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Abstract

Fuel bed models are the key to on the one hand side a better understanding of the combustion process and on the other hand side an important instrument to deliver reliable boundary conditions for CFD simulations. While the GKS-model has a significant plus at the description of the transportation and mixing in the fuel bed; the TNO-model has an advantage concerning a better prediction of the simulation temperatures.

All in all the available fuel bed models deliver more or less plausible results and are good instruments for predicting starting conditions for CFD-calculations.

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TABLE OF CONTENTS

Page

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 or release or the release of emissions by uncontrolled operation.

To keep a real commercial plant in good operation a lot of knowledge has be present for the operators. The knowledge about the combustion on the grate is really poor. Just the formation of the main combustion products as H2O, CO2, O2, N2, SO2 and HCl are easily to be calculated. It can hardy be foreseen where these components occur in the combustion chamber and what minor components will be formed, i.e. CO, CxHy, aerosols etc.

The use of CFD (computational fluid dynamics) will give the possibility to locate different reactions, flows, residence times etc. and get a further “feeling” about the plant. But all the CFD simulation, which is a very good instrument to describe specific behaviour of the flue gas, is depending on the boundary conditions. The main boundary conditions are:

- Geometry of combustion chamber and boiler
- Properties of the walls, inserted tubes and other internals
- Inlet of gases (for example secondary air or recirculation gas)
- Flow off of the flue gas and especially
- Inlet of fuel.

The last one is the most important but unfortunately the less known.

A lot of attempts had been made up to now, to build up models to describe the processes in the fuel bed. In this deliverable the differences of the two fuel bed models which had been developed by members of the consortium will be described.

2 OVERVIEW OF FUEL BED MODELLING

In the last thirty years several attempts had been made to describe the process in the fuel bed of grate systems. The main works are.

1. Univ. Sheffield – Prof. Swithenbank et al.
2. Univ. Bochum – Dr. Krüll et al.
3. Univ. Bochum – Dr. Wirtz et al.
4. Univ. Duisburg-Essen – Prof. Görner et al.
5. TU Clausthal – Prof. Beckmann et al.
6. Fraunhofer – Dr. Gruber et al.
7. FZK – Dr. Peters et al.
8. Umsicht – Dr. Wolf et al.
9. TNO – Dr. von Kessel et al.
10. GKS – Dr. Warnecke et al.:

