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TNO-rapport

R 94/303

Wood Combustion and Oxidation of Wet
Biomass – IEA – TASK X
(Technical Committee Meeting VTT
Jyväskylä, Finland, 25-27 mei 1994)

Bezoekverslag

Datum	augustus 1994
Auteurs	W.F. Sulilatu
Projectnummer	112326-25596
Trefwoorden	- biomassa - verbranding - emissies - energiewinning
Bestemd voor	Novem b.v. Ir. G. Smakman Postbus 8242 3503 RE Utrecht

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Colofon

Contractnummer: 355400/6130.

Dit onderzoek is uitgevoerd in het kader van het programma Energiewinning uit Afval en Biomassa (EWAB).

Beheer en coördinatie van het EWAB-programma berust bij:

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Samenvatting

In de periode van 25 tot en met 27 mei 1994 is in Jyväskylä, Finland, de Technical Committee Members meeting van de IEA-Biomass Combustion and Wet Oxidation, Task X, georganiseerd. Deze meeting werd gecombineerd met het 'Seminar on Small-Scale Combustion Technology'.

Op het Seminar werden 18 presentaties gehouden over kleinschalige biomassaverbranding. Ook vond een presentatie door leveranciers van Finse speksteenkachels plaats.

De Technical Committee meeting bestond uit een voortgangsbespreking en een excursie naar enkele biomassaverbrandingsinstallaties. Tijdens de meeting werden afspraken gemaakt over de afsluiting van het programma 1992-1994 (november, Londen) en een voorlopig plan voor de activiteiten in de periode 1995-1997 besproken.

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1 Inleiding

In de periode van 25 tot en met 27 mei 1994 is in Jyväskylä, Finland, gecombineerd met het 'Seminar on Small-Scale Combustion Technology', de Technical Committee members meeting van de IEA-Biomass Combustion and Wet Oxidation, Task X, georganiseerd. Het programma was als volgt ingedeeld:

- - 25 mei 1994, 'Seminar on Small-Scale Combustion Technology';
- - 26 mei 1994, IEA Technical Committee meeting;
- - 27 mei 1994, excursies.

De sprekers van het seminar bestonden met name uit medewerkers van VTT en de Finse kachelindustrie. In totaal zijn 18 presentaties gehouden die in de volgende hoofdonderwerpen zijn in te delen:

- General Topics;
- Combustion Technology;
- Emission From Small-Scale Combustion;
- Manufacturers' Presentation.

Hoofdstuk 2 gaat over de presentaties die op het seminar zijn gehouden. De meest actuele presentaties zijn in hun geheel aan dit verslag toegevoegd.

In hoofdstuk 3 wordt verslag gedaan van de Technical Committee meeting van de IEA. Naast een presentatie van de lopende projecten is aandacht besteed aan het genereren van nieuwe ideeën voor de periode 1995-1997 en aan de organisatie van de IEA-conferentie die in november 1995 in Cambridge, Engeland zal worden gehouden.

Het totale programma was georganiseerd door VTT-Jyväskylä, Finland.

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2 Seminar on Small-Scale Combustion Technology

Op dit seminar zijn achttien presentaties gehouden, in te delen in:

- General Topics;
- Combustion Technology;
- Emission In Small-Scale Combustion;
- Manufacturers' Presentation.

Het complete programma en de deelnemerslijst van dit seminar zijn in bijlage 1 van dit verslag opgenomen. Van alle onderwerpen wordt in het onderstaande een korte beschrijving gegeven. Van de meest actuele onderwerpen is de gehele presentatie in bijlage 1 van dit verslag opgenomen. Niet opgenomen presentaties zijn bij de auteur van dit verslag te verkrijgen.

2.1 General Topics

2.1.1 Liekki 2-Combustion Research Programme Bengt-Johan Skrifvars, Abo Akademi, Finland

Doel van het project

Het ontwikkelen van milieuvriendelijke energieproductietechnologieën op het gebied van verbranding en vergassing.

In Finland wordt momenteel in het kader van het **Liekki 2**-programma onderzoek verricht op het gebied van vergassing en verbrandingstechnologie. Het programma wordt onder meer gesponsord door het Ministerie van Handel en Industrie.

Het eerste deel van het Liekki-programma liep tot 1992. Na evaluatie van het project is besloten het programma uit te breiden met het Liekki 2, dat tot eind 1998 loopt. Vóór 1993 bedroeg het budget FIM 47 miljoen waarvan FIM 27 miljoen van het Ministerie van Handel en Industrie (210 FIM= 100 Dfl). Het resterende bedrag is afkomstig uit de industrie.

Onderzoeksgbieden

Pressurized fluid bed combustion and gasification
Black liquor gasifiers
Fluidized bed combustion
Black liquor recovery boilers
Diesel power plants
Waste incineration technologies
Conventional combustion

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2.1.2 Bioenergy Utilization and Research in Finland

Prof. Dan Asplund, VTT Energy, Finland

De belangrijkste Finse biobrandstoffen zijn turf en hout (18% van de primaire energie).

Het totale energie verbruik in Finland bedraagt 29.8 Mtoe.

Peat	4%
Wood + waste liquors	14%
Hydro power	13%
Nuclear power	15%
Natural gas	8%
Coal	9%
Oil	30%
Net import	7%

De energieconsumptie uit houtprodukten bedraagt 45 TWh/j.

Het onderzoekprogramma Bioenergy Programme 1993-1998 bestaat uit de volgende onderwerpen:

- produktie van biomassa brandstoffen (hout);
- produktietechnieken voor peat (turf);
- stimulering van gebruik van bio-energie;
- conversie van biomassa.

Dit onderzoekprogramma is nauw verweven met het Liekki 2-programma.

2.1.3 Overview of IEA Biomass Combustion Activities

Prof. Johan Hustad, Sintef, Norway

Johan Hustad geeft een uiteenzetting van de betekenis van de IEA en de activiteit die in Task X - Biomass Combustion and wet oxidation zijn ontwikkeld.

Voor de gehele presentatie wordt verwezen naar bijlage 1 van dit verslag.

2.1.4 Characterization of Biomass and Ashes

Dr. Herman Hoffbauer, Technical University of Vienna

Door de Universiteit van Wenen wordt onderzoek verricht naar de karakteristieke eigenschappen van verschillende soorten biomassa. Deze gegevens kunnen fungeren als een belangrijke basis voor de toepassingen van biomassa als brandstof en kunnen mogelijk informatie geven over de toepasbaarheid van de reststoffen in de industrie, nadat verbranding heeft plaatsgehad.

Ten behoeve van het onderzoek is een aantal soorten biomassa gekarakteriseerd. Met name is het asgehalte, het assmelpunt en het gehalte aan C, H, N, S, Cl en zware

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metalen bepaald. Significante verschillen van de onderzochte biomassa zijn te zien in het asgehalte, stikstof-, zwavel- en chloorgehalte, de smeltpunten van as, en de samenstelling van as.

De volledige presentatie is opgenomen in bijlage 1.

2.2 Combustion Technology

2.2.1 Wood Combustion in Stoves

Edvard Karlsvik

Na een inleiding over de energieverbruiken in de Noordelijke landen en de stookgewoonte in Noorwegen gaat Karlsvik in op de problematiek rond het testen van wood stoves.

Op dit moment (CEN-verband) is er een discussie gaande over de te hanteren testmethode. Met de name de Scandinavische landen geven de voorkeur aan een methode met natuurlijke trek. Afhankelijk van de ingestelde belasting varieert deze tussen de 10 en 20 Pa. Duitsland en Oostenrijk staan echter een testmethode voor met een ingestelde trek van 10 Pa (+/- 2 Pa).

Nederland heeft tot nu toe de methode met natuurlijke trek voorgestaan, maar neigt nu naar de methode met de ingestelde trek. Met name de reproduceerbaarheid van test-runs met deze laatste methode is groter (Dr. Hein van Rheinbraun). Bovendien komt, zoals uit de presentatie van Karlsvik blijkt, een trek van 10 Pa (4 Pa/m) dichterbij de buurt van de praktijksituatie.

Gezien de aandacht voor dit onderwerp in Nederland, is de presentatie in zijn geheel in bijlage 1 van dit verslag opgenomen.

2.2.2 Automatic Combustion Equipment for Wood Chips and Sod Peat

Heikki Oravainen

Het doel van dit project betreft de ontwikkeling van een automatisch brandersysteem met een vermogensbereik van 50-1000 kW voor wood chips en turf. De ontwerpeisen voor een dergelijke installatie waren gesteld op:

- rendement 85% bij vollast;
- CO 1000 ppm (O₂ onbekend).

Een prototype met een capaciteit van 200 kW is tijdens dit project ontwikkeld waarna de brander is gemonteerd in een zogenaamde ETNA bioboiler.

De eerste testen met beuken, chips en turf hebben de volgende resultaten opgeleverd:

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Tabel 1 Experimentele resultaten brandersysteem

Vermogen [kW]	Brandstof [-]	Vocht- gehalte [%]	CO ₂ [%]	CO [ppm]	Stof [mg/MJ]	NO _x [ppm]	Rendement [%]
202	chips	19	12,7	530	84	130	84,1
151	chips	23	13,4	585	90	230	84,9
75	chips	23	9,3	958	49	n.m.	80,2
147	sod peat	32	9,4	489	193	304	78

Vergeleken met de NeR-concepteisen voor CO (50 mg/m³) is de hier gemeten CO-emissie een factor 10 tot 20 hoger. Door de hoge emissies van CO (en waarschijnlijk ook C_xH_y) is het NO_x-gehalte relatief laag als wood chips worden gestookt. De verhoogde NO_x-emissie bij het verstoken van Sod Peat is mogelijk te wijten aan een verhoogd N-gehalte in de brandstof.

De slechte verbranding wordt mogelijk veroorzaakt door een slechte menging. Het brandersysteem bestaat uit een cilindrische verbrandingskamer waarbij de brandstof wordt ingeblazen. Door de deeltjesgrootte (~20 tot 30 mm) zal een gedeelte van de brandstof als het ware uitzakken en slechts gedeeltelijk deelnemen aan het verbrandingsproces. Menging van de brandstof met verbrandingslucht vindt gebrekkig plaats. Van getrapt verbranden (gunstig effect op het verbrandingsproces) is bij dit systeem nauwelijks sprake. Een mogelijke verbetering is te verwachten, indien de stuksgrootte van de toegepaste brandstof wordt verkleind.

2.2.3 Straw Pellet Combustion

Henrik Houman Jakobsen

Aan de TARM district heating plant in Denemarken zijn emissiemetingen uitgevoerd met kool en stro als brandstof. De duur van de experimenten bedroeg drie tot zes uur; de experimenten zijn uitgevoerd in de periode oktober 1992-november 1993.

De experimenten hebben plaatsgevonden in een oorspronkelijke koleninstallatie, voorzien van een kettingrooster. De installatie is uitgerust met een textiel (Dralon) filter. De resultaten zijn weergegeven in tabel 2.

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Tabel 2 Resultaten stroverbranding in koleninstallatie

Parameter	Unit	Coal reference	Straw pellets
Feed rate	kg/h	750	950
Infeed	MW	4.77	4.39
Boiler Output	MW	4.53	4.01
Boiler load	%	71.6	65.8
Flue gas temp.	°C	88	79
Losses:			
flue gas	%	3.6	2.9
CO	%	< 0.01	< 0.01
fly ash	%	< 0.01	< 0.01
radiation	%	1.7	2.7
Total:	%	5.4	5.7
Calculated boiler efficiency	%	94.6 ± 0.3	94.3 ± 0.4

Conclusies

- Verbranding van stro in oude kolengestookte installaties verloopt goed. De verbrandingskwaliteit is over het algemeen beter dan in installaties die voor het verbranden van stobalen zijn ontworpen.
- Het belangrijkste probleem dat opgelost dient te worden is het filterprobleem. Bij stroverbranding blijkt een verharding van het filterdoek op te treden, veroorzaakt door de een nog onbekende component in de vliegash.
- Voor Nederland kunnen deze experimenten van waarde zijn, indien men ertoe overgaat om bijvoorbeeld grassen te verbranden voor de opwekking van energie.

2.2.4 Wood Pellet Production and Use in USA

Don Hardesty, Sandia Lab., USA

Donald Hardesty is manager van het Combustion Research Facility, Sandia National Laboratories Livermore, California, USA.

Hardesty geeft een uitgebreide presentatie over de fabricagetechnieken, brandstofkarakteristieken en economische aspecten van pellets en briketten. Een uitgebreide lijst van testlaboratoria en producenten zijn in deze presentatie meegenomen.

Gezien de lengte van de presentatie, is deze niet in het verslag opgenomen, doch bij de auteur van dit verslag verkrijgbaar.

2.3 Emissions in Small-Scale Combustion

2.3.1 Emissions from Biomass Fired Combustion

Mats Lennart Karlsson, Sweden

In Zweden wordt onderzoek uitgevoerd naar de emissies van de best beschikbare technologieën op het gebied van kleinschalige industriële biomassaverbranding.

Het doel is de kritische factoren die bepalend zijn voor het emissieniveau te identificeren.

Verskillende typen installaties en brandstoffen zijn bij het project ingezet, waarbij de emissies bij verschillende vermogensinstellingen en luchtinstellingen van de verbrandingslucht worden onderzocht.

Tot nu toe zijn drie typen verbrandingsinstallaties onderzocht:

- stationaire fluid bed met wood chips;
- schuin-roosterverbranding met wood chips en briketten;
- horizontale roosterverbranding met wood chips en briketten.

De resultaten tonen de effecten aan bij een verlaagde luchtvermaat op de emissie van CO en NO_x. De emissie van CO zijn als volgt:

Fluid Bed	300-1000 mg/m ³ ind. 11% O ₂ ;
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Horizontal grate	500	„
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Moving grate	100-300	„
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De experimenten met de moving grate zijn het meest veelbelovend.

Voorts wordt, zoals ook door andere onderzoekers vele malen is gevonden, aangetoond dat het stikstofgehalte in de brandstof bepalend is voor de uiteindelijke vorming van de NO_x-emissie.

Verdere conclusies uit dit onderzoek luiden:

- Bij vochtige brandstoffen heeft de grootte van de installatie een gunstig effect op de emissies. Installaties < 3 MW bezitten over het algemeen een te kleine verbrandingskamer.
- Voor de verbranding van droge brandstoffen heeft de grootte van de installatie minder invloed.
- Wisselingen van het vermogen veroorzaken een toename van de emissies (dus installaties uitrusten met een vermogensregeling).

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2.3.2 Combustion Control and NO_x Emissions **Jürgen Good, VERENUM-Zwitserland**

De presentatie van Good is opgebouwd uit twee delen:

- NO_x-emissiereductie;
- controlesystemen van verbrandingsinstallaties.

NO_x-emissie

Na een algemeen verhaal over de vorming van NO_x bij verbranding wordt ingegaan op het terugdringen van deze emissie. Dit kan plaatsvinden door toepassing van primaire maatregelen en secundaire maatregelen.

Primaire maatregelen

- getrapte verbranding met gescheiden reductie kamer tussen de vergassings- en verbrandingskamer;
- getrapte luchttoevoer in de vergassingsfase;
- rookgasrecirculatie;
- combinaties van de bovenstaande maatregelen.

Secundaire maatregelen, te onderscheiden in:

Selective non catalytic reduction (SNCR)

- inspuiting van agents (NH₃ onverdund of verdund, ureum) in de verbrandingskamer bij een temperatuur van 850-950 °C.

Selective Catalytic Reduction

- inspuiting van agents in de rookgassen in combinatie met een katalysator bij een temperatuur van 250 °C.

Control systems

Van belang voor een goede verbranding is, naast een accuraat ontworpen verbrandingsinstallatie, tevens de toevoer van secundaire verbrandingslucht zonder verstoring van de vergassingsfase van de vaste brandstof.

Experimenten tonen aan dat de CO-luchtovermaat karakteristiek van een installatie verandert bij overschakeling naar deellast of bij overschakeling naar brandstof met een hoger vochtgehalte. Door Good is een CO-lambda control systeem ontwikkeld waarbij het setpoint van de lambda controller permanent wordt geoptimaliseerd. Een speciale algoritme, die gebruik maakt van de luchtovermaat en de gemeten CO, berekent het nieuwe setpoint.

Toepassing van een dergelijk regelsysteem kan leiden tot de volgende effecten:

- verbetering van het rendement met 1 tot 5%;
- verlaging van de CO-emissie met een factor 1,5 tot 2.

De presentatie is in bijlage 2 opgenomen.

De introductie van een CO-Lambda regelaar betekent dat voor elke installatie eerst de CO-lambda karakteristiek van de installatie bekend moet zijn die zowel gemeten

dient te worden bij deellast en vollast. Een CO-sensor is dan noodzakelijk. Een oxisonde is niet toereikend voor dit doel, omdat het CO- setpoint bij een vermogensverandering verandert. Met een CO-sensor is voorts directe informatie beschikbaar omtrent de verbrandingskwaliteit.

2.3.3 Reduction of Emissions of Chip Board Waste Combustion

Larjava K. et al., VTT Chemical Technology, Finland

In Finland bestaan momenteel geen richtlijnen op het gebied van kleinschalige verbranding van schoon afvalhout. Over het algemeen worden de TA-Luft-normen door de overheid gehanteerd bij het vaststellen van emissienormen. Door het Ministerie van Handel en Industrie is een budget beschikbaar gesteld om met name de emissies van met spaanplaatgestookte verbrandingsinstallaties in de meubelindustrie te verlagen.

De doelstelling van het project is om met low-cost oplossingen deze emissieverlaging tot stand te brengen. Onder meer zal een low-cost catalysator van KEMIRA worden getest.

Zes installaties zullen aan testen worden onderworpen. De effecten van de aangebrachte technieken op de emissies zullen worden gemeten.

Gestart is met het doormeten van de oorspronkelijke installaties. Er hebben voorts inleidende experimenten plaatsgevonden met de Kemira-katalysator. Een significante reductie van de CO-emissie, door de katalysator is aangetoond.

2.3.4 Progress in European Standardization of Residential Solid Fuel Burning Appliances

Prof. Kaye geeft een presentatie aangaande de CEN-activiteiten ten aanzien van wood stove testing.

Voor belangstellenden is deze presentatie beschikbaar bij de auteur van dit rapport.

2.4 Manufacturers' Presentations and Exhibition

Het onderwerp van deze presentaties betrof uitsluitend de technologie van zware speksteenkachels die in Finland als verwarming veel voorkomen. De presentaties betroffen onder meer de techniek van speksteenwinning, constructie en wijze van stoken. In Nederland zijn dit type kachels maar weinig in gebruik. Voor belangstellenden zijn de presentaties bij de auteur van dit verslag beschikbaar.

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3 Technical Committee meeting

3.1 Inleiding

De Technical Committee meeting bestond uit twee delen:

- voortgangsbespreking op 26 mei 1994;
- excursie op 27 mei 1994.

De complete agenda en deelnemerslijst is opgenomen in bijlage 2.

Na de opening door Prof. Otto Sonju en behandeling van de notulen van de vergadering in Borås Zweden worden de IEA-projecten behandeld.

3.2 Round Robin Test of a Wood Stove

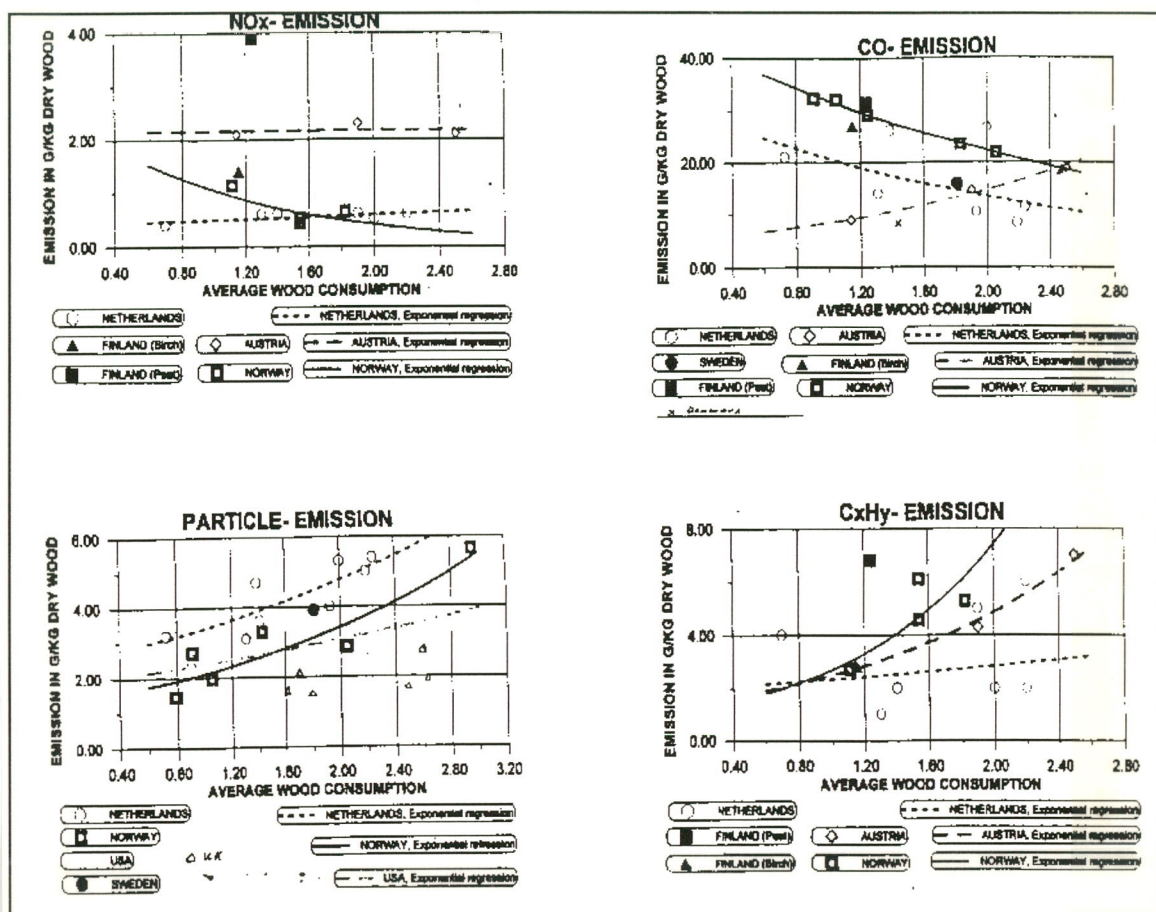
Edvard Karlsvik, Norway

Bij de Round Robin Test zijn de volgende landen betrokken: Oostenrijk, Canada, Denemarken, Finland, Noorwegen, Nederland, Zweden, Engeland en Amerika.

De Round Robin Test houdt in dat door elk van de deelnemende landen, conform de geldende nationale testmethode, emissiemetingen zijn uitgevoerd aan eenzelfde type houtkachel. De kachel is aan elk van de deelnemende landen ter beschikking gesteld door Jotul Noorwegen.

