process. In Figure 1.1 there can be seen three entries for this solution: Advanced-PID with model based control (A-PID-MBC) or model predictive control (MPC) or Neuronal Artificial Net (NN). From these three NN works with a more or less statistical model which can not really foresee the conditions because every set of variables can be a result of numerous conditions of heating value and source energy on the grate. This leads to only the two promising solutions with physical and chemical models:

1. A-PID-MBC and
2. MPC.

A physical and chemical model can help to get:

- a better understanding of the process
- starting conditions for CFD simulations
- additional online information for combustion control.

In the following these two approaches will be investigated and compared.

2 BASICS OF COMBUSTION CONTROL

The number of manipulable variables is manageable (Figure 2.1). For a single track grate the number is between 10 and 20 (see Figure 2.2). This leads to a numerous combinations, so that the influence on the interactions of the variables is not easy to handle anymore. With the above mentioned control systems in general this task would be able to handle, if the influencing variables would be measurable. Unfortunately in WtE-plants there are several variables not measurable. Mainly these are the parameters of the extremely heterogeneous fuel which leads to an “over-swell” (German “Überschüttung”) of fuel on the grate.

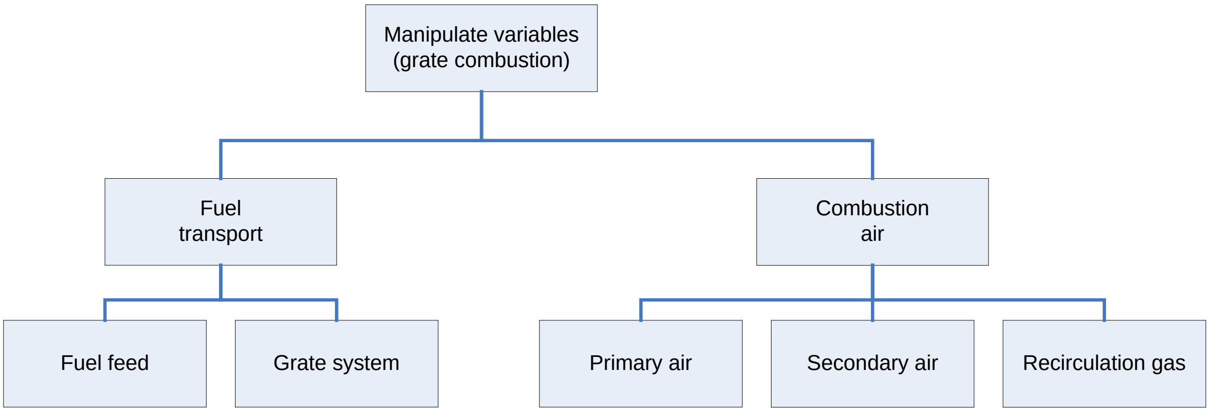


Figure 2.1: Groups of manipulable variables

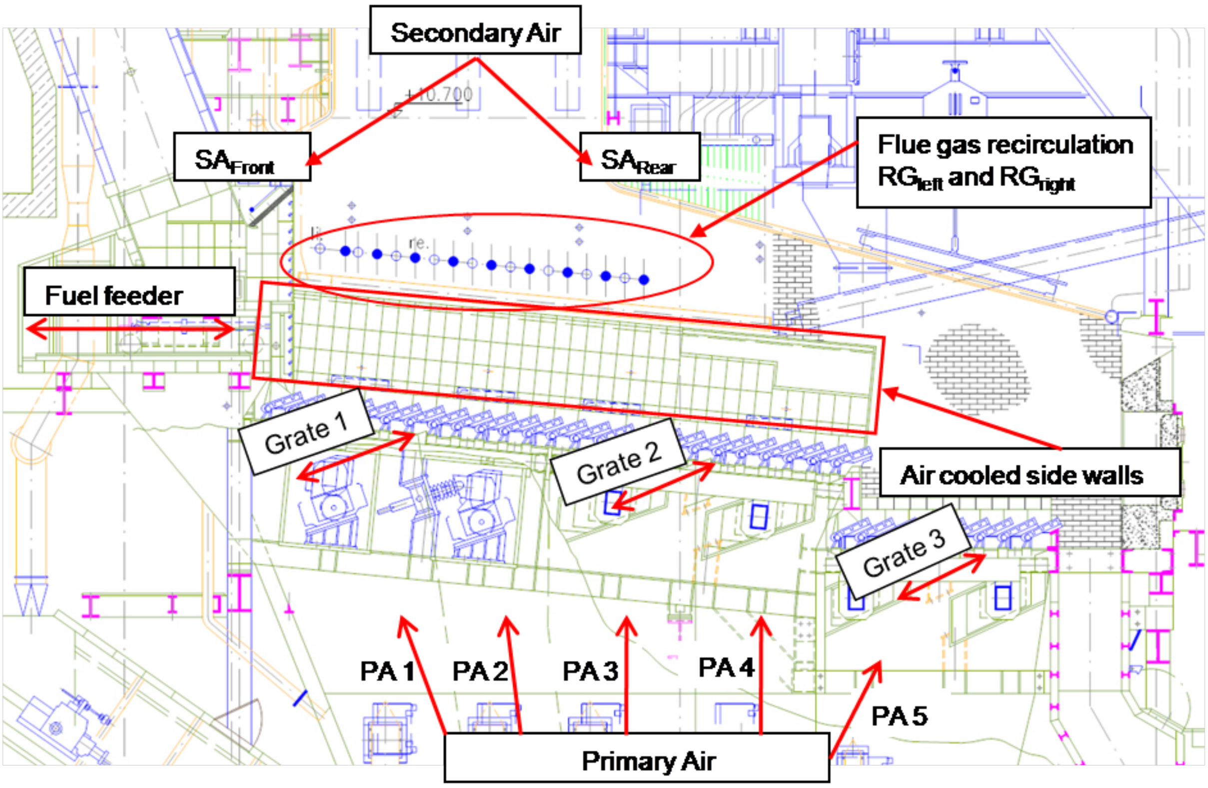


Figure 2.2: Manipulable variables in the GKS WtE plant

The combustion control system gets the data of the combustion situation from the plant via DCS (= Distributed Control System). These data are temperatures, pressures and concentrations, which are results of the combustion. Also the manipulable variables (MV) are logged within the DCS (i.e. revolutions of the fan) and the control variables (CV) as well which are the result of the MV (i.e. the flow of primary air). All necessary data are given from the DCS to the combustion control system (CCS). The CCS calculates the new MV with these data. The kind of “calculation” depends on the CCS.
To change additional information between DCS and CCS a bidirectional connection has to be realized between the two systems. One of the most common technologies for tasks like this is the so called OPC coupling.

The combination of the present combustion control system with the combustion model had been realised with a standard OPC connection (Figure 2.3). This coupling was installed and works very stable and reliable at GKS (see D2.2.3).

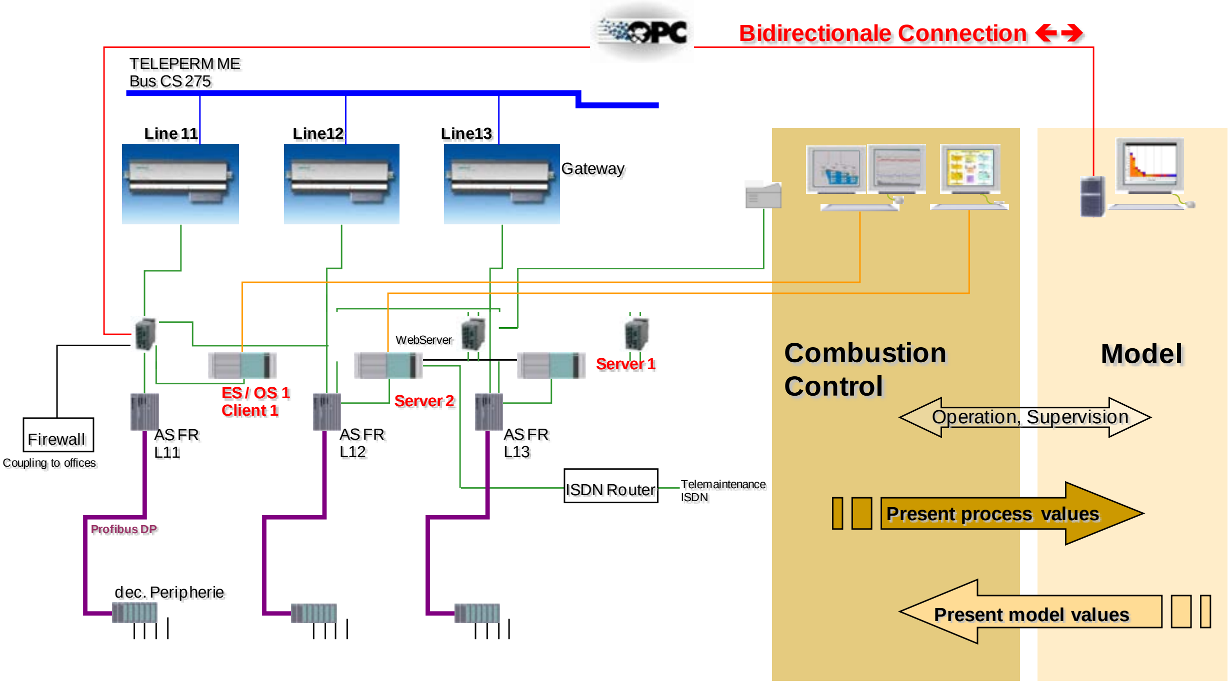


Figure 2.3: OPC coupling of “Model” and “Plant”

The DCS was connected via OPC with the new GKS combustion control system (CCS), which is a Advanced-PID-System. The CCS has a direct connection with the model also via OPC. The model is not directly connected with the DCS.

3 MODEL BASED CONTROL (MBC)

The Model Based Control (MBC) bases on:

1. a combustion control system (CCS) and
2. a physical-chemical model.

The CCS is described in detail in deliverable D2.2.3. Here the description of the model and the implementation of the model into the CCS is in the foreground.

3.1 Physical-chemical Model

The basis of the physical-chemical model had been developed at GKS in the previous ten years. The aim was to create a model in which directly plant variables can be integrated and which calculates the whole species, mass and energy balances. The variation of the plant variables should than lead to the right answers of the model. The simulation was carried out as iterative-differences-equations.
Therefore the different effects of the physical-chemical mechanisms had been programmed in different submodels. The use computer language is “C”.

There are three main parts of the model (Figure 3.1):

1. Boundary conditions
    a. Input
    b. Geometry
2. State-changes
    a. Transport
    b. Particles
    c. Reaction
3. State
    a. Gas
    b. Solid

The boundary conditions are given by the input of fuel and air as well as by the geometry of the grate and the combustion chamber.

3.1.1 Boundary Conditions

The fuel **input** is given by 13 fractions:

1. Fines
2. Coarse
3. Organic
4. Paper, paperboard
5. Plastics
6. Textiles
7. Mixed waste

8. Wood
9. Sanitary product
10. Leather, rubber, cork
11. Hazardous waste
12. Bulky waste
13. Inert

More or less every waste or biomass can be generated by combinations of these fractions. Each fraction has a specific behaviour which includes calorific value, element analysis and release of volatiles (Figure 3.2). The release of volatiles for each fraction is investigated by laboratory tests. The release of volatiles is described as a release of the following components:

- C3H8 (“tar”)
- CO2
- CO
- H2
- O2
- N2
- NO
- SO2
- HCl
- H2O
- KCl
- NaCl
- CaCl2
- C (solid coke)

depending on time and temperature. So the fuel is defined as a sum of combination of these species as a “pseudo fuel” and the release of these species to the gas phase is given as a function of temperature and time.
The reaction of C is given as an Arrhenius function of temperature. The time component is included by the transport and particle properties (see below).

All the fractions together bring the superposition of the gas phase species which is released to the combustion chamber.

In addition to the fuel air (and recirculation gas) is given as an input which is added to the different zones of the grate, the side walls and secondary air.

