International Energy Agency
Bioenergy Agreement
Task 19
Biomass Combustion

Workshop
Biomass Combustion Modelling

Arranged by:

Sjaak van Loo and Jaap Koppejan
TNO-MEP, The Netherlands

Content:

Minutes of the Meeting,
Biomass Combustion Modelling Workshop

Friday, June 9, 2000
Melia Lebreros hotel
Sevilla, Spain

IEA Bioenergy Task 19
Biomass Combustion Modelling Workshop
June 9, 2000, Sevilla, Spain

Content

Programme

Friday June 9, 2000, Location: Melia Lebreros hotel

9:00 Opening, *Sjaak van Loo, leader IEA Bioenergy Task 19*
9:15 Background of Task 19 and results of questionnaires, *Jaap Koppejan (NL)*
9:30 Presentations of individual models

- Modelling of biomass and waste combustion at TNO, A.R.J. Arendsen, TNO, Netherlands
- Biomass Modelling Tools at Åbo Akademi, Edgardo G. Coda Zabetta, Åbo Akademi, Finland
- Modelling of batch combustion processes, Øyvind Skreiberg, Norwegian University of Science and Technology, Norway
- Optimisation of Low-NOx biomass grate furnaces with CFD modelling, Robert Scharler, TU Graz, Austria
- Mathematical models for design and development of fixed-bed gasification systems, Colomba Di Blasi, Università degli Studi di Napoli "Federico II", Italy
- A numerical model for fixed bed combustion, Jenny Larfeldt, TPS, Sweden

10:20 Coffee
10:40 Presentations of various models (ctd)

- CFD modelling of biomass combustion, Xue-Song Bai, Lund Institute of Technology, Sweden
- Modelling of Solid Fuel Conversion and Transport with TOSCA, Bernhard Peters, FZK, Germany
- Modelling wood combustion in grate furnaces by calculation of the solid fuel transport and conversion on the grate followed by CFD calculations in the gas phase, Thomas Nussbaumer, Verenum, Switzerland
- Straw Bed Conversion, Robert van der Lans, CHEC, Inst. for Kemiteknik, DTU, Denmark
- Application of the 3D Combustion Code AIOLOS to Small Scale and Industrial Combustion Systems, Sven Unterberger, IVD, Stuttgart, Germany

11:30 Discussion on options for mutual co-operation and Task 19 involvement
12:30 Joint lunch with participants in modelling workshop and Task 19 members

Summary of the workshop

Opening, Sjaak van Loo, leader IEA Bioenergy Task 19

The modelling workshop was opened by Sjaak van Loo, welcoming all modellers and IEA Bioenergy Task 19 members and presenting the agenda. The workshop is part of the Task 19 activity on biomass combustion modelling and is a follow up activity of the questionnaire that was send out and evaluated in 1999. The role of Task 19 in this matter is to identify organizations that are involved in modelling biomass combustion processes, and provide a platform for exchanging information amongst these organisations.

Background of Task 19 and results of questionnaires, Jaap Koppejan (NL)

Prior to the organisation of the Sevilla modelling workshop, a questionnaire was send out amongst 59 R&D organisations, manufacturers etc. in the member countries to evaluate the contents and status of ongoing modelling projects and programmes. 38 questionnaires on modelling projects were returned to IEA. The results of the questionnaires were evaluated and shared with the respondents. A summary is attached in annex 2; the full report is available through IEA Bioenergy Task 19.

After the evaluation of the questionnaires, a subset of 13 organisations with models with common focus was selected, namely the modelling of biomass combustion and the calculation of emissions. These 13 organisations were invited to participate in the workshop, and 11 organisations decided to participate. Most of these models are on a process scale, describing wood combustion on a grate or in a fluidised bed. The majority of models is

- Still under development, validation or a detailed application
- Used for process design and meant for the calculation of emissions.
- CFD-based or dynamic physical
- About half of the models include drying, pyrolysis and gasification prior to combustion

Presentations of individual models

The participants presented the specifications of 11 individual models. Copies of the explaining overheads that were presented are included in the annex.

The models presented vary from the thermal decomposition of a single particle to a description of a full combustion system with a grate and secondary combustion in the gas phase. All models are applied for specific purposes, such as a better understanding of the principles of combustion to system and apparatus design for maximum efficiency and minimal emissions or the design of improved control systems and simulators for training purposes.

A significant amount of models that were presented describe biomass combustion in a grate fired boiler. While CFD models are often applied for modelling the behaviour of secondary combustion in the gas phase, the devolatilisation speed of the fuel bed is usually described by static or dynamic physical and chemical models. Depending on the application, the description of the fuel bed model can be fairly superficial (e.g. the TNO-model or the model of TPS) or detailed (e.g. the model of Dr. Peters, Research Centre Karlsruhe).

Discussion on options for mutual co-operation and Task 19 involvement

It was observed that the type of the model that is used and the accuracy of the outcome is closely related to the application for which the model should be used. One can distinguish between empirical, zero dimensional models and detailed application models.

While many application models are based on a CFD calculation code, the level of physical and chemical knowledge built into the CFD code may vary from one model to another, depending on the application of the model. Most models are developed together with an equipment manufacturer to provide insight in the effects of boiler modification on combustion quality. Although the accuracy of the models is typically insufficient to calculate emissions from a given combustion installation, modelling may be very instrumental in evaluating the effects of boiler modification on combustion quality (e.g. by placing additional nozzles or a baffle). One reason for the inaccuracy of CFD codes is the fact that most of these codes have in the past been developed for coal combustion.

However, there is still a great need for knowledge on the consequences for selecting a set of physical and chemical mechanisms on the accuracy of the model, depending on the type of application. While the chemical mechanisms are usually quite well understood and described, the physical mechanisms (turbulence, convections, etc) are much less understood. A steering guide that tells which model to use for what kind of situation would be welcome.

Many models are based on empirical results, and the accuracy of certain assumptions or equations chosen is unknown. Closely related to this is the problem that it may be difficult to solve some complex or implicit thermodynamic equations. It was therefore suggested to communicate proven approaches in this field.

In order to cross-check the validity of the various models applied, it was suggested to perform a validation test. Modelling a whole furnace makes it unclear where errors occur, therefore a validation test should be simple and describe only a submodel of an installation. It was agreed that the devolatalization of biomass on a fuel bed is least understood (e.g. the great influence of alkalis on the char yield) and therefore difficult to describe and calculate. However, since the data requirements of the various models for the fuel bed vary quite a bit, lots of data would be needed and it is questionable whether such a data set would be available at all. Other difficulties generally felt are related to the bed dynamics and the radiation mechanisms.

All participants are asked to list and prioritise the difficulties felt with the development of combustion models, in order to identify eventual follow-up activities.

Conclusion

The IEA Task 19 workshop on biomass combustion provided a floor for developers of various biomass combustion models from different organisations and countries to exchange experiences and difficulties in an open setting, which was much appreciated. It is anticipated that some of the problems identified during the discussions may be surmounted through bilateral or multilateral future cooperation.

ANNEX 1. Attendance list

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ANNEX 2: Results of the questionnaire on modelling thermal conversion of biomass

response to questionnaire

sent out:	13
returned:	13
projects that include modelling:	13

1. state of development

a. definition of goals:	0	0%
b. definition of system boundaries:	0	0%
c. selection of model type:	0	0%
d. determination of model input:	1	8%
e. experimentation:	2	15%
f. development:	7	54%
g. implementation:	4	31%
h. validation:	6	46%
i. application:	8	62%
j. others:	0	0%

2. What is the model type?

a. expert/data based:	0	0%
b. stationary empirical:	0	0%
c. dynamic empirical:	1	8%
d. thermodynamic:	0	0%
e. stationary physical / chemical:	2	15%
f. dynamic physical / chemical:	4	31%
g. CFD:	9	69%
h. fuzzy logic:	0	0%
i. neural network:	0	0%
j. others:	0	0%

3. Application of the model

a. fundamental understanding physics:	4	31%
b. process design:	8	62%
b1. thermodynamic:	3	23%
b2. energetic:	3	23%
b3. exergetic:	0	0%
b4. process control:	3	23%
c. scaling up:	4	31%
d. selection suitable biomass:	1	8%
e. calculation of emissions:	13	100%
f. operator training:	0	0%
g. operator advise system:	0	0%
h. start-up/shut down simulation:	1	8%
i. economic evaluation:	1	8%
j. others:	2	15%

39	calculation of gas composition, behaviour of fuel bed

40	calculation of combustion process

4. Scale of the model

a. micro scale (Kolgomorov):	1	8%
b. particles (0.5 mm):	2	15%
c. process:	4	31%
d. operation unit:	4	31%
e. system (combination of procesess):	4	31%
f. plant (comb. of operation units):	1	8%
g. others:	2	15%

36	large particles
37	Scale is dependent on the accuracy and computer limits

5. What parts of the process are modelled?

a. drying:	7	54%
b. feed system:	2	15%
b1. screw feeder:	0	0%
b2. lock hoppers:	1	8%
b3. others:	0	0%
		15%
c. pyrolysis:	6	46%
c1. fast:	3	23%
c2. slow:	2	15%
c3. others:	0	0%
d. gasification:	6	46%
d1. atmopspheric:	4	31%
d2. pressurised:	1	8%
d3. air blown:	3	23%
d4. oxygen blown:	2	15%
d5. indirect heating:	0	0%
d5. steam reforming:	2	15%
d6. others:	0	0%
e. combustion:	13	100%
e1. grate:	6	46%
e2. underfeed stoker:	2	15%
e3. fluidised bed:	2	15%
e4. others:	4	31%

1	wood log combustion
36	fixed bed, moving bed (current/co-current)

37	gas combustion chamber below the grate (down-draught firing)
40	homogeneous gas phase combustion in the burnout zone of domestic wood stoves

f. flue gas cleaning:	4	31%
f1. wet scrubber:	1	8%
f2. cyclone:	1	8%
f3. hot gas cleaning:	1	8%
f4. denox:	0	0%
f5. (tar) cracking:	2	15%
f6. others:	0	0%
g. energy conversion:	1	8%
g1. indirect turbine:	1	8%
g2. "closed loop" turbine:	0	0%
g3. gas motor:	1	8%
g4. IGCC:	1	8%
g5. co-combnustion:	0	0%
g6. steam cycle:	1	8%
g7. others:	0	0%
h. control system:	0	0%

6. on what kind of biomass is the model based?

general	2
straw	1
wood	5
wood, bark	1
wood, but other biomass can also be modeled	3

7. How is the transport of the biomass modelled?

a. not modelled:	4	31%
b. grate:	6	46%
c. fluidised bed:	4	31%
d. packed bed:	2	15%
e. circulating fluidised bed:	1	8%
f. rotary kiln:	0	0%
g. others:	1	8%

36	moving bed

8. What are the most important input variables of the model?

1	fuel composition burning rate CO2 level temperatures
4	properties chemical data of thermal degradation
5	Furnace geometry, air and flue gas injectors, mass and energy fluxes from fuel bed
7	Input to the combustion model: - Composition of biomass - Air ratio, distribution and velocity - depth of bed material in case of fluid bed Input to the emission model: - Composition of the flue gas (NOx, dust etc.)
10	MORE THAN ONE MODEL: amount of biomass
14	air flow rate and air inlet temperature, fuel properties
22	heat/mass transfer coefficients, physical properties of biomass, kinetic constants
24	- process conditions (temp, pressure) - furnace geometry and dimensions, fuel and air througput and geometry
35	chemical input geometrical data operating conditions
36	particles of the media, chemical kinetics, composition, (fuel-gaseous phase), load
37	Gas mixture flows of primary and secundary air temperature of the gas flows and some surfaces
39	fuel composition, furnace geometry, wall temperatures
40	gas concentration, volume flow (velocities), temperature (gas+wall) of all inlets, geometry

9. What are the most important output variables of the model?

1	emission levels in different denominations conversion factors efficiencies
4	specific concentrations over fuel bed rate of conversion
5	Flow and temperature profiles over the furnace, composition of the flue gas in different sections of the furnace, residence time distributio/n of gas and particles in the furnace are main present aims. Moreover the use of the output data as input data for NOx reduction kinetic calculations with Chemkin and/or with Fluent (postprocessing) are intended.
7	Output of the combustion model: - combustion parameters, e.g. oxygen contents Output of the emission model: - Composition of the flue gas (NOx, dust etc.)
10	various

14	pyrolysis and combustion rate combustion temperatures
22	temperature and specific progress, gas composition, liquid yields, etc.
24	- concentrations of minor and major components - geometrical distribution of flow, temperature and concentration
35	velocity and turbulence temperature species particle distribution, momentum and temperature emission levels
36	temperature profiles (gas, solid) and concentrations (CO, CO2, CxHy, O2, H2O, H2, C) as function of time
37	Flow pattern and mixing Gas concentrations Temperatures
39	gas composition released by the fuel bed, combustion behaviour of different fuels
40	gas concentration + temperature fields in the burnout zone, mixing between combustible gases and air

10. What language is used to program the model?

a. no programme language used:	1	#Naam?
b. Fortran:	10	77%
c. Basic / visual basic:	0	0%
d. pascal / object pascal:	0	0%
e. C / C++:	3	23%
f. Others:	1	8%

5	Fluent 5 (Fluent UNS) is written in C/C++. Submodels developed at the Technical University of Graz, Work Group Thermal Biomass Utilization, to be implemented in Fluent 5, will also be written in C/C++. The model concerning fixed-bed biomass combustion (drying, volatilization, char combustion) on the grate will be developed with Chemkin Digital Visual Fortran and Visual C++.

11. What commercial package is used

a. no commercial package used:	6	46%
b. MS Excel:	2	15%
c. Matlab:	0	0%
d. Matcad:	0	0%
e. ACSL:	0	0%
f. ASPEN:	1	8%
g. SPEED-UP:	0	0%
h. PC-TRAX:	0	0%
i. Others:	7	54%

4	for CFD: TASCFLOW
5	Fluent (Fluent 5, Gambit), Chemkin. Additional programmes: Digital Visual Fortran, Visual C++ (see also 10.), Microsoft Excel.

