# MODELLING OF THE PYROLYSIS OF BIOMASS IN ROTARY KILNS

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## Introduction

A lot of different processes have been developed for the thermal conversion of biomass. For the production of solids pyrolysis processes are used. The yield and properties of the products depend on the kind of biomass and the process conditions. Pyrolysis in indirect heated rotary kilns is a suitable process for handling biomasses with varying properties. Yield and product properties can be varied to a large extent by changing the process parameters of the kiln. A mathematical model is presented for process optimization regarding yield and product properties and energy consumption. The model has matched the experimental data of the biomass conversion presented by Wiest [1] satisfactorily.

## Model

Figure 1 shows the set up of the indirect heated baffleless rotary kiln with its main items. For all these items the energy balance is solved. Additionally the mass balance of each species is solved for the gas phase and the granular bed. The mathematical simulation is composed of the following submodels to take various chemical and physical changes into account.

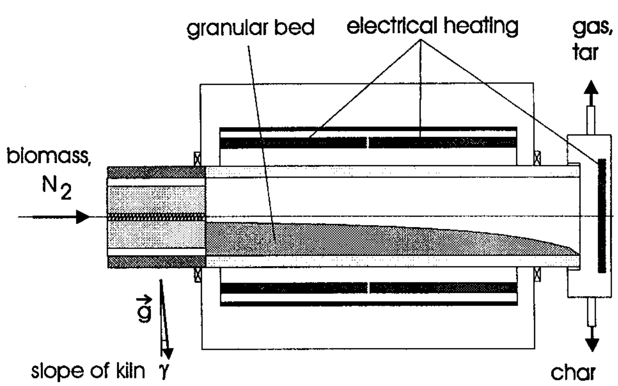


**Figure 1:** Rotary kiln with the diverse modeled items

***Transport model of the granular bed:***

The convective transport model is based on a differential equation suggested by Seaman[2]. This model transforms the bed motion at the top of the granular bed (active layer) to the bulk region beneath (passive layer). The solution could be interpreted as the axial component of the velocity field. The radial velocity component has been calculated by integration of the mass balance. The result is shown in Figure 2. The differential equation has been developed assuming the residence time of particles in the active layer is negligible compared to those in the passive layer. Hence only convective transport is considered in the active layer by the model of Seaman. Beside the convective transport, particle mixing in the active layer is important. This effect is taken into account by transforming the dispersion coefficient of the active layer into a dispersion coefficient of the passive layer.

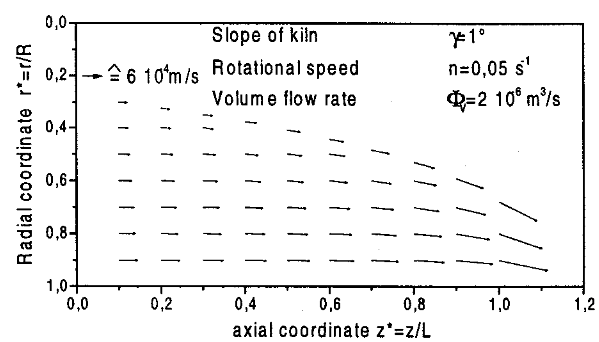


**Figure 2:** Velocity field of the granular bed

***Heat transfer model of the granular bed:***

To calculate the heat transfer coefficient between the kiln wall and the granular bed the model of Schlünder [3] is used. The heat transfer by radiation between the surface of granular bed and the wall is considered assuming optical thin gas medium. The convective heat transfer between the granular material and the gas phase is estimated by the convective heat transfer coefficient used for laminar flow in tubes.

***Chemical reaction model:***

Klose and Wiest suggested in [4] the following formal reaction scheme for the pyrolysis of biomass in a rotary kiln .

$$\mathrm{BM} \rightarrow 0{,}029\ \mathrm{CO} + 0{,}073\ \mathrm{CO_2} + 0{,}256\ \mathrm{S1} + 0{,}642\ \mathrm{L}$$

$$\mathrm{S1a} \rightarrow 0{,}072\ \mathrm{CO_2} + 0{,}141\ \mathrm{CH_4} + 0{,}786\ \mathrm{S2a}$$

$$\mathrm{S1b} \rightarrow 0{,}073\ \mathrm{CO} + 0{,}034\ \mathrm{H_2} + 0{,}891\ \mathrm{S2b}$$

$$\mathrm{La} \rightarrow 0{,}100\ \mathrm{CO} + 0{,}630\ \mathrm{CO_2} + 0{,}270\ \mathrm{H_2O}$$

$$\mathrm{Lb} \rightarrow 0{,}630\ \mathrm{CO} + 0{,}046\ \mathrm{CO_2} + 0{,}280\ \mathrm{CH_4} + 0{,}044\ \mathrm{H_2}$$

All reactions are assumed to be first order. The reaction rate is expressed by an Arrhenius equation. BM denotes the biomass feed, S1a, S1b and S2a, S2b different chars, and La and Lb denote different tar fractions.