Fuel and air flow is given in kg/s. All units within the program are given and calculated in SI units. While the properties of the air are clear (density, heat capacity etc.) the fuel got its properties (beside the data found above) by measurements made at GKS as there are:

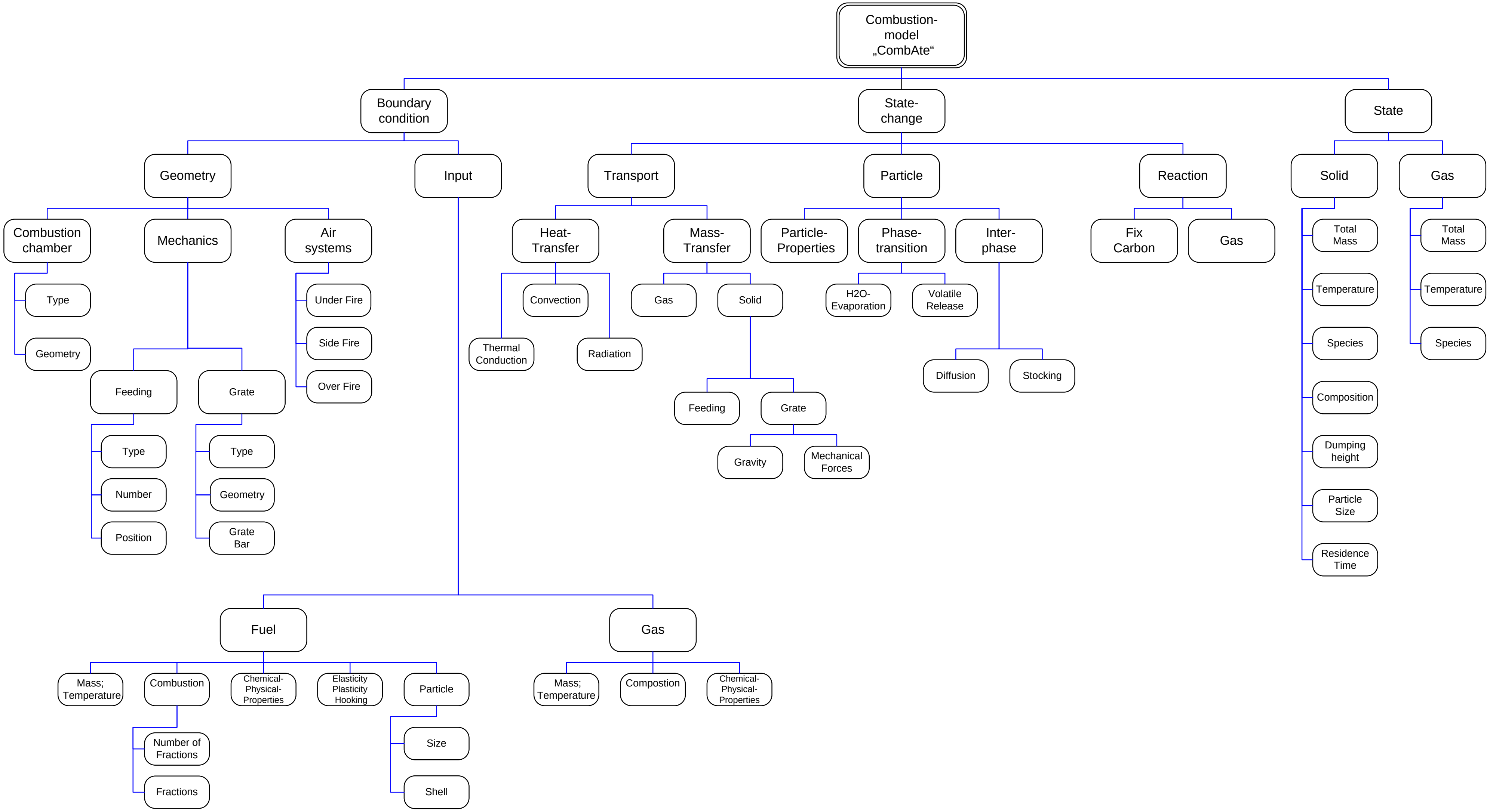


Figure 3.1: Overview over the sub-models of the computer program “CombAte”

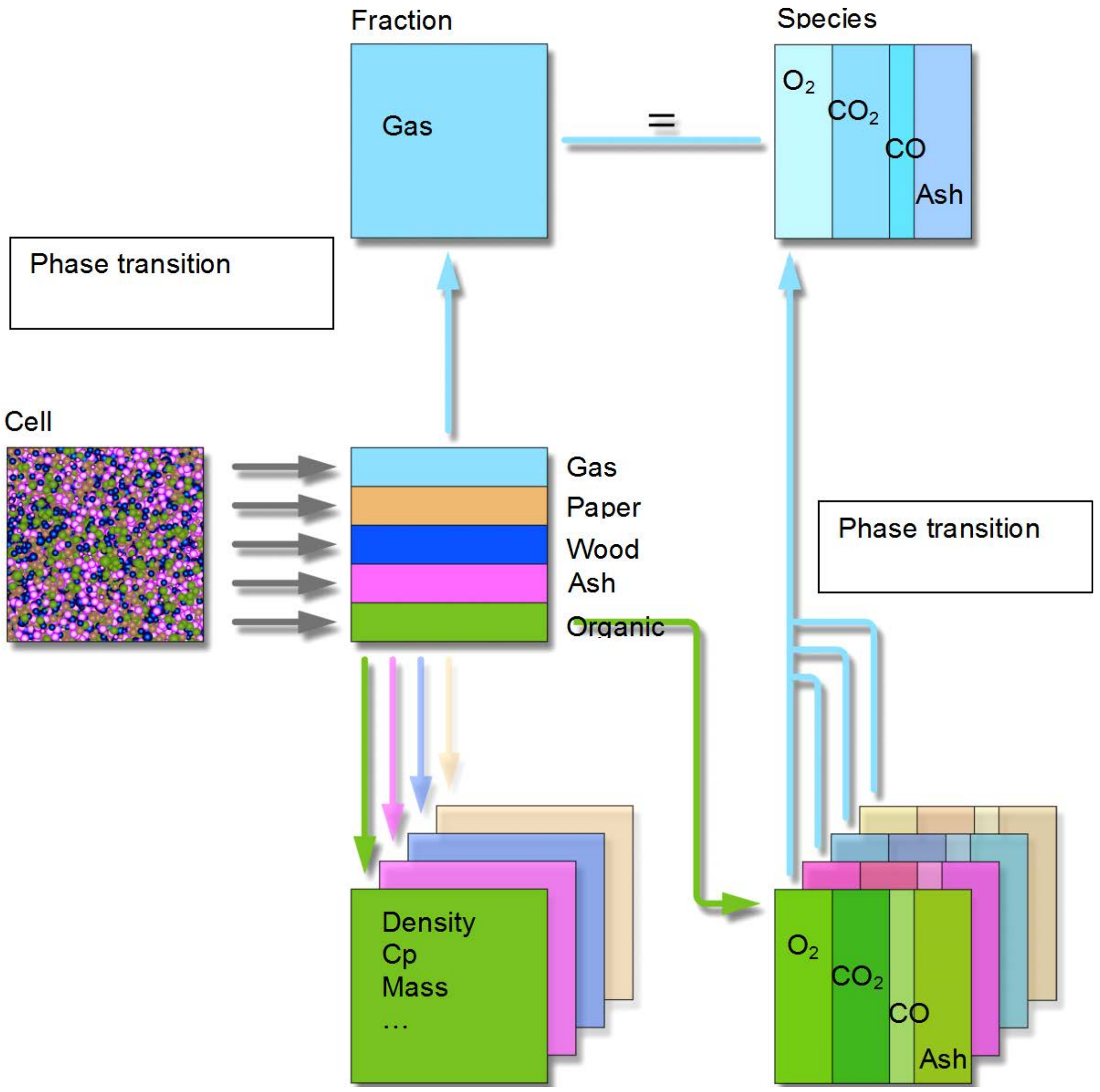


Figure 3.2: Including the in the external model calculated data into the combustion control

- Mass flow
- Calorific heating value
- Density
- Bulk density
- Heat capacity
- Heat conductivity
- Plasticity
- Elasticity
- Hooking
- Temperature
- Particle size

Beside the input the **geometry** and properties of the combustion chamber influence the combustion significantly. The combustion chamber is described by connected cells which represent its length, height and width. This includes steps in the grate (Figure 3.3). The grate itself is described by:

- Type of grate
- Number of grate lines
- Number of grate zones (with length, height and width)
- Angle of grate
- Parameter of the fuel feeder
- Grate bars (geometry, angle, mountings).

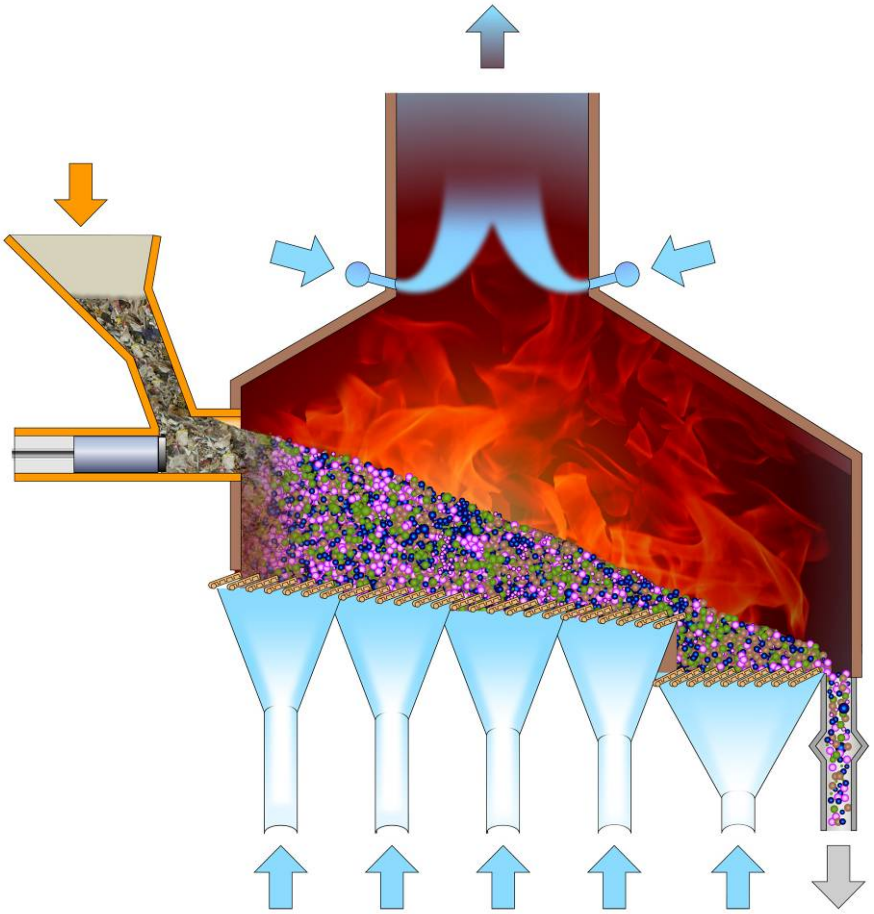


Figure 3.3: Geometry model

3.1.2 State changes

To describe the **transport** the aim was just to use data from the plant without calibrating each combustion chamber as new. The fuel input (mass flow) is realised by the movement of the feeder. These data are directly taken from the plant. The transport of the fuel over the grate is a function of the grate geometry and its movements. The movement data are also directly taken from the plant. It is described by the measured hydraulic action of the grate bars. All complicate movements including pauses can be taken into account by a multi-linear function. The control value is the “double stroke” of the grate, which is a typical value for real plants with forward and backward acting grates. The properties of the fuel connected with the multi-linear function of the grate movement and the influence of gravity describe the fuel movement. Validations of the preciseness of the transport model are the residence time of the fuel on the grate and the bed height. Both show very good accordance with the real plant.

Gas phase moves through the combustion chamber by forced directions given by the type of combustion chamber:

- Co-current
- Counter-current and
- Middle-current.