De resultaten van Canada zijn nog niet gereed, aangezien men, evenals Engeland, problemen heeft gehad met het niet-functioneren van de katalysator. De Finse experimenten zijn uitgevoerd met turf.

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Figuur 1 Emissieresultaten Round Robin Test

De resultaten van de binnengekomen gegevens zijn weergegeven in figuur 3. Voor het testen van kachels zijn er op dit moment twee methoden toonaangevend. Het meest kenmerkende verschil tussen beide methoden is de trek. De ene is gebaseerd op natuurlijke trek (EPA-testmethode) en de andere op een ingestelde trek (DIN 18891).

De voorlopige bevindingen zijn dat de landen die de EPA-testmethode hebben gehanteerd, gasvormige emissies (CO en C_xH_y) hebben gemeten die afnemen naarmate het vermogen stijgt. Dit in tegenstelling tot de DIN 18891 waarbij door Oostenrijk juist een toename van de emissies is gemeten bij toenemend vermogen.

De emissie van stofdeeltjes bij de EPA-methode stijgt, naarmate het vermogen toeneemt; bij de Oostenrijkers is dit onduidelijk.

(Opgemerkt zij dat de Oostenrijkers pretenderen de DIN 18891 methode te hantieren. Twijfels bestaan echter omtrent de juiste interpretatie van de methode.)

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De Engelse en Canadese experimenten zijn mislukt vanwege het disfunctioneren van de katalysator, waarmee de teststove was uitgerust.

Ten behoeve van de conferentie in Engeland zal aan alle landen nog een bijdrage worden gevraagd voor de rapportage. Deze zal bestaan uit een korte samenvatting van de gebruikte meetapparatuur.

3.3 Energy from Contaminated Wood Waste Frans Sulilatu, The Netherlands

Sulilatu geeft een overzicht van lopende projecten op het gebied van vervuild afvalhout en presenteert twee projecten:

1. *Gasification of waste preserved wood.*
2. *Firing Experiments with powder-wood/powder-coal in a 1 MWth pilot combustion installation*

Project 1

Gasification of waste preserved wood.

Doel van het project

Uitvoering van testprogramma's in een 200 kWth meestroomvergasser ten einde vast te stellen of via vergassing vervuild afvalhout op een milieuvriendelijke wijze thermisch kan worden verwerkt.

De projectleiding ligt bij Alice Kristiansen (DK). De deelnemende landen zijn: Nederland (TNO), Finland (VTT) en Denemarken (DTI).

Op het moment van de presentatie waren nog geen experimentele resultaten met de vergasser bekend.

In het kader van dit project heeft Nederland een inventarisatie van de mogelijke afkomst van vervuild afvalhout gemaakt. De sheets die zijn gepresenteerd zijn in bijlage 2 weergegeven.

Project 2

Firing Experiments with powder-wood/powder-coal in a 1 MWth pilot combustion installation.

Deze presentatie handelt over een co-firing project van verpoederd hout en poederkool. Experimenten zijn door KEMA-Arnhem uitgevoerd in een 1 MWth pilot plant.

De gepresenteerde sheets zijn in bijlage 2 weergegeven.

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3.4 Wood Chip Co-generation

H.H. Jacobsen (DK)

Jacobsen heeft een studie verricht naar wood co-generation systems. De geselecteerde technologieën zijn:

Steam Turbine Power Plants
Steam Engines
Stirling Engines
Indirectly fired gasturbine co-generation
Pressurized downdraft combustion of wood chips.

De studie omvat de identificatie van R&D-activiteiten, status van ontwikkeling, economische aspecten, technische haalbaarheid van introductie van de techniek en hoofdbeperkingen voor technische toepasbaarheid aan bestaande energie-infrastructuur.

De meest bekende toegepaste technologieën zijn die van de turbine en de stoommotor. Minder bekend is de Stirling motor, de indirect gestookte gas turbine en de zogenaamde pressurized down draft brander.

Stirling Motor

Met name de Stirling engine staat de laatste tijd veel in de belangstelling vanwege het hoog elektrisch rendement (tot 44%) en het lage geluidsniveau. Vanwege de achterblijvende commercialisatie blijft de Stirling engine voorsnog duur. Ter illustratie: de huidige produktiekosten voor de Zweedse V-160 motor (asvermogen 8 kWe) bedragen 37.500 US\$ of 4.690 US\$/kWe. De prognose is dat de kosten bij volledige commercialisatie (produktie 1000-200.000 st./j) zullen komen te liggen tussen de 62-240 US\$/kWe (kosten stoomturbine 300 US\$/kWe).

Beperkingen voor toepassing van de Stirling motor betreffen het elektrisch rendement bij deellast. Mede vanwege de brandstofflexibiliteit van de Stirling motor zijn weinig inpassingsproblemen in de huidige infrastructuur te verwachten.

Indirect gestookte gasturbine (IGT)

De indirect gestookte gasturbine (IGT) is gebaseerd op de conventionele gasturbine met dien verstande dat de verbrandingskamer is vervangen door een lucht/afgasen warmtewisselaar. Het probleem is de warmtewisselaar die tegen hoge temperaturen bestand dient te zijn waardoor de investeringskosten stijgen.

De investeringskosten (output 500 kWe) worden voor een IGT geschat op 4.500 US\$/kWe.

Voor wat betreft de technische inpassing in de bestaande infrastructuur zijn geen problemen te verwachten.

Pressurized Down Draft Combustion (PDC)

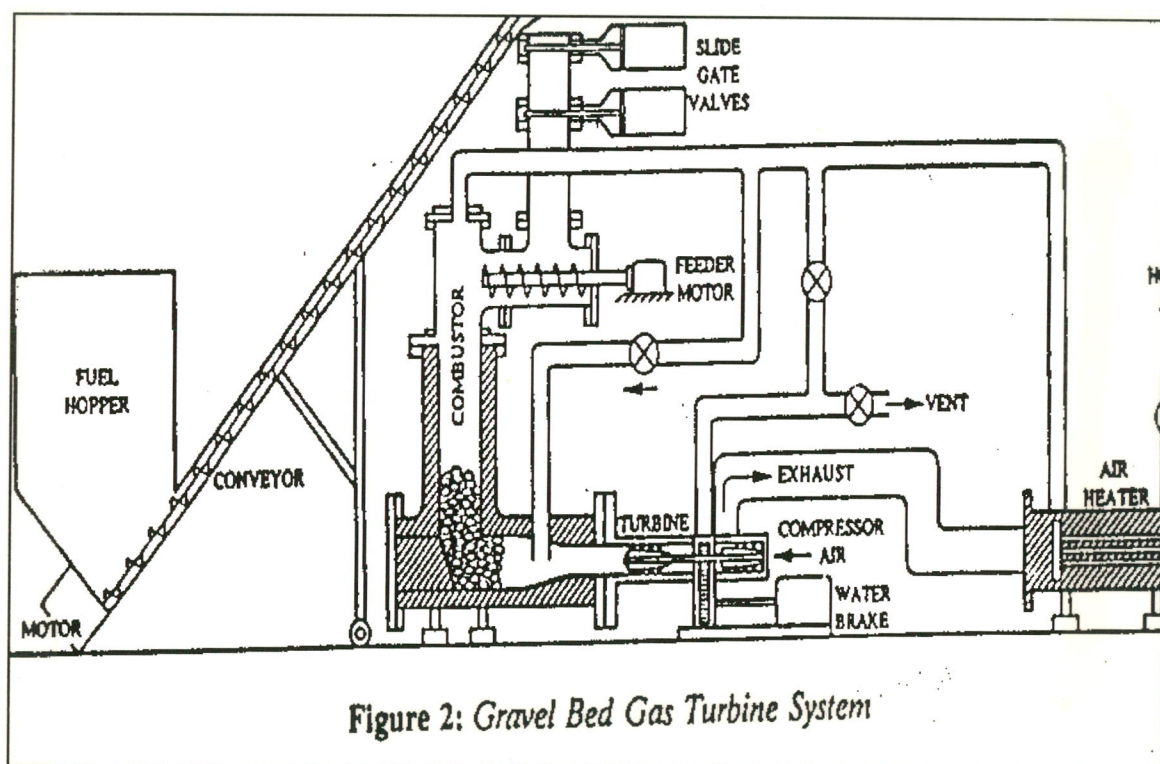
De pressurized Down Draft Combustor (zie figuur 4) is gebaseerd op het vergassen van hout. Het hout (chips) ligt op een bed van zand of gravel waardoor een uit het proces afkomstige hete luchtstroom wordt geleid. De hete verbrandingsgassen wor-

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den met lucht gemengd en naar een gasturbine geleid voor de productie van elektriciteit.

Het systeem is in Amerika op een aantal plaatsen beproefd en geschikt voor opwekking van elektriciteit vanaf 300 kWe. Problemen hebben zich voorgedaan met het stationair bedrijven van de installatie. Het gas hoeft niet verder te worden gereinigd. Het systeem is gereed voor commercialisering.

De investeringskosten worden geschat op 855 US\$/kWe.



Figuur 2 Down Draft Combustion Installation

Teneinde een indruk te verkrijgen van de economische haalbaarheid is door Jakobsen een economisch model gemaakt. Uitgangspunt is een 2 MWth installatie voor de opwekking van elektriciteit. Uit dit model blijkt dat bij volledige commercialisatie van de Stirling motor deze als meest economisch geëxploiteerd kan worden.

Rapport 'Technologies For Small Wood Co-Generation Systems' te bestellen bij DK Teknik (zie adreslijst bijlage 3).

3.5 Condensing Systems

H. Oravainen, Finland

De meeste energie-plants voor toepassing in een lange-afstandsverwarmingsketen staan nabij de lokatie waar de brandstof wordt gewonnen. Droging van de brandstof vindt plaats in ovens die zijn uitgerust met een voordroogkamer. Daarbij is de installatie tevens voorzien van een rookgascondensatiesysteem ten behoeve van de terugwinning van de latente warmte in de rookgassen. Een rendementsverhoging van de installatie kan worden verkregen door deze warmte weer toe te voeren aan het retourwater van het afstandsverwarmingsnet. Het rookgascondensatiesysteem bestaat uit een tweetraps impuls-scrubber waarbij water in direct contact wordt gebracht met de rookgasstroom. Na reiniging in een zogenaamde condens-clarififier, wordt het water weer hergebruikt. De uit de rookgasstroom afgescheiden componenten worden afgevoerd.

In Finland (VTT) is onderzoek gaande op het gebied van directe verbranding van hout en turf met een vochtgehalte van 35-55% en RDF. Deze brandstof wordt verbrand in twee verbrandingsinstallaties (bewegend schuin rooster) van respectievelijk 4 en 6 MW_{th} experimenten uitgevoerd. Parallel aan de installatie staan twee oliegestookte verbrandingsinstallaties van respectievelijk 1 en 3.7 MW_{th}. De installatie is aangesloten op het afstandsverwarming-ringleidingnet van Virrat.

Toepassing van de condensatietrap resulteert in de volgende effecten:

- toename van het rendement : 5-30%
- verwijdering van zwavel : 60-90%
- verwijdering van chloor : 95-99%

Voor de Nederlandse situatie is het denkbaar dat een dergelijk systeem toegepast kan worden, indien men houtafval uit bossen direct thermisch zou willen verwerken. Voor de afscheiding van stof zijn met een condensatietrap zeer goede resultaten geboekt (<30 mg/m³ 11% O₂).

Mogelijk kan de impuls-scrubber goede diensten bewijzen bij de thermische verwerking van vervuild afvalhout.

3.6 Characterization of Biomass

Thomas Linsmeyer/Hermann Hofbauer (Oostenrijk)

Deze presentatie komt overeen met de presentatie die is gehouden op het seminar, zie hoofdstuk 2.1.4 van dit verslag.

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3.7 Emissions from Biomass Combustion Jürgen Good (Zwitserland)

Namens Thomas Nusbaumer presenteert Good het volgende:

Emissies van biomassaverbranding

Het doel van dit project is informatie te verzamelen aangaande:

- actueel gebruik/potentieel van biomassabrandstoffen in IEA-landen;
- State of the art van biomassaverbranding;
- emissies van de huidige biomassaverbrandingssytemen;
- historie van emissietechnieken;
- vergelijking van de verschillende biomassasystemen in IEA-landen.

Op dit moment komt informatie nauwelijks of onvolledig binnen en wordt een oproep aan de IEA-membbers gedaan voor betere en meer informatie.

De volgende rapporten zijn in Zwitserland verschenen:

Wirkungsgradbestimmung bei Holzfeurungen
Jürgen Good/Thomas Nusbaumer, juni 1994
DIANA 7 Projekt Klein Holzfeurungen
Verenum, Sonnegasstrasse 25, 8006 Zürich

Reglung einer Stückholzfeuerung mit unterem Abbrand
Jürgen Good/Thomas Nussbaumer, juni 1994
Verenum, Sonnegasstrasse 25, 8006 Zürich

Stofffluss bei der Verbrennung und Vergassung von Altholz
(E 2000 Das Aktionsprogramm Energie 2000: unsere Energiepolitik)
Dr. Th. Nussbaumer
Verenum, Sonnegasstrasse 25, 8006 Zürich

Gasification of urban waste wood (Altholz)
Ph. Hassler, Verenum, Zürich (Switzerland)
R. Bühler, Energie + Umwelt, Maschwanden (Switzerland)

Lachgas Emissionen von Kleinfеurungen
Schriftenreihe Umwelt nr. 217
Bundesamt für Umwelt, Wald und Landschaft (BUWALL)
Verenum, Sonnegasstrasse 25, 8006 Zürich

Vergassung von Biomasse für die Methanol-Synthese
Ph. Hasler, Th. Nussbaumer, Ingenieurbüro Verenum
Ruedi Bühler, Ingenieurbüro Energie + Umwelt
april 1994, Zürich

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3.8 Combustion Study of Pyrolysis Oils and Chars and Pollution Formation and the Behaviour of Biomass-Derived Fuels

D. Hardesty, Sandia National Laboratories, California, USA

Op Sandia wordt onderzoek uitgevoerd op het gebied van 'renewable' energie (zonne-, geothermische- en windenergie en sinds kort ook biomassa). Voorts wordt onderzoek uitgevoerd op het gebied van milieu en afvalbehandeling. CRF houdt zich met name bezig met verbrandingsonderzoek (vloeibare en vaste brandstoffen en biomassa). Door middel van een diapresentatie toont Hardesty de activiteiten op Sandia (presentatie beschikbaar bij de auteur van dit verslag).

3.9 Co-firing Biomass and Coal

F. Dumbleton, UK

Dumbleton bestudeert de mogelijkheden van co-firing van biomassa en kolen in grotere bestaande ketels.

De problemen die hij verwacht zijn de volgende:

- De beschikbare installaties in Engeland zijn zogenaamde strategische installaties met een capaciteit van 500 MWe.
- Deze installaties staan in de nabijheid van coalfields of havens en ver van bossen.
- Beperkt houtresidupotentieel bij de bestaande installaties.
- Co-firing is mogelijk voor een beperkt percentage van hout < 10%.

3.10 Comments, Discussion and Future Plan for Biomass Utilization

1995-1997

Commentaar Sonju

Met betrekking tot de lopende projecten zijn er goede vooruitgangen geboekt. Behalve het project 'Biomass in Large-Scale Boilers' zullen alle projecten worden gecontinueerd. Twee andere projecten, voorgesteld op de laatste meeting in Zweden, 'Co-firing of biomass and Coal' en 'Indirectly fired gas turbines for electricity production' zullen, zoals gepland, doorgang vinden (respectievelijk Engeland en Canada zullen deze projecten trekken). Een presentatie van dit laatste onderwerp is gepland voor de conferentie in Engeland.

De resultaten van de projecten zullen worden samengevat in een IEA-rapport en worden gepresenteerd conform een standaard-format.

Voor de vergadering in Engeland worden de technische leden verzocht tenminste drie externe sprekers voor te dragen. Zes tot acht daarvan zullen worden uitgenodigd om een presentatie te houden op de in Engeland te houden conferentie die samen zal worden gehouden met de IEA-vergadering. Voorstellen moeten vóór juli 1994 bij het IEA-secretariaat binnen zijn.

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De presentaties die zullen worden gehouden door de technische comitéleden moeten vooral betrekking hebben op projectresultaten en niet alleen op de status van een project.

Het eerste gedeelte van de conferentie zal gewijd worden aan een evaluatie van de technologieën en activiteiten van de belangrijkste biomassa gebruikslanden, gevolgd door presentaties van de technische comitéleden over specifieke projecten. Een postersessie kan eventueel aan de conferentie worden toegevoegd.

Een voorlopig plan voor de conferentie moet eind augustus 1994 gereed zijn (actie UK, Fred Dumbleton).

Volgende vergadering

De volgende vergadering zal in combinatie met de conferentie in Engeland (29 november) op 30 november en 1 december 1994 worden gehouden.

New Agreement

Het plan voor een nieuwe overeenkomst (1995-1997) is in ontwikkeling en een voorlopig plan voor de te ontwikkelen activiteiten in Task XIII en de voorgestelde projecten voor de Biomass Combustion Activity is bijgesloten in bijlage 3.

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4 Excursies

Op 27 mei 1994 zijn de volgende lokale biomassa-installaties bezocht:

- 1. Rauhalahti Combined Heat and Power Plant in Jyväskylä*
- 2. Virrat-District Heating Plant*
- 3. Saarijarvi District Heating Plant*

Met name het bezoek aan Virrat-district heating plant is voor de Nederlandse situatie van belang voor verbranding van vochtige biomassa, zoals uit hout uit bossen en/of grassen. Informatie hieromtrent is bij de auteur beschikbaar.

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5 Verantwoording

Naam en adres van de opdrachtgever

Novem b.v.

Ir. G. Smakman

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3503 RE Utrecht

Namen en functies van de medewerkers

W.F. Sulilatu – researchmedewerker

Namen van instellingen waaraan een deel van het onderzoek is uitbesteed

N.v.t.

Datum waarop, of tijdsbestek waarin, het onderzoek heeft plaatsgehad

25 - 27 mei 1994

Ondertekening

Goedgekeurd door

W.F. Sulilatu
onderzoekleider

Ir. J. de Koning
werkgroep leider

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Bijlage 1 Seminar on Small-Scale Combustion Technology

Programma/Deelnemerslijst

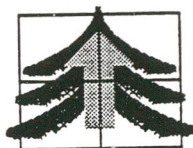
Overview of IEA-Biomass Combustion Activities

Characterization of Biomass and Ashes

Wood Combustion in Stoves

Emissions in Small-Scale Combustion

Combustion Control and NO_x Emissions



BIOENERGIA

SEMINAR ON SMALL-SCALE COMBUSTION TECHNOLOGY AND EMISSIONS

PIENPOLTON TEKNIikka JA PÄÄSTÖT - SEMINAARI

25.5.1994, Hotel - Hotelli Laajavuori
Jyväskylä, Finland

PROGRAMME - OHJELMA

GENERAL TOPICS

Yleiset aiheet

Chairman/Puheenjohtaja Heikki Oravainen, VTT Energy/VTT Energia,
Finland/Suomi

- | | |
|-------|--|
| 8.00 | Ilmoittautuminen - Registration
Aamukahvi - Coffee |
| 8.30 | LIEKKI 2-COMBUSTION RESEARCH PROGRAMME
Pienpolton tutkimus LIEKKI 2 - tutkimusohjelmassa
<i>Research scientist Bengt-Johan Skrifvars, Åbo Akademi,
Finland/Suomi</i> |
| 9.00 | BIOENERGY UTILIZATION AND RESEARCH IN
FINLAND
Bioenergian käyttö ja tutkimus Suomessa
<i>Prof. Dan Asplund, VTT Energy/VTT Energia, Finland/Suomi</i> |
| 9.30 | OVERVIEW OF IEA BIOMASS COMBUSTION ACTIVITIES
Katsaus IEA:n biopolttoaineiden polttotutkimukseen
<i>Prof. Johan E. Hustad, SINTEF, Norway/Norja</i> |
| 10.00 | Break - Tauko |

- 10.15 CHARACTERIZATION OF BIOMASS AND ASHES
Biomassojen luokitus ja laatu
*Dr. Hermann Hofbauer, Technical University of Vienna,
Austria/Wienin yliopisto, Itävalta*

COMBUSTION TECHNOLOGY

Polttotekniikka

Chairman/Puheenjohtaja Juha Huotari, VTT Energy/VTT Energia,
Finland/Suomi

- 10.45 WOOD COMBUSTION IN STOVES
Puun poltto kamiinoissa
Research Engineer Edvard Karlsvik, SINTEF, Norway/Norja
- 11.15 AUTOMATIC COMBUSTION EQUIPMENT FOR WOOD
CHIPS AND SOD PEAT
Automaattinen kiinteistöjen lämmitysjärjestelmä puulle ja
turpeelle
*Senior research scientist Heikki Oravainen, VTT Energy/VTT
Energia, Finland/Suomi*
- 11.45 Lunch - Lounas
- Chairman/Puheenjohtaja Johan E. Hustad, SINTEF, Norway/Norja
- 12.45 STRAW PELLET COMBUSTION
Olkipellettien polttotekniikka
Dr. Henrik Houmann Jakobsen, dk-Teknik, Denmark/Tanska
- 13.15 WOOD PELLET PRODUCTION AND USE IN USA
Puupellettien tuotanto ja käyttö USA:ssa
Dr. Don Hardesty, Sandia Laboratories, USA

EMISSIONS IN SMALL-SCALE COMBUSTION

Pienpolton päästöt

- 13.45 EMISSIONS FROM BIOMASS FIRED COMBUSTION
FACILITIES BETWEEN 0,5 - 10 MW
Biomassan polton päästöt 0,5 - 10 MW:n tehoisilla laitteilla
*Mats Lennart Karlsson, Swedish National Testing and
Research Institute, Sweden/Ruotsi*
- 14.15 Coffee break - Kahvitauko
- 14.45 COMBUSTION CONTROL AND NO_x EMISSIONS
REDUCTION
Palamisen säätö ja NO_x-päästöjen vähentäminen
Dr. Jürgen Good, Verenum, Switzerland/Sveitsi

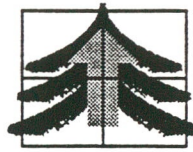
- 15.15 REDUCTION OF EMISSIONS OF CHIP BOARD WASTE COMBUSTION
Lastulevyn polton päästöjen vähentäminen
Dr. Kari Larjava, VTT Chemical Technology/VTT Kemianteekniikka, Finland/Suomi
- 15.45 PROGRESS IN EUROPEAN STANDARDIZATION OF RESIDENTIAL SOLID FUEL BURNING APPLIANCES
EU:n uusien normien valmistelu kiinteitä polttoaineita käyttäville kiinteistöjen lämmityslaitteille
William G Kaye, Chairman of CEN Technical Committee 295, CEN Normityöryhmän 295 puh.joht.