***Gas phase model:***
The gas heat transfer by radiation is neglected. Thus only convective heat transfer is taken into account. The energy and mass balances are calculated 1D.

## Results and Discussion

Temperature measurements and yields for a biomass carbonization process in an indirect heated rotary kiln are published in [1]. In Figure 3 the calculated temperature field is shown together with the temperature measurements in the granular bed for a biomass feed of $\dot{m} = 0{,}3 \cdot 10^{-3}\ kg/s$, a rotational speed of $n = 0{,}033\ s^{-1}$, a slope of the kiln of $\gamma = 2{,}5^{\circ}$, and a heating temperature of $\vartheta = 600\ ^{\circ}C$. The temperature measuring device was located in a dimensionless radial position between 0,8<r*<0,9. The relative error of the temperature measurement is indicated by error bars. The calculated results of the temperature field are in good agreement with the experimental data.

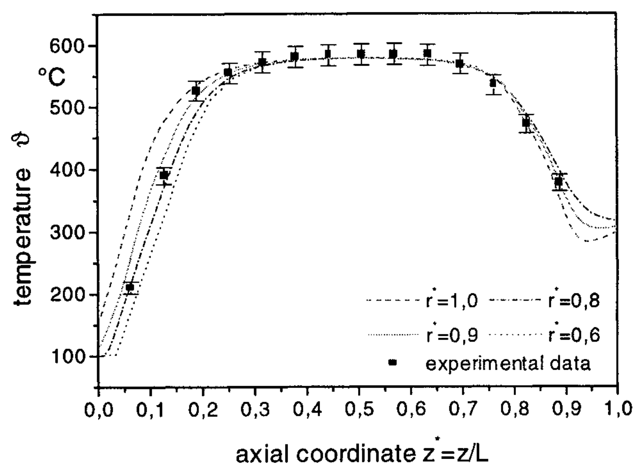


**Figure 3:** Calculated and measured temperatures of the granular bed.

In Figure 4 the calculated and measured yield mass fractions $\beta_i = m_i / m_{BM,0}$ of the solid products S1a, S1b and S2 are shown. The process parameters are the same as mentioned for Fig. 3. The mass fraction of the char S1 rapidly increases shortly behind the inlet of the kiln. This intermediate product decreases as the product S2 is formed. Additionally, the ratio of the heating values of the solid phase $H^s_{0,d}$ and of the biomass $H^s_{0,BM,d}$ is shown. This curve resembles that of the sum of the solid mass fractions S1a+S1b+S2. The heating value increases close to the inlet of the kiln due to the decreasing O/C ratio. The H/C ratio remains nearly constant during the first stages of pyrolysis. After reaching a maximum, the heating value decreases due to the decreasing H/C ratio in the solid product by the conversion of char S1 to char S2.

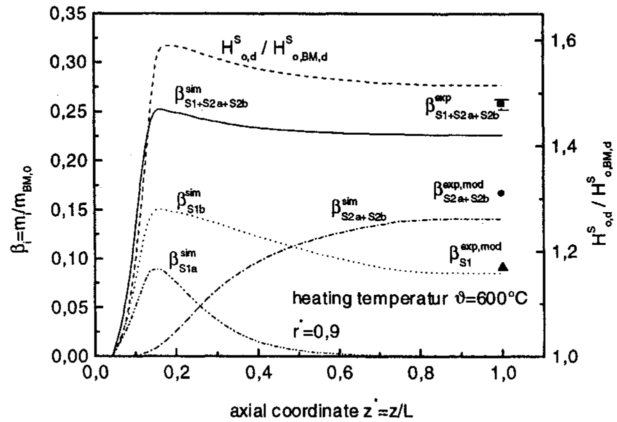


**Figure 4:** Calculated and measured mass fractions of different pseudo components and the dimensionless heating value of the solid phase.

## Conclusion

The simulation results are in good agreement with the experimental data, predicting the temperature distribution and the product properties .
The results show that biomass can be converted to very different solids in a rotary kiln. Depending on the process conditions, either a solid fuel with a high heating value or a char for active carbon production with a low O/C and H/C ratio can be produced.

## References


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