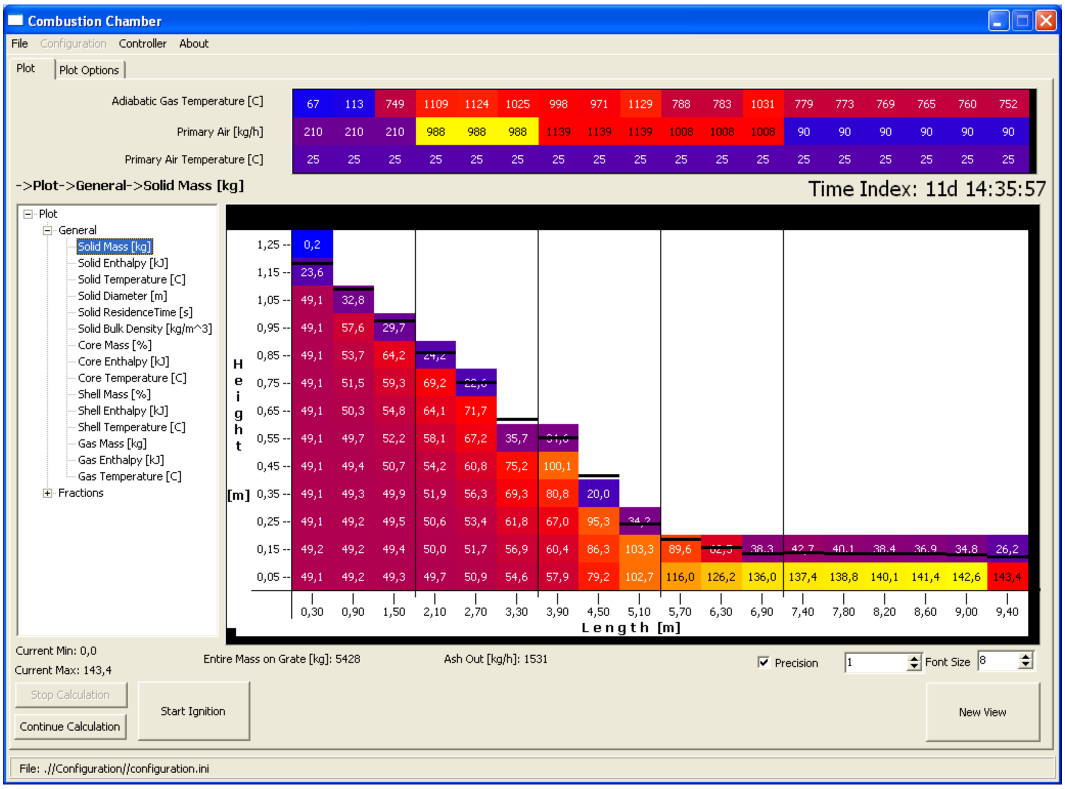
The movement is also influenced by the **particle size** of the fuel. The particles change size and consistence while moving and reacting over the grate. The particles have different shells with different properties depending on the state of heat transfer into the particle and the release of volatiles as wells as on the reaction of the coke and the content of inert fraction. The heat transfer is calculated by convection, heat conduction and heat radiation. The heat radiation is mainly efficient at the surface of the fuel bed (and at reacting coke particles). The convection and mixing of the particles play a minor role. The main heat transfer into the bed is caused by heat conductivity and mixing.

The chemical **reactions** of the gas phase above the fuel bed (between the species mentioned above on basis of complete gross reactions), the heat transfer into the bed and the coke inside the fuel bed bring the enthalpy for further release of volatiles. To start the reaction a virtual ignition burner which induced 1.000°C has to be launched off.

3.1.3 State

One of the boundary conditions of the model is to be fast enough to calculate faster than real time in order to give back data to the real plant. The program concept allows calculations velocities of 10 to 50 times faster than real time, so that this condition is fulfilled.
The data produced by the model are on the one hands side available as single data sets or visually by a graphic user interface (GUI) (Figure 3.4). The different specific data can be made visible by this tool. Figure 3.4 gives a view on the mass in the different cells on the grate. The black lines in the upper part of the coloured cells indicate the bed height. Further on e.g. residence time, shell temperatures, all fractions of species and other conditions can be made visible.

The states of conditions in the combustion chamber will be used to validate the model. The **gas phase** reactions cause temperatures in the combustion chamber which are comparable with the temperatures measured in the real plant. The observation of the **solids** refer mainly to residence time, bed height and coke content at the end of the grate.
Overall data that prove the reliability of the data are the calorific heating value, steam mass flow and the O2-content in the combustion chamber. The measured and calculated data are compared in Figure 3.5.



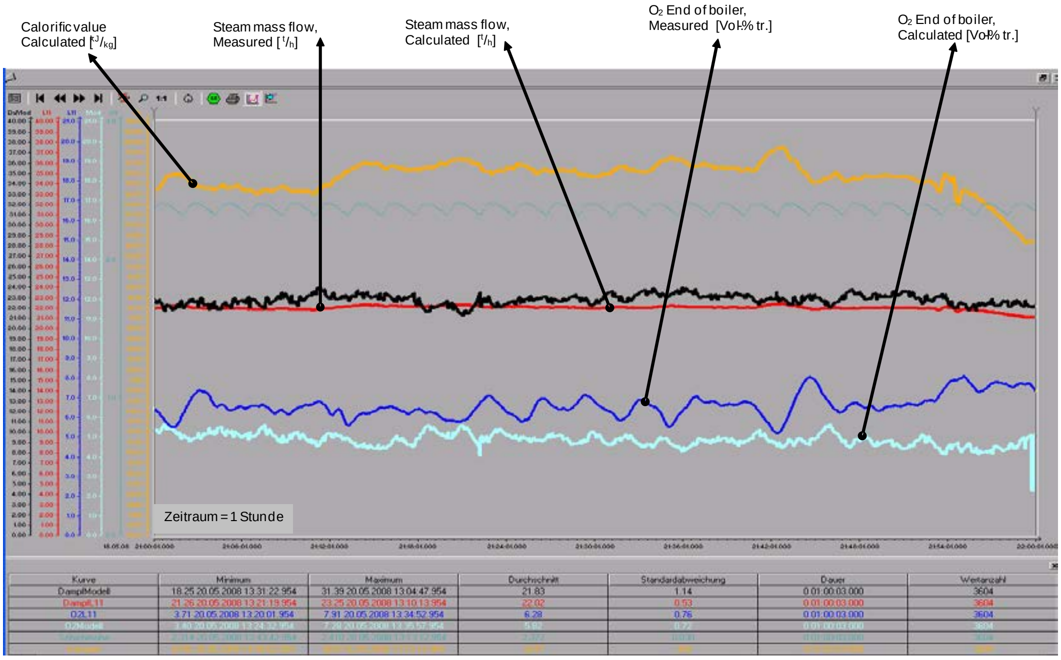
Adiabatic Gas Temperature [C]	67	113	749	1109	1124	1025	998	971	1129	788	783	1031	779	773	769	765	760	752
Primary Air [kg/h]	210	210	210	988	988	988	1139	1139	1139	1008	1008	1008	90	90	90	90	90	90
Primary Air Temperature [C]	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25

Time Index: 11d 14:35:57

Height [m]	0,30	0,90	1,50	2,10	2,70	3,30	3,90	4,50	5,10	5,70	6,30	6,90	7,40	7,80	8,20	8,60	9,00	9,40
1,25	0,2																	
1,15	23,6																	
1,05	49,1	32,8																
0,95	49,1	57,6	29,7															
0,85	49,1	53,7	64,2	24,2														
0,75	49,1	51,5	59,3	69,2	22,6													
0,65	49,1	50,3	54,8	64,1	71,7													
0,55	49,1	49,7	52,2	58,1	67,2	35,7	31,6											
0,45	49,1	49,4	50,7	54,2	60,8	75,2	100,1											
0,35	49,1	49,3	49,9	51,9	56,3	69,3	80,8	20,0										
0,25	49,1	49,2	49,5	50,6	53,4	61,8	67,0	95,3	34,2									
0,15	49,2	49,2	49,4	50,0	51,7	56,9	60,4	86,3	103,3	89,6	[illegible]	38,3	42,7	40,1	38,4	36,9	34,8	26,2
0,05	49,1	49,2	49,3	49,7	50,9	54,6	57,9	79,2	102,7	116,0	126,2	136,0	137,4	138,8	140,1	141,4	142,6	143,4

Current Min: 0,0
Current Max: 143,4
Entire Mass on Grate [kg]: 5428
Ash Out [kg/h]: 1531
☑ Precision 1
Font Size 8
File: .//Configuration//configuration.ini

Figure 3.4: Graphic user interface of the model



Calorific value Calculated [kJ/kg]

Steam mass flow, Measured [t/h]

Steam mass flow, Calculated [t/h]

O_2 End of boiler, Measured [Vol-% tr.]

O_2 End of boiler, Calculated [Vol-% tr.]

Kurve	Minimum	Maximum	Durchschnitt	Standardabweichung	Dauer	Wertanzahl
DampfModell	18.25 20.05.2008 13:31:22.954	31.39 20.05.2008 13:04:47.954	21.83	1.14	0:01:00:03.000	3604
Dampf.11	21.26 20.05.2008 13:21:19.954	23.25 20.05.2008 13:10:13.954	22.02	0.53	0:01:00:03.000	3604
O2L11	3.71 20.05.2008 13:20:01.954	7.91 20.05.2008 13:34:52.954	6.28	0.76	0:01:00:03.000	3604
O2Modell	3.80 20.05.2008 13:24:32.954	7.29 20.05.2008 13:35:57.954	5.92	0.72	0:01:00:03.000	3604
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3604
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Figure 3.5: Comparison of calculated and measured data

Example for bed heights over 12 hours (calculated by modell) :

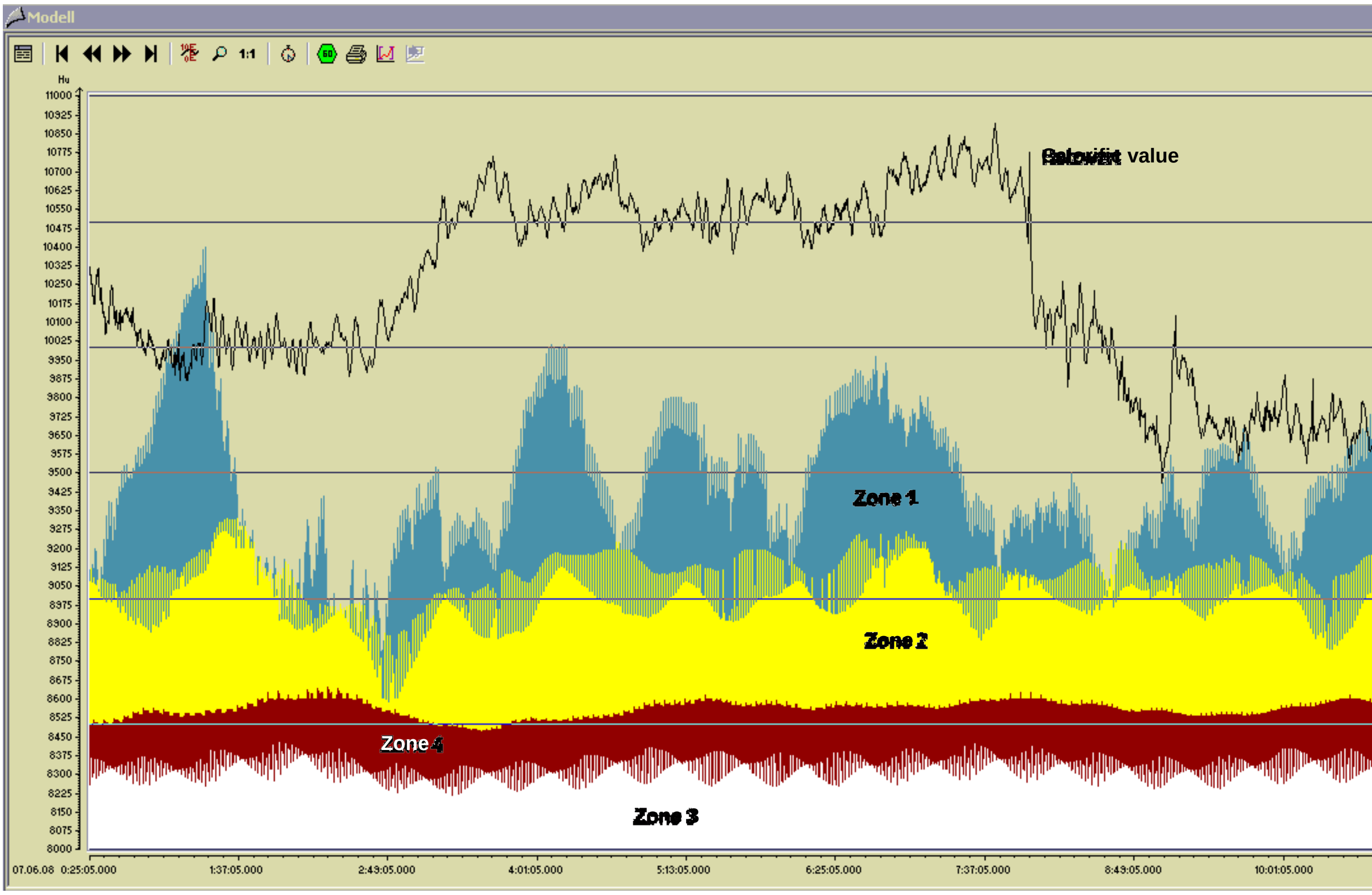


Figure 3.6: Example for calculated bed heights

An advantage of the model is that data which can not be measured but calculated are now available. Figure 3.6 shows the bed heights at different grate zones which normally can not be measured. This information can help to improve the combustion control system especially in situations, when the properties of the waste change significantly (e.g. calorific value, water content).