MANUFACTURERS PRESENTATIONS AND EXHIBITION

Laitevalmistajien puheenvuorot ja posternäyttely

Chairman/Puheenjohtaja Eija Alakangas, VTT Energy/VTT Energia, Finland/Suomi

- 16.15 NATURE - NEW GENERATION BOILER FUELED BY WOOD PILLETS, Jämä-Yhtiöt
Nature - uuden sukupolven puukattila, Jämä-Yhtiöt
Presentation/esittely Torsti Siltanen, VTT Chemical Technology/VTT Kemianteekniikka
- 16.25 NUNNANLAHDEN UUNI OY
Juhani Lehikoinen, Nunnanlahden Uuni Oy
- 16.45 MASONRY FIREPLACES AND CHIMNEYS
Muuratut tulisijat ja savupiiput
Jukka Suonio, Finnish Brick Industry Association/Suomen Tiiliteollisuusliitto
- 17.05 FUTURE PROSPECTS OF HEAT RETAINING FIREPLACES AND BAKEOVENS
Varaavien uunien tulevaisuuden näkymät
Esko Teerikorpi, Tulikivi Oy
- 17.25 TURUN UUNISEPÄT
Markku Valtonen, Turun Uunisevät
- 17.45 SOLID FUEL BURNERS
Kiinteän polttoaineen stokerpolttimet
Antti Ala-Talkkari, Veljekset Ala-Talkkari Oy
- 18.05 EXHIBITION AND POSTER SESSION - Posternäyttely
Cocktails and evening snack - Cocktails-tilaisuus ja iltapala
- 20.30 End of the programme
Ohjelma päättyy



BIOENERGIA

SEMINAR ON SMALL-SCALE COMBUSTION
TECHNOLOGY AND EMISSIONS

PIENPOLTON TEKNIikka JA
PÄÄSTÖT - SEMINAARI

25.5.1994, Hotel - Hotelli Laajavuori
Jyväskylä, Finland

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OVERVIEW OF IEA BIOMASS COMBUSTION ACTIVITIES

by

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Presented at:

**SEMINAR ON SMALL-SCALE COMBUSTION TECHNOLOGY AND EMISSIONS
MAY 1994 JYVÄSKYLÄ, FINLAND**

INTRODUCTION

The Implementing Agreement (IA) for a programme of Research, Development and Demonstration on Bioenergy and its Annexes are the formal documents which contain the rules for the collaborative work within the Agreement.

The IA was originally started as an Agreement on "Forestry Energy" (in 1978) but was later (in 1986) revised to "Bioenergy". The latest printed version of the IA includes amendments up to 21 September 1988. The IA has presently four Annexes in progress. Each of the Annex Documents defines a "Task", and generally the work performed under such an Annex is called a Task.

The main text of the IA mainly deals with issues such as

- objectives of the Agreement
- identification and initiation of Tasks
- the Executive Committee (EC)
- the Operating Agents (OAs)
- administration and staff
- finance
- admission and withdrawal of Contracting Parties
- etc.

The IA has presently no fixed date of termination, but will probably be given a limited time of duration shortly. This is now being requested by the IAEA Headquarters for all IAs.

The Annexes - on the other hand - have a well defined duration. Lately, the Annexes within the IA on Bioenergy have been of three years duration. The presents Annexes VIII - XI are active during the period 1 January 1992 - 31 December 1994. Annexes I - VII have been terminated and results reported.

The Implementing Agreement is administered through the Executive Committee and its secretariat. The Tasks are administrated by the Operating Agent for each Task. The scientific work of the whole Agreement is carried out in the main through the Activities. The roles of the Operating Agents and of the Activity Leaders (AL) are central to the success of the whole Agreement.

The objectives of the IEA bioenergy programme are:

- To encourage cooperative research, development and use of energy and the increased utilisation of alternatives to oil.
- To establish increased programme and project cooperation between participants in the whole field of bioenergy.

This objectives are achieved by providing opportunities for co-ordination via task-sharing, workshops, field studies etc. It should be noted that the Agreement does not purport to be a comprehensive bioenergy programme, or in any way replace the need for active national programmes. Work in the Agreement inevitably reflects the current interests in participating countries, and provides a way for national programmes to be more efficiently and effectively planned and executed.

The role of the Executive Committee (EC) is defined in the IA. The EC has about the same role as the board of directors of a company. It makes the planning for the future, appoints the Operating Agents, approves the budget and (through its members) raises the money for the funding of the work.

The EC also scrutinized the progress reports from the Tasks (presented by the OAs twice per annum) and the annual audited accounts.

The EC also organizes seminars of a more general interest to the bioenergy area.

The Operating Agent for a Task is appointed by the EC. Formally it is one of the Contracting Parties (representing a country) which is appointed OA, but the EC also pays very great attention to the person who in turn is appointed by the Operating Agent to do the OA job. In everyday work that person is called the Operating Agent.

The Technical Advisory Committee (TAC) is described in article 3 (d) of the Annex Document. There is one TAC for each Task and only those countries participating in a Task are represented in its TAC. The TAC members are designated by the Contracting Parties. The TAC shall assist the Operating Agent through the provision of Task-relevant information on national energy programmes and shall advise the OA on other questions related to the performance of the Task. The TACs generally have two meetings per year, some of them by phone.

It should be noted that the work within the Bioenergy Agreement is a cooperation between nations (including CEC, which has about the same status as a separate nation in this case). When a new country has indicated interest in joining the IEA Bioenergy Agreement, a formal invitation is issued by the EC to the government of that country, which then in turn appoints an organisation (ministry, institute, company etc.) to represent the country. That organisation - the Contracting Party - will then sign the Implementing Agreement and appoint one Member and one Alternative Member to the EC. Further contacts between the country and the IAEA Bioenergy Agreement can then be handled by the EC representatives.

At the end of 1993 sixteen countries or organisations participated in the collaboration on Bioenergy: Austria, Belgium, Canada, Denmark, Finland, France, Italy, Japan, Netherlands, New Zealand, Norway, Sweden, Switzerland, United Kingdom, United States and CEC (The Commission of the European Communities).

There are four Task Annexes to the Implementing Agreement during the period 1992-94:

- Task VIII Efficient and Environmentally - Sound Biomass
Production Systems
- Task IX Harvesting and Supply of Woody Biomass for Energy
- Task X Biomass Utilization
- Task XI The Conversion of Municipal Solid Waste Feedstock to Energy

Task X has the following eight activities and activity leaders:

<u>Activity</u>	<u>Leader</u>	
Biomass Combustion	Otto K. Sønju	(Norway)
Liquefaction/Pyrolysis	Yrjö Solantausta	(Finland)
Gasification/Gas Turbines	Suresh Babu	(USA)
Biotechnology for Fermentation	Jack Saddler	(Canada)
Anaerobic Digestion	Søren Tafdrup	(Denmark)
Straw Utilization	Carsten Nielsen	(Denmark)
Environmental Systems	Keith Mackie	(New Zealand)
Interface Activity	Don Stevens	(USA)

BIOMASS COMBUSTION ACTIVITIES

For activity 1 "wood combustion" in the period 1989-91, a separate publication [1] summarizing the activities has been issued. In the period 1992-94 also wet oxidation is included in the programme, and the title of the activity is changed to "wood combustion and oxidation of wet biomass".

Some general features of the activity are given below:

Objective: To determine methods to improve the efficiency and environmental acceptability of using wood biomass to provide heat energy including partial oxidation and combustion of moist biomass feedstocks.

Participating countries: Austria, Canada, Denmark, Finland, Netherlands, Norway, Sweden, Switzerland, United Kingdom and USA.

Activity leader: Otto K. Sønju, Norway

Technical committee members:

- H. Hofbauer (Austria)
- J. Robert (Canada)
- H.H. Jacobsen (Denmark)
- H. Oravainen (Finland)
- F. Sulilatu (Netherlands)
- O.K. Sønju (Norway)
- J.E. Hustad (Norway, coordinator)
- M. Karlsson (Sweden)
- T. Nussbaumer (Switzerland)
- F. Dumbleton (UK)
- D. Hardesty (USA)

Meetings: Two activity meetings was arranged in 1992: in Switzerland, May 1992 and in USA, November 1992.

Two Technical Committee meetings have been arranged in 1993, one in May in Austria and one in November in Sweden. Both meetings also comprised a presentation of national activities within biomass combustion and excursions to industrial plants.

All activities are summarized in separate reports for each meeting.

General

experience:

- * Good participation in the meetings
- * Satisfactory project progress
- * Comprehensive information exchange
- * Good industry participation at meetings

In the previous triennium, the work was organized in two working groups.

For the triennium 1992-94 the work is organized in projects with a leading country which is responsible for the project lead.

Projects in the period 1992-94 are:

- | | |
|--|---------------|
| - Round robin test of a wood stove | (Norway) |
| - Emissions from biomass combustion | (Switzerland) |
| - A pilot project confiring biomass with oil to reduce SO ₂ emissions | (Canada) |
| - Small scale biomass chip handling | (Canada) |
| - Energy from contaminated wood waste combustion | (Netherlands) |
| - Modelling of biomass combustion | (Norway) |
| - Wood chip cogeneration | (Denmark) |
| - Combustion of wet biomass feedstocks, ash reinjection and carbon burnout | (Canada) |
| - Oxidation of wet biomass | (UK) |
| - Catalytic combustion in small wood burning appliances | (Finland) |
| - Characterization of biomass fuels and ashes | (Austria) |
| - Measurements techniques (FTIR). | (Sweden) |

The countries who are interested in a project based on national activities/priorities; participate in the project by reporting ongoing research and results on the subject to the project leader. The project leader put the information together and correlate data from the different countries and present the results on the meetings. The coordinated results then will be available for all countries in the activity.

Below is a brief presentation of the different projects:

Project title: ROUND ROBIN TEST OF A WOOD STOVE

Participating countries: Austria, Canada, Denmark, Finland, The Netherlands, Norway, Sweden, UK and USA.

Leading country: Norway

Activity objective: A Jøtul 3TDIC-2 catalytic stove is being tested. The objective is to compare and evaluate the influence of different test standards and experimental procedures on the measured emission levels.

Status: Preliminary results from Norway, the Netherlands, Austria, USA, Sweden and Finland on emissions of particles, CO, hydrocarbons and NO_x show quite good accordance between different laboratories. Results from Canada, Denmark and UK will be available this year.

Future work plans: Collection of emission data from the remaining countries, further analysis and final evaluation.

Project title: EMISSIONS FROM BIOMASS COMBUSTION

Participating countries: Austria, Canada, Denmark, Finland, the Netherlands, Norway, Sweden, Switzerland, UK and USA.

Leading country: Switzerland

Activity objective: Collection of emission data from various biomass combustion equipment in different countries.

Status: Status on emission from combustion of wood and urban waste wood has been presented. Collection of emission data from different combustion techniques is ongoing. Information from some countries is still missing. Evaluation of new emission reduction techniques is ongoing.

Future work plans: Inclusion of studies on:

- Combustion of grass and miscantous
- Slagging
- Ash behaviour/deposits
- TGA-FTIR
- Power production

Project title: SMALL SCALE BIOMASS CHIP HANDLING

Participating countries: Canada

Leading country: Canada

Activity objective: Reveal technical status on different equipment in biomass chip handling

Status: A report will be released summer of 1994

Project title: ENERGY FROM CONTAMINATED WOOD WASTE COMBUSTION

Participating countries: The Netherlands

Leading country: The Netherlands

Activity objective: Investigation of the possibilities for, and consequences of, utilizing contaminated wood for energy production

Status: Preliminary results have been presented. A feasibility study for the gasification of contaminated wood with commercial available gasifiers has been done in cooperation with the gasification activity. The conclusion is that gasification of contaminated wood in combination with gas turbines is not commercial available within five years. A preliminary report on emission comparisons between combustion and gasification is performed in the gasification activity.

Future work plans: Collection of information on energy and emissions from contaminated wood combustion is continuing.

Project title: MODELLING OF BIOMASS COMBUSTION

Participating countries: Austria, Denmark, Finland, Norway, Switzerland and USA

Leading country: Norway

Activity objective: Comparing and developing of models to mathematically describe and simulate biomass combustion problems.

Status: Ongoing modelling in the different countries varies in objective and purpose of the modelling, and it is very time consuming to condense the modelling aspects into some general results and conclusions. Some models have been reviewed. Charcoal reactivity have been compared to various coals.

Future work plans: Less weight on comparisons between different models and more weight on presentation of specific models, with comparisons between modelling results and experimental results when possible.

Project title: WOOD CHIP CO-GENERATION

Participating countries: Denmark

Leading country: Denmark

Activity objective: Evaluate technologies for small wood co-generation systems with respect to feasibility, economical aspects and adaptability to existing energy infrastructure.

Status: Report containing aspects on different technologies for small wood co-generation systems were presented in Sweden in November 1993 and will be published as an IEA-report.

Selected technologies for the study of wood cogeneration systems:

Steam Turbine Power Plants

Steam Engines

Stirling Engine

Indirectly fired gasturbine co-generation

Pressurized downdraft combustion of wood chips

Future work plans: An updated report will be published during 1994.

Project title: COMBUSTION OF WET BIOMASS FEEDSTOCKS, ASH REINJECTION AND CARBON BURNOUT.

Participating countries: Austria, Canada, Denmark, Norway and Sweden

Leading country: Canada

Activity objective: Review the importance of moisture content in the fuel on carbon burnout.

Status: A study on carbon burnout has been initiated in Canada on large boilers

Future work plans: Information collection is ongoing in various countries

Project title: OXIDATION OF WET BIOMASS

Participating countries: Norway and UK

Leading country: UK

Activity objective: Evaluate technologies for oxidation of wet biomass with respect to technical- and energy aspects.

Status: Technical aspects and systems have been presented

Future work plans: Investigations and collection of information are ongoing.

Project title: CATALYTIC COMBUSTION IN SMALL WOOD BURNING APPLIANCES

Participating countries: Austria, Finland, Norway and Sweden

Leading country: Finland

Activity objective: Investigation on utilization of catalytic combustors in small wood burning appliances. Important aspects are possibilities for emission reduction and operational aspects.

Status: Aspects on catalytic combustion in wood stoves have been presented including the effect on the emission levels of CO, HC, PAH and tars by introducing a catalyst.

Future work plans: Experiments with other types of wood stoves and catalysts will be done.

Project title: CHARACTERIZATION OF BIOMASS FUELS AND ASHES

Participating countries: Austria and USA

Leading country: Austria

Activity objective: Collecting data of biomass fuels and ashes from biomass combustion (data base).

Identifying problems (deposits, emissions, ..) and possibilities (utilization of ashes, . .)

Finding out correlations between characterization data and behaviour during combustion.

Status: Work on characterization using various standards and tests on ongoing in many countries. Some of this work has been reported within the activity. Data of major importance is:

Fuel: calorific value
water content
ash content
ultimate analysis (C, H, O, N, S, Cl, F)
heavy metals

Ash: P_2O_5 , SiO_2 , Fe_2O_3 , CaO, MgO
 Na_2O , K_2O
 SO_3 , CO_2 , Cl, F
heavy metals
ash softening temperature
PAH, PCB, PCDD/DF

Project title: MEASUREMENTS TECHNIQUES (FTIR)

Participating countries: Norway, Sweden and Switzerland

Leading country: Sweden

Activity objective: Report and discuss experiences and progress using FTIR-technique among different laboratories within the activity.

Status: In principle, this technique gives the following advantages:

- a number of substances can be measured at the same time with the same instrument
- the spectra which you receive can be used afterwards to determine the contents of components which did not seem interesting at the time when the measurements were made, and also to validity of the measurements
- interferences from disturbing elements can mathematically be reduced in the software which evaluates the spectra
- the method of working of the instrument can to a great extent be adjusted to various measuring situations
- the calibration which has been made is physically regulated by law and is therefore valid in the future without having to make a new calibration (under certain circumstances).

A status report from the different activities will be made and presented at an international conference in UK in November this year. A report from the activity will be made at the end of the triennium 1992-94 and published early 1995. However, some of the activities will continue in the next triennium 1996-1998 together with new activities based on national priorities.

Future work plan: Make a state of the art report on FTIR at the end of the triennium.

REFERENCES

1. HUSTAD, J.E. AND SØNJU, O.K.: Biomass Combustion in IEA Contries, Biomass and Bioenergy, vol.2, Nos 1-6, pp. 239-261. Pergamon Press Ltd., 1992.

Characterization of Biomass and Biomass-ashes

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1.) Introduction

Wood and biomass combustion facilities are increasingly used in district heating plants, in the wood working industry and in the pulp and paper industry. These combustors are fired with pure biomass like bark and woodchips, with production wastes like fiberboard residues or black liquor or with contaminated wood waste like railroad sleepers and pylons. In these industries, combustion technologies such as grate burning systems, conventional suspension burners and fluidized bed systems are in use in sizes from 0.5 MW up to 130 MW. Grate burning systems are widely used at wood-fired facilities. They have been used for many decades, and their design, operation and maintenance requirements are well understood. There are four types of grate burning systems including spreader stokers with either fixed or traveling grates, underfeed stokers, inclined grates and pile burners. Suspension burners that combust wood fuel are usually found in primary and secondary forest product industries and are used where very fine, dry fuels are available such as dry sawdust or kiln-dried mill residue from furniture, particleboard or veneer manufacturing. The use of fluidized bed systems for wood combustion began in the 1980s. They are increasingly common at power plants to burn significant amounts of processed wood, pulp and paper residues and agricultural and sewage sludge.

With the increasing number of biomass combustion facilities both the amount of biofuels and the amount of ashes from biomass is increasing too. The differences between several kinds of biofuels and their ashes show the necessity of a detailed description of the feedstock biomass as an important base for many applications. The ashes are a great financial burden, dependent on their composition and their classification according to the ÖNORM S-2100, "Abfallkatalog" (catalogue for waste), the ÖNORM S-2101, "gefährlicher Abfall" (dangerous wastes) and the ÖNORM S-2072, "Eluatklassen" (Classification of waste by leaching test). On the other side, these ashes are raw materials of considerable potential for industry, because the elements which originally in the biomass are more concentrated in the ashes and thereby more easy accessible.

2.) Characterization of Biomass

For the characterization the biomass was divided into 4 groups, carbohydrates, proteins, oilseeds and lignocelluloses. Characterization focused on the ash content, the ultimate analyses and heavy metal analyses and the ash melting behaviour. Significant differences can be seen in the ash content, the nitrogen, sulfur and chlorine content, the ash softening temperatures and the ash composition of the different kinds of biomass (figures 1, 2, 3). Because of the importance of the ash composition on the ash fusibility, this influence was investigated, but no good correlations between the spherical temperature and the calcium content was found. Currently the databasa includes about 100 different biomass feedstocks. The following tables and pictures show some results. These results are given in weight-percent or ppm on dry basis. The detailed data are published in [1].

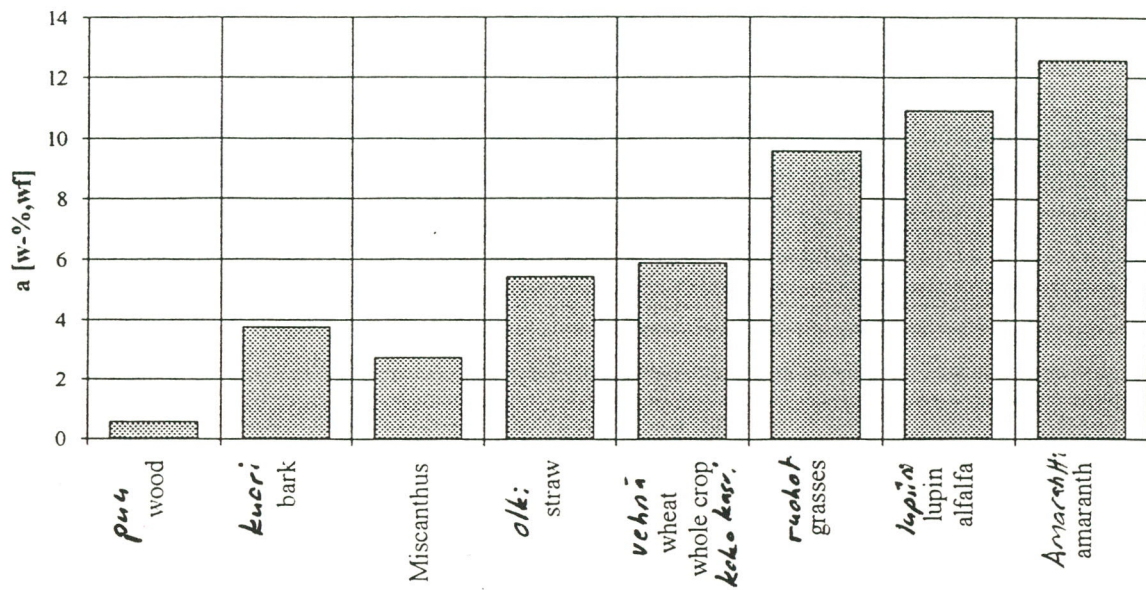
		Eri biomassilajien alkuaine- ja tuhkapitoisuuksia Ultimate analysis of several sorts of biomass					
		tuhka ash	C	H	N	S	Cl
vehnä	wheat (whole crop)	5,88	46,53	5,31	1,05	0,09	0,35
sokeridurra	sweet sorghum, Jer. art.	7,09	45,81	5,26	0,97	0,06	0,31
lupiiini	lupin, alfalfa	10,92	44,64	4,98	2,34	0,23	0,46
rypsi	rape	7,64	48,52	5,88	1,85	0,45	0,62
puu (kuusi)	wood (spruce)	0,58	50,88	5,62	0,11	0,01	0,01 -
kuori	bark	3,76	51,57	5,07	0,42	0,05	0,02
olki	straw	5,44	47,00	5,32	0,47	0,07	0,49
ruohot	grasses	9,58	45,83	5,08	2,23	0,18	0,88 -
Miscanthus	Miscanthus	2,76	48,57	5,45	0,45	0,04	0,23
Amaranthipuu	Amaranth	12,58	41,14	4,75	1,81	0,26	0,56

figure 1
kuva 1

Miscanthus = energiaruoho

Biomassalajien tuhkipitoisuuksia

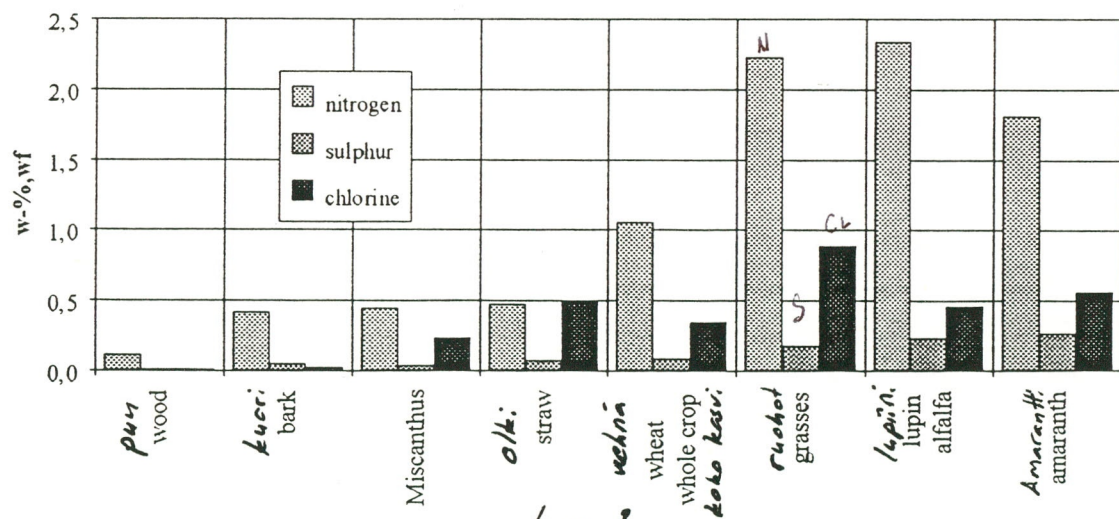
Ash content of different sorts of biomass



Kuva 2
figure 2

Biomassojen typpi-, rikki- ja klooripitoisuuksia

Nitrogen, sulphur and chlorine content of different sorts of biomass



Kuva 3
figure 3

Essential for the characterization of biomass fuels is the nitrogen content, because in Austria there are emission limits for NO_x , that cannot be met by wood fired combustors. Therefore an investigation of the influence of the nitrogen content in wood on the emission of nitrogenoxides were performed. First, an ultimative analysis of different types of wood under this consideration were made. The results can be seen in figure 4 and figure 5. Figure 5 shows the different nitrogen contents for wood with and without bark, which varies between 0,07 and 0,21 wt.-%. The nitrogen content in the bark itself is about 5-times higher. Combustion tests were performed in an comercial wood stove and the NO_x emission were measured. Figure 6 show the nearly linear relationship between the N-content in wood and nitrogenoxide in flue gas. For the investigation of the influence of the nitrogen content on the emission of nitrogen oxides in combustion processes, ultimate analyses of different kinds of wood were made. The conversion rate for this type of stove is about 35%. So, if one knows the nitrogen content in wood, it is possible to calculate the NO_x emissions.