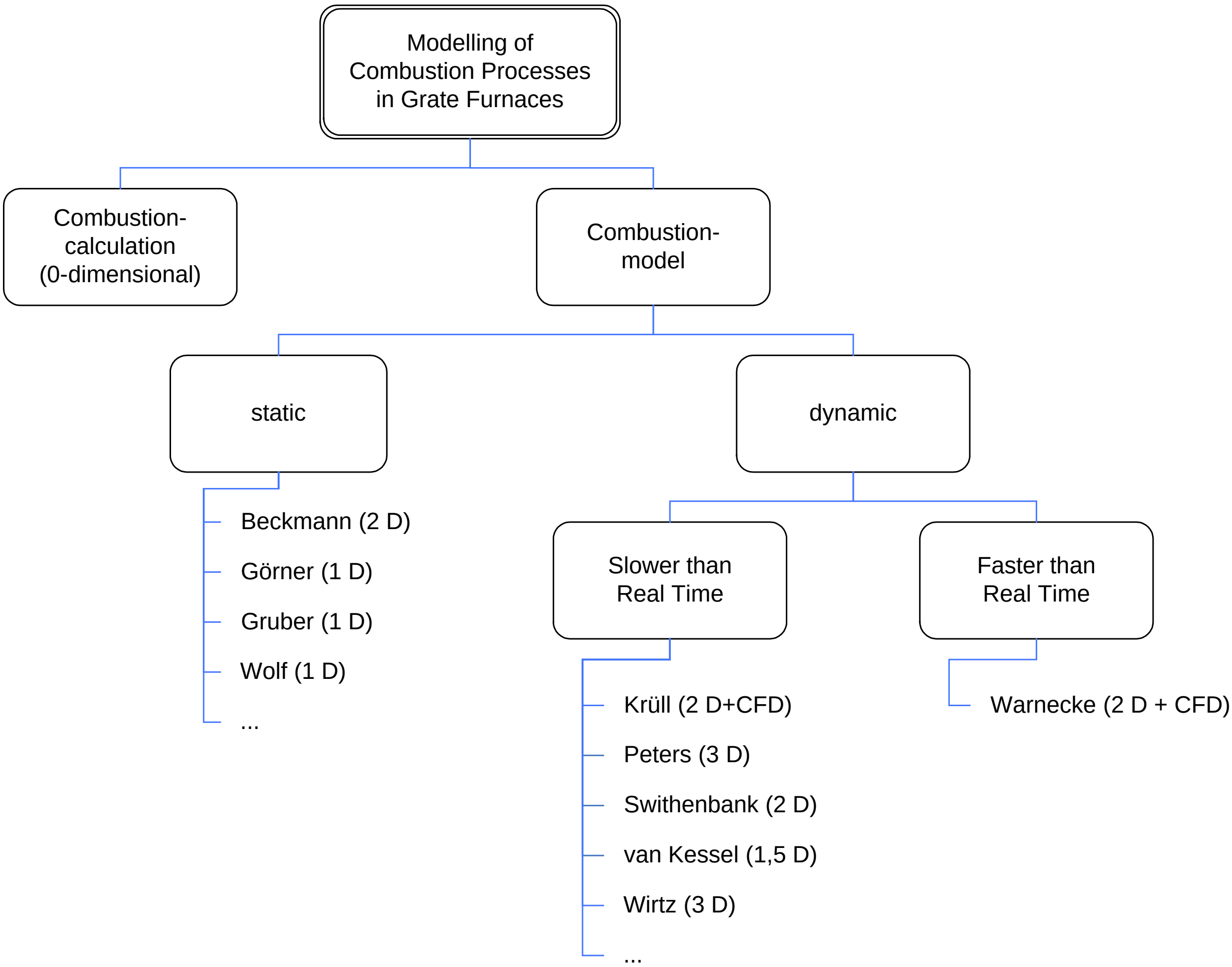

Figure 2.1: Overview of activities about grate furnace modelling

There are several other attempts, mostly based on Excel-files, which can all not been quoted. Figure gives an overview about the models structured in static and dynamic models. “Static” means here that the model runs with one set of boundary conditions and delivers one result. In “Dynamic” models the user is able to change boundary conditions and the model delivers continuously new results. The intermediate output data of the dynamic models between two stationary simulation results with two different boundary conditions are physically and chemically plausible (and meet measurements of real plants).

A systematic overview for the different models can be taken from [Wolf, 2005].

3 FUEL BED MODELS FROM TNO AND GKS

Two main developers of the above listed fuel bed models have been part of the NGBW consortium. It was the aim to use the results of these models as boundary conditions for CFD simulations as they had been carried out in deliverable D2.6.26. For this it should be described what the differences between these two models are. A detailed description of the TNO model is given in D2.5.15.

3.1 Basics in about the models

The general difference is the kind of reactor model. While the TNO-model uses a 1,5-dimensional plug flow reactor the GKS-model bases on a 2,5-dimensional multi steering reactor. Both, plug flow and steering reactor, are the two used models in process engineering. The differences are given in the time depending relations.
While the TNO-model simulates the fuel bed partially at a defined time step at a certain position of the grate the GKS-model simulates the whole grate from the feeding ramp to the deslagger simultaneously in real time or faster. So the TNO-model needs more time and more manpower to generate the data from a complete grate.
To get an overview about the two models Fig. 3.1 gives a view on the model of TNO and Fig. 3.2 of the GKS-model. In general the GKS-model is similar to the TNO-model but do run more or less simultaneously for all cells while TNO has the focus on one cell at one time.