7	not used, but output can be read into these packages
24	chemkin, fluent
36	Fluent, Limex, Phoenics
39	developed model will be coupled with FLUENT
40	ALOLOS programme, developed by IVD

12. Under what operating system does the model work?

a. UNIX:	9	69%
b. Linux:	2	15%
c. MS DOS/MS Windows 3.11:	3	23%
d. MS Windows 95/98:	4	31%
e. MS Windows NT:	6	46%
f. Mac:	0	0%
g. VAX/VMS:	1	8%
h. others, e.g.:	0	0%

13. What is the user interface?

a. no user interface (file-input):	10	77%
b. keyboard:	5	38%
c. graphical (mouse controlled):	5	38%
d. others:	1	8%

37	graphical is under development

14. What is the availability of the model?

a. free, with source code:	2	15%
b. free, without source code:	2	15%
c. commercial:	5	38%
d. not available, calculation by order:	5	38%
e. others:	4	31%

4	not decided yet
14	not available yet
22	literature

37	for research only, a small fee for documentation and administration is required. See www.cranfield.ac.uk/sme/sofie

15. Are there references to literature in which the model is described?

1 PhD. thesis: Theoretical and experimental studies on emissions from wood combustion, by Øyvind Skreiberg

4 For model of decomposition of wood: not yet

For CFD applications:
1) Bruch, C.; Nussbaumer, Th.: CFD Modelling of Wood Furnaces. Biomass for Energy and Industry. 10th European Conference and Technology Exhibition, June 8-11, 1998, Würzburg, Germany, 1366-1369
2) Bruch, Ch.; Nussbaumber, Th.: verbrennungsmodellierung mit CFD zur optimierten Gestaltung von Holzfeuerungen. Innovationen bei Holzfeuerungen und Wärmekraftkopplung, 5. Holzenergiesymposium, 16. Oktober 1998 ETH Zürich, Bundesambt für Energie, Bern 1998, 189-202

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14	several

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15. Do you have interest in cooperation?

Yes:	12	92%
No:	1	8%

1	Combustion of wood
4	experimental data for validation comparison to other models for packed bed combustion
5	Modeling of fixed-bed combustion on grate systems (drying, volatilization, char combustion); CFD modeling of gas phase combustion in fixed bed furnaces; exchange of experience concerning reaction and flow models used.
7	Thermodynamic conversion of biofuels and waste
10	All thermochemical biomass conversion processes
22	pyrolysis and gasification of biomass and waste

24	combustion and gasification emission chemistry
35	modelling measuring velocity, concentration, particle size and particle velocity
36	Computer simulation of firing systems
39	application and validation of the model
40	- Experimental and numerical investigations of the combustion process in small scale wood heaters or other biomass fired furnaces - Applications of the ALOLOS code on different firing systems

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	Project:	Improved energy generation based on biomass FBC with minimum emission (Joule 980200)		

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Project: IEA Bioenergy Task 22: Techno-economic assessments for bioenergy applications

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Project: Fixed bed gasification of agricultural residues (JOR3-CT95-021)

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Project: Development of selective oxidation technology for NOx emission reduction reduction in gasification power plants

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Project: Modelling of the combustion of biomass

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Project: CFD modelling of small scale biomass-fired boilers

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Project: Optimised combustion of wood and wood-waste fuels in a stoker fired boiler

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Project: Newly designed wood burning systems with low emissions and high efficiency

Questions 1 to 4

ID	1: status of development										2: model type										3: application of the model														4: scale of the model						
ID	a	b	c	d	e	f	g	h	i	j	a	b	c	d	e	f	g	h	i	j	a	b	b 1	b 2	b 3	b 4	c	d	e	f	g	h	i	j	a	b	c	d	e	f	g
1								✔					✔																✔									✔			
4						✔	✔									✔	✔					✔		✔					✔										✔		
5						✔											✔					✔	✔			✔	✔		✔								✔				
7							✔	✔	✔								✔												✔								✔				
10									✔													✔	✔				✔		✔				✔						✔	✔	
14						✔									✔							✔				✔			✔							✔					
22									✔							✔	✔				✔	✔		✔		✔	✔	✔	✔			✔							✔		
24									✔						✔		✔				✔								✔								✔				
35					✔	✔	✔	✔	✔								✔				✔	✔	✔	✔			✔		✔						✔	✔			✔		
36						✔		✔	✔							✔	✔				✔	✔							✔									✔			✔
37				✔	✔	✔		✔	✔								✔					✔							✔									✔			✔
39						✔	✔									✔													✔					✔				✔			
40								✔	✔								✔												✔					✔			✔				

Question 5

ID	5: parts of the process that are modelled																																			
ID	a	b	b 1	b 2	b 3	c	c 1	c 2	c 3	d	d 1	d 2	d 3	d 4	d 5	d 6	d 7	e	e 1	e 2	e 3	e 4	f	f 1	f 2	f 3	f 4	f 5	f 6	g	g 1	g 2	g 3	g 4	g 5	g 6	g 7
1																		✔				✔															
4	✔					✔	✔	✔		✔	✔							✔	✔	✔																	
5																		✔	✔				✔		✔												
7																		✔			✔																
10	✔	✔		✔		✔	✔			✔	✔	✔	✔	✔				✔			✔		✔	✔		✔		✔		✔	✔		✔	✔		✔	
14	✔					✔												✔	✔	✔																	
22	✔					✔				✔	✔		✔	✔		✔		✔	✔				✔					✔									
24										✔								✔																			
35	✔	✔				✔				✔								✔					✔														
36	✔					✔	✔	✔		✔	✔		✔			✔		✔	✔			✔															
37																		✔				✔															
39	✔																	✔	✔																		
40																		✔				✔															

Question 6 to 10

ID	6. fuel	7: transport of biomass							10: language					
		a	b	c	d	e	f	g	a	b	c	d	e	f
1	wood	✓								✓				
4	wood, but other biomass can also be modeled		✓										✓	
5	wood		✓											✓
7	general			✓						✓			✓	
10	wood, but other biomass can also be modeled			✓		✓			✓					
14	straw		✓							✓				
22	wood			✓	✓					✓				
24		✓								✓				
35	wood		✓	✓	✓					✓				
36	wood, bark		✓					✓		✓				
37	general	✓								✓			✓	
39	wood, but other biomass can also be modeled		✓							✓				
40	wood	✓								✓				

Questions 11 to 16

ID	11: commercial package									12: operating system								13: user interface				14: availability					16: co-op?
	a	b	c	d	e	f	g	h	i	a	b	c	d	e	f	g	h	a	b	c	d	a	b	c	d	e	
1		✓										✓	✓	✓				✓	✓	✓		✓	✓				✓
4	✓								✓	✓								✓								✓	✓
5		✓							✓					✓				✓	✓	✓				✓	✓		✓
7									✓	✓	✓	✓	✓	✓					✓	✓					✓		✓
10						✓							✓							✓				✓			✓
14	✓											✓	✓	✓				✓								✓	✓
22	✓									✓								✓								✓	✓
24									✓	✓						✓		✓						✓	✓		✓
35	✓									✓	✓			✓				✓	✓			✓					✓
36									✓	✓								✓		✓					✓		✓
37	✓									✓				✓					✓		✓		✓			✓	
39									✓	✓								✓						✓	✓		✓
40	✓								✓	✓								✓						✓			✓

ANNEX 3: Copies of the overheads presented

Modelling of biomass and waste combustion at TNO
A.R.J. Arendsen, TNO, Netherlands

Modelling of biomass and waste combustion

TNO

Netherlands Organization for Applied Scientific Research

Institute of Environment, Energy and Process Innovation

Department of Thermal Conversion Technology

A.R.J. Arendsen, M.Sc.
Sevilla, June 9th 2000

MEP afd auteur datum

Contents

- **Department of Thermal Conversion Technology**
- **Types of models**
- **Computational Fluid Dynamics**
- **Dynamic modelling**
- **Our experience and conclusions**

MEP afd auteur datum

Department of Thermal Conversion Technology

Mission statement : development and implementation of new technology for thermal conversion of biomass and waste

Technology : combustion, gasification, pyrolysis, liquefaction

Type of work : technology development, applied research, studies, consultancy

MEP afd auteur datum

Types of models

Application	Thermo-dynamic	Empirical regression	Empirical process identification	Expert	Physical / chemical stationary	Physical / chemical dynamic	CFD
System design / optimization	++			+	++	++	
Apparatus design / optimization		+		+	++	++	++
Control design / optimization			++			++	
Selection biomass				+	++	++	
Operational management			+			++	

MEP afd auteur datum

Computational Fluid Dynamics (1)

Development and demonstration of an improved wood combustion installation (Under Feed Stoker: 1.2 Mw_{th})

Problems:

- **Emissions (CO, CxHy, NOx) did not comply with emission standards**
- **Unstable process behaviour**

Computational Fluid Dynamics (2)

Optimize configuration by means of CFD:

- **Make secundair air nozzels smaller**
- **Install a baffle**
- **Optimization tertiar air injection**

Optimize process control strategy:

- **Feed forward control**
- **Optimization blower control**
- **Improved O_2-sensor**

Dynamic modelling

Model development:

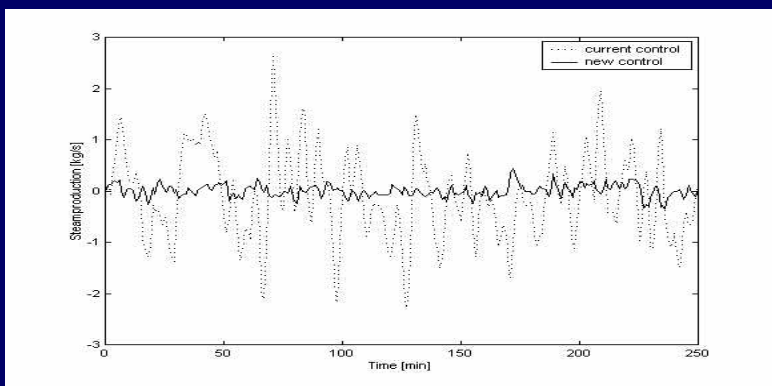
- **Dynamic models of a grate combustion plants for biomass and waste**
- **Overall dynamic system model of CFBG-STEG**

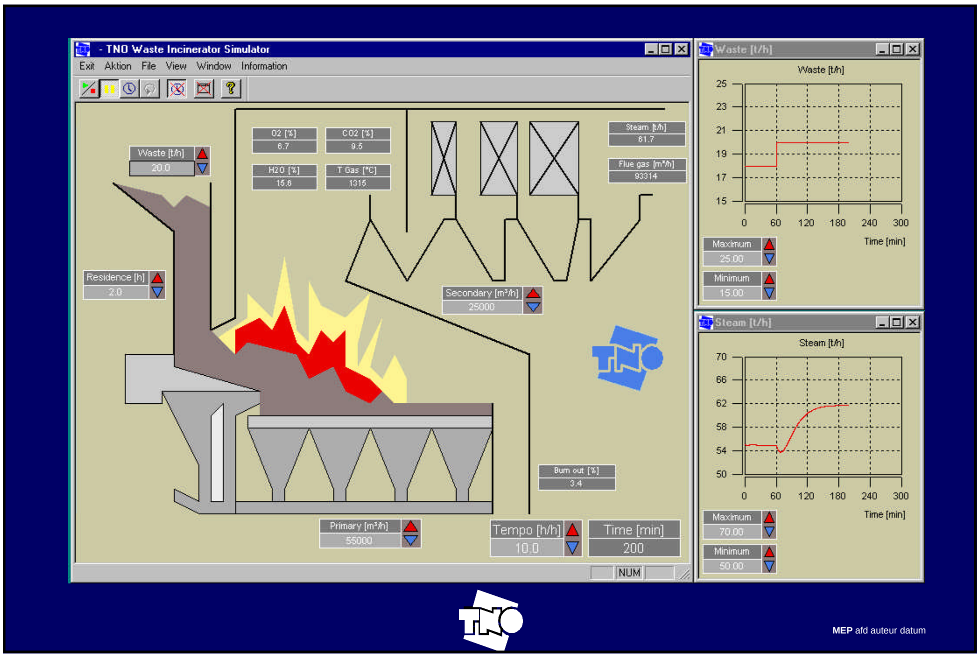
Applications:

- **Process identification of dynamic behaviour for validation of the models**
- **Optimization and development of control systems**
- **Software sensors for monitoring of combustion processes**
- **Simulators for operator training and advising**

Process control optimization

Example combustion process





Our experience and conclusions

- **Choose the right type of model for a specific application**
- **Models match with reality**
- **Process identification techniques are important for validation**
- **Optimization and development of control systems is possible with dynamic models**

MEP afd auteur datum

Biomass Modelling Tools at Åbo Akademi

Edgardo G. Coda Zabetta, Åbo Akademi, Finland

Modelling of batch combustion processes
Øyvind Skreiberg, Norwegian University of Science and Technology, Norway

Optimisation of Low-NOx biomass grate furnaces with CFD modelling
Robert Scharler, TU Graz, Austria