Puun tyypipitaisuuksia

Nitrogen content of wood

(weight-%, dry basis)
(P. - % kuivapainesta)

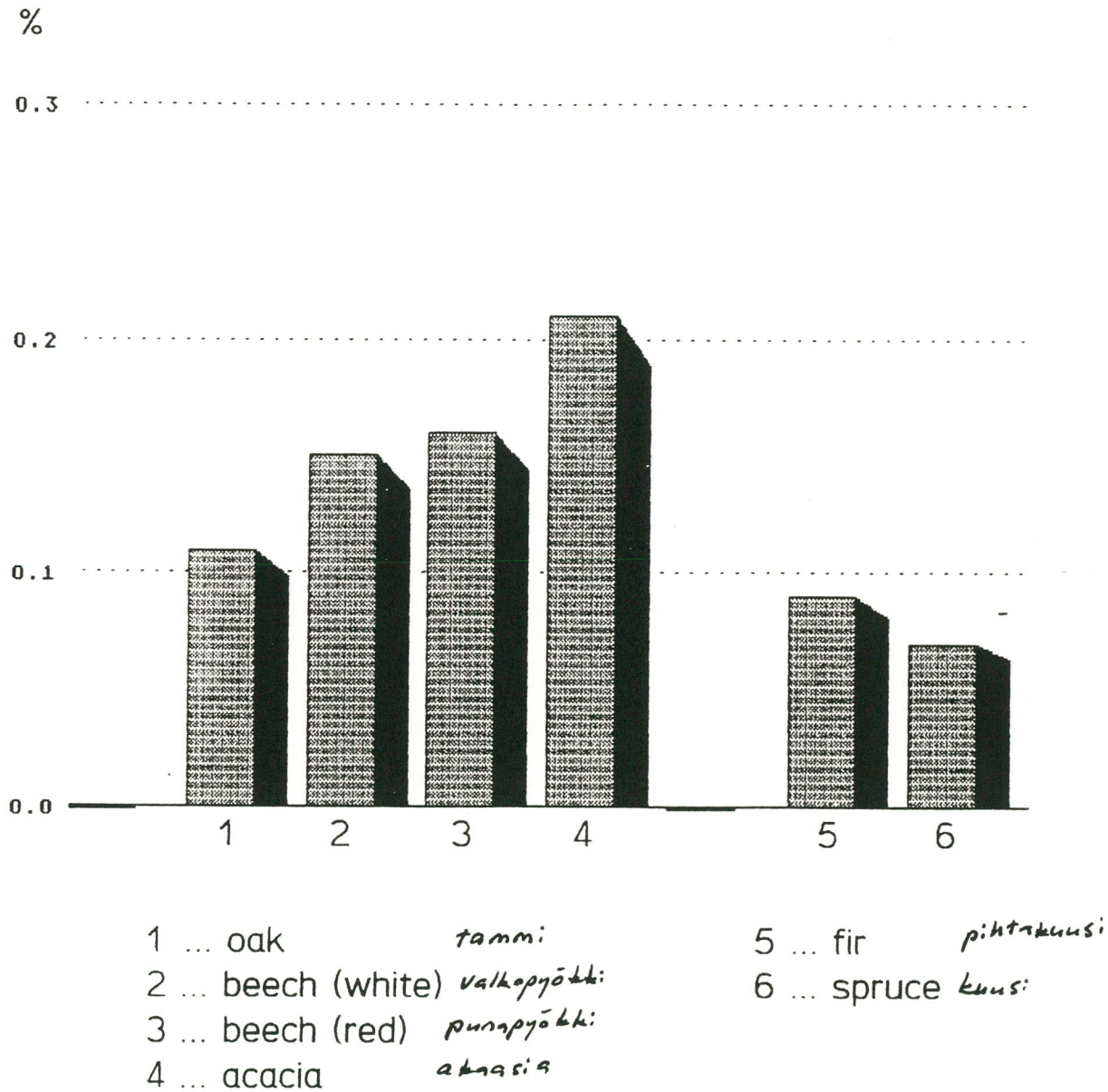
	oak <i>tammi</i>	white beech <i>valkopyökki</i>	red beech <i>puna- pyökki</i>	acacia <i>akasia</i>	fir <i>pihta- kuusi</i>	spruce <i>kuusi</i>	briquette fir + spruce	<i>briquetit pihtakuusi + kuusi</i>
<i>pihtapuu</i>	sapwood	0,10	0,13	0,15	0,15	0,07	0,06	
<i>kuoretan</i>	without bark	0,11	0,15	0,16	0,21	0,09	0,07	
<i>kuori:</i>	bark	0,49	0,66		1,43	0,35	0,37	
<i>keskiarvo</i>	average	0,12	0,22	0,16	0,31	0,17	0,12	
<i>pihtapuu</i>	sapwood							
	% C	49,9	48,2	49,0	50,6	51,3	51,2	50,4
	% H	5,12	5,40	5,70	5,48	5,59	5,56	5,76
	% O	44,9	46,3	45,2	43,8	43,0	43,3	43,7

kuva 4
figure 4

Puun tyypipitoisuus

NITROGEN CONTENT IN WOOD

wood without bark *kuoreton puu*
(weight-%, dry basis)
(p. - % kuivapainosta)



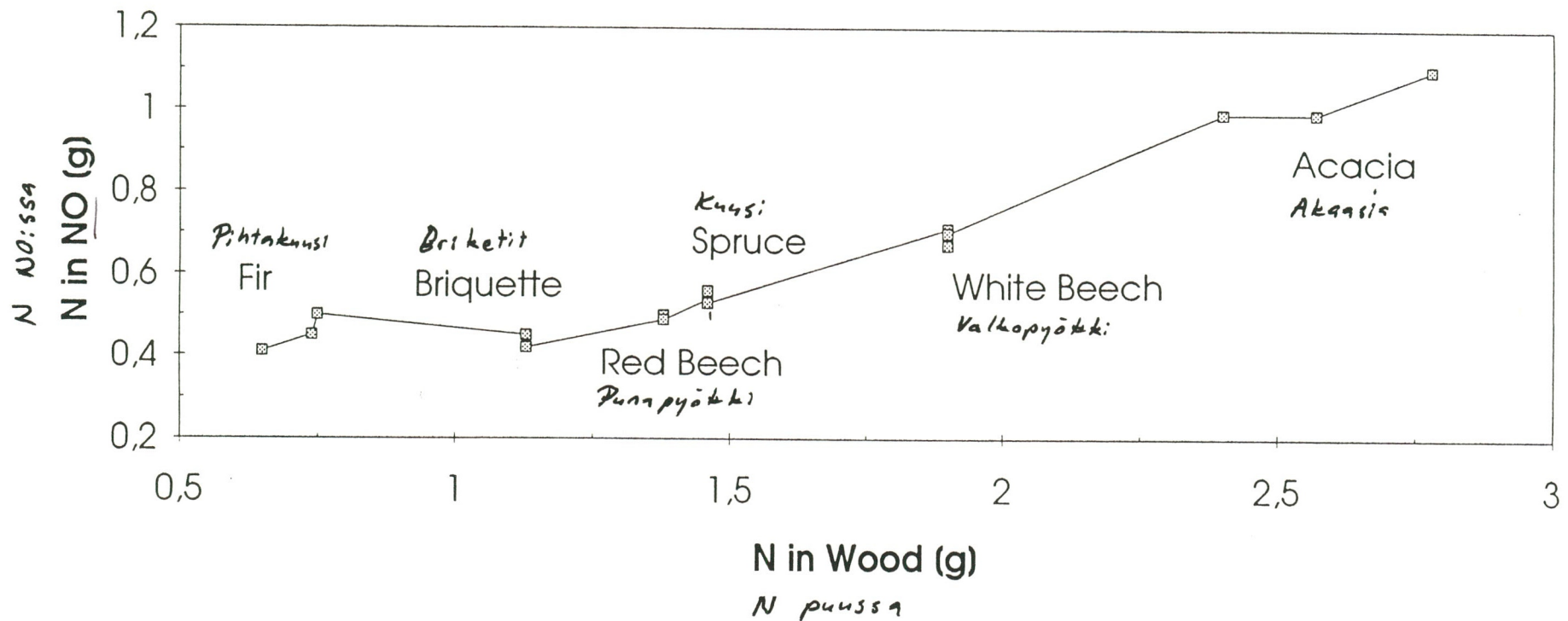
kuva 5

figure 5

Typen konversiosuhde

Conversion Ratio of Nitrogen

N → NO_x



3.) Characterization of Ashes from Biomass and biogenous Wastes

3.1) Laboratory ashes

Typical compositions of ashes from different biofuels are shown in figure 7 and 8. Because of the importance of the ash fusion temperature for biomass combustion, the influence of the ash composition on the ash fusion temperatures was investigated. At first the ash components were correlated with the ash softening temperature. No good correlation was found. The correlation of the ash softening point with the calcium content is shown in figure 9. Thus a statistical analysis was made. A multivariable linear analysis showed better results than many formulas given in the literature. These formulas are often investigated for coal ashes. One simple formula, found by the linear multivariable regression is:

$$EP = 970 + 14,6 * \%CaO - 10,9 * \%K_2O + 29,3 * \%P_2O_5 \text{ in } ^\circ C$$

Figure 10 shows the measured softening point versus the calculated one.

Biomassalajien tuhke-analyysien
Ash analyses of various biomass ashes

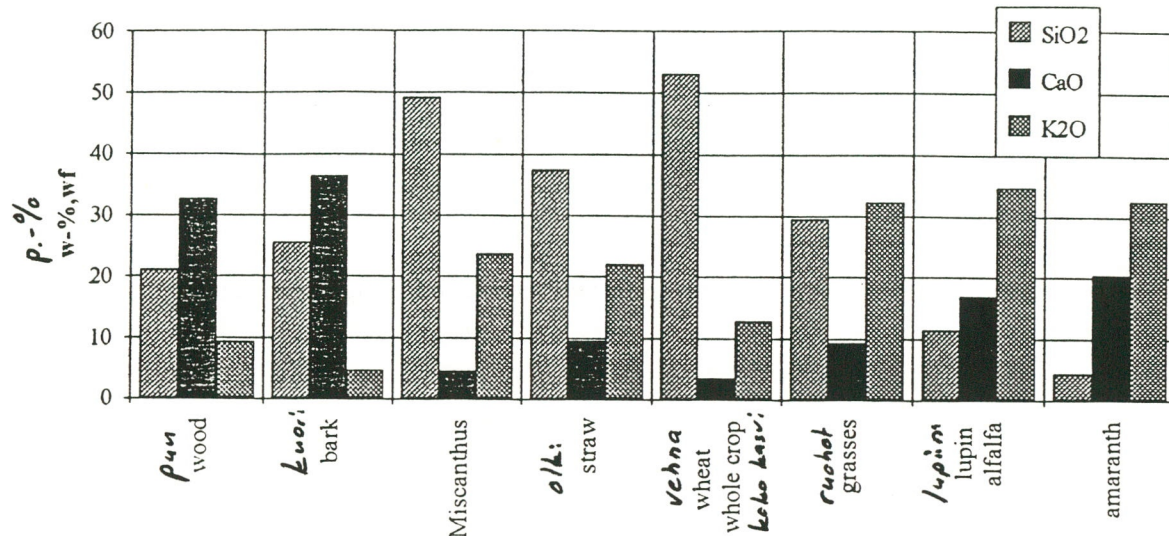
	CO ₂	SO ₃	Cl	P ₂ O ₅	SiO ₂	Fe ₂ O ₃	Al ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O
wheat, whole crop	1,31	1,46	2,47	4,82	53,02	0,21	0,33	3,54	1,56	0,11	12,86
lupin, alfalfa	16,93	5,08	4,12	5,50	11,50	0,52	1,11	16,88	2,61	0,61	34,75
wood	21,63	1,14	0,12	3,32	21,10	1,12	1,29	32,68	3,15	0,24	9,43
bark	13,70	1,19	0,06	1,81	25,47	2,00	2,75	36,47	2,67	0,28	4,70
straw	7,12	2,90	5,47	2,61	37,45	0,29	0,40	9,56	2,10	1,23	22,00
grasses	1,77	3,61	6,55	8,02	29,44	0,43	0,68	9,42	2,70	0,61	32,30
Miscanthus	4,53	3,42	3,39	3,00	49,17	0,20	0,20	4,57	3,25	0,21	23,74
amaranth	16,20	4,39	3,56	6,78	4,40	0,30	0,41	20,48	4,19	0,27	32,52

kuva 7
figure 7

*vehä, kaka
kasvi
Lupini
puu
kuori
alki
ruohot*

Biomassetuhtien pii, kalsium- ja kaliumpitoisuksia

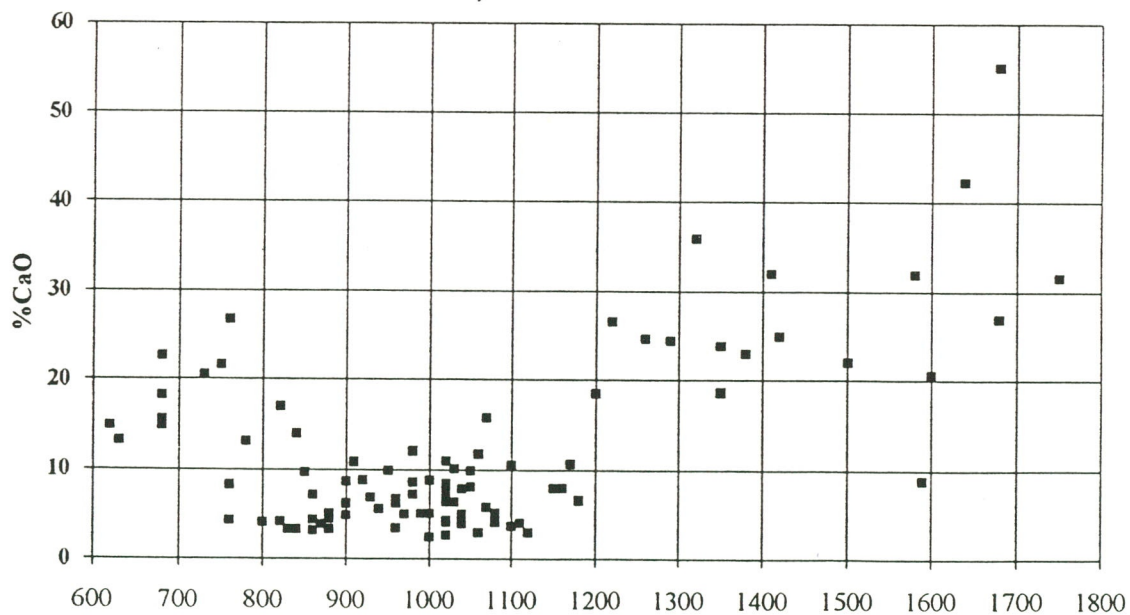
Silica, calcium and potassium content of different biomass ashes



kuva 8
figure 8

Tuhkan pehmenemislämpötila (DIN 53170) kalsiumpitoi-

Ash softening temperature (DIN 53170) vs. calcium content of the ashes *suden funktiona*



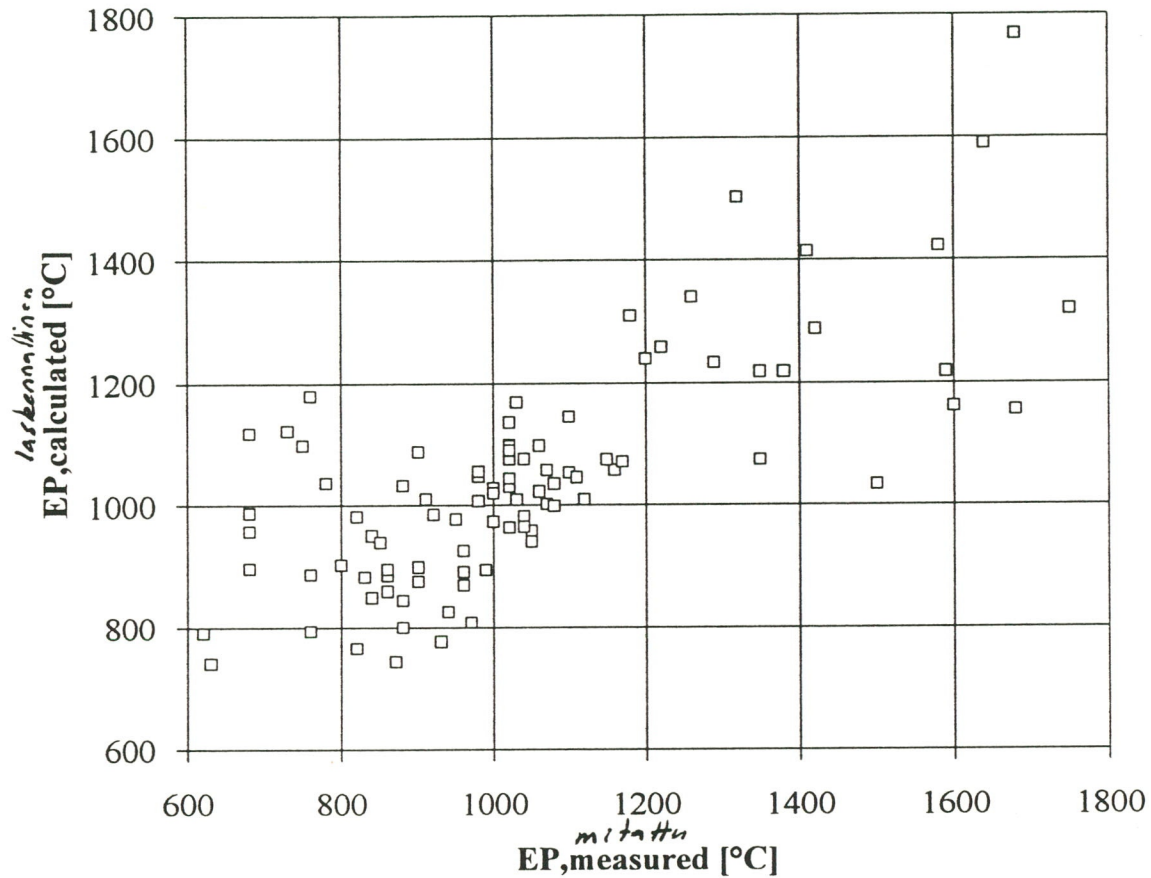
Ash softening temperature in °C

Tuhkan pehmenemislämpötila °C

figure 9

kuva 9

Laskennallinen tuhkan pehmenemispiste mitattu pehme-
Calculated ash softening point vs.
measured ash softening point
nemispisteeseen suhteeseen



Kuva 10
 figure 10

Ashes derived from wood and wood waste combustion are shown in figure 11. This figure shows both the concentration of the dry ashes and the concentration of the ashes calculated on the ignition loss at 815°C.

3.2) Industrial ashes

Ashes from industrial combustors at district heating plants, at the wood working industry and at the pulp and paper industry were examined. For the detection of the element-concentrations, the ashes are dissolved using $\text{HCl} / \text{HNO}_3$ for 30 minutes (figure 11). The detection of the sulfate content was carried out by nephelometric analysis and the detection of the chloride content by an ion sensitive electrode. The sodium and potassium content was determined by a flame photometer. The detection of the phosphorus concentration in the ashes was carried out photometrically with ammonium-molybdate-vanadate. The other elements were measured by atomic absorption analysis.

Essential for the utilization and therefore for the characterization of ashes is not only the water content and the ignition loss, but also the content of nutrients like phosphorus, potassium or magnesium, the content of calcium or silica, the content of metals like iron, aluminium or zinc and the content of heavy metals and minor elements like copper, chromium, cadmium, nickel or lead, but also the chemical availability of these elements. The content of anions such as chloride ions or sulfate ions and the content of organical compounds are also essential for some applications.

Different water contents can be explained by hygroscopic behaviour of the ashes, the use of wet dust separators and the moistening of the ashes for fire-protection.

A look at the ignition loss and thereby at the unburned carbon shows a relationship with the combustion efficiency of different combustion technologies. It shows, that the losses are lowest in fluidized bed systems. It has to be taken into consideration that the ignition loss is carried out at 815°C as standardized for coal in ISO 1171. At this temperature certain carbonates can decompose and alkalisalts can evaporate. The determination at this temperature is necessary, because at 550°C , as suggested in [2], some ashes show a reproducible increase in weight during heating. The ashes contain a great amount of unburned carbon during their separation from the combustion chamber to the secondary combustion chamber. They stay for a too short time in the secondary combustion chamber and are cooled down so fast that no formation of carbonates, as expected from a chemical balance can occur. This causes the increase in weight. There are therefore great amounts of oxides and unburned carbon in the ashes. The unburned carbon is oxidized to CO_2 during glowing. The increase of weight is a result of the reaction of the oxides with this CO_2 to carbonates, which are thermodynamically stable, during the CO_2 diffusion out of the ashes at the glowing at 550°C .