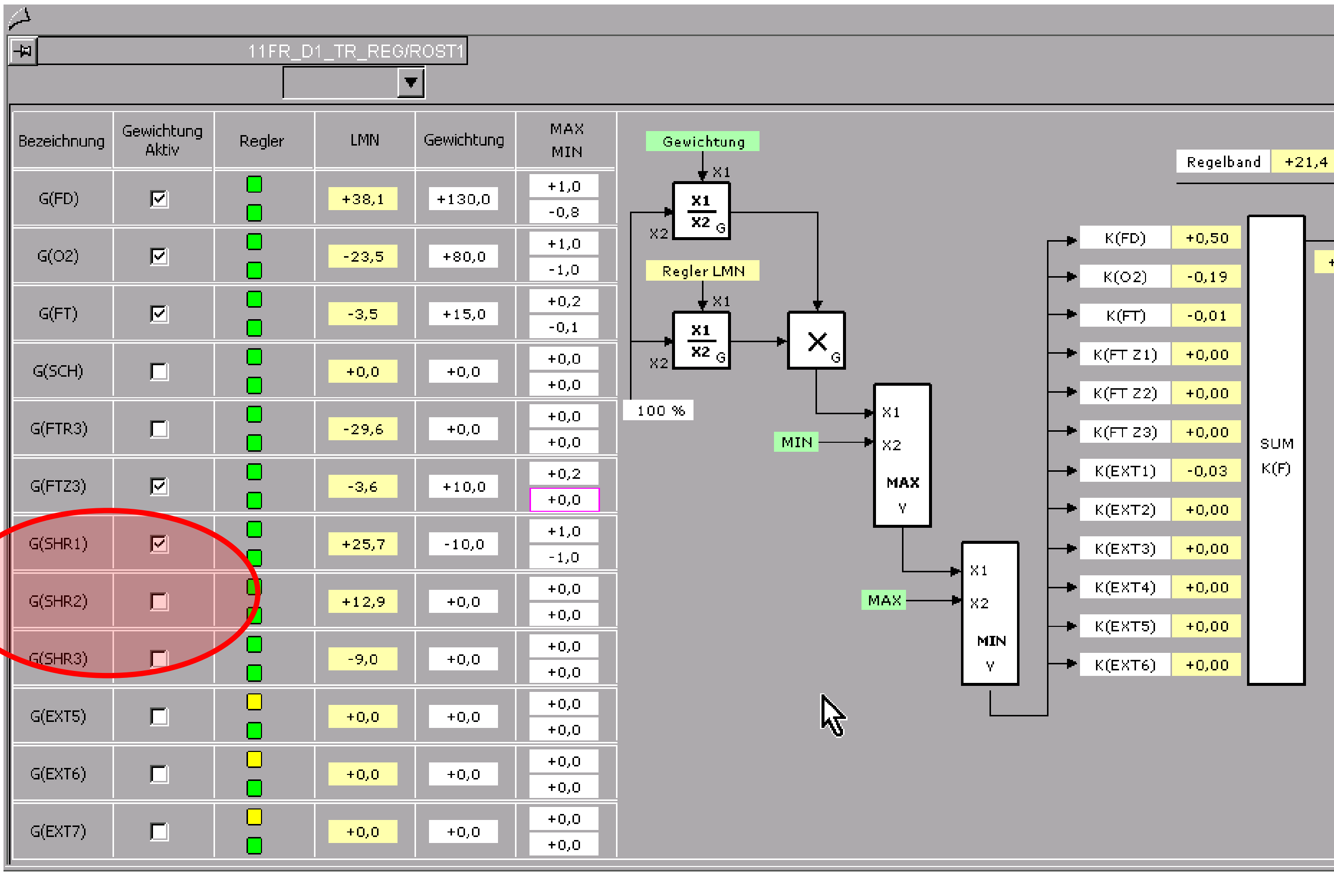
The most data fit quite good to the real plant so that the model can be taken as a very realistic description of the truly conditions. Some optimisation should be made in the future to get yet more precise results. But nevertheless the model can give e.g. good data for calorific value, steam production and bed height. So the preconditions to integrate the model into CCS are given.

3.2 Integration of the model into CCS

After having proven the functionality of the model the integration into the CCS at GKS had to be realised. At GKS within the A-PID system there had been made arrangements to be able to include variables which will be sent by the model to the combustion control system. These variables can be included into the control mechanism by switching them on in a weighting table (Figure 3.7).

The data send from the model will be calculated by a PID mechanism to a contribution of the manipulable variables. For this investigations the I and the D part had been set to zero. In further applications there can be made variations with integral and differential control parameters.

The contribution of the bed height onto the movement or air can be visualised in the PID parameter tables. Each section (movement and air) has it own sheet (Figure 3.8; Figure 3.9).

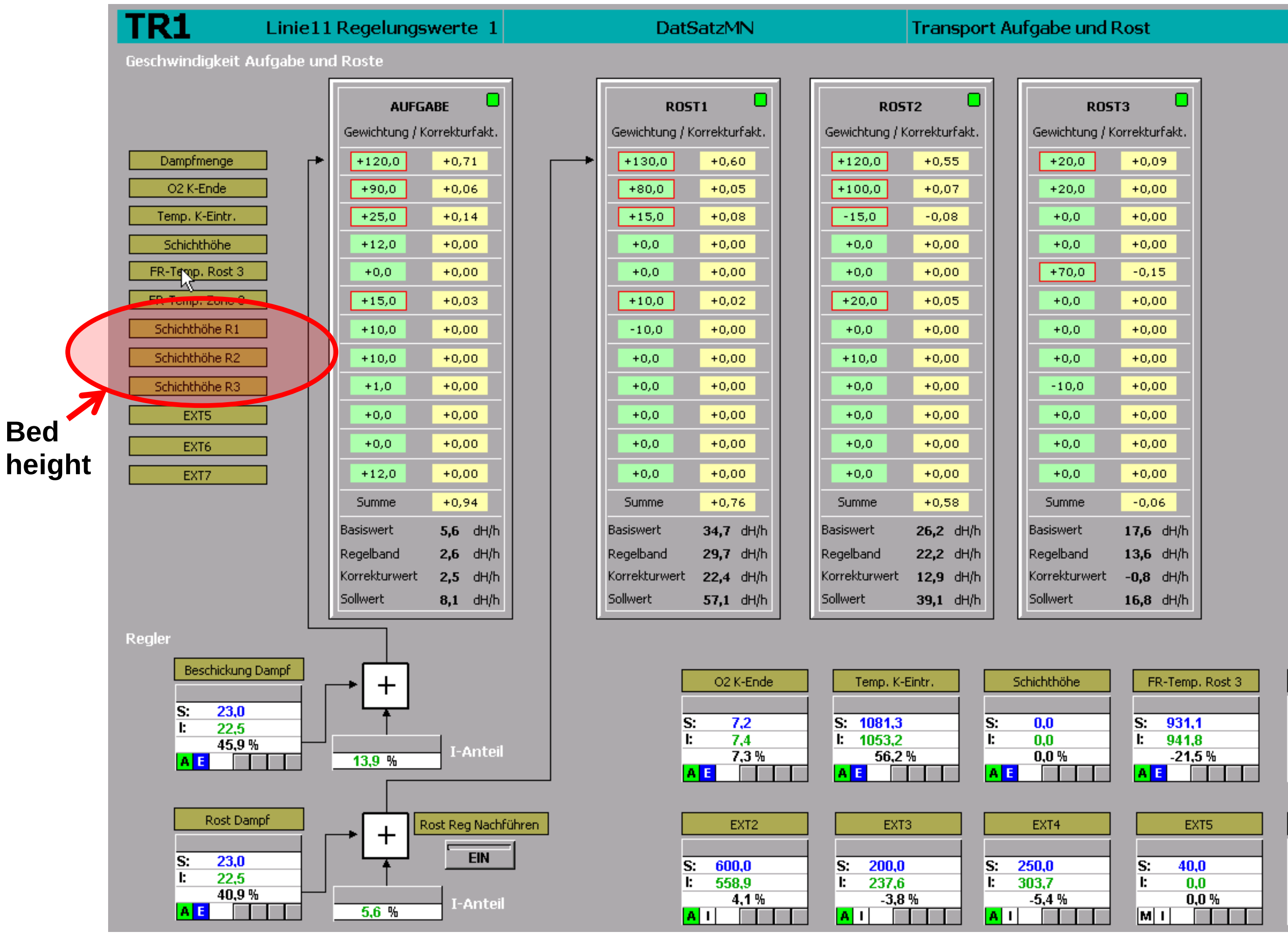


Bezeichnung	Gewichtung Aktiv	Regler	LMN	Gewichtung	MAX MIN
G(FD)	☑	🟩 🟩	+38,1	+130,0	+1,0 -0,8
G(O2)	☑	🟩 🟩	-23,5	+80,0	+1,0 -1,0
G(FT)	☑	🟩 🟩	-3,5	+15,0	+0,2 -0,1
G(SCH)	☐	🟩 🟩	+0,0	+0,0	+0,0 +0,0
G(FTR3)	☐	🟩 🟩	-29,6	+0,0	+0,0 +0,0
G(FTZ3)	☑	🟩 🟩	-3,6	+10,0	+0,2 +0,0
G(SHR1)	☑	🟩 🟩	+25,7	-10,0	+1,0 -1,0
G(SHR2)	☐	🟩 🟩	+12,9	+0,0	+0,0 +0,0
G(SHR3)	☐	🟩 🟩	-9,0	+0,0	+0,0 +0,0
G(EXT5)	☐	🟨 🟩	+0,0	+0,0	+0,0 +0,0
G(EXT6)	☐	🟨 🟩	+0,0	+0,0	+0,0 +0,0
G(EXT7)	☐	🟨 🟩	+0,0	+0,0	+0,0 +0,0

Regelband +21,4

K(FD)	+0,50
K(O2)	-0,19
K(FT)	-0,01
K(FT Z1)	+0,00
K(FT Z2)	+0,00
K(FT Z3)	+0,00
K(EXT1)	-0,03
K(EXT2)	+0,00
K(EXT3)	+0,00
K(EXT4)	+0,00
K(EXT5)	+0,00
K(EXT6)	+0,00

Figure 3.7: Including the in the external model calculated data into the weighting table of the combustion control system (here for grate 1)