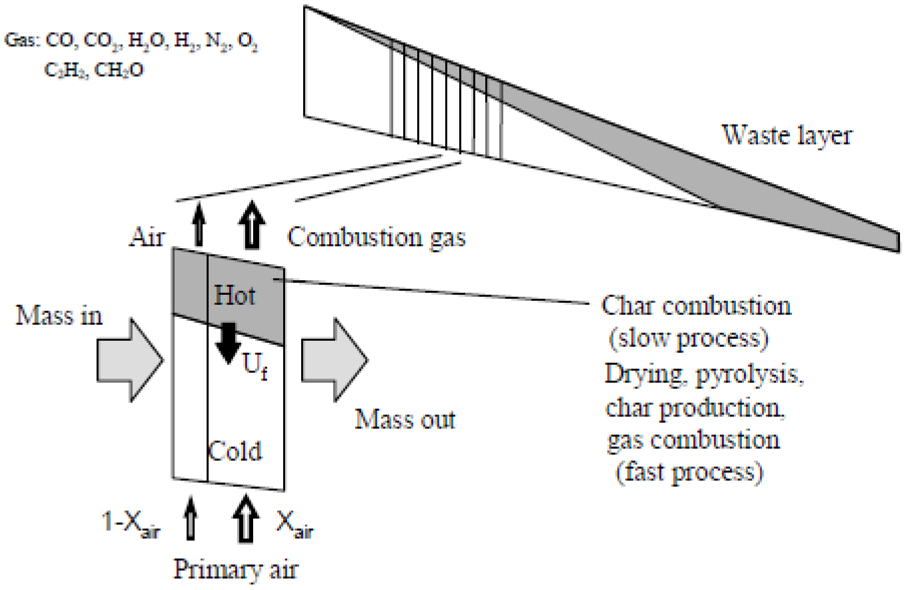

Fig. 3-1: TNO-model for one cell

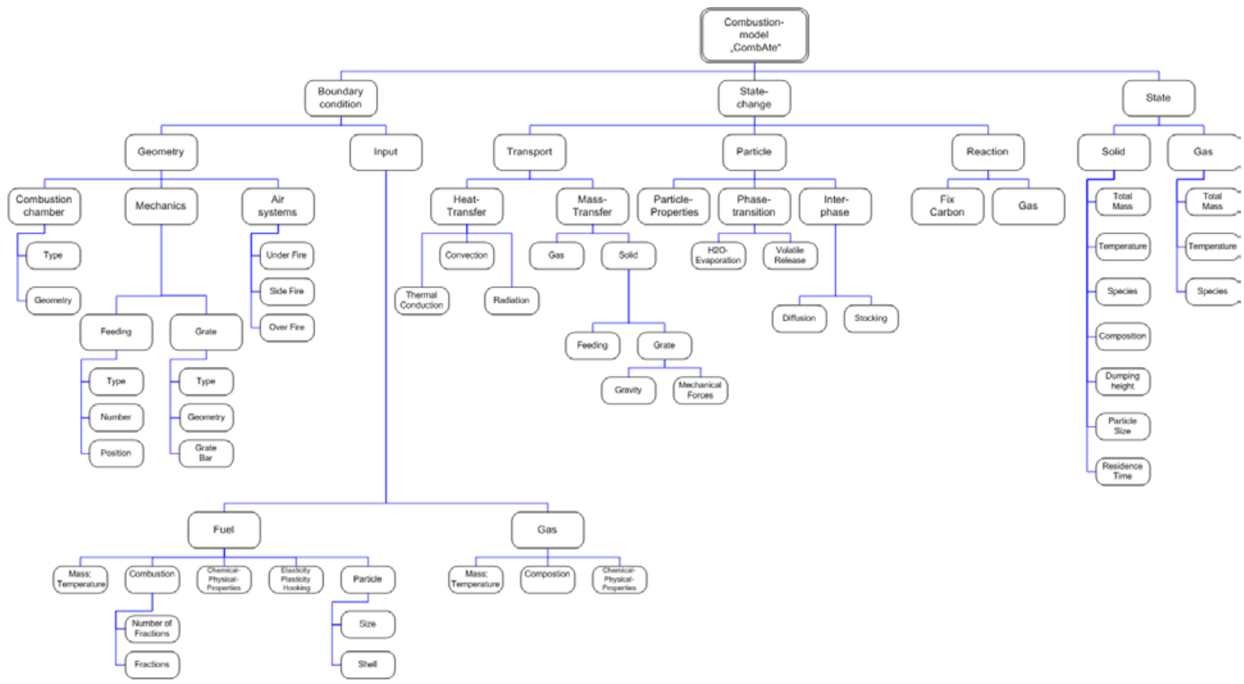

Fig. 3-2: GKS-model for one cell

3.2 Particle model

The particle model of TNO bases on a uniform composition. The drying rate is linear depending on the overall concentration in the particle. GKS-particle have 3 different shells. One particle consists of one waste fraction. Usually 13 different waste fractions are defined (i.e. paper, organic, plastics, inert etc.). Each waste fraction consists of about 10 species (i.e. $H2O$, CO, $CO2$, $O2$ etc.). At the beginning the species concentration in one particle is distributed equal. With increasing temperature the concentration of the species begin to change; normally at the outer shell at first.

3.3 Heat transfer

The heat transfer mechanisms into the fuel bed are for both models conduction, convection and radiation. TNO uses a relation factor, based on a specific triangle, for the downward velocity of the pyrolysis front into the fuel bed. In contrary to that in the GKS-model the velocity of reaction into the bed is a function of the transport mechanism of the grate and the fuel properties. In opposite to the TNO-model GKS assumes that no gas phase reaction takes place in the fuel bed. Both models have a reaction model for the coke in the bed and have incorporated a radiation heat transfer between fuel bed and upper gas phase in both directions, i.e. from bed to gas and from gas to bed.

3.4 Water

Within both models the liquid water content in the wet waste is heated up. In the GKS-model there is a temperature profile in the particle while in the TNO-model there is a constant temperature for the whole particle. Increasing the temperature up to 100°C H2O will be evaporated. GKS has a limitation by release of the water due to 3 different shells per particle where the mass and heat transfer is limited. TNO has a limitation to the evaporated water by the maximum content that the gas flow can take over. The maximum content is given by the water saturation $\Phi w = U \cdot A\ (p_{w,s} - p_{w,g})$, where $U = f(Sh, Re)$.