Along with the unburned carbon certain alkalisalts will evaporate and carbonates will be decomposed while glowing at 815°C , but because of the prevailing temperature which is quite similar to that in real combustors, statements about ignition loss that can be in real combustion systems, can be made. These statements also say something about easy reachable weight-reductions.

Ash - analyses

Ash - analyses																			
sample no.	sample 1	sample 2	sample 3	sample 4	sample 5	sample 6	sample 7	sample 8	sample 9	sample 10	sample 11	sample 12	sample 13	sample 14	sample 15	mean	standard deviation		
	wood waste	bark, pulp & paper resid.	bark, wood waste	bark, prod. resid.	particleboard, prod. resid.	particleboard, prod. resid.	prod. resid.	wood	particleboard, prod. resid.	fiberboard, prod. resid.	bark	bark	bark	e-filter	bark	wood			
size	33 MW	65 MW	3.2 MW	102 MW	7 MW		1.8 MW		4.5 MW	33 MW	11 MW	22 MW	7 MW	7 MW	4.9 MW				
technology	FB	FB	Grafe	FB	Grafe		Grafe	stove	Grafe	FB	Grafe	Suspension	Grafe	Grafe	Grafe				
water content	0.10	0.1	23.3	0.1	67.4	17.1	0.4	3	3.3	0.1	0.1	11.6	0.1	69	34.6				
ignition loss 815°C	12.6	6.5	13.5	7.1	46	7.8	9.8		77.1		9.1	13.1	6.7	29.6	32.2				
CSB g/kg	2.9	2.4	117	38	342	8.4	63	164	1409	18.2	121.8	104.2	7.68	113.2	368.3				
% HCl - insoluble	4.7	18.5	22.9	10	17.1	42.6	54.3	15.9	63.6	19.4	44	7.7	13.8	7.6	23.8				
g H2SO4 / kg	800	835	323	648	231	307	253	745	304	824	496	455	651	651	313				
dry ash																			
kuiva fuhe																			
P %	0.49	0.47	0.57	0.61	1.15	0.28	0.71	0.76	0.44	0.56	0.52	0.48	0.76	1.71	0.66	0.66	0.354		
Mg %	12.65	8.25	2.38	2.68	2	2.33	1.54	3.34	1.28	10.8	2	2.7	5.6	2.4	3.67	0.66	0.354		
K %	1.9	1.8	2.86	1.1	1.2	1.35	1.44	7.86	1.86	1.37	2.09	3.15	3.29	1.16	4.28	4.12	3.58		
Ca %	24.4	24.9	14.7	28.8	17.14	10.74	10.1	21.96	10.13	24.3	18.8	25.67	34.8	28.3	34.86	2.28	1.696		
SO4 %	1.8	3.2	3.52	13.6	2.35	1.81	1.7	1.03	1.65	4.4	3.1	26.9	2	2.2	36.5	20.89	7.426		
Cl %	0.3	0.1	0.03	0.3	0.07	0.01	5.1	0.01								4.75	6.831		
Na %																	1.766		
Al %	1.46	2.67	3.28	2.84	0.68	1.63	1.44	0.35	0.17	1.66	3.22	1.6	1.94	1.34	2.17	0.69 (n=7)	1.162		
Fe %	1.22	1.46	2.41	1.63	1.33	2.01	0.72	0.37	0.22	1.35	1.75	0.84	1.59	1.46	1.15	1.71	0.951		
Zn %	0.12	0.13	0.16	3.8	0.09	0.06	0.09	0.06	0.2	0.26	0.12	2.02	0.12	0.74	0.28	1.32	0.585		
																0.54	1.032		
Cu ppm	153	124	74	103	87	246	57	118	46	146	120	137	88	850	186				
Cr ppm	44	72	70	81	42	42	80	12	10	67	102	64	61	76	73	160.3	197.21		
Cd ppm	9	10	12	10	19	8	6	3	14	7	10	34	4	48	46	63.07	35.459		
Ni ppm	51	66	110	95	63	42	78	62	11	50	40	534	42	64	725	13.33	12.205		
Pb ppm	290	110	130	280	141	108	2339	62	16	387	62	65	27	241	89	84.47	125.722		
																283.73	679.782		
calculated at the ignition loss																			
laskettu syttymishäviöstä																			
P %	0.56	0.5	0.66	0.66	2.13	0.3	0.79	1.3	1.92	0.62	0.57	0.55	0.81	2.43	0.6	0.96	0.664		
Mg %	14.4	8.73	2.75	2.88	3.7	2.53	1.71	5.71	5.59	12.11	2.2	3.11	5.94	3.41	2.7	5.16	3.794		
K %	2.17	1.9	3.31	1.18	2.22	1.47	1.6	13.44	8.12	1.52	2.3	3.66	3.49	1.65	2.7	3.38	3.257		
Ca %	27.9	26.3	17	31	31.7	11.67	11.2	37.54	44.2	27	20.68	29.54	36.9	37.36	27.51	27.83	9.534		
SO4 %	2.06	3.39	4.07	14.6	4.35	1.97	1.88	1.76	7.2	4.89	3.41	30.96	2.12	3.12	2.94	6.91	7.648		
Cl %	0.34	0.1	0.03	0.32	0.13	0.01	5.65	0.02								0.82 (n=8)	1.954		
Na %																	1.309		
Al %	1.67	2.82	3.79	3.06	1.3	1.77	1.6	0.6	7.42	1.84	3.54	1.84	2.06	1.9	2.08	0.84 (n=7)	1.309		
Fe %	1.4	1.54	2.79	1.76	2.46	2.18	0.78	0.63	0.96	1.5	1.96	0.97	1.69	2.07	2.13	2.22	0.915		
Zn %	0.14	0.14	0.18	4.09	1.67	0.06	0.1	0.1	0.87	0.29	0.13	2.32	0.13	1.06	0.25	1.65	0.6316		
																0.77	1.14		
Cu ppm	175	131	86	111	161	267	63	202	201	162	132	168	93	1207	83	215.47	279.606		
Cr ppm	50	76	81	87	78	46	89	20	44	63	112	62	64	108	227	79.8	47.666		
Cd ppm	10	10	14	11	35	9	7	5	61	8	11	39	4	68	9	20.27	20.71		
Ni ppm	58	70	127	102	117	46	86	89	48	56	44	614	44	91	43	109	142.463		
Pb ppm	332	116	150	301	261	117	2593	89	70	430	68	75	29	342	12	332.33	638.72		

A correlation between the ignition loss and the chemical oxygen demand (COD), (typically 3 to 1400 g/kg) is not observable. Due to this, it is not possible to make assertions about the quality of the combustion using the COD.

A general assertion about the industrial utilization of the ashes is, based on the distribution of the elements at different particle sizes and the HCl- and the H₂SO₄-soluble fraction, possible. The distribution of the elements in the different particle sizes makes it possible to separate certain elements from the ashes by methods of mechanical and chemical engineering. The HCl insoluble matter relates to the silica content. This and the chloride content of the ashes are the main factors governing for the possibility of industrial utilization for concrete. The consumption of H₂SO₄ gives information concerning the expected demand of chemicals for the production of gypsum, fertilizers or the separation of several elements from the ashes.

3.3) Chemical Characterization

First results point out that ashes derived from biogenous production waste, such as fiberboard residues or contaminated wood from pylons and railroad sleepers are both in view of the nutrient content and the heavy metal content statistically equal to ashes from pure biomass, such as bark or wood chip when burnt in industrial combustion facilities.

The wet-chemical analysis gives information concerning how the elements are bound in the ashes and shall state about the behaviour by leaching. The aim is to provide the foundation for developing methods for ash-treatment. The following treatments were used for the characterization of coal-ashes was used for the characterization of the chemical reactivity of the ions in the ashes:

extraction with	1m MgCl ₂ -Lösung	exchangeable ions
	1m NaOAc / HOAc	carbonates
	0,05m NH ₂ OH·HCl / HOAc	adsorbed oxides
	0,02m HNO ₃ + H ₂ O ₂	organically complexed ions
and	conc. HNO ₃	

Initial results point out, that in average 75 to 100% of the elements are extractable using this procedure. The only exception is phosphorus, with on average 200% (figure 12). This is attributed to solubilization of the ashes by HCl / HNO₃ or HF / HNO₃. These reagents solubilize almost all elements, depending on the temperature, the reaction time and silica which forms a blue coloured complex with the ammonium-molybdate-vanadate and which lowers the detection of phosphorus by masking. Higher phosphorus concentrations in the ashes are therefore to be expected as shown in figure 11.

Uuttuvien aineiden määrä %
total extractable amount in %

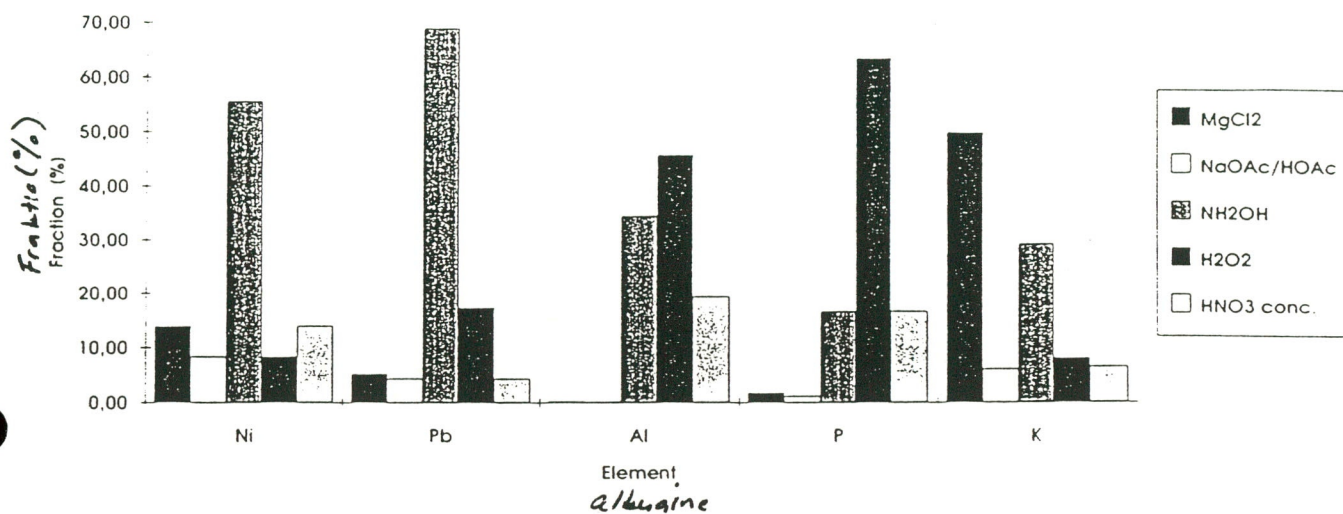
<i>alkuaine</i>	<i>näyte 1</i>	<i>näyte 4</i>	<i>näyte 11</i>	<i>keskiarvo</i>	<i>keskilpohka</i>
element	sample 1	sample 4	sample 11	mean	std.dev.
Zn	84	80	60	75	13,2
Fe	109	106	81	99	15,4
Cu	97	99	90	95	4,3
Ca	76	92	99	89	11,7
Cd	99	60	114	91	28,2
Cr	104	98	104	102	3,4
Ni	70	97	114	94	22,3
Pb	79	44	147	90	52,8
Al	89	104	93	96	7,8
P	170	221	202	198	26,0
K	101	89	114	101	12,4

Kuva 12
figure 12

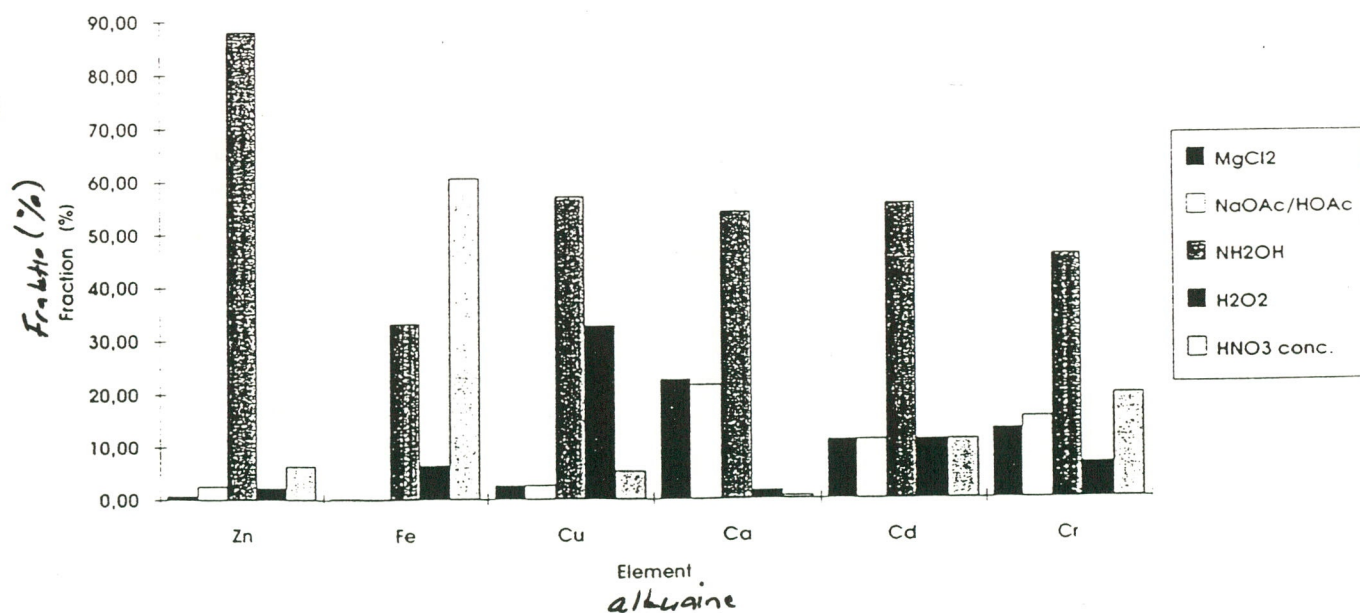
Figures 13, 14, 15 and the explanations shows the different distribution of the elements at the extraction-levels:

- zinc:** over 90% of the extractable amount are carbonates or adsorbed oxides;
there are considerable differences between the ashes;
- iron:** 90% of the iron are oxides or organically complexed;
there are considerable differences between the ashes;
- copper:** up to 30% are carbonates;
there are considerable differences between the ashes;
- calcium:** more than 95% of the extractable calcium are carbonates or oxides;
- cadmium:** there are no regularities in the distribution at the extraction levels;
- chromium:** there are no regularities observable;
- nickel:** 70% are carbonates or oxides;
there are considerable differences between the ashes;

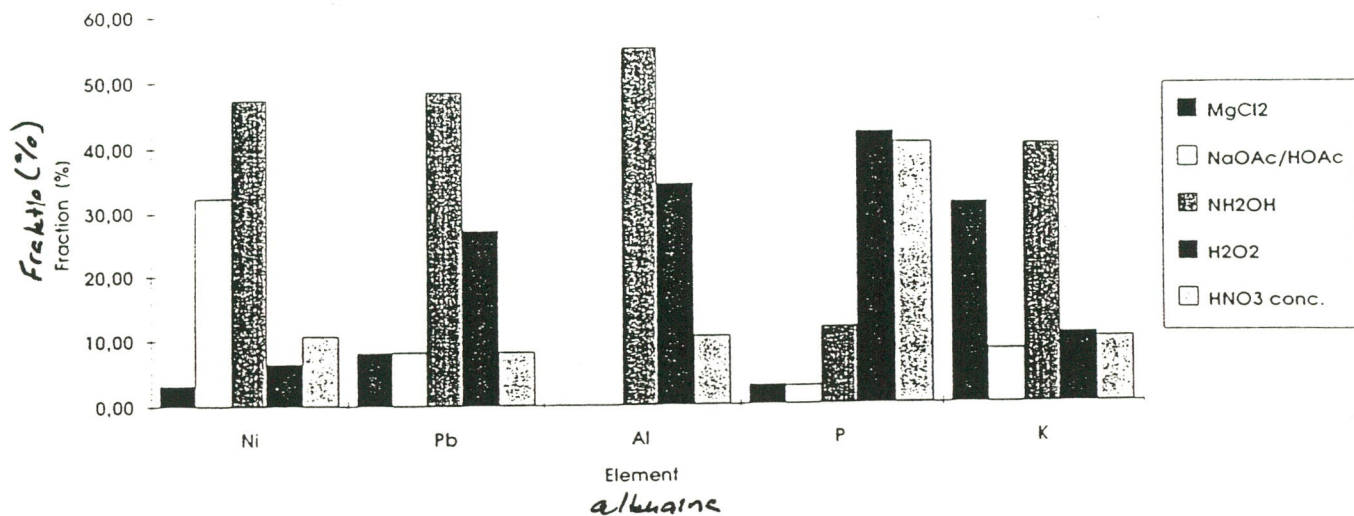
Uuttumisominaisuudet: näyte 1.
Leaching characterization: sample 1



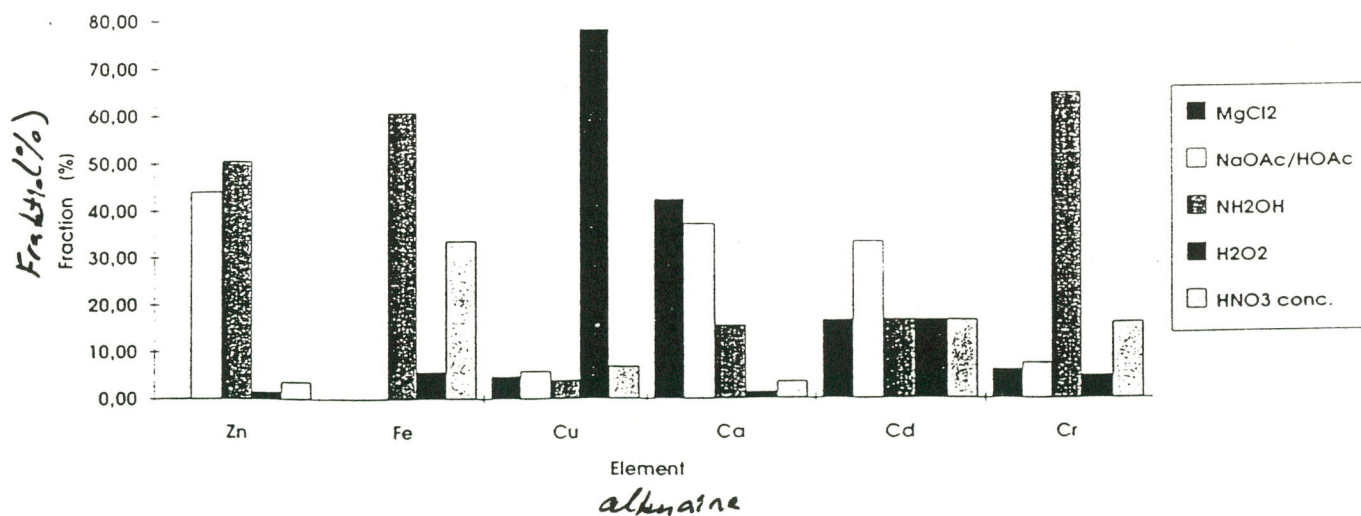
Uuttumisominaisuudet: näyte 1
Leaching characterization: sample 1



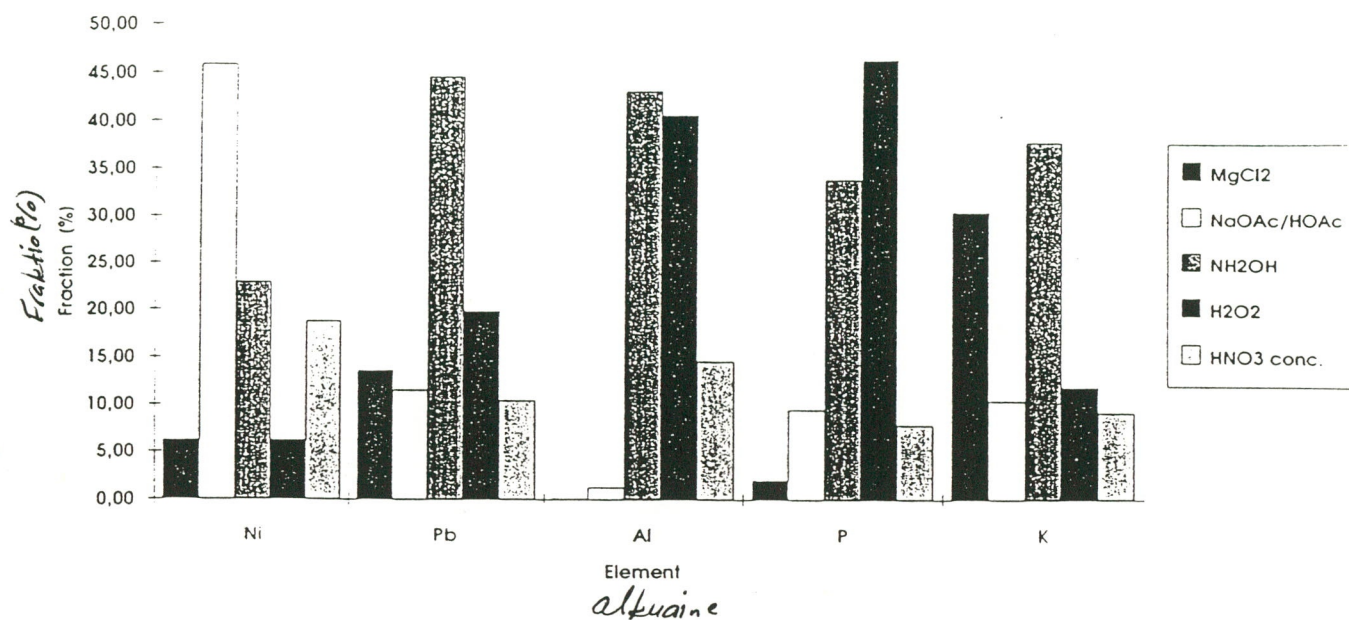
Uutumisominaisuudet: näyte 4
Leaching characterization: sample 4