Optimisation of Low-NOx Biomass Grate Furnaces with CFD Modelling

Robert Scharler

Alexander Weissinger

Ingwald Obernberger

Research Group: THERMAL BIOMASS UTILISATION
Head: Dr. I. Obernberger

Institute of Chemical Engineering Fundamentals and Plant Engineering

Technical University of Graz, AUSTRIA

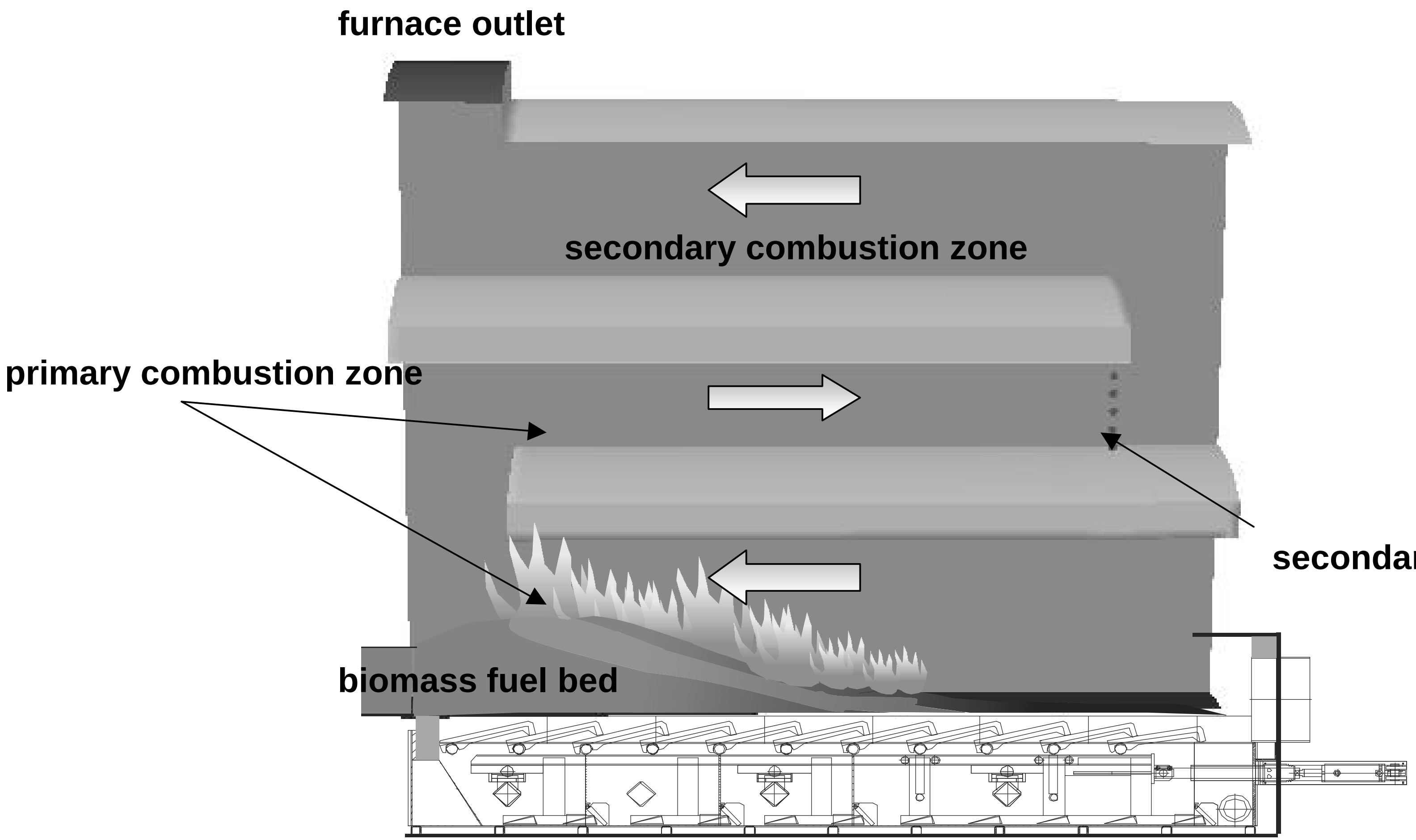
Structure

- Objectives
- Description of the furnaces modelled
- Modelling approach & future improvements
- Results of CFD application to biomass grate furnaces
- Conclusions
- Options for co-operation

Purpose of CFD modelling

- CFD based optimisation of biomass grate furnaces
- CFD analysis of operating conditions
- Development of guidelines for furnace design and process control
- Pre-evaluation of new combustion technologies and furnace geometries
- Reduction of test runs

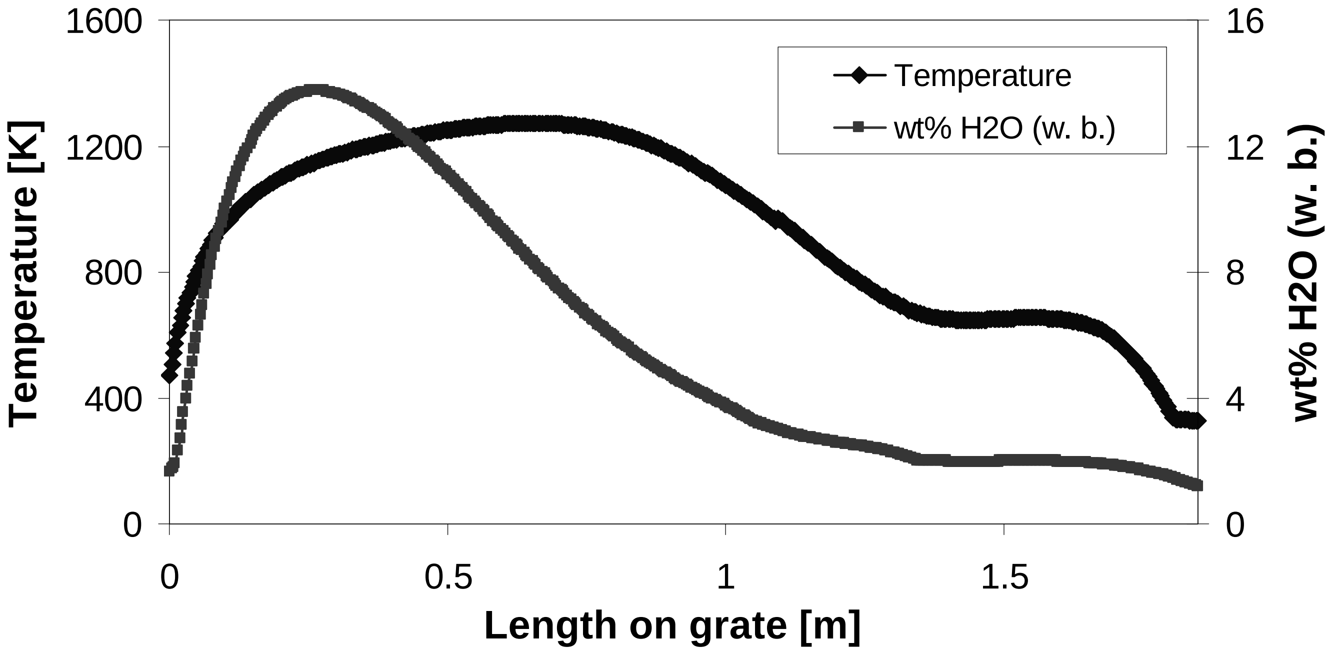
Low-NO_X biomass grate furnaces



Pilot-scale Low-NO_x furnace (440 kW_{th}) equipped with a horizontally moving grate

Modelling of solid biomass combustion

- Definition of profiles regarding the thermal decomposition of solid biomass along the grate on the basis of test runs
- Definition of conversion parameters for the calculation of CH_4, H_2, CO, CO_2, H_2O, and O_2 concentrations in the flue gas formed
- Stepwise balancing of mass, species and energy



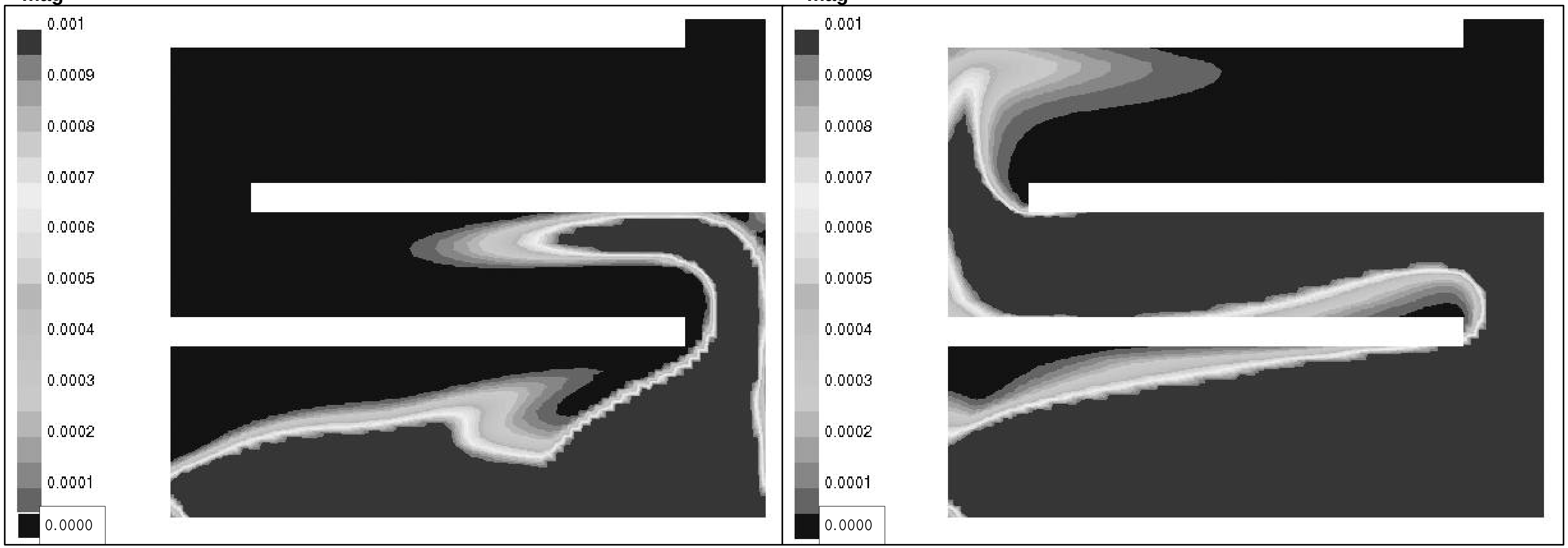
Profiles of temperature and H_2O concentration of the flue gas along the grate

➢ **Turbulence**	**Realizable k-e Model**
➢ **Gas phase combustion**	**Eddy Dissipation Model (EDM)/ global 3-step mechanism**
➢ **Radiation**	**Discrete Ordinates Model**
➢ **Fly-ash particle trajectories / erosion rates**	**Lagrangian particle tracing procedure**
➢ **Residence time distribution of the flue gas**	**Lagrangian particle tracing procedure**

Gas phase combustion - Eddy Dissipation Model (EDM)

Contours of CO concentrations in the furnace calculated with different mixing constants A_{mag}

$A_{mag} = 4.0$ $A_{mag} = 0.6$

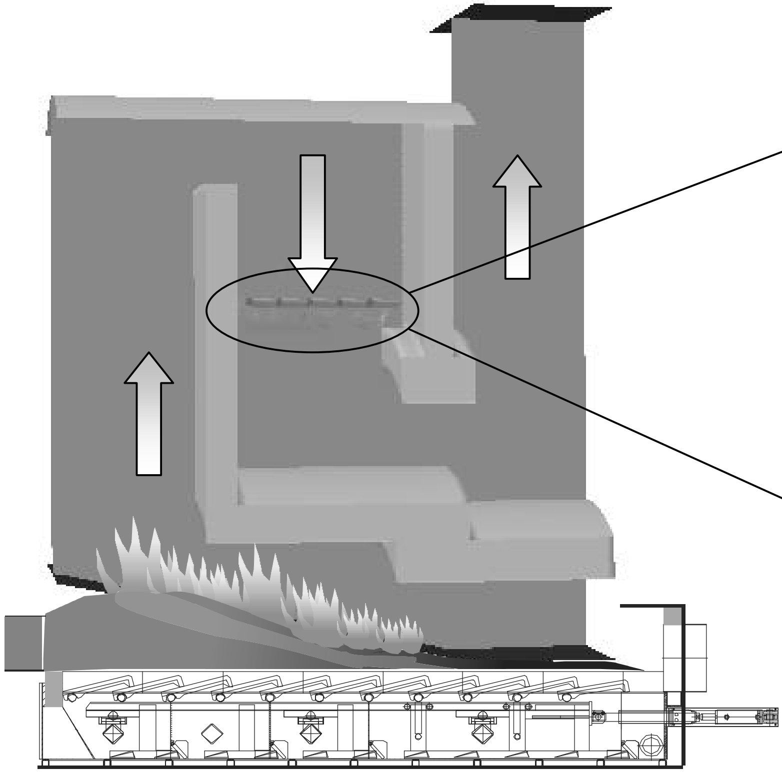


- **Reaction rate is given by the limiting (lower) value of mixing and kinetic rates**
- **Cannot properly account for interaction of turbulence and chemistry**
- **Empirical constants of the mixing rates are not universally valid**

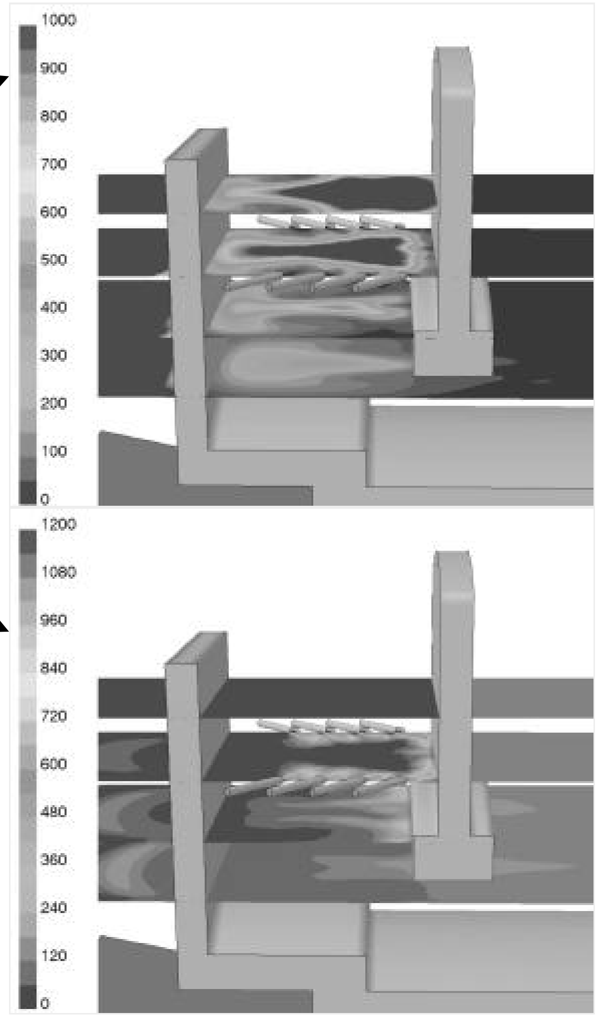
Research group
THERMAL BIOMASS UTILISATION
Technical University Graz