	AUFGABE Gewichtung	AUFGABE Korrekturfakt.	ROST1 Gewichtung	ROST1 Korrekturfakt.	ROST2 Gewichtung	ROST2 Korrekturfakt.	ROST3 Gewichtung	ROST3 Korrekturfakt.
Dampfmenge	+120,0	+0,71	+130,0	+0,60	+120,0	+0,55	+20,0	+0,09
O2 K-Ende	+90,0	+0,06	+80,0	+0,05	+100,0	+0,07	+20,0	+0,00
Temp. K-Eintr.	+25,0	+0,14	+15,0	+0,08	-15,0	-0,08	+0,0	+0,00
Schichthöhe	+12,0	+0,00	+0,0	+0,00	+0,0	+0,00	+0,0	+0,00
FR-Temp. Rost 3	+0,0	+0,00	+0,0	+0,00	+0,0	+0,00	+70,0	-0,15
FR-Temp. Zone 3	+15,0	+0,03	+10,0	+0,02	+20,0	+0,05	+0,0	+0,00
Schichthöhe R1	+10,0	+0,00	-10,0	+0,00	+0,0	+0,00	+0,0	+0,00
Schichthöhe R2	+10,0	+0,00	+0,0	+0,00	+10,0	+0,00	+0,0	+0,00
Schichthöhe R3	+1,0	+0,00	+0,0	+0,00	+0,0	+0,00	-10,0	+0,00
EXT5	+0,0	+0,00	+0,0	+0,00	+0,0	+0,00	+0,0	+0,00
EXT6	+0,0	+0,00	+0,0	+0,00	+0,0	+0,00	+0,0	+0,00
EXT7	+12,0	+0,00	+0,0	+0,00	+0,0	+0,00	+0,0	+0,00
Summe		+0,94		+0,76		+0,58		-0,06
Basiswert	5,6 dH/h		34,7 dH/h		26,2 dH/h		17,6 dH/h	
Regelband	2,6 dH/h		29,7 dH/h		22,2 dH/h		13,6 dH/h	
Korrekturwert	2,5 dH/h		22,4 dH/h		12,9 dH/h		-0,8 dH/h	
Sollwert	8,1 dH/h		57,1 dH/h		39,1 dH/h		16,8 dH/h	

Regler	S:	I:	%	Mode
Beschickung Dampf	23,0	22,5	45,9 %	A E
Rost Dampf	23,0	22,5	40,9 %	A E
O2 K-Ende	7,2	7,4	7,3 %	A E
Temp. K-Eintr.	1081,3	1053,2	56,2 %	A E
Schichthöhe	0,0	0,0	0,0 %	A E
FR-Temp. Rost 3	931,1	941,8	-21,5 %	A E
EXT2	600,0	558,9	4,1 %	A I
EXT3	200,0	237,6	-3,8 %	A I
EXT4	250,0	303,7	-5,4 %	A I
EXT5	40,0	0,0	0,0 %	M I

I-Anteil 13,9 %

Rost Reg Nachführen EIN

I-Anteil 5,6 %

Figure 3.8: Influencing of grate movement by bed height (transport of fuel)

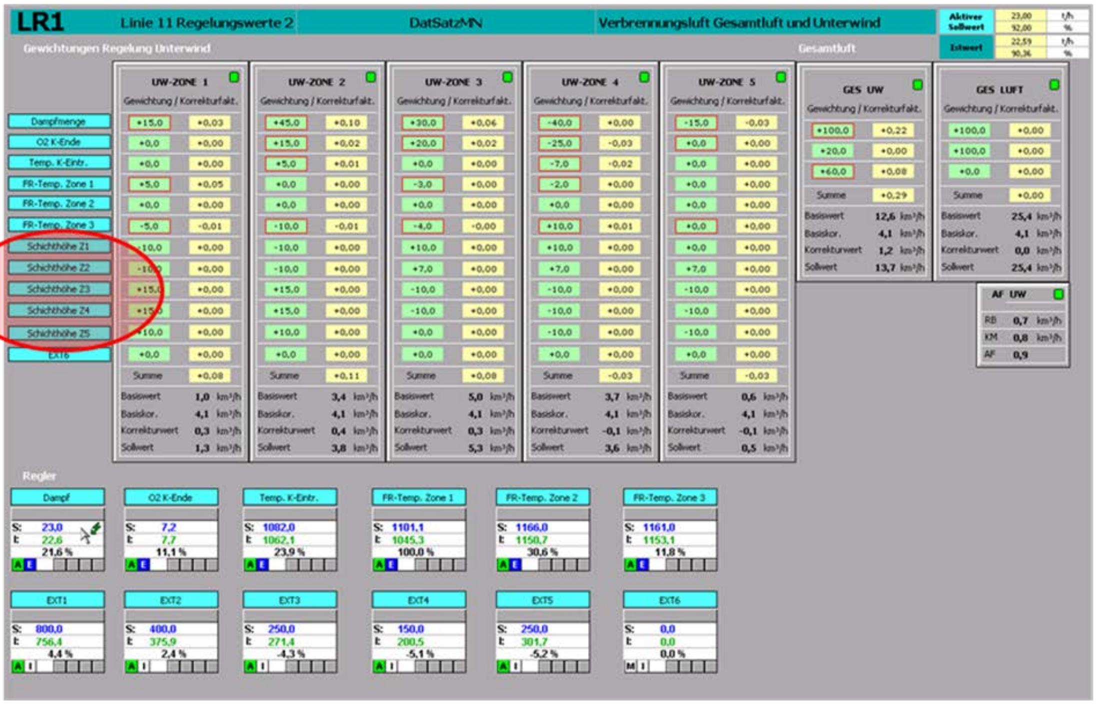


Figure 3.9: Influencing of amount of combustion air by bed height (flow of air)

As it can be seen, the amounts of manipulable variables on the grate and in the air zones are different because there are three grate zones only but five air zones that can be manipulated in the real plant. The model gives data for more zones so that the zones of the model have to be merged together (Figure 3.10), in order to give an average value to the grate and air parameter.

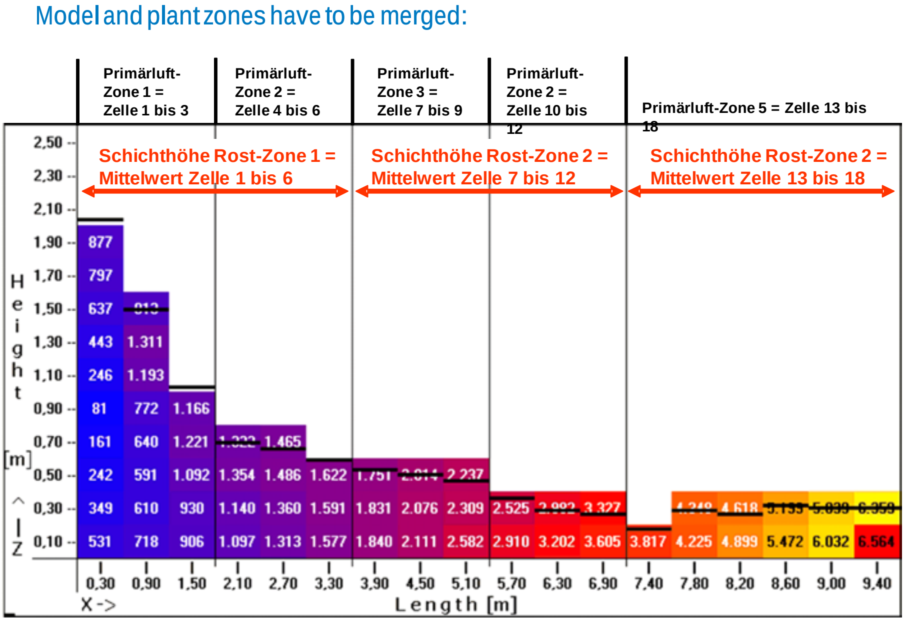


Figure 3.10: Merging model zones for air and grate together

The following activation of the model-variable should influence the combustion control system positively.

3.3 Results of MBC

All control variables (e.g. temperatures, pressure) and the present state of the manipulable variables influence the manipulable variables of the next time step (e.g. next second). That means that for example low temperature at primary air zone 5 wants to decrease the air flow and the grate speed in this zone. At the same time for example the steam production of the boiler is to low (and other influencing variables are also affecting the PID controller). At the end of one control loop the air flow in zone 5 is not decreased but increased and the grate speed is decreased. This gives an idea that the value of a manipulable variable at the end of one control loop cannot be interpreted as an information of one single effect.
To assess the effect of the single signal of an increased bed height the PID value of this single effect has to be isolated. To get this information the CCS had got a more detailed programming. The access to this data allows now to detect the effect of the bed height directly. Although the CCS runs excellent there are single states of instabilities and after some weeks of operation at GKS plant some instabilities of combustion could be detected (Figure 3.11). In the figure below it can be seen, that the temperatures decrease, especially at position 4 and 5 (that is above primary air zone 4 (beige) and 5 (purple). In parallel the steam production decreases and the CO content (light blue) in the flue gas at the end of the boiler increase significantly. The changes occur within less than half an hour and last for some hours. When the temperatures in the combustion chamber (FR1 to FR5) decrease it is nearly too late to react with the combustion control. The temperature reaction is caused by an instable combustion which could be detected by the bed height some 5 minutes before. When this signal would be available by the model the instable situation as presented in Figure 3.11 should be able to be avoided.

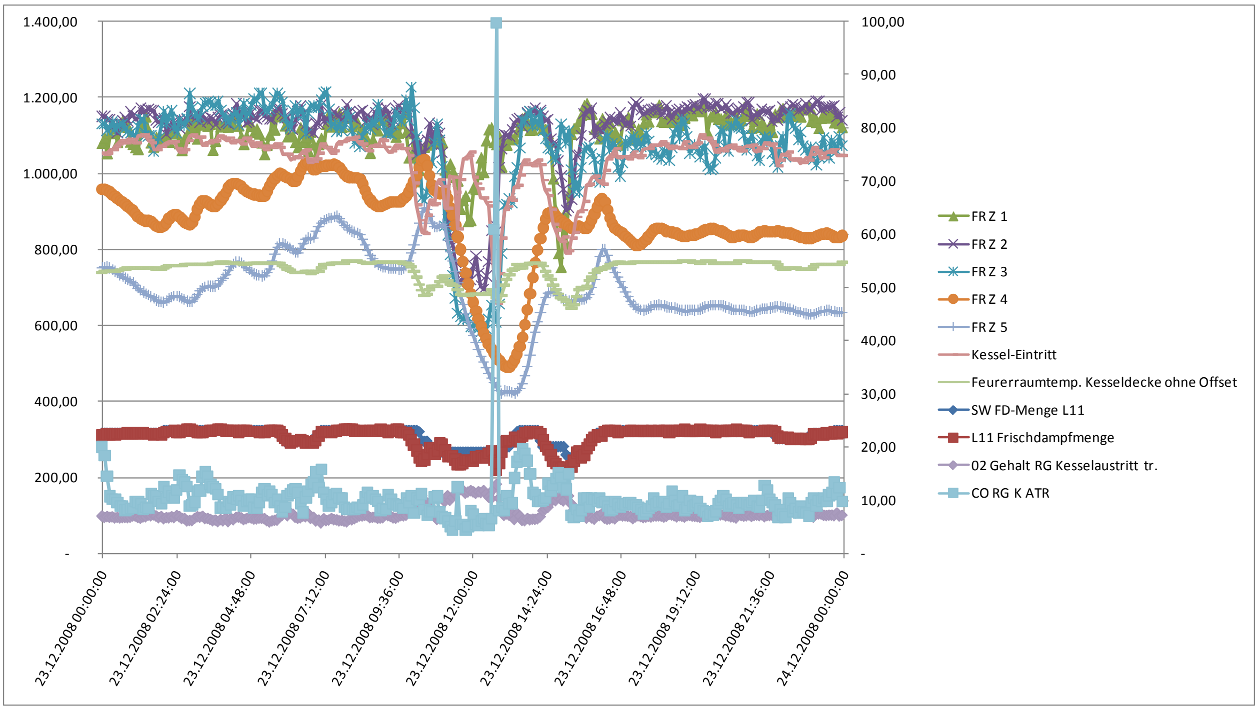


Figure 3.11: Instability with “long fire” and high bed height

One significant instability on the grate that had been occured is detected and presented here in a picture in Figure 3.12. A long fire with a high amount of flames at the last grate zone just before the deslagger can be seen.