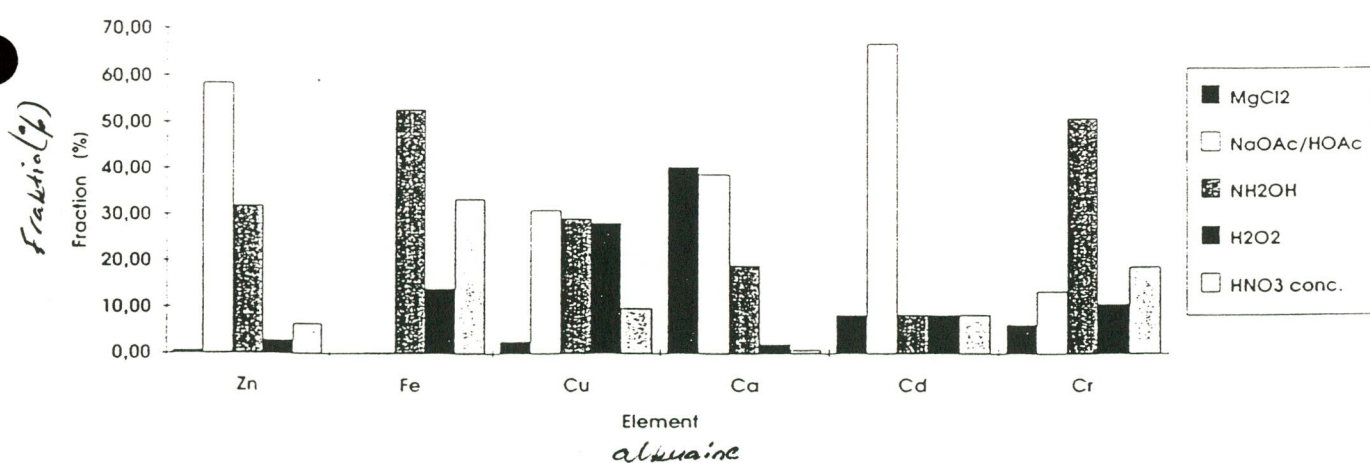
Uutumisominaisuudet: näyte 4
Leaching characterization: sample 4



Näyte 11
Sample 11



Uuttumisominaisuudet: näyte 11
Leaching characterization: sample 11



aluminium: 35 to 55% are oxides and 35 to 45% are organically complexed;

phosphorus: 15 - 35% are oxides and 50-80% are organically complexed;

potasium: potasium was found in the first four extraction levels;
there are considerable differences between the ashes;

4.) Biomass and Ash Database

The characterization of the feedstock biomass and biogenous wastes is a fundamental requirement for all applications, especially combustion and gasification processes or the production of chemicals. A database for biomass and biogenous wastes analyses give a systematic description of many sorts of biomass, biogenous wastes, energy crops and ashes. The aim of this database is to gather systematically informations about the behaviour of the different kinds of biomass-fuels during combustion and about the characteristics of the ashes. The characteristics of the different combustion technologies including laboratory-ashing are then combined with data from the biomass-analysis and ash-analysis. The data will be evaluated using statistical methods. Difficulties in characterization results from the use of different analytical methods and thereby incomparable results are investigated. The incomparability is founded in insufficient international standards (standards for coal-analysis) and a lack of practical experience. Therefore this database will use the proposal of [2] for the characterization of the biomass and the ashes from biomass. According to this, the following statements are essential for the **"Characterization of Biomass and biogenous Wastes"** :

- description (physical properties)
- amount
- utilization (incl. amount)
- composition
- analytical methods
- ultimate analysis (C, H, O, N, S, Cl)
- trace elements
- ash content
- calorific value
- volatile organic compounds
- literature abstract

The following statements are of interest for the "**Characterization of Ashes**" :

- description (physical properties)
- amount
- utilization / possibilities for utilization (incl. amount)
- analytical methods
- water content
- ignition loss
- ash softening temperature
- sulfur content
- chlorine content
- phosphorus content
- major elements (Ca, Si, Mg, K, Na, Fe, Al, Zn,...)
- minor elements (Cu, Cd, Cr, Ni, Pb, Hg, ...)
- unburned carbon
- CO₂ content
- organic components (PAH, PAK, PCB, PCDD/PCDF, ...)
- literature abstract

To be able to relate the different kinds of biomass and biogenous wastes to the different combustion-technologies by using the data of the ash analyses, the following data about the "**Combustion Technology**" will be incorporated into the database:

- combustion technology (laboratory ashing, stove, fluidized bed systems, grate burning systems, conventional suspension burners)
- size (MW)
- literature abstract

Literature:

- [1] "Analysen von biogenen Brennstoffen", A. Schmidt, A. Zschetzsche and W. Hantsch-Linhart [1993]
- [2] "Analysis of Straw and Strawashes"; IEA - Biomass Utilization Task X: "Utilization of straw and similar agricultural residues". [1994]

WOOD COMBUSTION IN STOVES

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INTRODUCTION

The Nordic countries have big variations in use of energy resources. In Denmark approximately 85% of the energy comes from oil, oil products, coal and coke. Only 2.5% of the energy consumption is covered by biomass. In Finland oil, oil products, coal and coke contribute with nearly 50%. Finland is the Nordic country that is using most biomass in % of total energy consumption. The biomass contribution is almost 17%. However, Sweden is the Nordic country using most biomass, 65 TWh/Year. This is approximately 11% of Sweden's energy consumption. Oil, oil products and nuclear power is the most important energy resource in Sweden. Norway is also a heavy user of oil and oil products. Approximately 50% of the energy used in Norway comes from oil and oil products. Renewable energy is also a very important resource in Norway. Nearly 40% of the energy consumption is covered with this recourse. More about this numbers you can read from Table 1.

ENERGY CONSUMPTION IN THE NORDIC COUNTRIES IN TWH AND % OF TOTALE CONSUMPTION IN PARENTHESES

	DENMARK	FINLAND	SWEDEN	NORWAY
COAL AND COKE	78.7 (36.5)	48.4 (13.7)	33.1 (5.7)	13.3 (5.0)
OIL AND OIL PRODUCTS	103.7 (48.2)	126.2 (35.9)	200.0 (34.6)	134.0 (50.4)
NATURAL GAS	18.6 (8.6)	18.1 (5.1)	3.9 (0.7)	6.1 (2.3)
NUCLEAR POWER		53.7 (15.2)	199.9 (34.7)	
RENEWABLE ENERGY	0.6 (0.3)	38.6 (10.9)	69.8 (12.1)	102.0 (38.3)
BIOMASS	5.3 (2.5)	59.5 (16.9)	65.1 (11.3)	9.7 (3.6)
ELECTRICITY IMPORT	4.1 (1.9)	8.1 (2.3)	5.0 (0.9)	
OTHER ENERGY	4.4 (2.0)			1.1 (0.4)
TOTAL CONSUMPTION	215.4	352.6	576.8	266.2

Ref.: Energi og Miljø, Birgitte Holm Christensen, dk-TEKNIK, 1991

Table 1. *Energy resources in the Nordic countries*

In Norway most of the energy from biomass comes from wood. Of a yearly theoretical energy potential of biomass at 143 TWh there is not used more than approximately 11.5 TWh. More than the half of the wood is used in small stoves and fireplaces for house heating. A description of the biomass situation for energy is given in Table 2.

BIOMASS FOR ENERGY PURPOSE

	YEARLY THEORETICAL ENERGY POTENTIAL IN TWH	POSSIBLE OBTAINABLE ENERGY IN TWH	
		1990	2000
WOOD	88	7.5–8	12.2
PEAT	8	—	—
AQUA BIOMASS	34	—	—
STRAW	5	1.7	2.1
MANURED FROM HUSBANDRY	8	2.1	2.7
TOTAL	143	11.3–11.8	17

Data given by SEFO

Table 2. Biomass for energy

The use of energy for heating (i. e. to cover losses in transmission and ventilation) has decreased with approximately 50% for houses of same size built in 1990 compared with houses built in 1970. This can be shown from Figure 1. For only some decades ago there lived several generations in the same house and there was always someone that could do the firing. To day many houses have none to do the firing through the day when the house owners are working somewhere else, or through the night when they are sleeping. To keep the house warm during the night or when the house owners are at work there has been more usual with loading the stove complete full of wood and nearly closing the air supply to the stove. This way of firing the traditional wood stoves have made very bad combustion and big amounts of emissions. Batch firing with natural draught in traditional stoves at low heat output has been claimed to be a serious emission problem in Norway. An illustration of the firing habits in Norway is given in Figure 2.

ENERGY CONSUMPTION IN A NORWEGIAN HOUSE

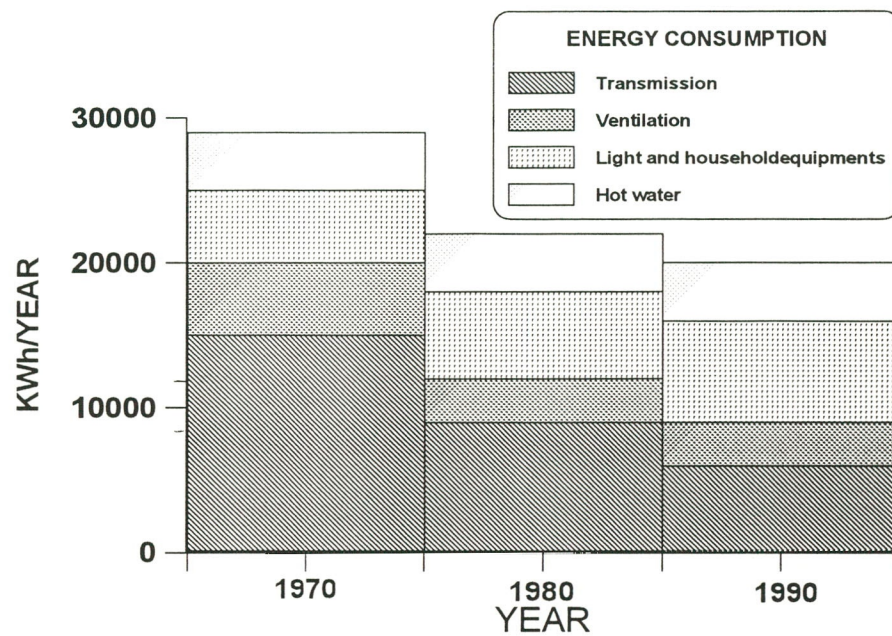


Figure 1. Energy consumption in a Norwegian house

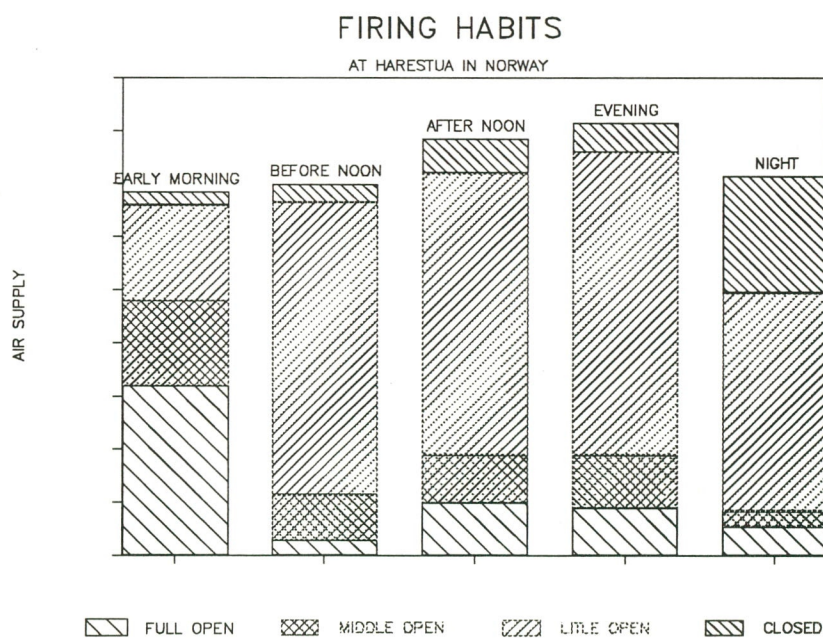


Figure 2. Firing habits

Batch combustion

For carrying out calculations, it is important to know the compounds in the fuel. In a batch process you do not know the compounds. You can know the compounds when loading, but only a few minutes later the relative amounts of the compounds have changed. Wood consists by weight on dry basis mainly of carbon, C, hydrogen, H, oxygen, O, and ash. There have been carried out work to give a prediction of the C, H and O concentration during a combustion process in a stove. The Canadians have made a prediction of fuel compounds through a combustion process of wood in a wood stove. This prediction is based upon weight loss. The prediction is given by the following three equations.

$$(1) \quad C(X) = C_0 * (0.5886 + 1.344 \cdot 10^{-2} * X - 3.344 \cdot 10^{-4} * X^2 + 3.412 \cdot 10^{-6} * X^3)$$

$$(2) \quad H(X) = H_0 * (1.293 + 4.875 \cdot 10^{-3} * X - 1.61 \cdot 10^{-4} * X^2)$$

$$(3) \quad O(X) = 100 - \%Ash - C(X) - H(X)$$

X - Weight % combusted fuel on dry basis

C₀ - Weight % C in fuel at loading on dry basis

H₀ - Weight % H in fuel at loading on dry basis

O₀ - Weight % O in fuel at loading on dry basis

Using the prediction or model for a specific run the curves giving the variations in C, H and O will have the shape given in Figure 3.

In Norway there have been carried out a program that can calculate the weight % C, H and O based upon the measured weight loss, gas flow and the compounds of the gas. However, this program has not yet a model for vaporisation of the water in the fuel and the H and O therefore includes the contribution from the water. Since the moisture content of the water is approximately 15% the results from these calculations should give in order 18% lower values of C and 18% higher values of H and O during the gasification period. The values from the program and the model from Canada seems to be not too far from each other. The results from the calculation program are presented in Figure 4.

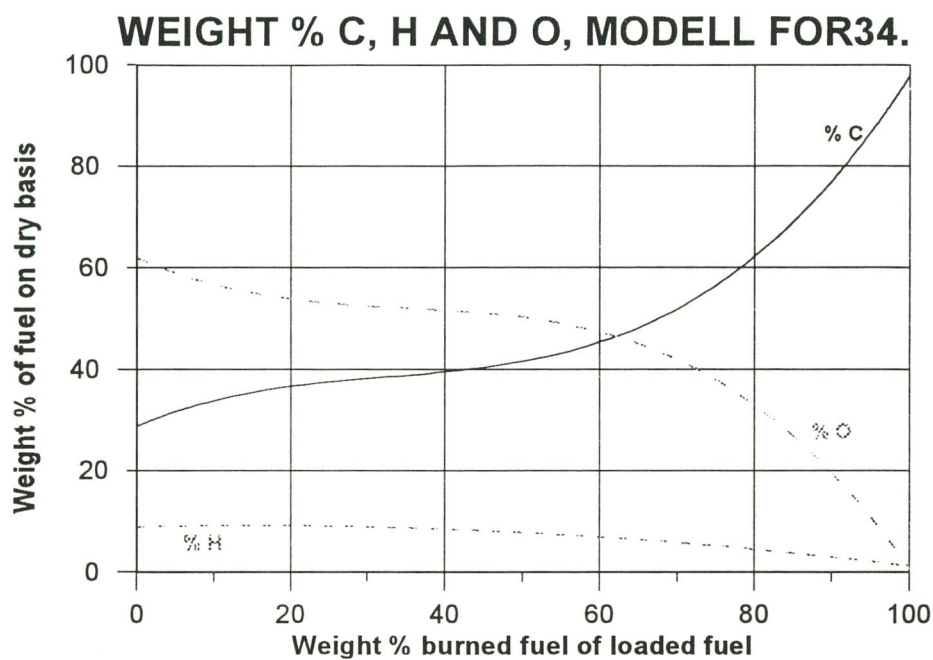


Figure 3. Weight % C, H and O

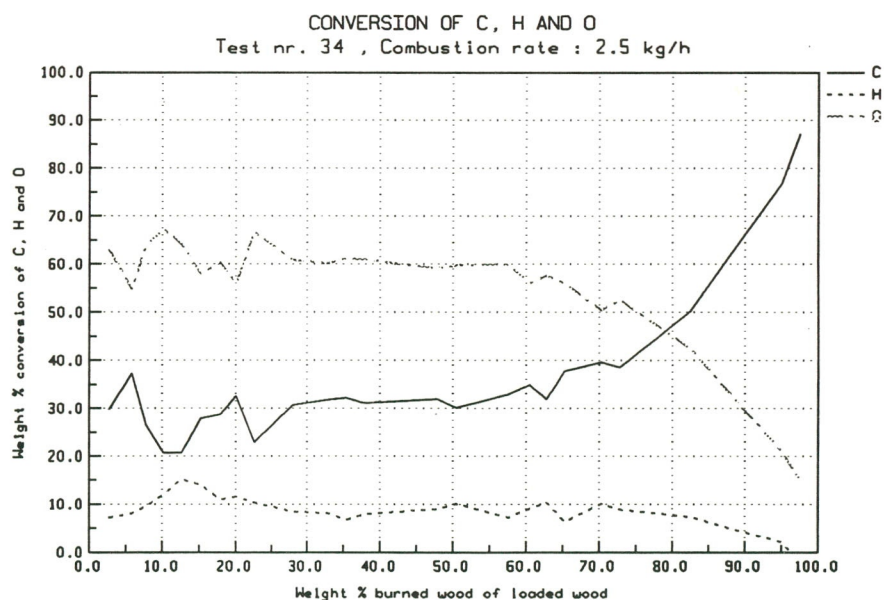


Figure 4. Conversion of C, H and O

Looking at the shape of the curves, it seems that the Canadian model can be good as a first approximation of the weight % C, H and O during a combustion process of wood in a wood stove. However, I believe the model can be more complete by putting in some more parameters like density and burning rates. If we can come up with a good enough model of the reaction compounds from the wood we have solved many of our problems with the calculation during the combustion process in a wood stove.

Not only the compounds of the wood can be modelled as a function of weight % burnt fuel of loaded fuel. The Canadians have also modeled the calorific value of the burnt fuel as a function of dry fuel burnt. The shape of this curve is given in Figure 5.

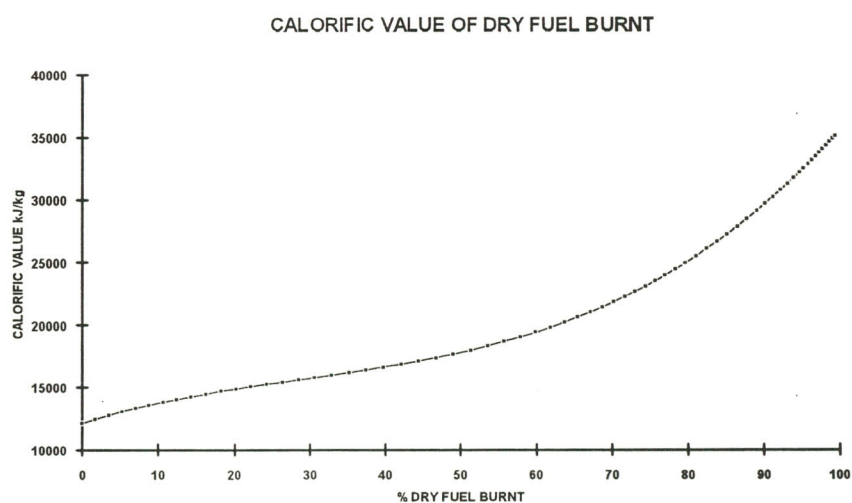


Figure 5. *Calorific value of dry fuel burnt*

Draught

The draught is very important for the combustion process in a wood stove. In the Nordic countries, Canada and USA the emission testing of wood stoves is based upon natural draught given by an insulated chimney with height approximately 4.5 m. In a normal chimney for a wood stove the draught is mainly based upon the chimney height and the average gas temperature in the chimney. An illustration of the draught as a function of average gas temperature in the chimney is given in Figure 6.

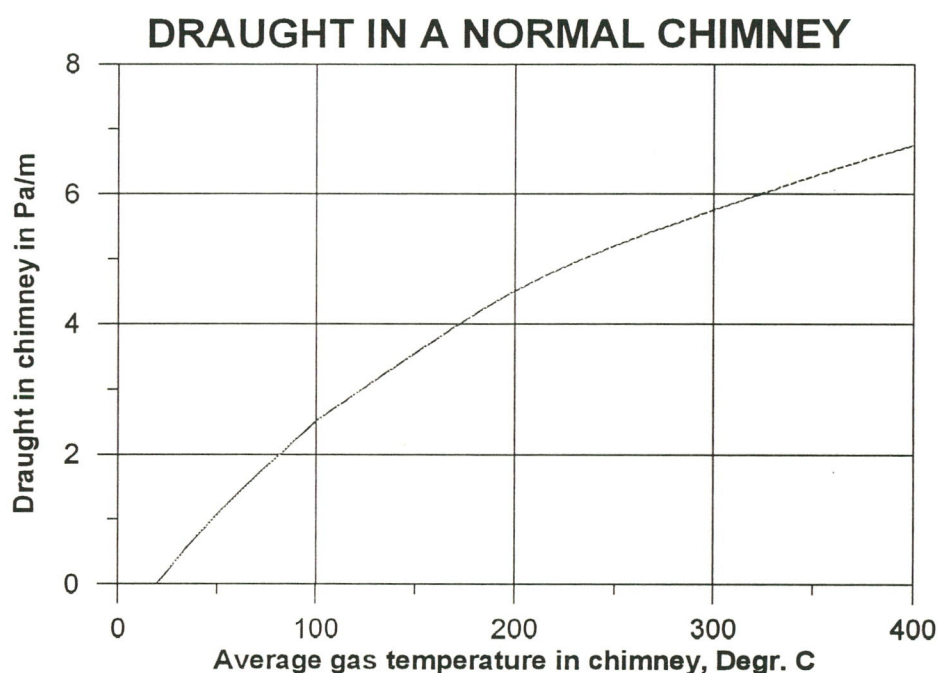


Figure 6. Draught in a normal chimney. Ambient temperature 20 °C

As seen from Figure 6 the average gas temperature is very important for the natural draught. The situation will be complete differently when using forced draft made for instant by a fan in the chimney. In the CEN (European Committee for Standardization) work there is proposed using forced draft for testing. Schematic figures showing the difference on natural and forced draught are shown in Figure 7 and 8.

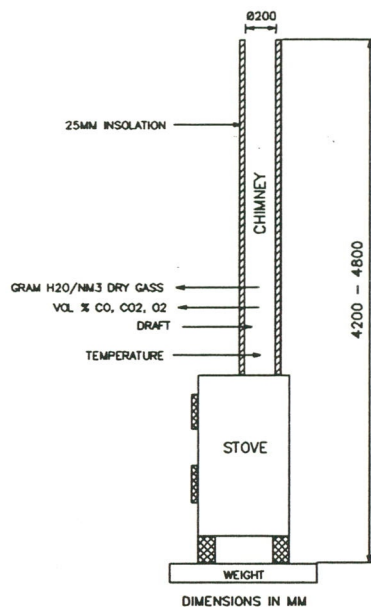


Figure 7. A schematic drawing of a test facility based on natural draught

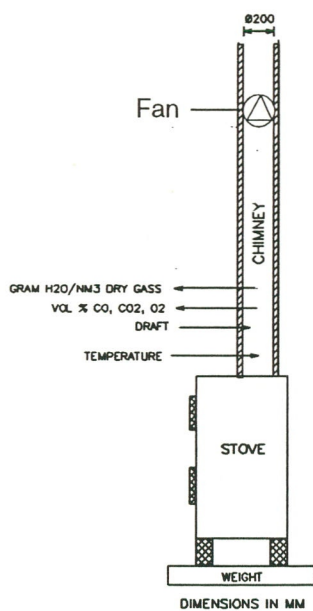


Figure 8. A schematic drawing of a test facility based on forced draught by a fan

In the IEA cooperation (International Energy Agency) tests have been carried out with a stove. In these tests only Austria used forced draught. Using CO as an indication of the quality of the combustion forced draught gives better combustion conditions at low average wood consumption than for natural draught. At higher average wood consumption the difference in the combustion quality between natural draught and forced draught is not very big. This results are given in Figure 9.