Optimisation of secondary air nozzles

Newly developed biomass grate furnace equipped with a horizontally moving grate



CO concentrations [vol-ppm] (above) and temperature distribution [°C] (below) in different cross-sections near secondary air injection



- **Homogenisation of flue gas flow by improved mixing conditions**

Conclusions

- **CFD modelling is an efficient tool for the technological and economic optimisation of biomass grate furnaces**

    - **Comparison of CFD modelling results with hot gas in-situ measurements of flue gas components in the primary combustion zone and with continuous CO measurements at boiler outlet showed reasonable accuracy**

    - **Applicability has been proven by practical applications**

    - **Reduction of investment costs and operation costs is possible**

Current and future improvements

- Experimental investigation on the release of gaseous compounds from solid biomass fuels at a lab-scale reactor (improving the definition of boundary conditions for CFD modelling and chemical kinetic simulations)
- Implementation of an advanced Eddy Dissipation Concept
- Implementation of a NO_x post-processor

Options for co-operation

➢ Exchange of experience

- ☞Combustion modelling
- ☞CFD modelling of biomass grate furnaces
- ☞Modelling of heterogeneous biomass combustion on the grate
- ☞CFD applications

➢ Exchange of experimental results

- ☞HCN, NO, NH3 conversion rates for different reactors and biomass fuels
- ☞Conversion rates for different fuel particle sizes

Mathematical models for design and development of fixed-bed gasification systems

Colomba Di Blasi, Università degli Studi di Napoli "Federico II", Italy

A numerical model for fixed bed combustion

Jenny Larfeldt, TPS, Sweden

CFD modelling of biomass combustion

Xue-Song Bai, Lund Institute of Technology, Sweden

CFD Modeling of Biomass Combustion

Xue-Song Bai
Division of Fluid Mechanics
Lund Institute of Technology, Sweden

Turbulent Combustion related projects at LTH-FM

Flame/turbulence interaction

- LES of flame kernel propagation
- LES of swirling stabilized flames

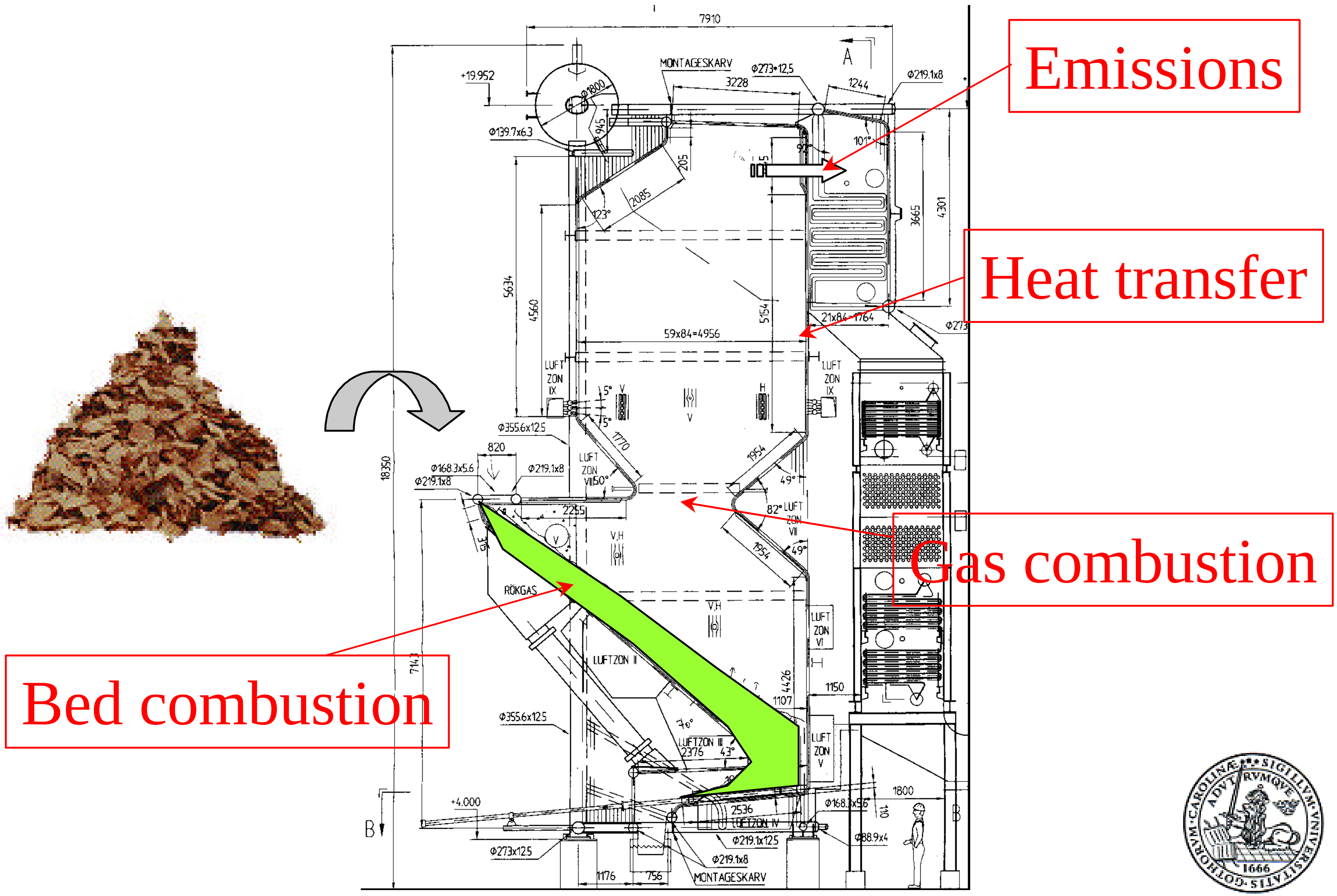
Modeling with detailed chemistry

- soot formation in turbulent diffusion flame
- CO, NOx formation in premixed turbulent combustion

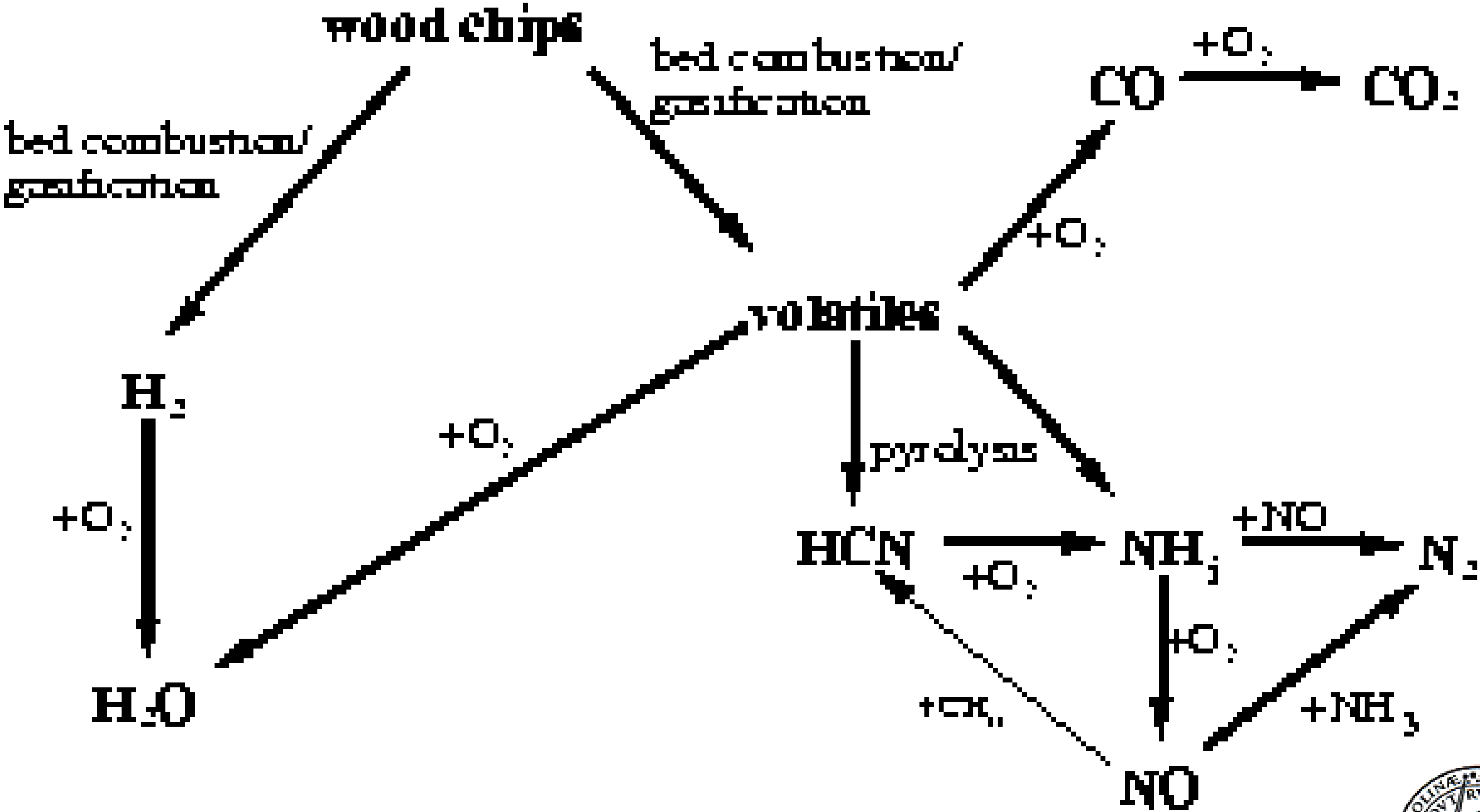
Biomass

- small-scale biomass combustion

A biomass furnace studied



Biomass Combustion



CFD Modeling at LTH-FM

Gas phase oxidation - turbulent combustion

- volatile ---- CO_2, H_2O, CO, NO_x, soot, heat ...

Model used:

- Favre averaged N-S, enthalpy and species transport eqns.
- k-ε turbulence model, Bossinesq hypothesis
- Eddy dissipation concept (EDC) model for the mean reaction rates
- Global reaction mechanism
  - hydrocarbon oxidation
  - NOx formation

CFD Modeling at LTH-FM

Model under development

- Coupling detailed chemical kinetics
  - Can one employ detailed chemistry based on EDC?
  - Flamelet approach: flamelet library with presumed PDF
    - when it is valid?
    - Multiple inlets
    - partially premixed
  - modeling the influence of turbulence (flame stretch, local quenching …)
    - flamelet approach?

CFD Modeling at LTH-FM

Particle combustion - two-phase flow

- char ---- CO, CO2, heat …

Two-phase flow combustion

- Eulerian/Lagrangian two-way coupling, source terms
- Char oxidation

$$C + 0.5O_2 \rightarrow CO$$

$$C + O2 \rightarrow CO_2$$

$$C + CO_2 \rightarrow 2CO$$

CFD Modeling at LTH-FM

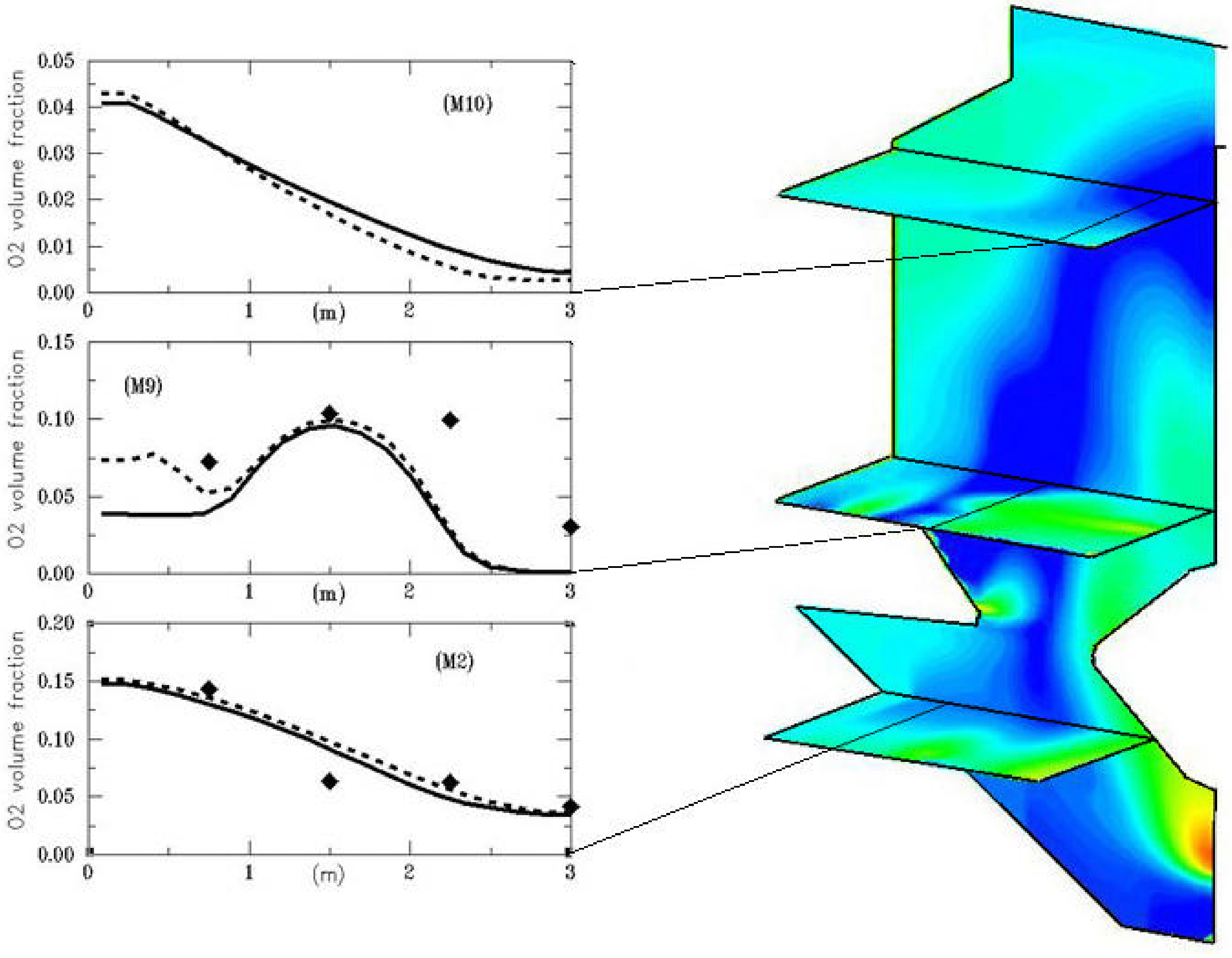
Bed combustion

- wood, biomass convert
  - tar, light HC, CO, H2, CO_2, H_2O, HCN, NHx ...