3.5 Volatiles

Both fuel models refer to a limited number of species. These species are chosen as representative “gases” which are “solids” at ambient conditions. With influencing heat, the “solids” evaporate, or lets better call it pyrolyse. The used enthalpy for the pyrolysation is set to zero in both cases. The release of these volatiles is based in the GKS-model on measured data which had been found together with [Marzi, 2005] by analysing the temperature and time depending release f(t,T) of volatiles from 13 different waste fractions. TNO uses a release rate f(T) and a formation of species by error-functions. A difference is not only in the model itself but also in the used species. Tab. 3.1 gives an overview of the different species.

Tab. 3.1

GKS-species	TNO-species
N2	N2
O2	O2
H2	H2
H2O	H2O
CO	CO
CO2	CO2
C3H8	C2H2
	CH2O
C	C

The hydrocarbons are representatives of the pyrolysis tar and C is the placeholder for coke.

3.6 Reaction in the gas phase

As yet mentioned the TNO-model includes gas phase reaction in the fuel bed. GKS assumes that in general the flow velocity is the fuel bed channels is higher than the flame velocity, so that there will not be reactions in the gas phase inside the bed; while there is a solid phase reaction of coke. GKS simplifies the gas phase reaction above the bed by a complete combustion calculation at gas phase temperatures for all the components except coke and the tar placeholder (C3H8). For C and C3H8 there had been chosen reduced kinetic parameter sets to decrease the reaction velocity.
In the TNO-model the reactions of the non-tar components are calculated by Gibb's Minimisation at gas phase temperatures. An error-function at a specific temperature deliver the relation between the tar components C2H2 and CH2O.