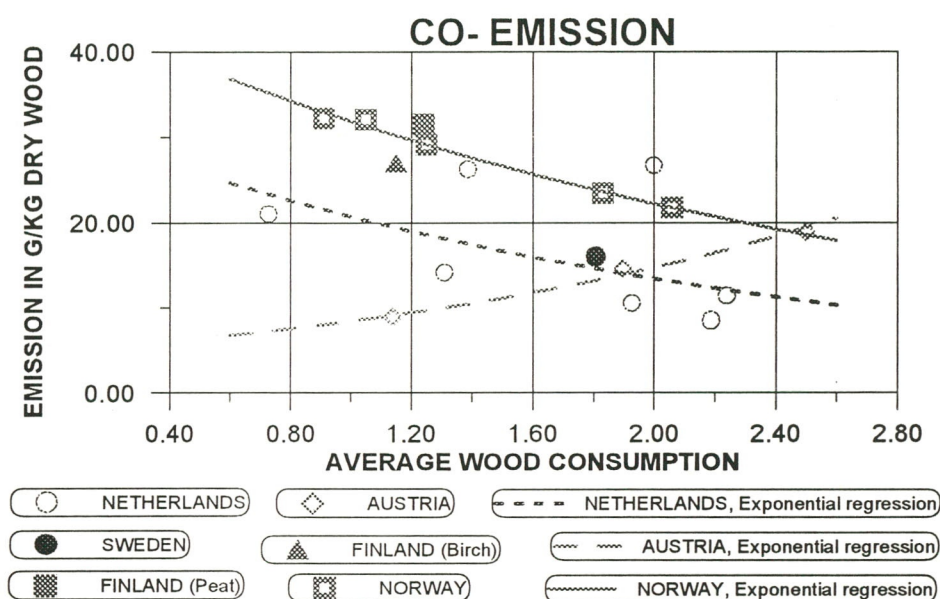


Figure 9. CO- emission

This results are in accordance with a study done by the convener of CEN TC295/WG5 Knud J. Hansen at Dansk Teknologisk Institut. The conclusion is therefore that forced draught is not suitable for emission testing at low heat output.

Emissions

Tests done at SINTEF based upon the national standards shows big emissions at low average wood consumption (i. e. low heat output) from traditional stoves on the market. However, stove A which is a catalytic stove and the lab stove that is a stage combustion unit stove shows low emissions even at low heat outputs. For particles this is shown in Figure 10.

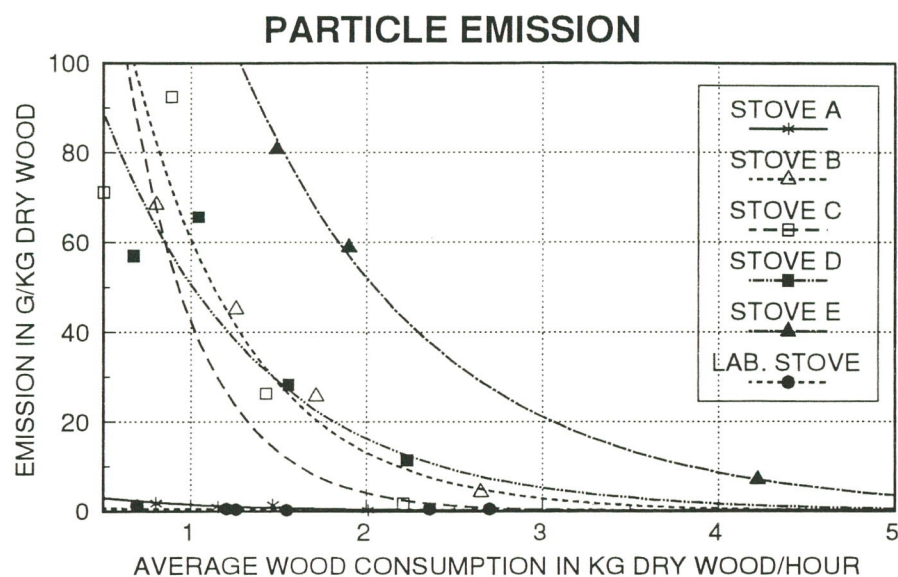


Figure 10. Particle emission from six different stoves/fireplace

The particle emissions consist mainly of tar. This is shown when looking at Figure 10 and Figure 11. At Figure 11 the tar emissions from five of the tested stoves are given. As seen the shapes of the curves are nearly the same as for the particles.

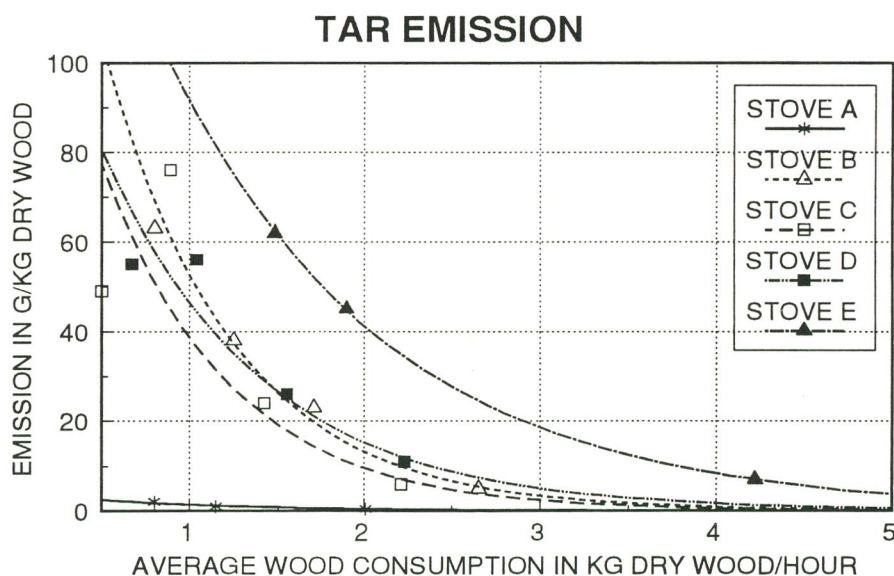


Figure 11. Tar emission from five stoves/fireplace

In Sweden there are put restrictions upon tar emissions. Even if they do not have the same firing procedure the maximum level for tar in Sweden is put together with the numbers for tar emissions from the tested stoves/fireplace in Norway. In Figure 12 there can be seen that to have possibilities to obtain the Swedish restriction the traditional stove have to be fired at a high heat output. However, this is not the case with the tested catalytic stove, Stove A.

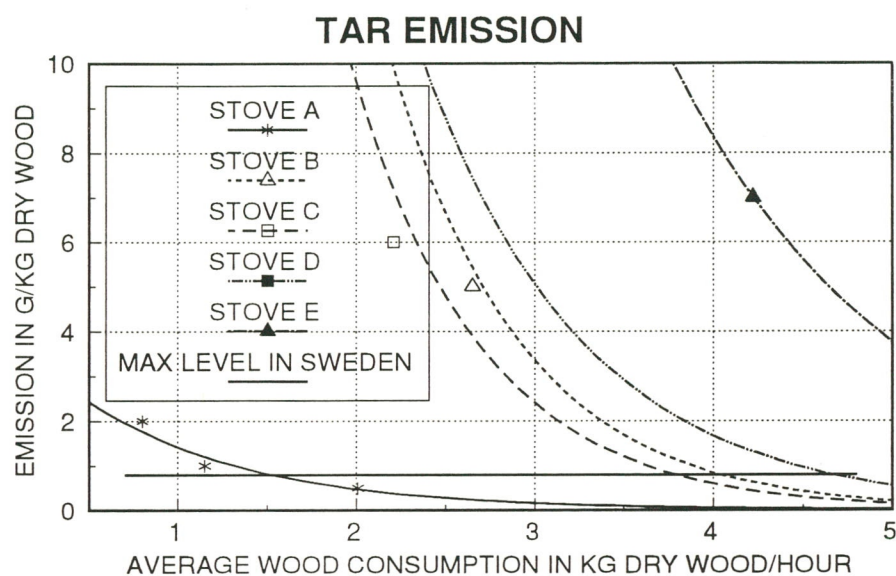


Figure 12. Tar emissions wit maximum levels for Sweden

All stoves do not have to have the same shape of the emission curves. The catalytic stove tested in the IEA cooperation have another shape of the particle emission curves than the other stoves tested at SINTEF. The numbers for the particles from this stove are given in Figure 13.

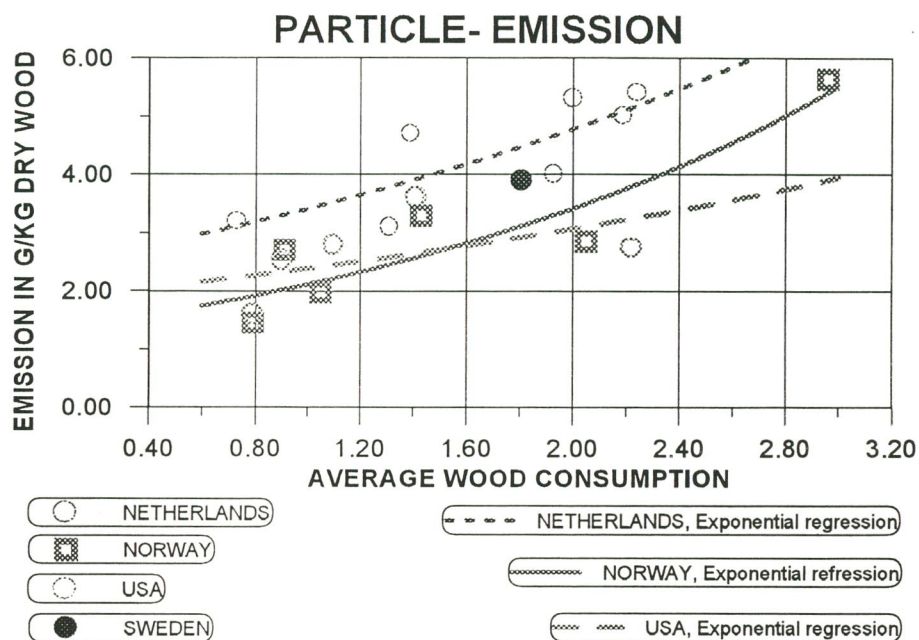


Figure 13. Particle emissions from the stove tested in the IEA cooperation

In Denmark they are using CO as a level for emission restrictions. Denmark have also another firing procedure than Norway, Canada and USA. However, to make an idea of the CO emission levels accepted in Denmark the emission level is put together with the test results from four of the tested stoves at SINTEF. The results are given in Figure 14. As seen from the figure traditional stoves fired at a high heat output will have possibilities to pass the restriction level in Denmark.

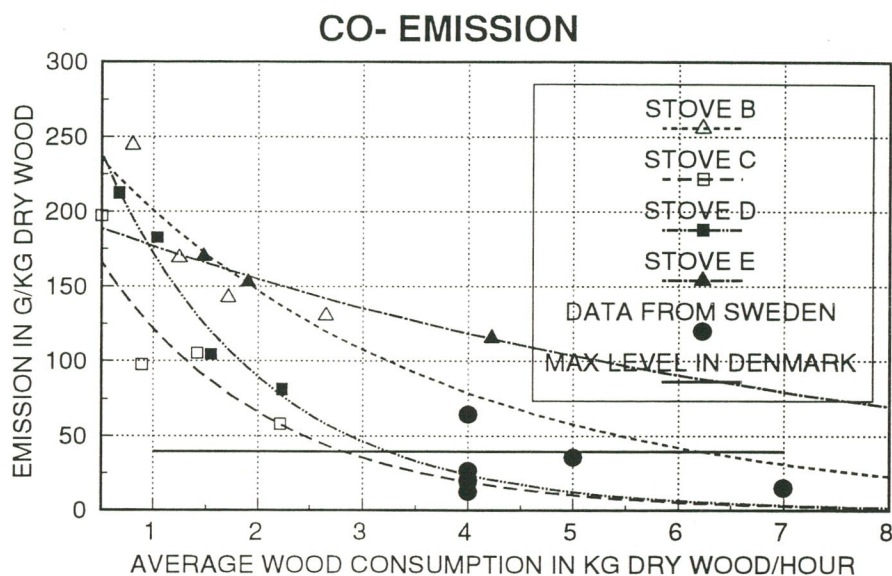


Figure 14. CO emission with restriction level from Denmark

To give a comparison of the emissions values for a traditional stove, a catalytic stove and the stage combustion unit, the emission values for the catalytic stove is set to 1.

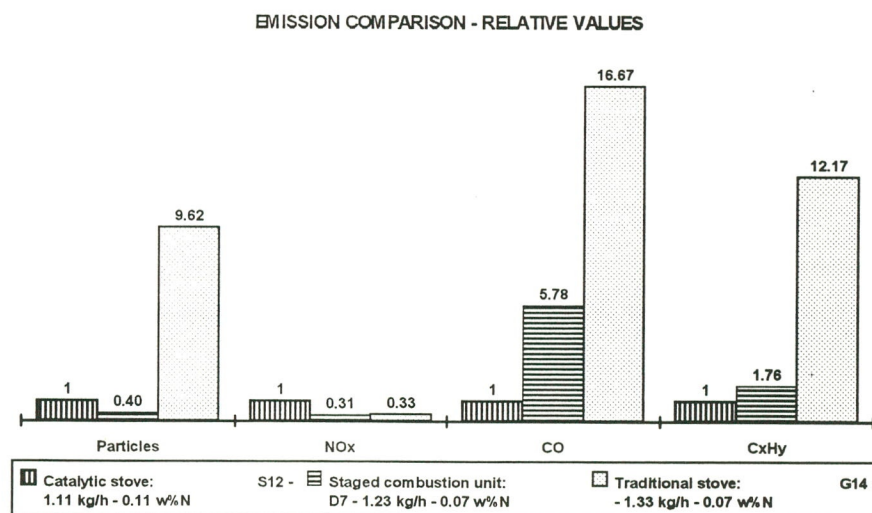


Figure 15. Emission comparison - relative values

As seen from Figure 15 the catalytic stove and the stage combustion unit are good in reduction particles, CO and hydrocarbons (CxHy) compared with traditional stoves. When it comes to NOx the catalytic stove have a problem. The emissions of NOx are much higher from the catalytic stove than for the stage combustion unit and traditional stoves. An investigation of the catalytic stove is done at SINTEF by measuring in sequences the values of NOx before the catalyst and after the catalyst. This results are given in Figure 16 and show that the NOx emission nearly double through the catalyst.

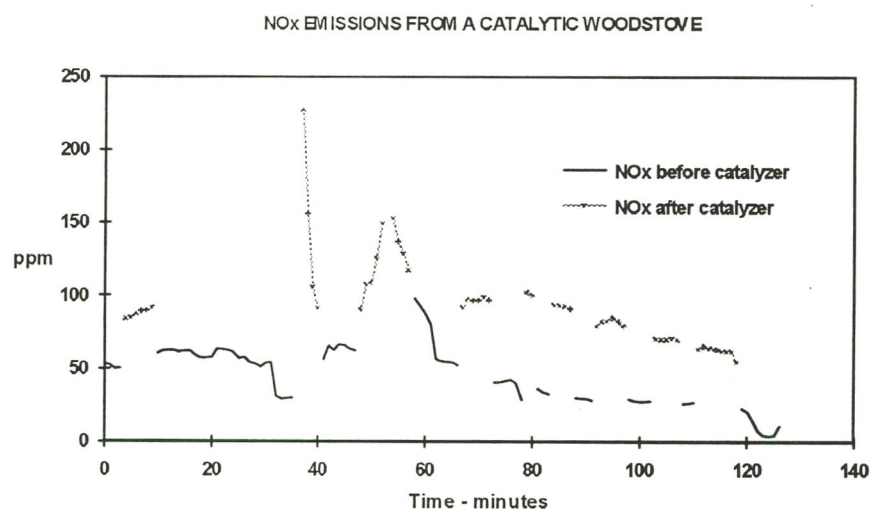


Figure 16. NOx emissions from a catalytic wood stove

Greenhouse gases

The influence of the greenhouse gases converted to CO₂ equivalents for the traditional stoves, catalytic stoves and the stage combustion unit have been investigated at SINTEF and compared with the CO₂ equivalents from corresponding units burning oil and kerosene. This results shows that stoves based upon new technology, the catalytic stove and the stage combustion unit, has very low contribution to the greenhouse effect compared with traditional stoves and corresponding units burning kerosene and oil. The values are given in Table 3.

	CO ₂	CO	CH ₄	NO _x	N ₂ O	CO ₂ eq.
TS	0	34	19.6	0.34	1.8*	55.74
CS	0	2.04	1.61	1.02	1.11	5.78
SCU	0	11.8	2.84	0.32	1.58	16.54
OIL	75*	0.04*	0.028*	1.7*	4.5*	81.27
K	74*	0.6*	0.028*	1.02*	4.5*	80.15

TS = Traditional stoves
CS = Catalytic stove
SCU = Stage Combustion Unit
K = Kerosene
***** = SFT 1990

Table 3. Greenhouse gases, CO₂ equivalents.

Combustion Control and NO_x Emissions Reduction

J. Good*, Th. Nussbaumer*

Abstract

Two main groups of pollutants from biomass combustion can be distinguished:

- unburnt pollutants: CO, HC, PAH, soot
- oxidized pollutants: NO_x and CO₂.

The unburnt pollutants can be reduced effectively if the combustion air, especially the secondary air is mixed homogenously with the combustible gases and the burnout takes place in a hot combustion chamber. Furthermore the fuel/air ratio must be at its optimum. The correct setting of the excess air ratio is necessary to guarantee

- a high combustion temperature and a high efficiency (low excess air) and
- complete combustion (high excess air to avoid unburnt pollutants).

The optimum excess air ratio is influenced by the construction of the firing system, the actual load and the quality of the fuel (moisture content etc.). Combustion control is necessary to ensure a high combustion quality and high efficiency for biomass combustion. The most important control systems used today are control of the temperature in the combustion chamber (*combustion temperature control*) and control of the excess air ratio (*lambda control*). A new control system combining lambda control with setpoint optimization (*CO/lambda control*) was applied to a 1 MW understoker firing. Measurements showed that especially at part load operation the efficiency was improved by up to 5% and CO emissions were reduced by a factor 2.

NO_x emissions from biomass combustion originate mainly from the fuel bound nitrogen. Thermal NO_x are of minor importance since the combustion temperature is usually below 1'300°C. For the reduction of NO_x primary and secondary measures can be taken.

Staged combustion can be used as a primary measure for NO_x reduction. In a test reactor with an externally heated reduction chamber between the gasification and the combustion an NO_x reduction of 50% compared to conventional combustion was reached. The parameters for a relevant NO_x reduction are as follows: residence time in the reduction chamber ≈ 0.5 s, reduction temperature ≈ 1'200°C, primary excess air ratio ≈ 0.7.

The injection of ammonia or urea can be used as a secondary measure for NO_x reduction. For the *selective catalytic reduction (SCR)* with a catalyst at about 250°C an NO_x reduction of 95% can be reached without significant slippage of ammonia (< 5 mg/m³). For the *Selective non-catalytic reduction (SNCR)* a temperature between 850°C and 950°C and an over stoichiometric amount of ammonia are necessary. Further a separate reduction chamber is needed to achieve a relevant NO_x reduction without significant slippage of ammonia. For the SCR process the long term behaviour of the catalyst can be a major problem where for the SNCR process the accurate control of the temperature seems to be critical.

* Dr. Jürgen Good, Dr. Thomas Nussbaumer

Introduction

Note: All datas are calculated at 11 Vol.-% O₂. NO_x (NO and NO₂) are calculated as NO₂.

When heated to temperatures over 300°C biomass as wood, grass, straw or miscanthus turns into volatile components (CO, H₂, CH₄ and others) and char. At 500°C about 85% by weight of the wood substance is in the form of gaseous compounds. There is only a small variation in the pyrolysis temperature between different sorts of biomass [Nussbaumer 1993]. However the ash content and the ash behaviour (ash softening and melting point) of different biomass vary in a wide range. Therefore the ash removal system and the grate must be designed for the type of biofuel used. Furthermore sintering of ash on the grate or at the walls of the combustion chamber must be avoided by local cooling if biomass with low ash softening temperature is used.

Wood combustion can be described as a two-stage process: Gasification of the solid substance and oxidation of the gases. Thus two main groups of pollutants from wood firings can be distinguished (fig. 1):

- unburnt pollutants: CO, HC, PAH, soot
- oxidized pollutants: NO_x and CO₂

The unburnt pollutants can be diminished effectively if the secondary air is mixed homogeneously with the combustible gases and the burnout of the gases takes place in a hot combustion chamber. On the opposite NO_x as an oxidation product is usually maximally at high combustion quality. Since the NO_x emissions from biomass combustion are higher than from modern oil and gas boilers measures for NO_x reduction will become more and more important.

Combustion Control

Important for a successful combustion control is an accurate construction of the firing system. The secondary air is to be mixed homogeneously with the combustible gases and must not influence the gasification of the solid substance.

To show the influence on the optimal excess air ratio of the variation of the load and the fuel quality (fuel moisture etc.) experiments were done on a 45 kW understoker firing (fig. 2). The results show that the CO/lambda-characteristic is shifted to higher excess air ratio when operating at part load or when burning wet fuel (fig. 3). Combustion control systems measuring temperatures or the excess air ratio only cannot realize that shift.

The shift of the CO/lambda-characteristic can be realized by measuring the content of unburnt pollutants. Therefore a control concept basing on measurements of

- excess air ratio (i.e. oxygen) and
- CO emission

, *CO/lambda control* (fig. 4), was designed [Good 1992, 1994]. It is a further development of the control of the excess air ratio, *lambda control*. The setpoint for the lambda controller is permanently being optimized. A special algorithm using the input of the excess air ratio and CO emission calculates the new setpoint.

As an application of the experimental studies, a 1 MW understoker firing was equipped with CO/lambda control. Measurements are still going on but some results are already evident (fig.5).

At nominal power:

- the efficiency was improved by 1%
- CO emissions were reduced by a factor 1.5.

At part load operation (30% of nominal power):

- the efficiency was improved by up to 5%
- CO emissions were reduced by a factor 2.

As another example of use of advanced combustion control technology a 35 kW stickwood firing was equipped with an oxygen detector (lambda detector). The firing was to be supposed to run at nominal power and at 50% of the nominal power.