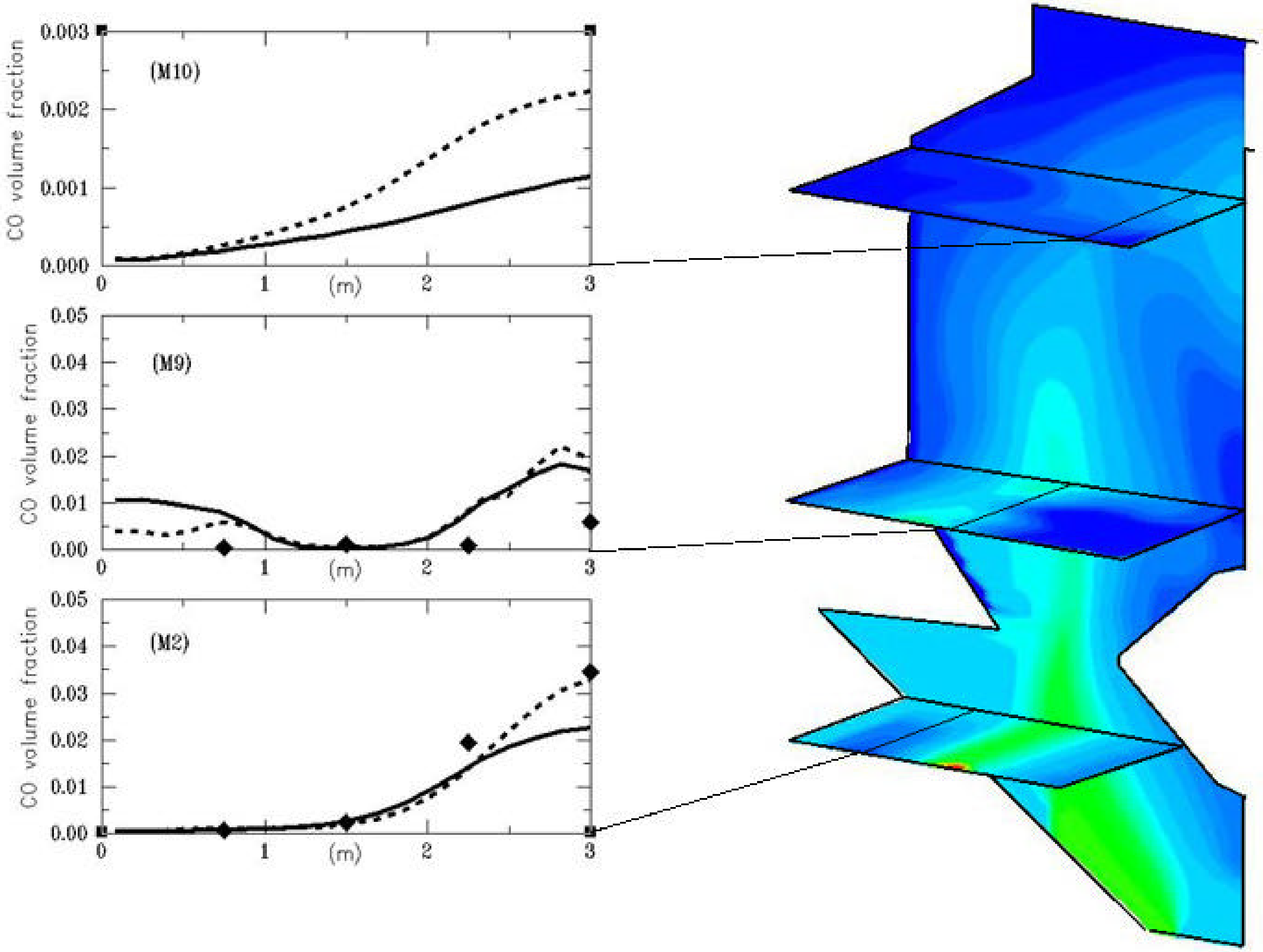
Model used

- a simplified model
  - derived from element mass and energy conservation
  - assigning a few non-zero concentration species
  - a number of species and temperature have to be obtained from experimental measurement

Model validation -O2



Model validation, CO



Model validation

Major species and Temperature

- generally agreeable with experiments
- with difficulty in modeling the EDC rate in case of partially premixing above the bed

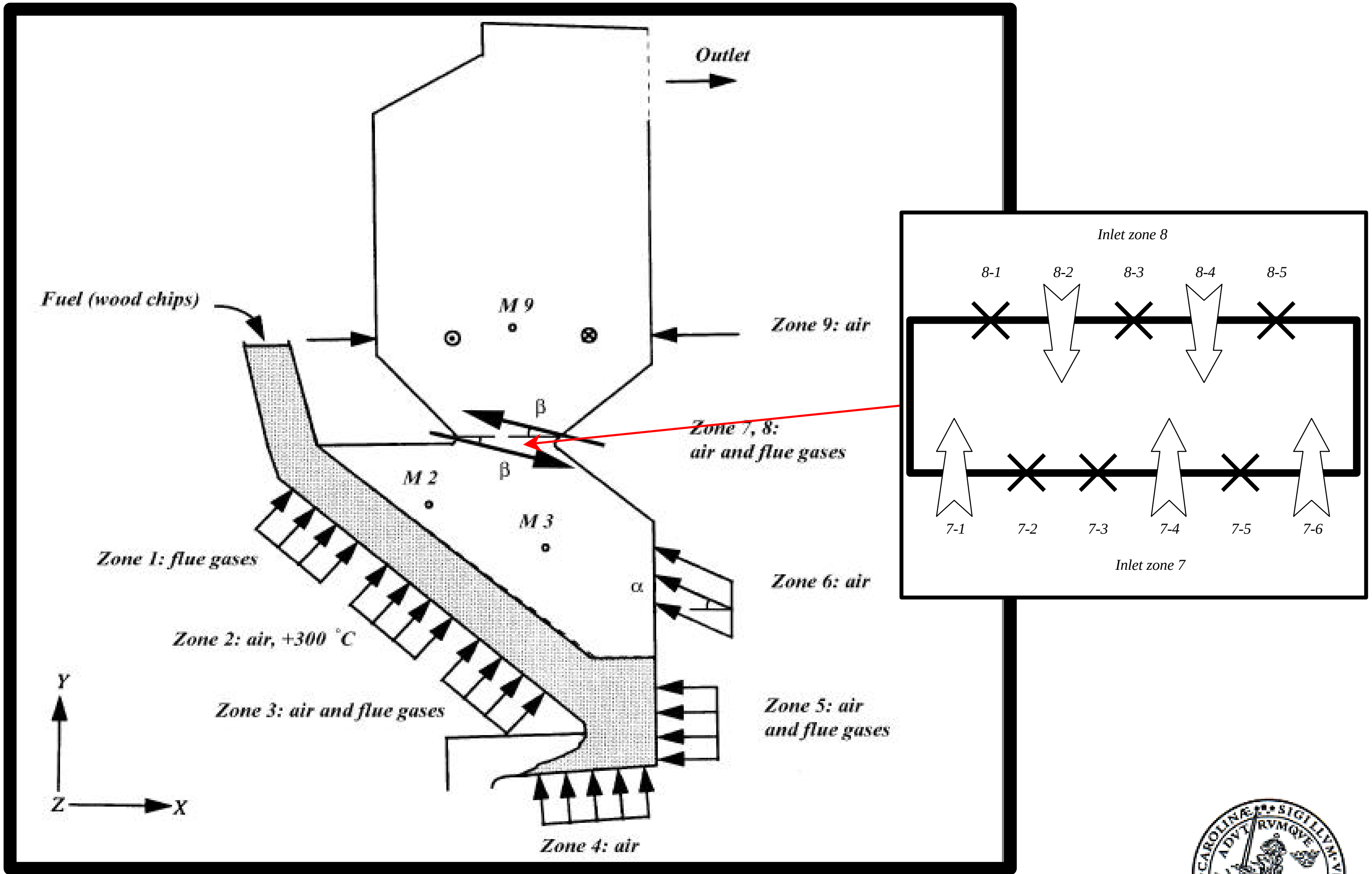
CO

- not accurate, can differ by more than 50%
- two-phase char combustion may be very influential

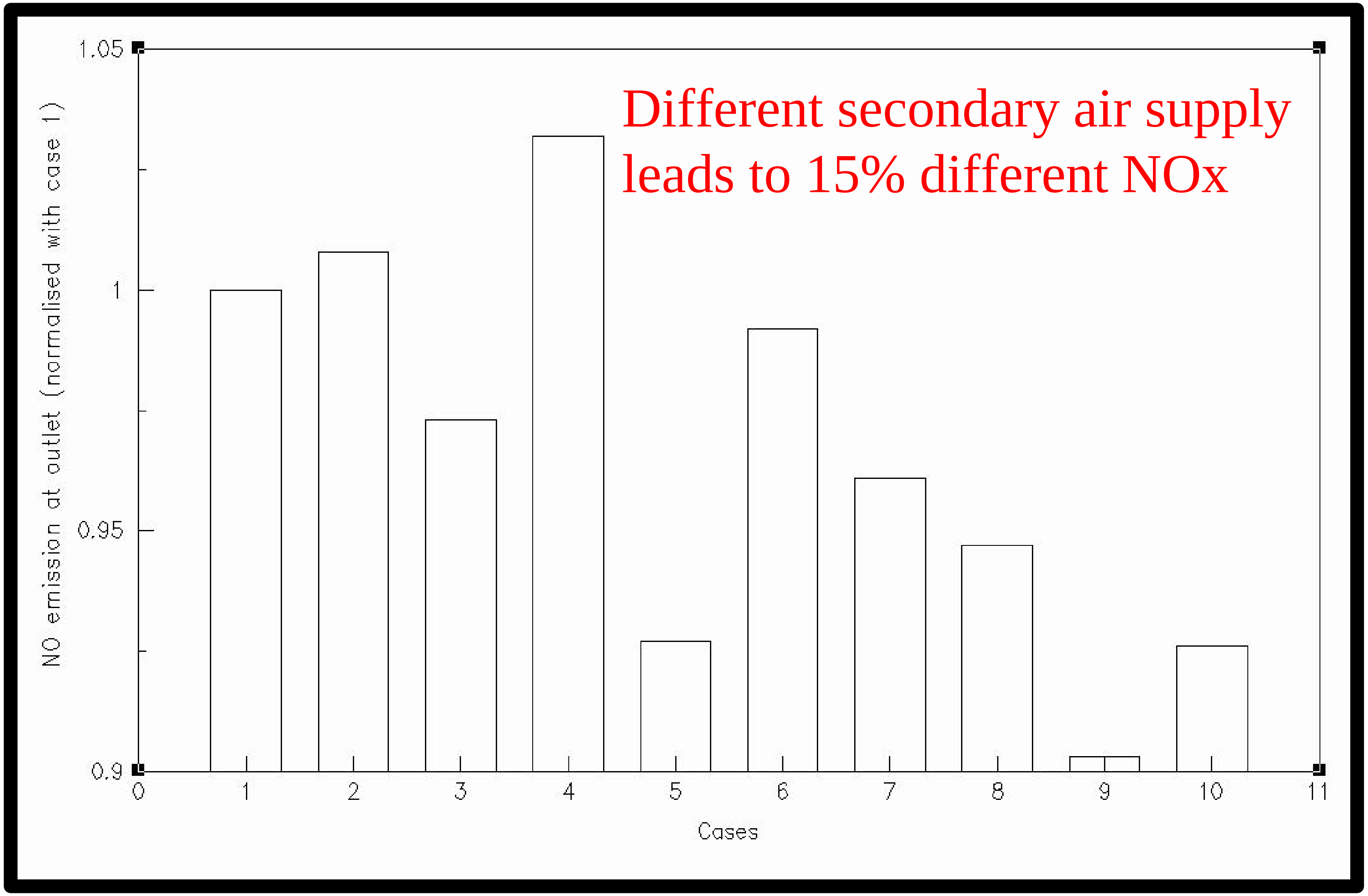
NOx

- order of magnitude has been found agreeable with exp.
- Need to model radicals for fuel-NO path