3.7 Transport and Mixing

Because the stationary TNO-model bases on a pot-furnace-model and the calculation have to be made by step-by-step along the grate there is neither a transportation nor a mixing model included. The pot furnace will be observed as a function of time f(t).
The instationary GKS-model has a transport model which implements the mixing of the fuel. The transportation is described by the movement and the geometry of the grate bars in relation to the properties of the fuel. The grate movement is given by the strokes of the grate bars. A higher grate bar is able to move more fuel. It has been taken further into consideration the angle of the grate bars as well as the angle of the grate itself. This allows to include the effect of gravity on fuel movement. The influence of properties of the fuel, as there are weight, density, elasticity etc., had been taken into account as well.

4 RESULTS

On basis of the same boundary conditions calculations with both models have been made. The boundary conditions are given in the following.

Fuel:

	Mass flow [kg/s]	Temperature [°C]	Heating value [kJ/kg]
Fuel mass	2.2	25	10.075

Primary air (or: under fire air):

	Flow [Nm³/h]	Mass flow [kg/s]	Temperature [°C]	Velocity [m/s]
UA 1	800	0.2873	25	0.04
UA 2	3650	1.3110	25	0.19
UA 3	4180	1.5013	25	0.22
UA 4	3790	1.3612	25	0.19
UA 5	640	0,2299	25	0,03

Side air (or: plate air):

	Flow [Nm³/h]	Mass flow [kg/s]	Temperature [°C]	Velocity [m/s]
PL1 one Side	1800	0.6437	120	0.50
PL2 one Side	975	0.3487	120	0.25
PL3 one Side	525	0.1877	120	0.14
PL4 one Side	450	0.1609	120	0.17
Side air both Sides	7500	1.3410	120	

Secondary air

	Mass flow [kg/s]	Temperature [°C]	Velocity [m/s]	Velocity x [m/s]	Velocity y [m/s]
Front wall Nozzle 1 - 6	0.166	120	52.2	52.199	-0.166
Rear wall Nozzle 1-4	0.248	120	78.299	-76.322	-17.483

Rezi nozzles (1-9) at side walls:

Mass flow [kg/s]	0.137
Temperature [°C]	150
Velocity [m/s]	61.032
CO_2 [kg/kg]	0.2032
H_2O [kg/kg]	0.1066
O_2 [kg/kg]	0.0404
N_2 [kg/kg]	0.6498
Molecular weight [kg/kmole]	28.56

With these data the models deliver the following figures (Fig. 4-1 and Fig. 4-2). It can be seen, that the GKS-model predicts an earlier (means closer to the feeder) end of pyrolysis and combustion than the TNO-model. Here the GKS-model is obviously more reliable. On the other hand the GKS-model has a too high temperature at the end of the grate, what is not true compared with reality. Investigations showed that the radiation model is a bit global and therefore delivers not realistic results concerning the temperature distribution.