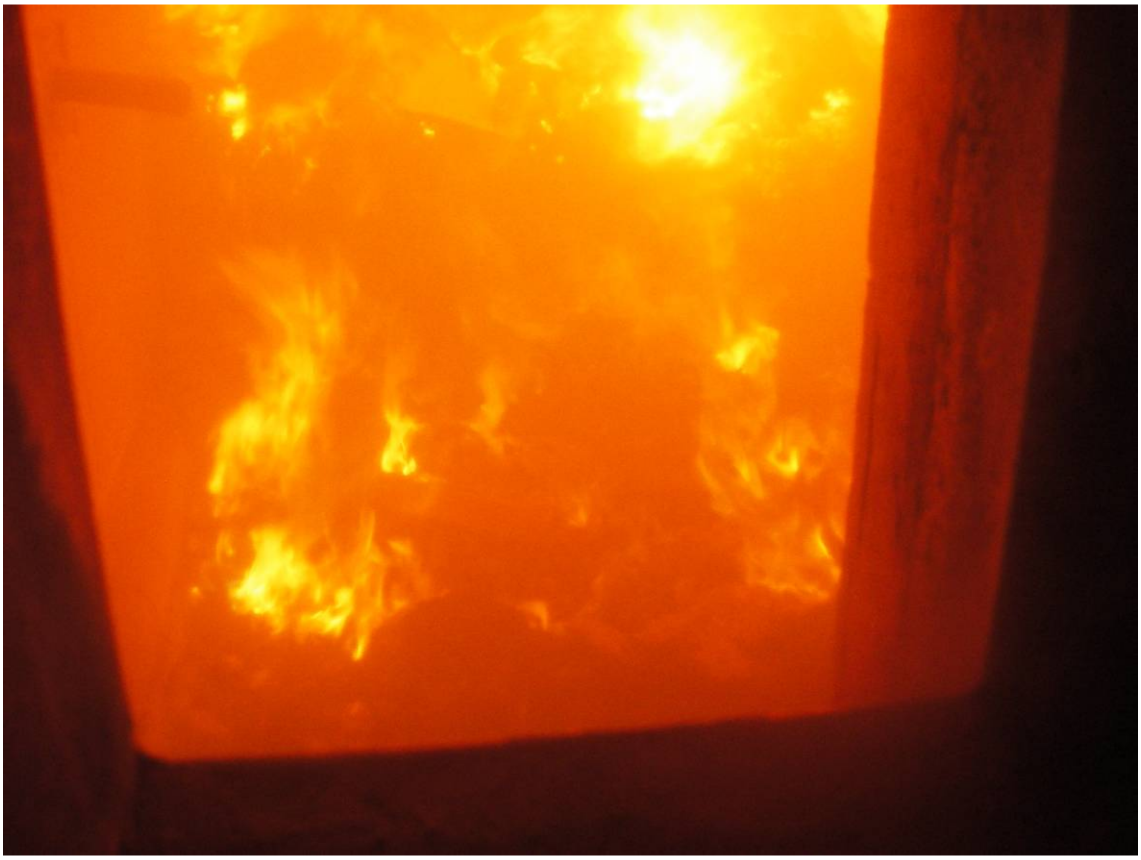
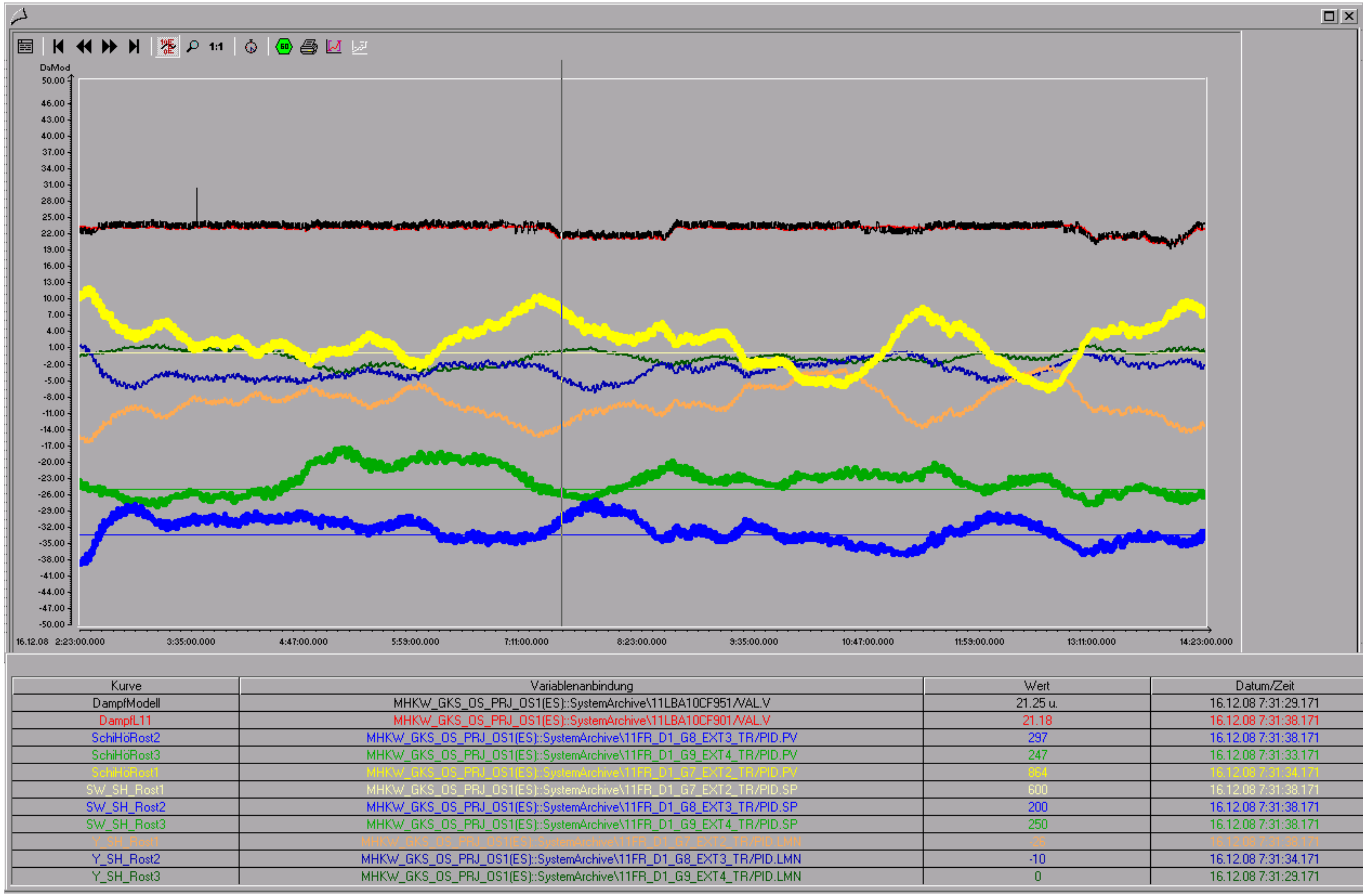


Figure 3.12: Instability with “long fire” and high bed height photographed from the deslagger side of the combustion chamber

Just one single “over-swell” can force a need to shut down the plant and clean the deslagger. This can cause 3-4 days of a standstill with all its negative influences as no throughput, no income, danger for the operators of the plant etc. It is clear, that cases like these should be avoided.

As shown in Figure 3.13 the bed height on grate 1 begins to increase (thick yellow line in relation to thin yellow line). The control variable of the CCS which processes the model information about the high grate reacts in opposite direction (beige line). This leads to a reduction of bed height in grate zone 1 and in the following hours induce a normal height at zone 2 (thick blue line in relation to thin blue line) and 3 (thick green line in relation to thin green line). This excellent result was reproducible for a lot of cases.



Kurve	Variablenanbindung	Wert	Datum/Zeit
DampfModell	MHKW_GKS_OS_PRJ_OS1(ES)::SystemArchive\11LBA10CF951/VAL.V	21.25 u.	16.12.08 7:31:29.171
DampfL11	MHKW_GKS_OS_PRJ_OS1(ES)::SystemArchive\11LBA10CF901/VAL.V	21.18	16.12.08 7:31:38.171
SchiHöRost2	MHKW_GKS_OS_PRJ_OS1(ES)::SystemArchive\11FR_D1_G8_EXT3_TR/PID.PV	297	16.12.08 7:31:38.171
SchiHöRost3	MHKW_GKS_OS_PRJ_OS1(ES)::SystemArchive\11FR_D1_G9_EXT4_TR/PID.PV	247	16.12.08 7:31:33.171
SchiHöRost1	MHKW_GKS_OS_PRJ_OS1(ES)::SystemArchive\11FR_D1_G7_EXT2_TR/PID.PV	864	16.12.08 7:31:34.171
SW_SH_Rost1	MHKW_GKS_OS_PRJ_OS1(ES)::SystemArchive\11FR_D1_G7_EXT2_TR/PID.SP	600	16.12.08 7:31:38.171
SW_SH_Rost2	MHKW_GKS_OS_PRJ_OS1(ES)::SystemArchive\11FR_D1_G8_EXT3_TR/PID.SP	200	16.12.08 7:31:38.171
SW_SH_Rost3	MHKW_GKS_OS_PRJ_OS1(ES)::SystemArchive\11FR_D1_G9_EXT4_TR/PID.SP	250	16.12.08 7:31:38.171
Y_SH_Rost1	MHKW_GKS_OS_PRJ_OS1(ES)::SystemArchive\11FR_D1_G7_EXT2_TR/PID.LMN	-26	16.12.08 7:31:38.171
Y_SH_Rost2	MHKW_GKS_OS_PRJ_OS1(ES)::SystemArchive\11FR_D1_G8_EXT3_TR/PID.LMN	-10	16.12.08 7:31:34.171
Y_SH_Rost3	MHKW_GKS_OS_PRJ_OS1(ES)::SystemArchive\11FR_D1_G9_EXT4_TR/PID.LMN	0	16.12.08 7:31:29.171

Figure 3.13: Influencing of amount of combustion air by bed height (flow of air)

4 MODEL PREDICTIVE CONTROL (MPC)

The model predictive control (MPC) had been developed by TNO. This concept uses an analysis of historic data of the plant to develop a mathematical model of the behaviour of the plant. An internet data connection from TNO to GKS had been implemented. So the data could easily been taken from the plant by GKS (computer safety by firewall and manual plug on at GKS after telephone call). In detail the background of analysing the data is described in deliverable D2.1.1. For the analysis a measurement of CO2 is necessary. This is not obligatory at WtE-plants and even at GKS. A CO2-measurment was chosen. Sick GmbH, Reute, Germany, was well known in measuring CO2 and so a device of this company had been selected by TNO and installed at GKS (Figure 4.1). After a specific time it was noticed, that the CO2 concentration would be too low. The Sick equipment listed an average of about 7,3 Vol.-%,wet. Combustion calculations estimated the concentration at about 10 Vol.-%,wet. (Figure 4.3) which fits to experiences that had been made in the past.