CFD analysis of furnace performance

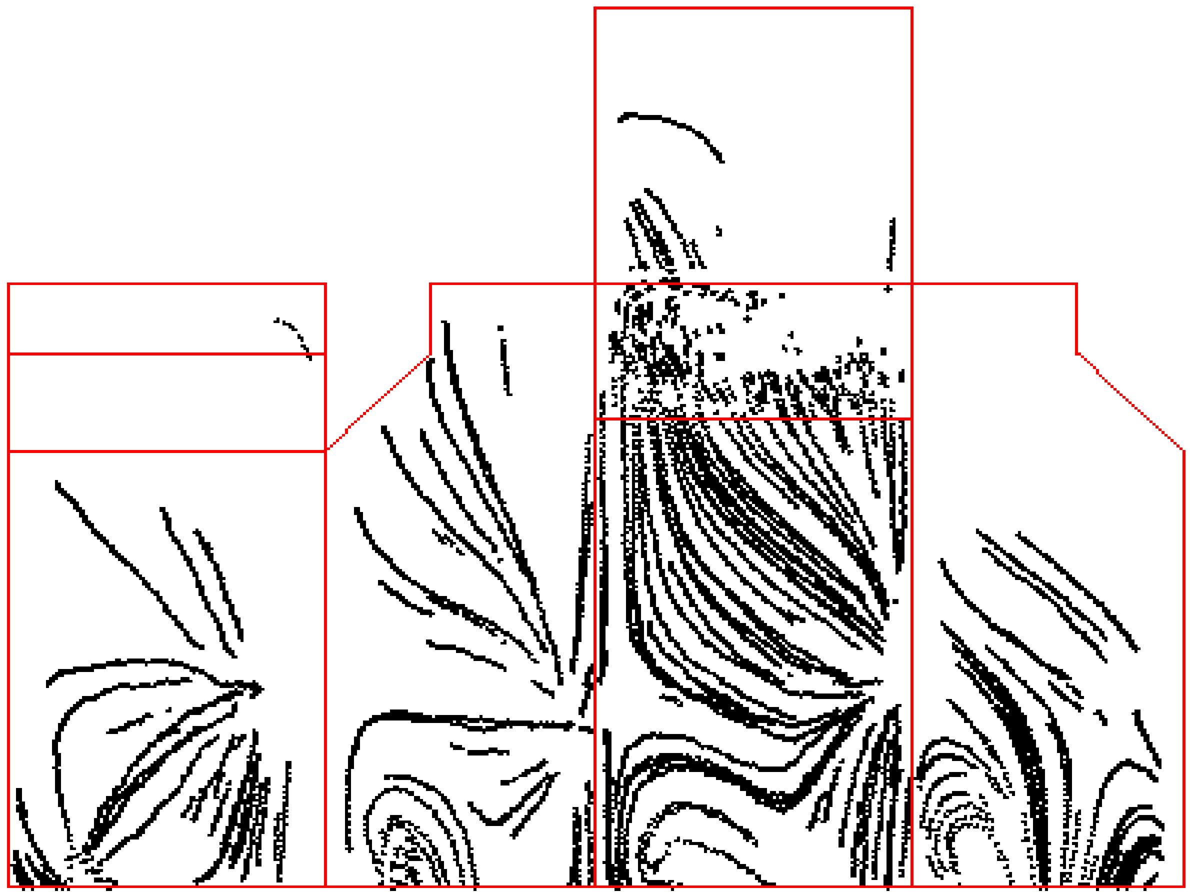


NOx emissions



Particle erosion on the walls

Case 1: 1.e-6 m



Modelling of Solid Fuel Conversion and Transport with TOSCA
Bernhard Peters, FZK, Germany

Modelling of Solid Fuel Conversion and Transport with TOSCA (**T**ools of **O**bject-oriented **S**oftware for **C**ontinuum Mechanics **A**pplications)

Workshop
"Biomass Combustion Modelling"
Sevilla, June 5 - 9, 2000

Bernhard Peters
Research Centre Karlsruhe, Germany

Outline

1. Introduction

2. Objectives

3. Model Approaches

4. General Remarks

Objectives

1. Description of governing processes

   - thermal conversion of solid fuel particles

   - heat/mass transfer betwenn solid and gas phase

   - transport and mixing of solid fuel particles

   - gas flow and conversion in the void space of a particle ensemble

2. Fudamental understanding of solid fuel combustion

3. Environmental friendly incineration through determination of pollutant formation and destruction

Global Approach

Description of entire process by
coupling of models for sub-processes

$$\text{Process} = \sum \text{Sub-processes}$$

Sub-processes:

- Conversion of a finite number of solid fuel particles
- Transport of a finite number of particles
- Fluid and thermodynamics of void space

Particle Model

Purpose: Prediction of conversion of particles of different sizes and materials

- Particle processes: heating, drying, pyrolysis/devolatilisation, gasification/combustion

- One-dimensional (sphere, cylinder, plate) and transient conservation equations for energy, mass, porosity and specific inner surface

- 13 gaseous, 3 liquid and 24 solid species available in data base in conjunction with 55 different reactions in various combinations

- Yields distribution of relevant variables versus time and length together with integral properties for solid fuel conversion

Transport Model

Purpose: Prediction of the motion of a particle ensemble on a grate, in a kiln or a fluidised bed

- Takes into account different shapes and materials
- Motion described by 2^{nd} law of Newton for position and orientation
- Forces acting on a particle include:
  - Visco-elastic contact forces
  - Buoyancy forces
  - Drag forces

CFD-Model

Purpose: Prediction of the gas flow in the void space of a particle ensemble

- Prediction of turbulent reactive flow within the void space of a packed bed as a porous material
- Solution of the conservation equations for mass, momentum and energy with SIMPLER algorithm
- Friction approximated by Darcy/Forchheimer relationship
- Global kinetics for gas phase reactions
- Release of species and energy due to solid fuel conversion (heat/mass transfer) into upper gas plenum

General Notes

- Object-oriented programming with C++ (C and Fortran)

- Operating systems: UNIX and MS-Windows

- Graphical user interface under development

- Mesh generation and post processing carried out with public and commercial packages (NetGen, Data Explorer)

Modelling wood combustion in grate furnaces by calculation of the solid fuel transport and conversion on the grate followed by CFD calculations in the gas phase

Thomas Nussbaumer, Verenum, Switzerland

Straw Bed Conversion

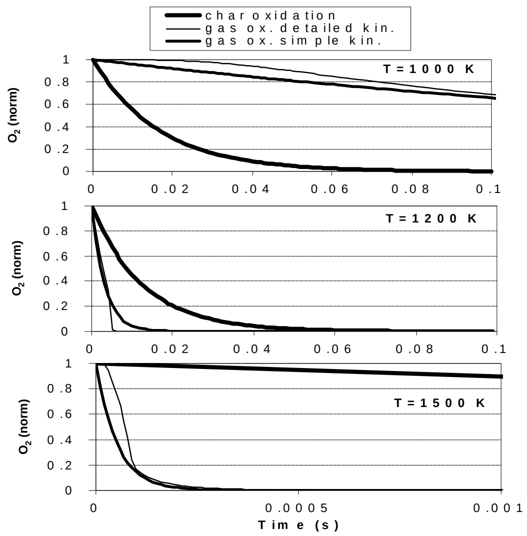
Robert van der Lans, CHEC, Inst. for Kemiteknik, DTU, Denmark

Straw Bed Conversion

CHEC Research Centre
Dept. Chem. Eng.
Technical University of Denmark

Robert P. van der Lans
A. Jensen, P. Glarborg, K. Dam-Johansen

Gas Phase Modelling

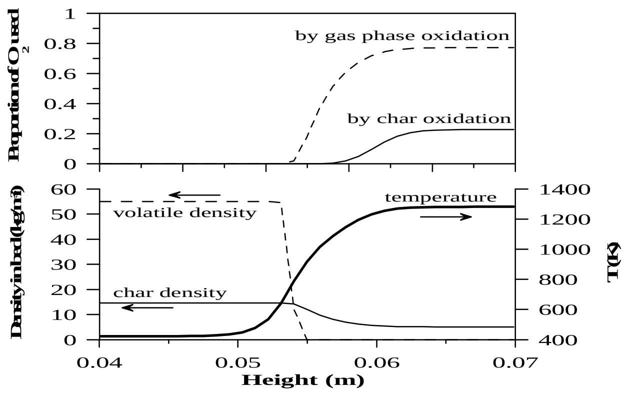


Bed Conversion Model

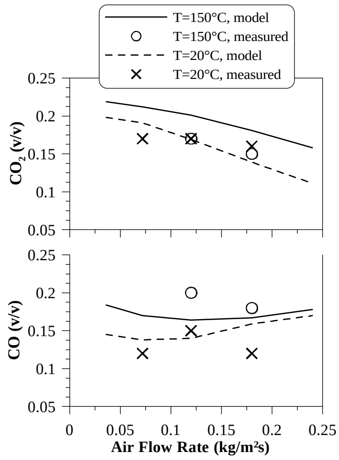
- Char oxidation kinetics (first order in O_2)
- Pyrolysis kinetics
- Single film diffusion of O_2 to the particle
- Effective heat transfer coefficient
  - Based on measurements with char (no fluid flow)
  - Corrected for fluid flow
- CO/CO_2 (reaction products from char oxidation) is Arrhenius from exp.
- volatiles react with O_2 : Kinetics from Senkin calc.
- water evaporation and condensation

Reaction Front

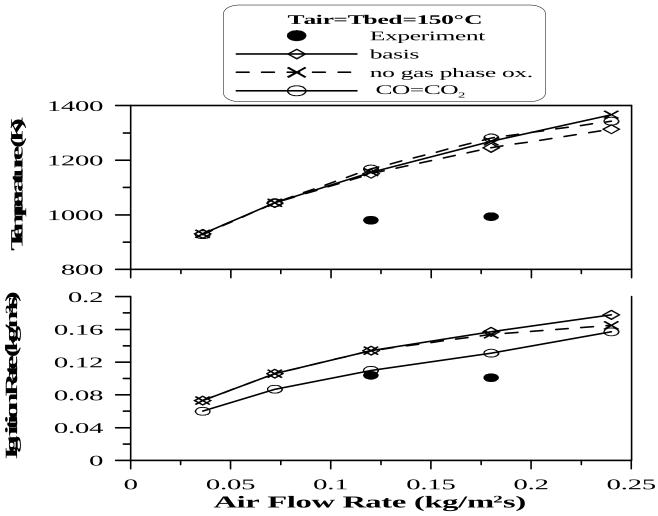
- Char and volatile density in the bed
- O_2 consumed by char and volatiles



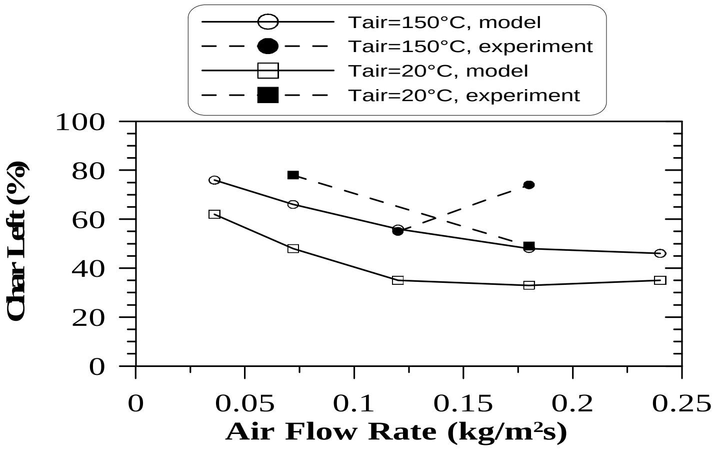
Concentrations of Gases Leaving the Bed



Front Propagation



Residual Char after the Reaction Front Passed



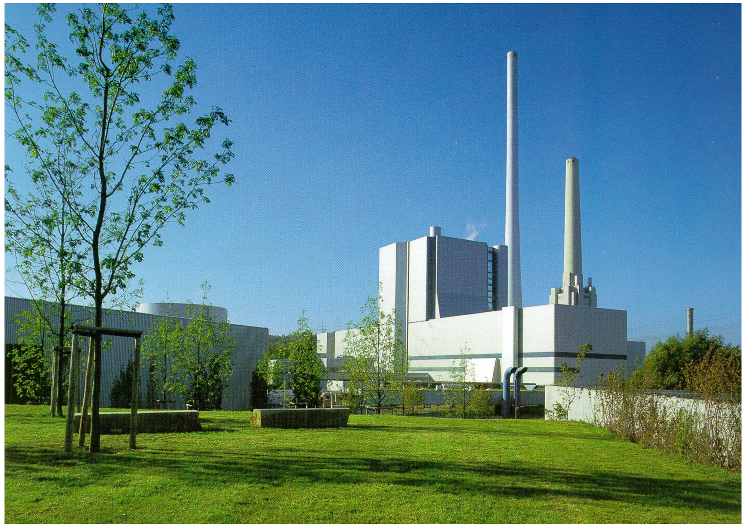
Application of the 3D Combustion Code AIOLOS to Small Scale and Industrial Combustion Systems

Sven Unterberger, IVD, Stuttgart, Germany

University of Stuttgart

University of Stuttgart
Institute of Process Engineering and Power Plant Technology
Prof. Dr.-Ing. K.R.G. Hein