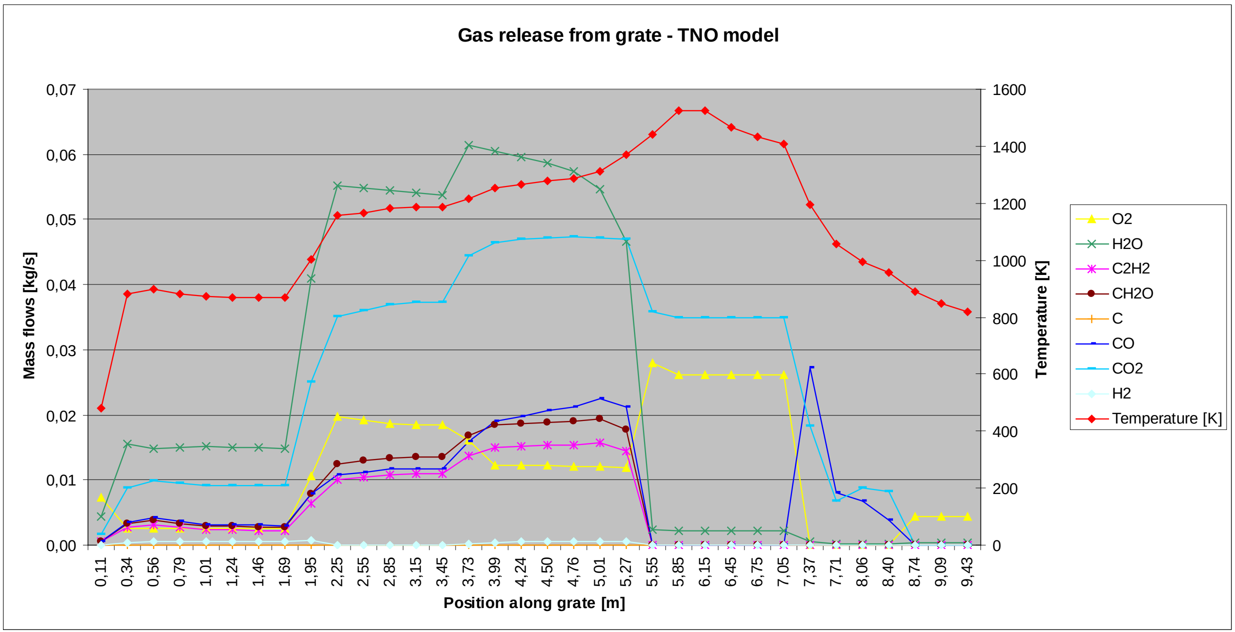

Fig. 4-1: Species data of the TNO-model

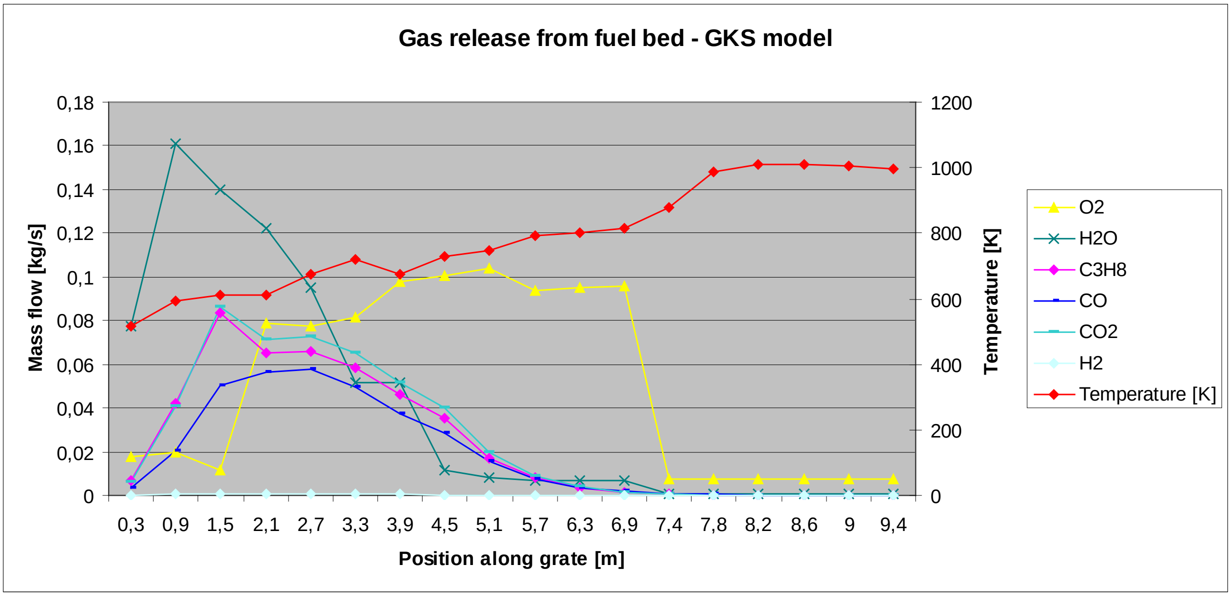

Fig. 4-2: Species data of the GKS-model

5 SUMMARY AND OUTLOOK

Tab. 5.1 gives an overview about the different constituent parts of the two different models. The GKS-model includes much more physical-chemical subject than the TNO-model; but the TNO-model delivers a better temperature distribution above the fuel bed.

Tab. 5.1: Comprehensive comparison of the two fuel bed models

	GKS	TNO
0.) Basics	● 2,5 dimensional cascade multi steering reactor model	● 1,5 dimensional plug flow reactor model (pot furnace)
	● simulates the whole grate from feeding ramp to deslagger simultaniously in real time or faster	● simulates the fuel bed partially at a defined time step at a certain position of the grate
	● closed element, mass and energy balances	● closed element, mass and energy balances
1.) H_2O	● wet particles are heated up	● wet particles are heated up
	H_2O → evaporisation	H_2O → evaporisation
	● Temp.-profil within the particle	● Temp-profil ← to be checked by Bertus
	● evaporation limited by mass-/heat transfer	● special: saturation equation
		Øw = U · A · (Pw,s - P w,g)
		↑
		f (Sh,Re)
2.) Volatiles	● model of measured data from 12 + 3 waste fractions as f (T,t) [Marzi]	● pyrolysis model for C_2H_2, CH_2O with release rate f (T) [Shasivadee] and formation of species by error-functions
3.) Particle modell	● several layers	● to be checked by Bertus
4.) Heat transfer	● pyrolysis enthalpy = 0 (except H_2O)	● pyrolysis - enthalpy = 0 (except H_20)
	● heat transfer into the bed: conduction, convertion, (radiation of particles) and additionally as a result of the transport model	● heat transfer into the fuel bed: conduction, convection, radiation in one equation and a relation for downward velocity of the pyrolysis front (triangle)