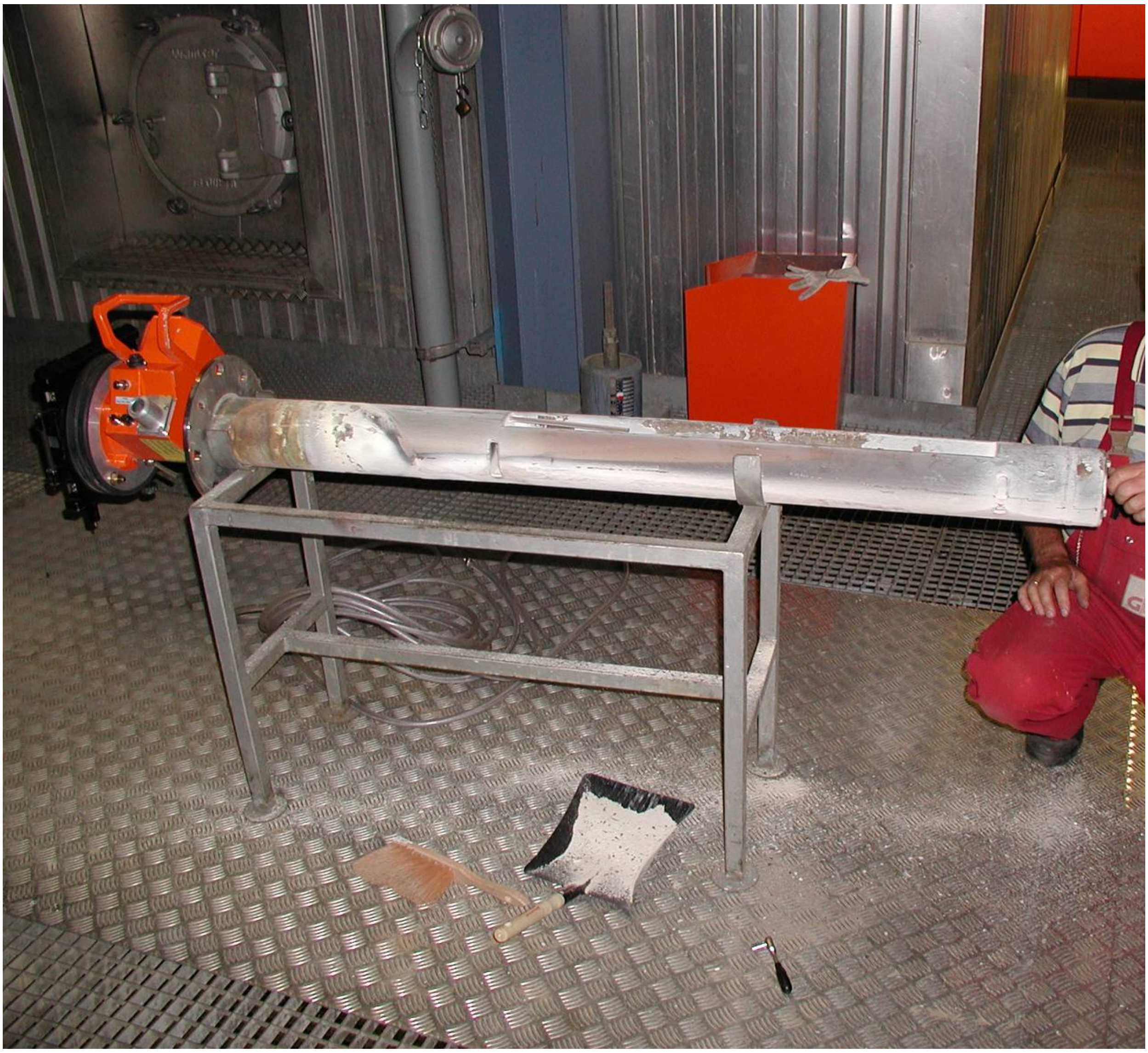
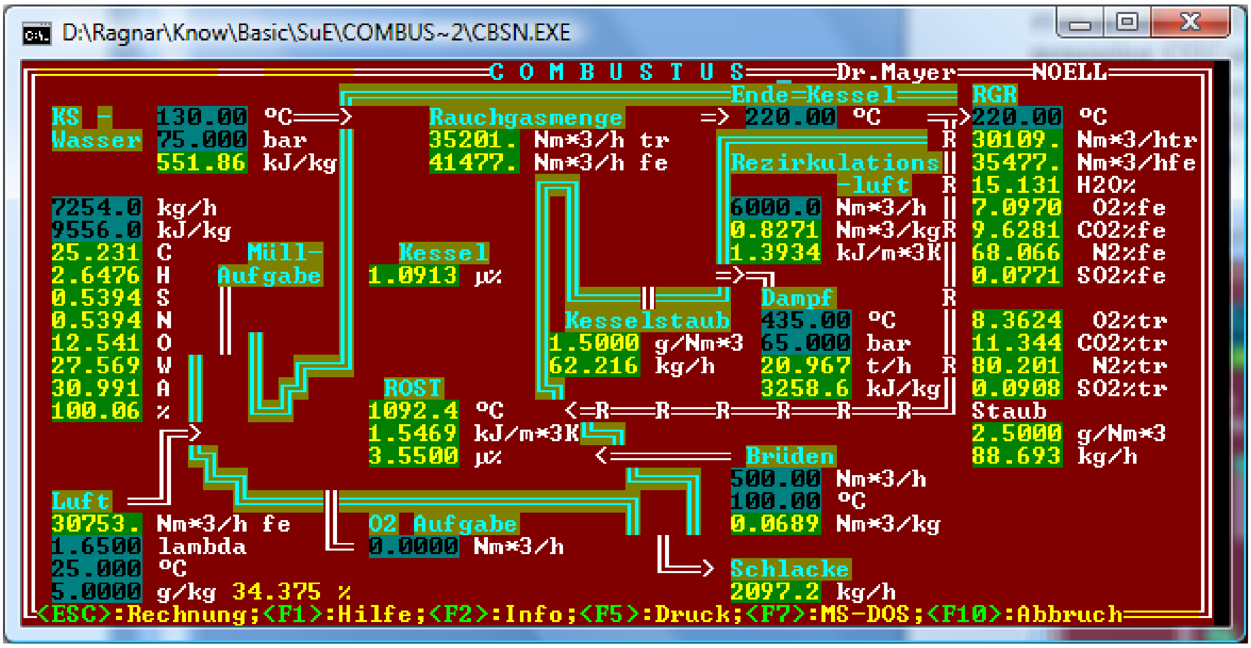