AIOLOS



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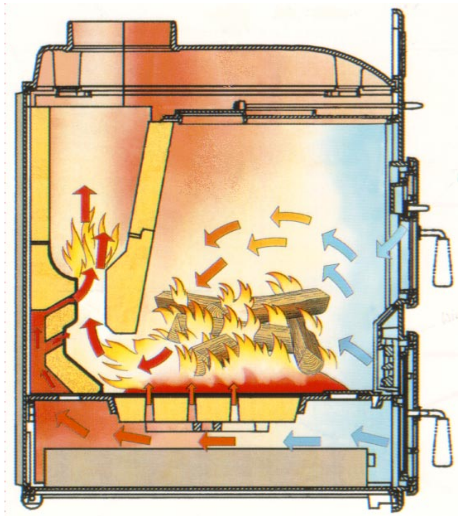
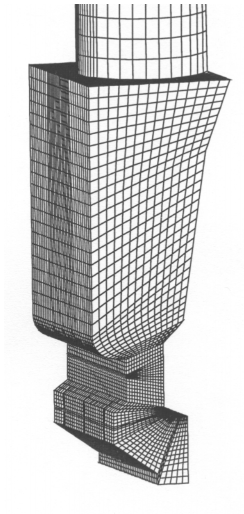
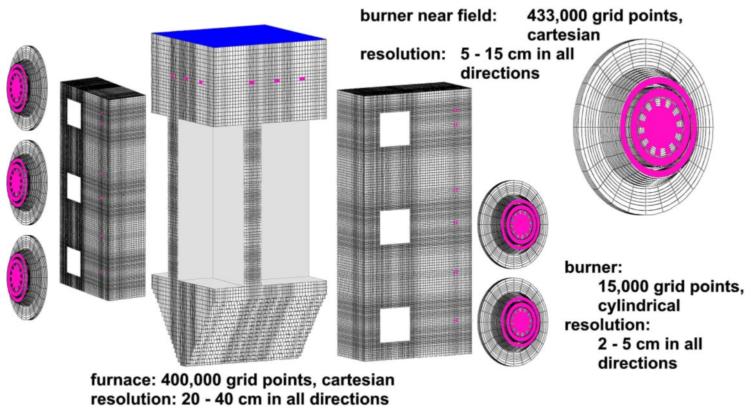
S. Unterberger,

IVD, University of Stuttgart







- New and improved furnace design from pilot to large scale
- Optimisation of operational performance of existing boilers
- Investigation of parametric effects, e.g.:
  - fuel characteristics (fuel composition, particle size, etc.)
  - burner layout
  - furnace geometry (air distribution, heat transfer, etc.)
- Advantages compared to experimental procedures:
  - cost and time reduction
  - reproducability of boundary conditions
  - insight in to complex inter-linked physical phenomena

Cost-effective Tool for Analysis and Optimisation

- AIOLOS: - originally designed for simulation of pulverised coal (fuel) combustion
  - gas combustion

- using models for:
  - turbulent two phase flow
  - (radiative) heat transfer
  - heterogeneous and homogenous reactions

(Original) Objectives of AIOLOS

Industrial Partner	Power Plant	Output	Combustion System	Fuel
Saarberg AG	MKV Völklingen	490 MW_{th}	Swirl burners on opposite walls	bitum. coal
RWE Energie AG	Niederaußem B	150 MW_{el}	Roof firing with six swirl burners	brown coal
OKA (Austria)	Riedersbach II	160 MW_{el}	tangential firing (corner firing)	bitum. coal
EVT GmbH	St. Andrä	270 MW_{th}	tangential firing (corner firing)	bitum. coal
EVT GmbH	Bexbach	750 MW_{el}	tangential firing (corner firing)	bitum. coal
Steinmüller GmbH	Tiefstack	252 MW_{th}	Six swirl burners on front wall	bitum. coal
Steinmüller GmbH	Niederaußem H	600 MW_{el}	tangential firing (all-wall firing)	brown coal
EVT GmbH	Bexbach	750 MW_{el}	tangential firing (corner firing)	bitum. coal
Steinmüller GmbH	Schkopau	450 MW_{el}	tangential firing (all-wall firing)	brown coal
ENEL (Italy)	Fusina #2	450 MW_{th}	tangential firing (16 burn./4 levels)	bitum. coal
Eskom (R.S.A.)	Hendrina #9	200 MW_{el}	wall firing with 24 swirl burners	bitum. coal
Badenwerke AG	Rheinhafen	550 MW_{el}	32 swirl burners on opposite walls	bitum. coal
ENEL (Italy)	Vado Ligure #4	320 MW_{el}	24 low NOx swirl burners (wall fir.)	bitum. coal
Neckarwerke AG	Altbach HKW II	334 MW_{el}	tangential firing (all-wall firing)	bitum. coal
Eskom (R.S.A.)	Kendal	680 MW_{el}	tangential firing, tilting burner nozzle	bitum. coal

Application of AIOLOS to Industrial Utility Boilers

- 3D Finite Volume code for weakly-compressible, turbulent reactive flows
- Boundary-fitted, cartesian and cylindrical co-ordinates
- Non-staggered grid with SIMPLEC pressure correction scheme
- Higher-order discretisation schemes
- Solution algorithms: SOR, SIP and ILU-preconditioned CG-methods
- Domain decomposition technique
- Temporal discretisation with Euler Implicit (transient)
- Hybrid parallelisation strategy

General features of AIOLOS

Turbulent flow

- k-ε model and Differential Reynolds Stress model (RSM)
- Eulerian approach
- Lagrangian particle tracking method

Heat transfer

- Discrete Ordinates Method
- Discrete Transfer
- Flux Model
- Finite Volume Method
- Semi-stochastic Monte Model Carlo-Model
- Moment Method

Reaction Model

- Global reaction scheme for pulverised solid fuel combustion, (pyrolysis, volatile combustion (EDC), char burnout)
- Consideration of particle size distribution
- NO_x post-processor (fuel-NO and thermal-NO)

Mathematical models

Volatile Combustion

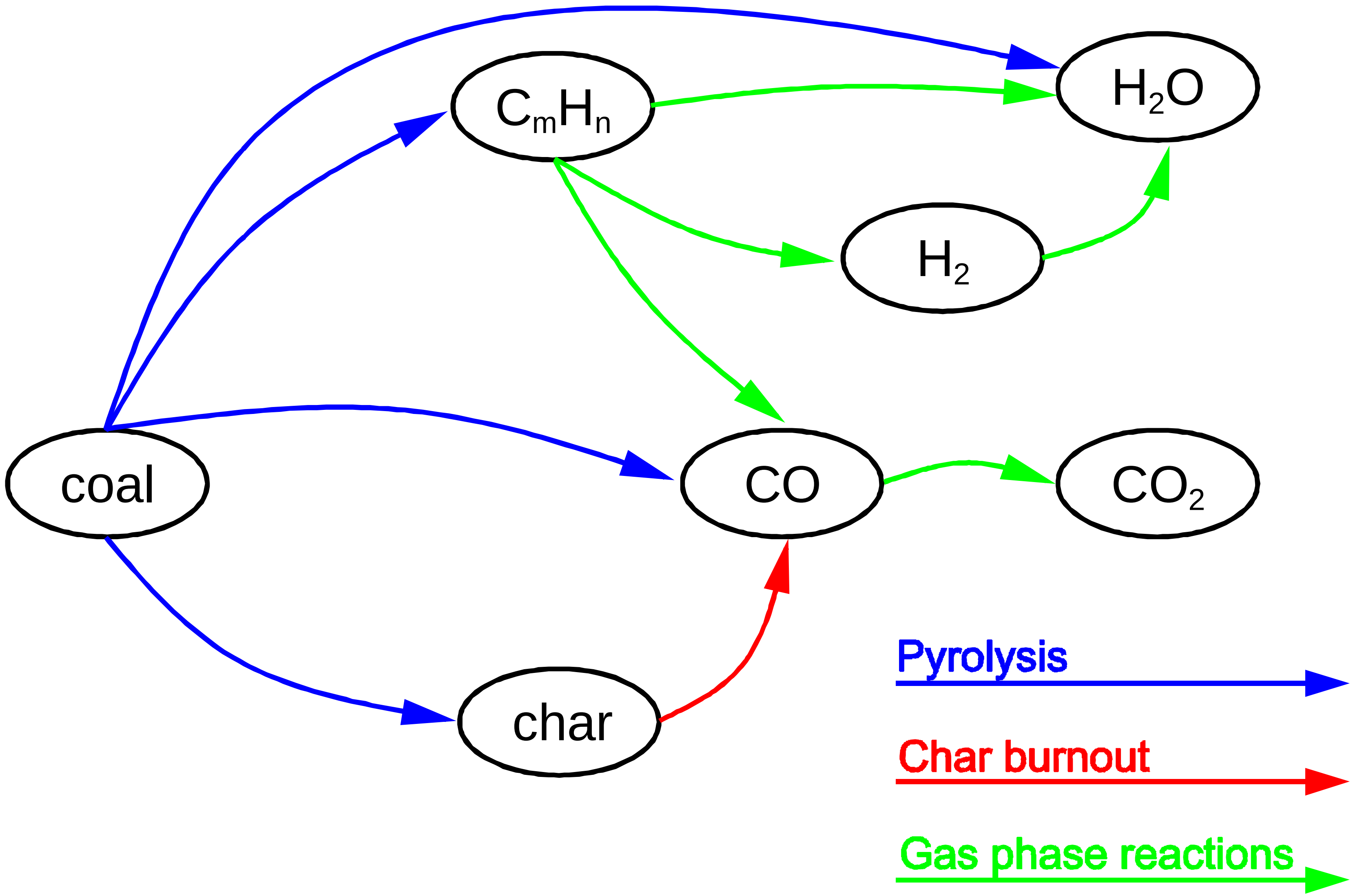
$$C_nH_m + \left[\frac{m}{2} + \alpha\frac{n}{4}\right] \cdot O_2 \Rightarrow m \cdot CO + \left[\frac{n}{2} + \alpha\frac{n}{4}\right] \cdot H_2 + \alpha\frac{n}{2} \cdot H_2O$$

α from water-shift reaction

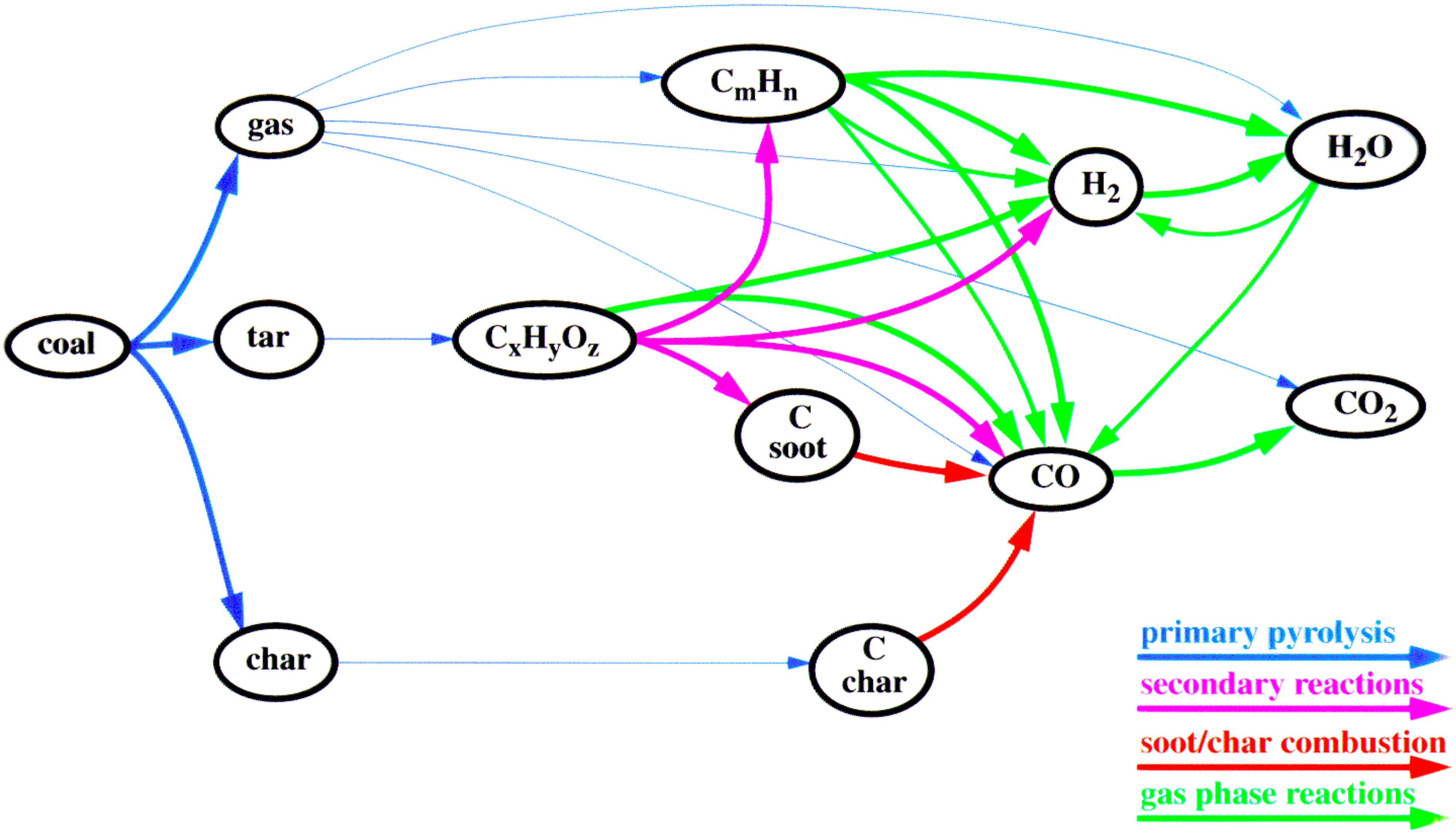
$$CO + \frac{1}{2} \cdot O_2 \Rightarrow CO_2$$

