Bergdala
BioenergyProf AB

Combustion, a two-day introduction course

Session 1: Introduction
Lecture 1 – Three perspectives on fuel fundamentals
Lecture 2 – An introduction to emissions
Lecture 3 – A graphic representation of combustion (start)

Session 2: Environmentally friendly combustion and diagnostics
Lecture 3 – A graphic representation of combustion (cont.)
Lecture 4 – Air staging for NOx-reduction
Lecture 5 – Fuel quality variations (I)

Session 3: How to achieve stability
Lecture 6 – Fuel quality variations (II)
Lecture 7 – Ignition and combustion stability (I)
Lecture 8 – Ignition and combustion stability (II)

Session 4: Combustion chambers, emissions and practical aspects
Lecture 9 – Residence time distributions
Lecture 10 – Different combustion chambers and their properties

Literature: Compendium distributed with the course

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Björn Zethræus

Contents

Session 1 – Day one until lunch

The first session is to introduce some basic concepts of combustion, concepts and processes that are common to all types of combustion processes regardless of fuel and technology. The treatment is certainly very simplified but aims at giving some useful tools for the contiued course as well as to set a common terminology with all participants.

Lecture 1: What is a fuel?

40 slides

1-3	Photosynthesis simplified
4-5	Cellulose and introduction to chemical notation
6	Other components in biomass and their properties
7-11	Plant cells connected to (bio)fuel properties, density, ash etc
12	Woody biomass moisture content
13	Woody biomass heating value
14-15	From biomass to fossil fuel
16-17	Conclusions from the photosynthesis
18-23	Proximate analysis: Components
24	Heating and drying
25-26	Pyrolysis and gas combustion
27-28	Char combustion and burnout
29	Conclusions from the proximate analysis
30-32	Combustibles, Contaminants and air
33-34	Incomplete combustion and imperfect mixing
35-37	Primary emissions from nitrogen, sulphur and chlorine
38-39	Secondary reactions involving ash
40	Conclusions from the combustibles contaminants view

Lecture 2: Introducing emissions

14 slides

1-2	Introduction
3-5	Three categories of emission formation
6-10	Actions to abate the emissions and responsibilities
11-14	Where do the emissions go in the environment?

Lecture 3: A general combustion diagram

19 slides

1-2	The air factor
3-8	Oxygen, unburnt and temperature in perfect mixing conditions
9-12	Introducing mixing imperfections
13	Optimal conditions
14-19	Introducing nitrogen oxides in the diagram

Session 2 – Day one after lunch

Session 2 is to introduce environmentally friendly combustion and to outline how this can be achieved in practice. Splitting the combustion process in two does not only help to reduce nitrogen oxides but it also introduces the problem and the conflict between nitrogen oxides and unburnt hydrocarbons. By the end of the session it will be mentioned how the flue gas analysis may provide a means to diagnose malfunctions or fails in the over-all design of the combustion chamber.

Lecture 4: NO_x-reduction by air staging

18 slides

1-4	The efficiency-unburnt-NOx nexus
5-7	The fate of fuel nitrogen with surplus oxygen – and without
8	The main reaction pathways
9-11	SNCR and SCR for NOx-reduction after the combustion chamber
12-14	NOx-reduction inside the combustion chamber
15-17	The over-all strategy with air staging
18	Conclusion

Lecture 5: What if the fuel quality is variable?

23 slides

1-2	Introduction
3-5	Random fluctuations in the primary zone
6	Scale dependence in the primary zone
7-11	Gas characteristics as the primary zone fluctuates
12-14	Random fluctuations in the secondary zone
15	Mixing dependence in the secondary zone
16-19	Gas characteristics as the secondary zone fluctuates
20-22	Expected gas with secondary zone malfunction
23	Expected gas with a well-functioning secondary zone

Session 3 – Day two until lunch

Session 3 is to use the simplified theoretical concepts introduced previously and to draw some conclusions that can be valid for practical control strategies. It will be shown that two factors are more important than most, namely the proportions of primary and secondary air and the secondary air momentum.

Lecture 6: Primary-to-secondary air proportioning

23 slides

1-4	Introduction and the over-all aims
5-6	Cross-sectional combustion intensity and fuel properties
7	Volumetric combustion intensity and moisture content
8-9	Fuel moisture uniformity and scaling aspects
10-11	Ash and ash properties
12	Fuel-and-plant interaction
13-15	Gas composition through the combustion chamber
16-17	Gas composition through the combustion chamber with sec. air
18-22	Gas composition with different operating conditions
23	Conclusions

Lecture 7: What's not ignited escapes unburnt

16 slides

1-2	Introduction
3-6	Identifying the energy release curve
7-9	Identifying the energy loss curve
10-14	Identifying the equilibria
15-16	The ignition temperature and conditions for stable ignition

Lecture 8: Maintaining stable ignition conditions

24 slides

1-4	Introduction
5-6	Influence of residence time
7-8	Influence of gas flow rate as by excess air increase
9-10	Combinatory effect
11-12	Influence of air preheat
13-14	The problem with thermal NO_x
15-18	Flue gas recirculation
19-20	Thermal radiation
18	Summary
19-22	Introducing real-life variations
23	Ignition and combustion temperature intervals
24	The importance of flow-field control

Session 4 – Day two after lunch

The simplified theories henceforth used to explain the phenomena will now be combined to provide over-all characteristics of a few common types of combustion chambers. It will be seen how some of the over-all characteristics of different boiler types can be attributed to fundamental properties and it will be clarified what can realistically be expected by different types of equipment.

Lecture 9: The residence time is not a simple concept

9 slides

1-2	Mean residence time and the residence time distribution
3-4	Turbulent diffusion and the Peclet number
5	Break-through time and mean residence time
6-9	Examples of experimentally obtained residence times

Lecture 10: Combining time, temperature and mixing

30 slides

1-2	Introduction
3-4	Conditions for emission of unburnt hydrocarbons
5	Conditions for thermal NO_x emissions
6-9	Residence time distributions with grate firing and pulverized fuel
10-13	Temperature distributions with grate firing and pulverized fuel
14-15	Distributions with a circulating fluidized bed
16-18	Mean values for most every type of combustion chamber
19-21	Tails with grate firing and with CFB
22-25	What happens with load variations?
26-28	What happens with variable moisture content?
29-30	Conclusions and over-all course summary