Figure 4.1: CO2-Sonde



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                                        C O M B U S T U S════Dr.Mayer════NOELL═══
                                                Ende=Kessel         RGR
 KS -   130.00 °C==>      Rauchgasmenge     => 220.00 °C   ==>220.00 °C
 Wasser 75.000 bar        35201. Nm*3/h tr                  R 30109. Nm*3/htr
        551.86 kJ/kg      41477. Nm*3/h fe   Rezirkulations|| 35477. Nm*3/hfe
                                                    -luft   R 15.131 H2O%
 7254.0 kg/h                                 6000.0 Nm*3/h || 7.0970  O2%fe
 9556.0 kJ/kg                                0.8271 Nm*3/kgR 9.6281 CO2%fe
 25.231 C      Müll-      Kessel             1.3934 kJ/m*3K|| 68.066  N2%fe
 2.6476 H    Aufgabe    1.0913 µ%           =>              || 0.0771 SO2%fe
 0.5394 S                                     Dampf         R
 0.5394 N                          Kesselstaub 435.00 °C    || 8.3624  O2%tr
 12.541 O                          1.5000 g/Nm*3 65.000 bar || 11.344 CO2%tr
 27.569 W                          62.216 kg/h 20.967 t/h   R 80.201  N2%tr
 30.991 A                 ROST                 3258.6 kJ/kg|| 0.0908 SO2%tr
 100.06 %               1092.4 °C     <=R══R══R══R══R══R═   Staub
                        1.5469 kJ/m*3K                      2.5000 g/Nm*3
                        3.5500 µ%      <════════ Brüden     88.693 kg/h
                                               500.00 Nm*3/h
 Luft                                          100.00 °C
 30753. Nm*3/h fe       O2 Aufgabe             0.0689 Nm*3/kg
 1.6500 lambda          0.0000 Nm*3/h
 25.000 °C                                  ══> Schlacke
 5.0000 g/kg 34.375 %                          2097.2 kg/h
<ESC>:Rechnung;<F1>:Hilfe;<F2>:Info;<F5>:Druck;<F7>:MS-DOS;<F10>:Abbruch═══
```

Figure 4.2: Combustion calculation as an indication of the correctness of the CO2-measurement

Calibration measurements had been ordered by GKS from TÜV-Germany, to come to better results with the Sick-measurement. Figure 4.3 shows the good relation between the calibration measurement of TÜV and the Sick measurement after calibration. Figure 4.4 demonstrates the significant differences between the specific methods.

The CO2 sonde at the end of the boiler had additional problems. One is that the optical glas is overlaid with sticking dust (Figure 4.5). This makes necessary to dismantle the sonde nearly every month. Another barrier to stable operation is the destruction of the outer tube of the sonde after about one year of operation (Figure 4.6). The coarse dust from the flues gas had so much impulse that the metal got strong erosion.

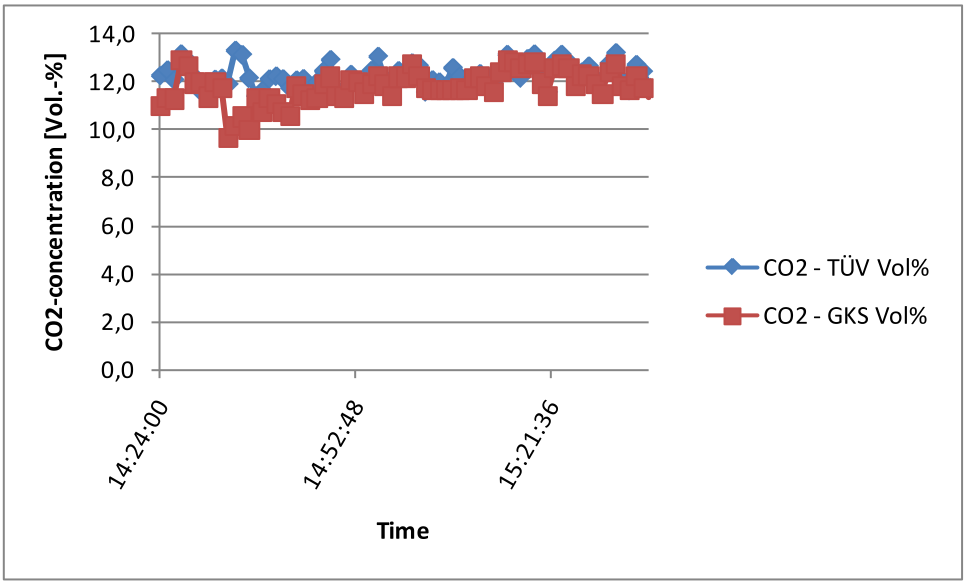

Figure 4.3: Influencing of amount of combustion air by bed height (flow of air)

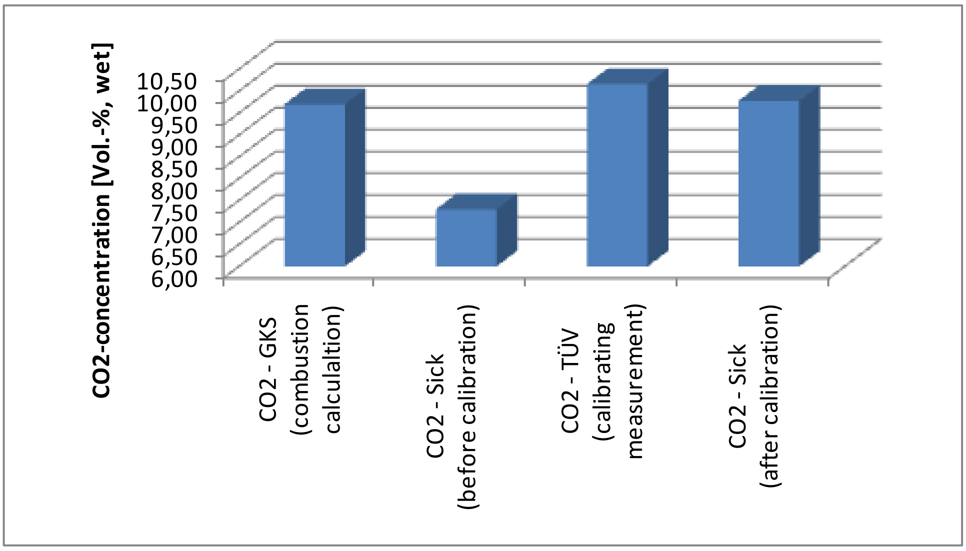

Figure 4.4: Differences in the methods of CO2 measurement

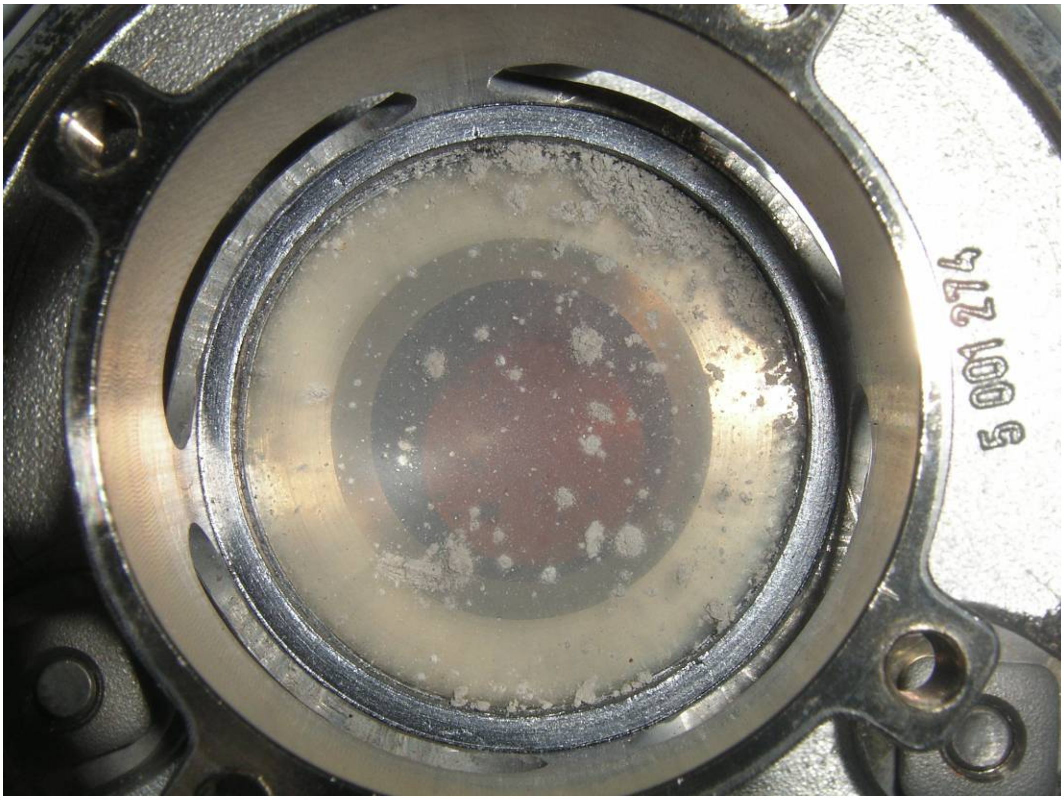

Figure 4.5: Sticking dust on the optic of the sonde

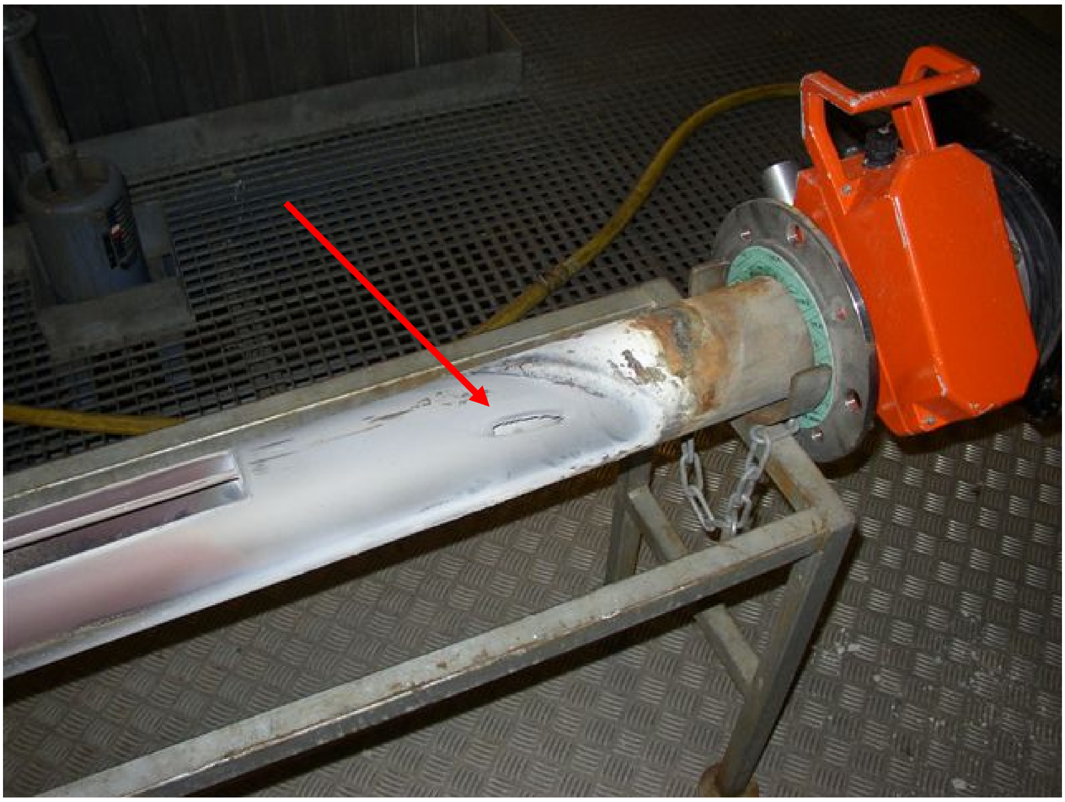

Figure 4.6: Destroyed outer tube after about one year of operation

At the end the measurement delivered sufficient results and the work for keeping the CO2-probe running was acceptable after further several optimisations.
Figure 4.7 gives an overview of the variations that had been carried out at GKS to get the necessary data for the mathematical model for MPC.

	Min	Max
Mullaufgabe	2.9	10
RostGeschwin 1	2.7	70.7
2	2.8	50.4
3	6	22
SecundairLuft	4970	6504
Unterwind_1	450	1775
2	1358	4964
3	2866	5935
4	3244	5060
5	492	1343
Plattenluft		
Frischdampf	20.9	25.9
O2	3.6	9.6

Figure 4.7: Plan of variation of plant operation to get the necessary data for the mathematical model for MPC

Over some weeks TNO had been at the plant and the GKS operational staff supported them and kept an eye on the plant. Sometimes it was necessary to stop the tests to avoid damage or an exceeding of emissions. As said above the results are presented in deliverable D2.1.1.

5 COMPARISON OF MBC AND MPC

The following table (Table 5.1) gives an overview of the performance of the two investigated systems. It can be seen that the Advanced-PID system had an advantage compared with the MPC system. It should be taken into account that PID bases on a well experienced system while the MPC is quite high sophisticated and needs probably more time to be adjusted properly. Although both systems are non-linear systems the MPC model has no information about the amount of the waste on the grate up to now.

Table 2: Measured performances of INCA (MPC) and GKS (Advanced-PID-MBC) controller (see D2.1.1)

Controller	**Length data set [hr]**	**STD(Steam) [t/h]**	**STD(O2) [%]**
INCA	3.75	0.23	0.57
INCA	5.63	0.45	0.74
INCA (∈ previous data set)	1	*0.16*	*0.50*
INCA, average	**3.75+5.63**	**0.34**	**0.66**
GKS	1.88	*0.12*	*0.32*
GKS	3.33	0.20	0.47
GKS	1.67	0.14	0.36
GKS, average	**1.88+3.33+1.67**	**0.15**	**0.38**

The figure below shows the recorded steam production from the same period of time from Line 11 with the INCA controller (red line) and the steam production from Line 12 with the Advanced-PID controller. The set point for both plants was 23.0 t/h. The duration of this test was about 6 hours.

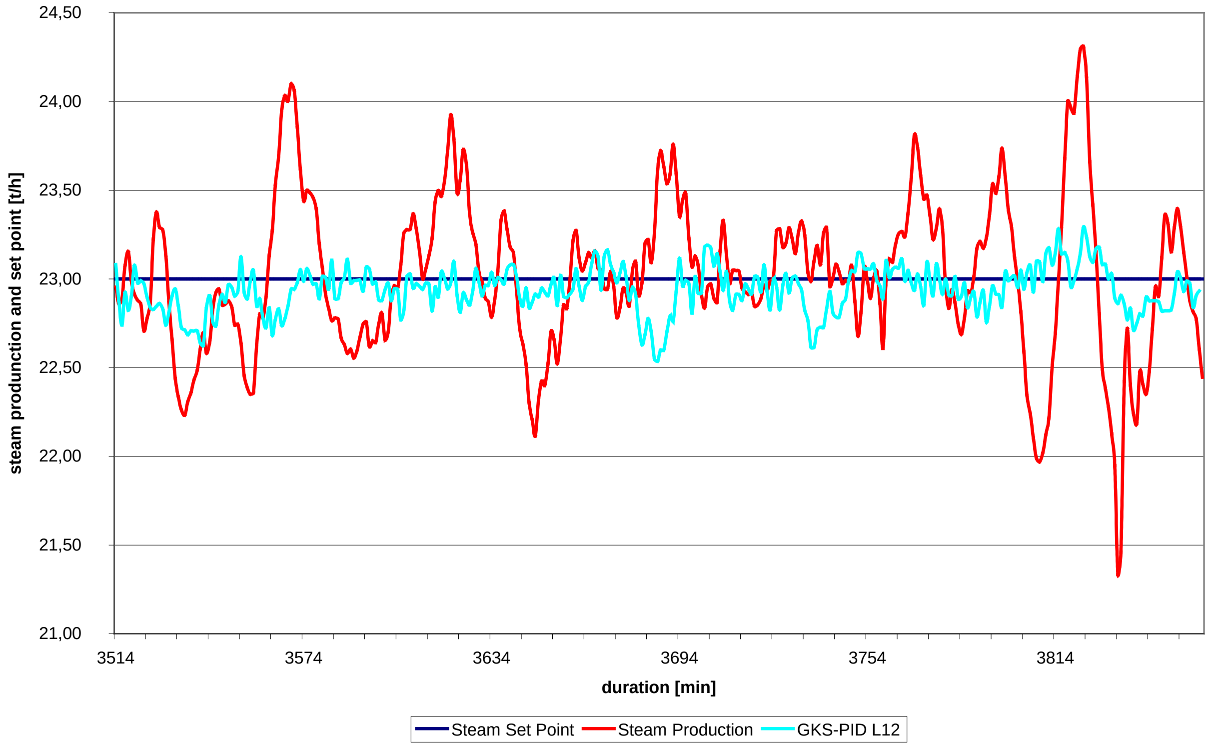

Figure 5.1: Measured steam production of INCA (MPC) controlled plant and GKS-PID controlled plant

6 SUMMARY

The two most promising combustion control systems had been investigated at the WtE plant of GKS:

- Advanced-PID-MBC
- MPC

The Advanced-PID system made an excellent control of the combustion. The additional physical-chemical model is connected via OPC to the combustion control system (CCS). The connection runs reliable and fast. The model could give valuable information to the CCS. One significant information is the bed height of the fuel bed over the different zones above the grate. The information had been transformed into the PID system and the reaction of the Advanced-PID system had shown at examples that it can avoid critical situation on the grate (e.g. “over-swell”)
The MPC had been installed by TNO at the GKS WtE plant. To use the mathematical model the installation of a measurement of CO2 was necessary. To get a validated measurement there had to be done a lot of optimisation. At the end the MPC delivered good results which are not so good as the Advanced-PID system but seem to have a high potential. One probably promising way would be to integrate the MBC into MPC to get information about the source of enthalpy which is available within the fuel bed on the grate which has a total enthalpy of nearly that amount that is fed into the combustion chamber within one hour.

To summaries is can be said that both CCS deliver very good results and a significant improvement compared to the old CCS concerning efficiency and emissions.