$$H_2 + \frac{1}{2} \cdot O_2 \Rightarrow H_2O$$

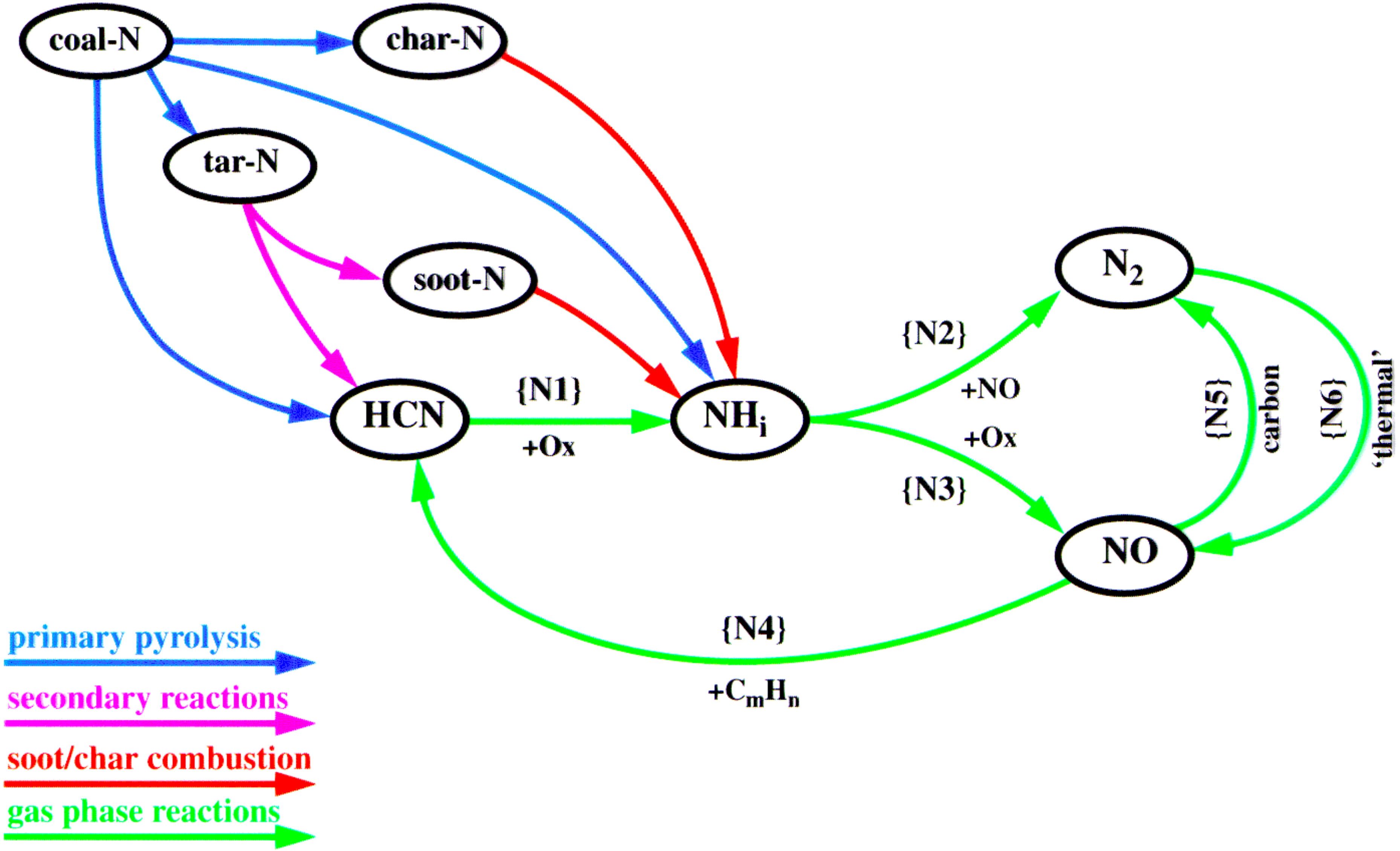
Volatile Combustion



Reaction Scheme of Coal Combustion



Extended Kinetic Reaction Scheme of Pulverized Coal Combustion



Kinetic Reaction Scheme of Fuel-Nitrogen Conversions

possible biomass combustion systems

fixed bed combustion

- wood logs
- wood pellets
- wood chips in :
  - underfeed firings
  - grate firings

pulverised fuel combustion

(co-)combustion of pulverised biomass fuels, such as:

- wood
- straw
- miscanthus

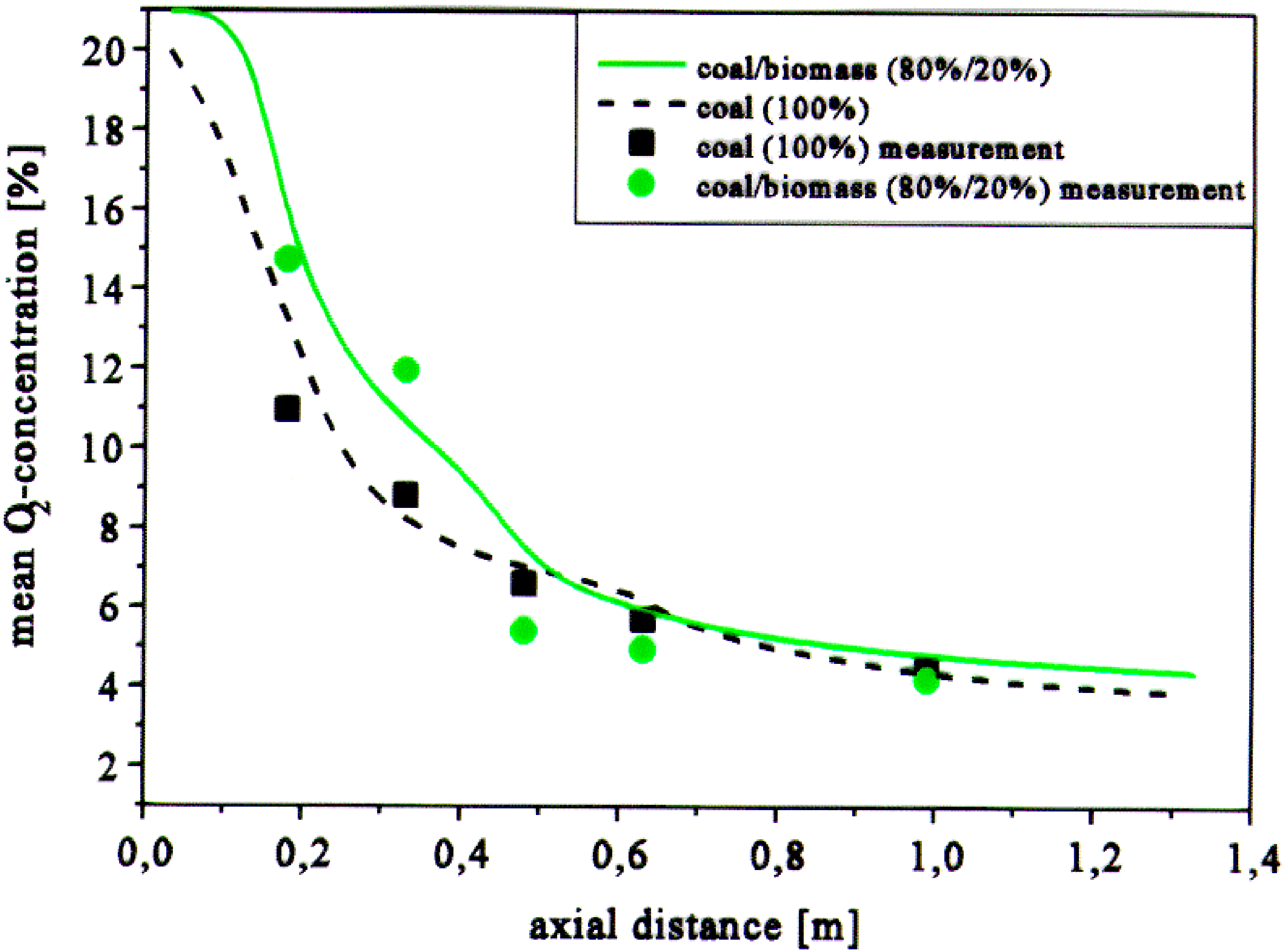
gaseous fuels

pre-treatment of biomass by:

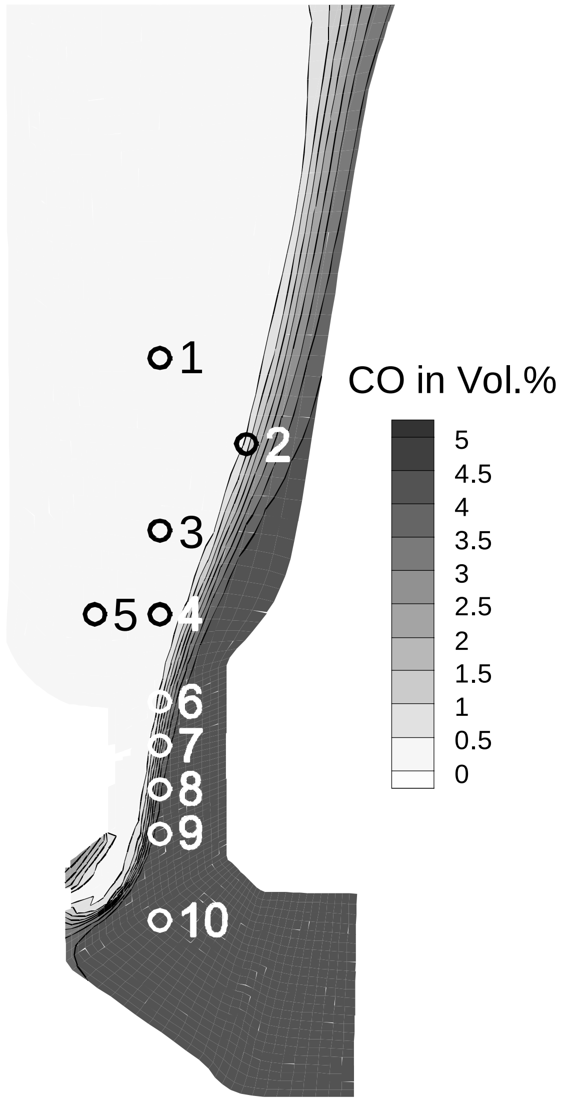
- pre-pyrolysis
- pre-gasification

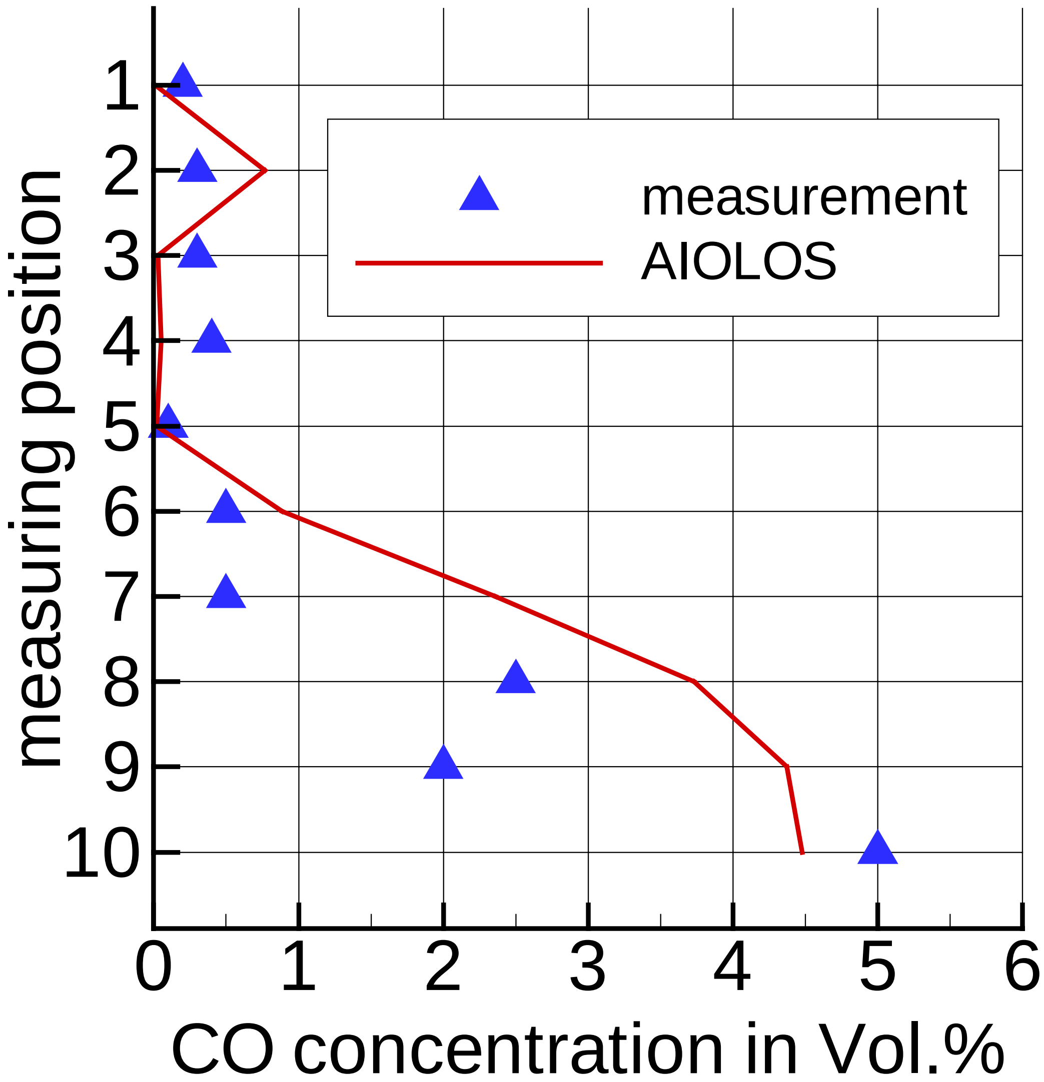
use of gas as reburn fuel in coal boilers

Application to Biomass (Co-)Combustion Systems



(Co-)Combustion of Biomass in PF-Systems





Investigations on Domestic Heating Appliances

- Models for solid fuel conversion including transport and reaction kinetics
- Interface between fixed bed model and gas phase model (grid, heat transfer, pyrolysis gases and combustion products)
- Further development of gas phase reaction model (consideration of species and pollutants released from biomass)
- Validation of models by experimental investigations in combustion system of various scales

Future Improvements/ Extensions