	● **no** gas phase reaction in the bed (ignition speed low)	● gas phase reaction and radiation in bed
	● radiation from above gas phase (both directions)	● radiation from above gas phase (both direction)
5.) Transport / Mixing	● transport model f (grate bar, grate velocity, all movements of grate, feeding ramp, grate angle, lastic parameter of waste + viscosity, ...)	● no transient calc. (pot furnace)
	● mixing as a result of transport model	● no mixing
	● transient cascade multi steering reactor	● pot furnace as f(t)
6.) Reaction in gas pahse	● reaction realised in CFD pgm.; complete combustion calculation for stand alone operation of programme included	● Gibb minimisation O_2, H_2O, CO_2, CO, H_2, C and gas phase temperature; error function + T delivers relation between tar components
	● no channeling of primary air (no need for)	● channeling of primary air
	● tar: C_3H_8	● tar: C_2H_2, CH_2O
	⏟	⏟
	"model" - components	"model" - components
	(kinetic parameters filled)	(kinetic parameters filled)

Both fuel bed models deliver mainly plausible values. While the TNO-model is better concerning the temperature distribution, the GKS-model includes much more physical effects. An optimisation of both models should be promising.

6 LITERATURE

[MARZI, 2006] MARZI, T.; WARNECKE, R.: Freisetzungsverhalten unterschiedlicher Abfallfraktionen und deren Chlor- und Schwefelfracht zur Beschreibung der Vorgänge im Feuerraum. In: VDI-Wissensforum (Hrsg.): *Beläge und Korrosion, Verfahrenstechnik und Konstruktion in Großfeuerungsanlagen – Seminar am 25.-26. April 2006 in Würzburg.* Düsseldorf: VDI-Verlag, 2006