As the variation of the humidity of stickwood usually is small and the variation of the load was known, the use of lambda control only was sufficient. It was shown that part load operation (40%) was reached and maintained without increase of unburnt pollutants [Good, Nussbaumer 1993].

Formation of NO_x during biomass combustion

Nitric oxides NO and NO₂ (= NO_x) from combustion processes are formed in three different reactions:

- Thermal NO_x are formed at high temperature by the oxidation of nitrogen in the air
- Prompt NO_x can be formed during the combustion of hydrocarbons in reactions of molecular nitrogen with free radicals in the flame
- Fuel NO_x are formed from the nitrogen contained in the fuel.

Since typical combustion temperatures in today's wood firings are between 800° and 1200°C only fuel NO_x are of great importance. This was shown earlier [Nussbaumer 1988]:

- Wood was burnt in a conventional firing a) with air and b) with a nitrogen free mixture of oxygen and argon. Since no difference in the emission of NO_x was found the nitrogen in the air is not responsible for the formation of NO.
- The emission of NO_x during the combustion of different wood samples in a laboratory furnace showed no influence of the flame temperature in the range from $800^\circ - 1300^\circ\text{C}$.
- The expected amount of NO_x by the Zeldovic mechanism which describes the formation of thermal NO_x is neglectable in relation to the measured emission of NO_x from wood firings.
- Further it was shown that that nitric oxide emissions increase with increasing nitrogen content in the wood (table 1).

During the pyrolysis of wood approximately 20% of the nitrogen compounds remain in the char and 80% form volatile substances. As a first approximation, the volatile nitrogen conversion to NO and the char conversion to NO can be assumed as independent [Levy et al. 1979].

The volatile fraction consists of HCN, NH_2/NH_3 , NO and N_2 . HCN is converted homogeneously to NH_2/NH_3 which can be oxidized to NO or react with NO to N_2 [Nussbaumer 1988, Keller et al. 1993]. The overall reaction from fuel nitrogen to NO or N_2 can be influenced by the reaction conditions, especially by the temperature, the concentration of oxidizing agents as O_2 and H_2O , the residence time in the different zones of the combustion and the turbulence.

Primary measures for NO_x reduction

To ensure combustion with low NO_x emissions the fuel nitrogen should be converted into N_2 . Different concepts of staged combustion for NO_x reduction have been investigated for the combustion of coal, oil and gas [Beér 1990, Folsom et al. 1989, Jansohn et al. 1989, Kolb 1990, Spliethoff 1989]. For the combustion of wood the following reactions are considered to be important for the NO_x emissions [Nussbaumer 1989, 1990 c] (see fig. 6):

- During the gasification HCN, NH_i radicals as NH_2 and NH_3 are formed. These components can react in different reactions to form molecular oxygen:



- Where there is a shortage of oxygen NO_x acts as an oxidizing agent for carbon monoxide, methane, hydrocarbons, hydrogen and carbon:



Staged combustion with reduction chamber and air staging

To show under which conditions the above mentioned reactions can reduce NO_x a test reactor with fixed bed updraft gasification followed by a gas phase combustion was built (fig 7). The reactor can be operated as an under stoker firing which was used as reference for conventional combustion. The following concepts of staged combustion have been investigated:

- *staged combustion with separate reduction chamber* between the gasification and the combustion chamber (fig. 8)
- *air staging* in the gasification chamber (fig. 9)
- flue gas recirculation
- combinations of the listed measures.

Due to the results of different experiments carried out in the fixed bed reactor reaction (1) is supposed to be most important for fixed bed combustion of wood. Reaction (2) might be of importance together with catalytic effects on ash while for reaction (4) and (5) no effects were found during wood combustion in the test reactor. Reaction (5) is supposed to be of major influence during fluidized bed combustion of coal [Beér 1989].

In the 25 kW test reactor an NO_x reduction of 50% compared to conventional fixed bed combustion (from 200 mg/m³ to 100 mg/m³ for native wood) can be reached by a staged combustion with a (heated) reduction chamber between the gasification and the combustion. Further it is shown that flue gas recirculation is of minor influence on NO_x emissions. However to reach minimal NO_x emissions the reaction conditions must be as follows:

- residence time in the reduction chamber ≈ 0.5 s (> 0.3 s) and turbulence to ensure mixing
- reduction temperature $\approx 1'200^\circ\text{C}$ ($1'150^\circ\text{C} - 1'250^\circ\text{C}$)
- primary excess air ratio ≈ 0.7 (0.6 – 0.8).

The primary excess air ratio in the gasification chamber is of great influence on the NO_x emissions (fig. 10):

- Primary air ratio $\ll 0.7$ (gasification): Only NH-components are formed during the gasification (no NO). The NH-components are oxidized in the combustion chamber to NO.
- Primary air ratio > 1 : The pyrolysis gases are burnt immediately in the gasification chamber (= combustion). The concentration of NH-components to reduce NO in the reduction chamber is close to 0.

The temperature window for the reduction of NO_x by staged combustion with reduction chamber is about 300°C higher than for the SNCR process. It is assumed that methane in the gas consumes OH radicals and therefor inhibits the formation of NH_2 radicals which are necessary for the NO reduction [Keller 1994]. The results confirm the datas from a kinetic model from [Kilpinen et al. 1991].

To guarantee a constant primary air ratio and a reduction temperature of 1'200°C a suitable process design as well as an accurate combustion and gasification control are necessary. Therefor further work is needed for a transfer of the results into practice.

Staged combustion with process internal fuel staging

It is assumed that the NO_x emissions could be reduced by *process internal fuel staging* (fig. 11), where a part of the wood is gasified ($\lambda < 1$) and another part is burnt immediately ($\lambda > 1$) and the two gas flows are mixed. The NO_x in the flue gas of the combustion ($\lambda > 1$) can be reduced with NH_3 and other components of the gas from the gasification ($\lambda < 1$) by the above mentioned reactions and the fuel-N can be converted to N_2 . This option of NO_x reduction has not yet been investigated.

Secondary measures for NO_x reduction

For natural wood the NO_x emissions are usually between 150 and 300 mg/m^3 at 11 Vol.-% O_2 (calculated as NO_2). If chip boards or similar wood residues are burnt, the nitrogen contained in glue and bonding agents (urea) lead to typical NO_x emissions between 500 and 1000 mg/m^3 . For biofuels as straw, miscanthus and grass NO_x emissions are close to those of wood residues since short living plants show a far higher nitrogen content than wood.

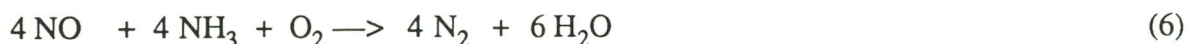
In Switzerland secondary measures will be necessary for larger boilers ($> 1 - 2 \text{ MWth}$) fired with wood residues or other biomass with high nitrogen content to fit the Swiss emission standard of 250 mg/m^3 (standard of the air pollution control ordinance for large wood firings).

For the secondary measures a reduction agent is injected for a selective NO_x reduction. The most important reduction agents are:

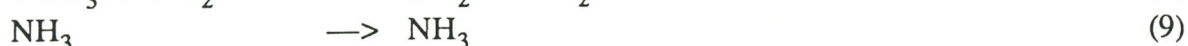
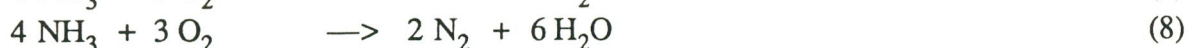
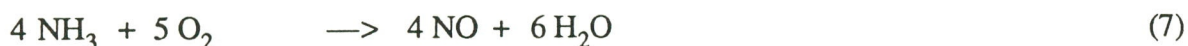
- Ammonia (NH_3) which is gaseous at atmospheric pressure and is usually stored in a pressure tank. It is toxic and has a low smell limit.
- Sal ammonia (water, containing solved ammonia, usually 24 wt.%) is easier to store than ammonia. The problems with smell by leakage are similar to ammonia.
- Urea ($(\text{NH}_2)_2\text{CO}$) is a white solid powder which is usually stored as a granulate. To use it as a reduction agent it can be solved in water. It is easy to handle and doesn't smell.

The reaction in the SCR and SNCR process are mainly the same. The desired reaction is the reduction of NO with NH -reactants, mainly NH_2 . If urea is used, it has to be decomposed before the reaction with NO_x . Therefore a temperature of at least $250^\circ\text{C} - 300^\circ\text{C}$ is necessary.

Desired reaction:



Side reactions and slippage of reducing agent (4):



In reality reaction (6) is a radical reaction mainly with NH_2 as described as reaction (1) for primary measures: $\text{NO} + \text{NH}_2 \rightarrow \text{N}_2 + \text{H}_2\text{O}$. Therefore to start reaction (6) a temperature of about 850°C or the use of a catalyst is necessary.

If the temperature is greater than 1000°C the side reactions (7) and (8) become more and more important. Therefore the conditions for the NO_x reduction show an optimum in the temperature window between 850°C to 950°C . Because of the side reactions an over stoichiometric amount of reducing agent is necessary. The molar ratio of reducing agent is defined as follows:

$$n = \text{NH}_3/\text{NO}_x \text{ (mol/mol)} \quad \text{where } \text{NO}_x = \text{NO} + \text{NO}_2 \text{ (mol)} \quad (10)$$

If the mixture is not homogenous or a high molar ratio is needed slippage of NH_3 can lead to high ammonia emissions (9).

Selective non-catalytic reduction SNCR

From other investigations is known that the reaction temperature is most important for the non-catalytic reduction. The highest reduction rate is usually achieved in the temperature window from 850° to 950°C [Schu 1989]. However the temperature window can be influenced to lower temperatures by certain components in the gas such as H_2 or alcohols which produce OH-radicals. CH_4 can shift the reactions to higher temperatures because it consumes OH-radicals. Experiments with non-catalytic NO_x reduction have been carried out in an existing 500 kW grate firing by injection in the combustion chamber. Sal ammoniac with a cone nozzle and ammonia with a one layer nozzle were injected in the combustion chamber (fig. 12, fig. 13). The emission of NO_x and NH_3 slippage have been measured for the combustion of natural wood and wood residues. Further experiments have been carried out with a pre oven firing and a separate reduction chamber for the SNCR process (fig. 14). At the moment experiments are carried out in an optimized grate firing with a hot chamber for the SNCR process (fig. 15).

SNCR process under non-ideal conditions in an existing grate firing:

- For wood residues an NO_x -reduction of about 50% can be obtained with the following conditions:
 - an over stoichiometric amount of reduction agent is needed ($n = 3 - 5$)
 - a reaction temperature $> 850^\circ\text{C}$ is needed
 - the NH_3 -slippage may be far above the limit ($> 30 \text{ mg/m}^3$).
- It was shown that the non-ideal mixing of the gases is responsible for the slippage of ammonia.
- For wood residues with high nitrogen content and high NO_x emissions in the raw gas a higher reduction rate can be achieved than for natural wood.

Results with the SNCR process under ideal conditions in a plug flow reactor:

- For wood residues an NO_x -reduction of up to 90% was obtained at a molar ratio $n = 2$ and with NH_3 -slippage $< 10 \text{ mg/m}^3$. To obtain this result a residence time in the reduction chamber of about 1 s is needed at a reaction temperature of 900°C .

SNCR in an optimized grate firing with reduction chamber:

- The results under ideal conditions have partly been confirmed. An NO_x -reduction of up to 80% was obtained with the following conditions:
 - an over stoichiometric amount of reduction agent, molar ratio $n \approx 2$
 - reaction temperature $> 850^\circ\text{C}$, residence time $> 0.7 \text{ s}$
 - the NH_3 -slippage below the limit ($< 30 \text{ mg/m}^3$).
- Three control systems for the SNCR process are investigated:
 - The NO_x emissions of the wood residues are estimated. The amount of reducing agent is calculated taking into account the combustion air flow and the prefixed molar ratio of the reducing agent (advantage: no on line measurement of NO_x emissions).
 - As above, but the NO_x emissions are measured before the injection place.
 - A closed NO_x control loop, using NO_x measurement after the injection place.
- However the temperature control is a major problem in practice. Further experiments are in progress.

Selective catalytic reduction SCR

In the present investigations two types of catalysts and reduction agents have been used: Catalyst type A with sal ammonia ($220^\circ - 250^\circ\text{C}$) and catalyst type B with urea ($400^\circ - 450^\circ\text{C}$ to decompose urea). Both types were used in low dust and in high dust system (fig. 16, fig. 17).

- For wood residues an NO_x -reduction $> 90\%$ can be obtained with the following conditions (fig. 18):
 - A stoichiometric amount of reduction agent is sufficient ($n = 1$).
 - A catalyst temperature of about 250°C or greater is needed.
 - The NH_3 -slippage is below 10 mg/m^3 for $0.7 < n < 2$
- If different catalysts are combined in a suitable way a reduction of CO, HC, dioxines and furanes can be reached in the second stage of the catalyst.

Conclusions

Combustion control

The CO/lambda-characteristic is shifted to higher excess air ratio when operating at part load or when burning wet fuel. CO/lambda control is able to deal with that fact. On a 1 MW understoker firing it improved the efficiency by 1% at nominal power and 5% at part load. It reduced the CO emissions by a factor 1.5.

By the use of lambda control the actual load of a 35 kW stickwood firing was reduced to 40% and maintained stationary without increase of unburnt pollutants.

Primary measures for NO_x reduction

In a test reactor with an externally heated reduction chamber between the gasification and the combustion chamber an NO_x reduction of 50% compared to conventional combustion can be reached. However for a relevant NO_x reduction the temperature should be 1'200°C and the primary excess air ratio = 0.7.

The temperature window for the reduction of NO_x by staged combustion with reduction chamber is about 300°C higher than for the SNCR process. It is assumed that the presence of methane in the gas consumes OH radicals and therefore inhibits the formation of NH₂ radicals which are necessary for the NO reduction.

Since a constant primary air ratio and a reduction temperature of 1'200°C have to be guaranteed the realisation of this low-NO_x concept in practice is a challenge for the design and control of future biomass combustion devices.

Secondary measures for NO_x reduction

Selective catalytic reduction (SCR): With injection of ammonia or urea in the flue gas and the use of a catalyst at a temperature of 250°C an NO_x reduction of 90% – 95% can be reached without significant slippage of ammonia (< 10 mg/m³). For the use in practice a suitable control system for the injection of the reducing agent is currently being developed. Further the use of SCR in practice has to show the lifetime of the catalyst which can be reached in low dust and high dust processes.

Selective non-catalytic reduction (SNCR): For the SNCR process a temperature between 850°C and 950°C is needed. To achieve a relevant NO_x reduction an over stoichiometric amount of ammonia is used. With injection of ammonia in the combustion chamber of a grate firing an NO_x reduction of 50% was reached. However relevant emissions of ammonia (> 30 mg/m³) were found. By use of a separate reduction chamber (residence time 1.5 s) between the combustion chamber and the heat exchanger an NO_x reduction of 90% can be reached without significant slippage of ammonia. Also for the SNCR process a suitable control system for the injection of reducing agent has to be developed. First results showed that due to changing in fuel quality an accurate temperature control is a major problem for the successful use of SNCR.

Tables

	Fuel-N [Wt. %]	NO _x [mg/m ³]	U [%]
Pine wood	0.07	173	67.3
Beech	0.2	231	36.0
Chip board (UF)	2.85	921	8.4

Table 1 Nitrogen content of pine wood, beech and chip board, concentration of NO_x and conversion rate (U) of fuel nitrogen to NO_x resulting from the isothermal combustion in a laboratory furnace (NO_x at 11 Vol.-% O₂) [Nussbaumer 1988].

Figures

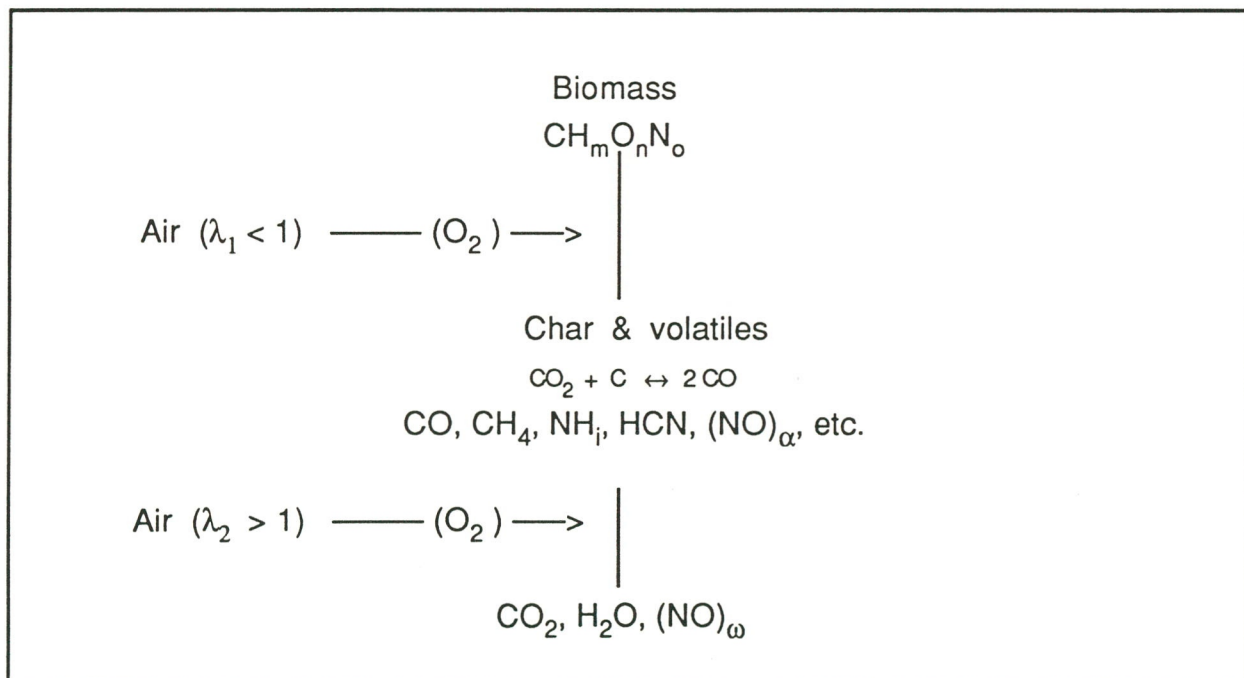


Fig. 1 2-stage combustion of wood with primary air for the gasification and secondary air for the burn out of the combustible gases. Contemporary wood firings often use primary air in excess (excess-air ratio $\lambda_1 > 1$).

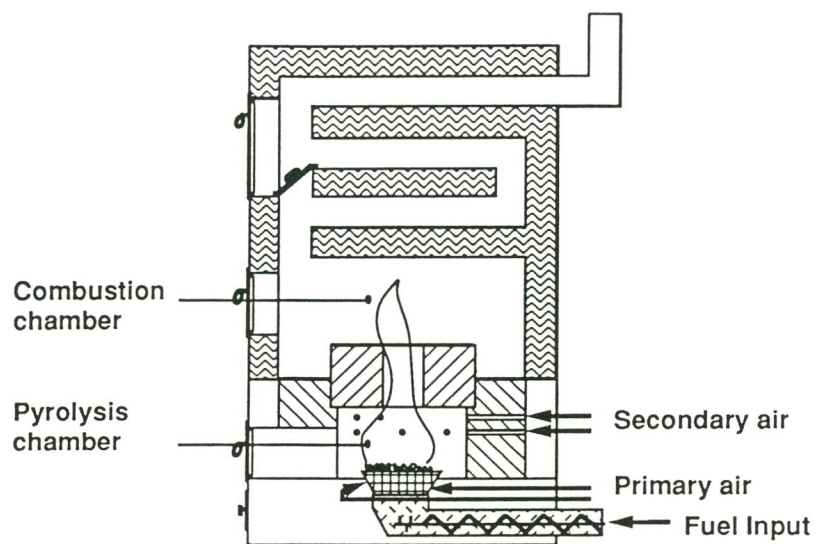


Fig. 2 Experimental 45 kW understoker firing.

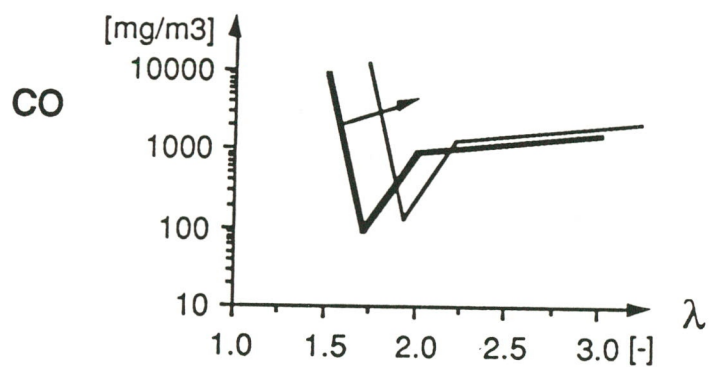


Fig. 3 Shift of CO/lambda-characteristic.

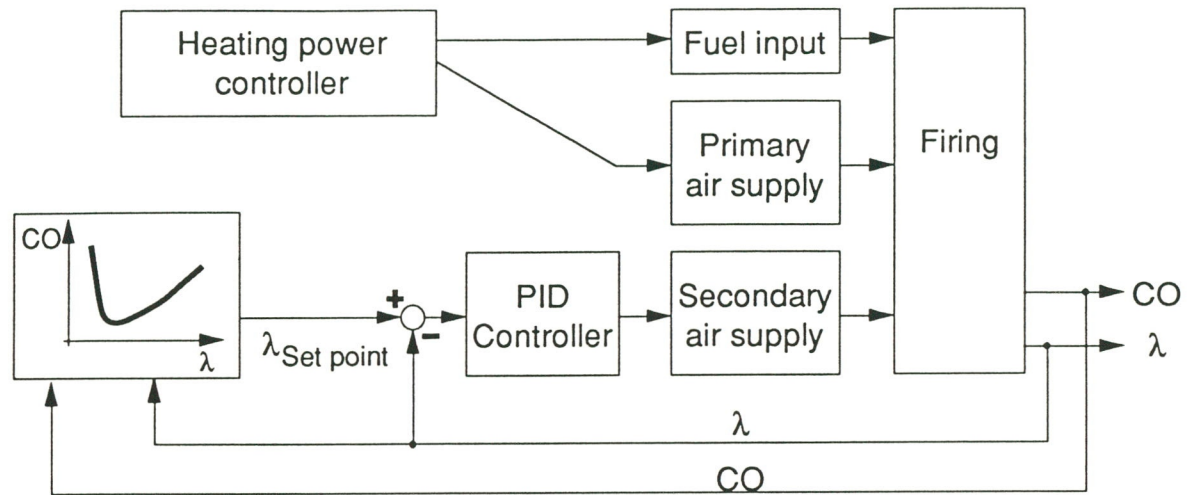


Fig. 4 CO/lambda control [Good 1994].

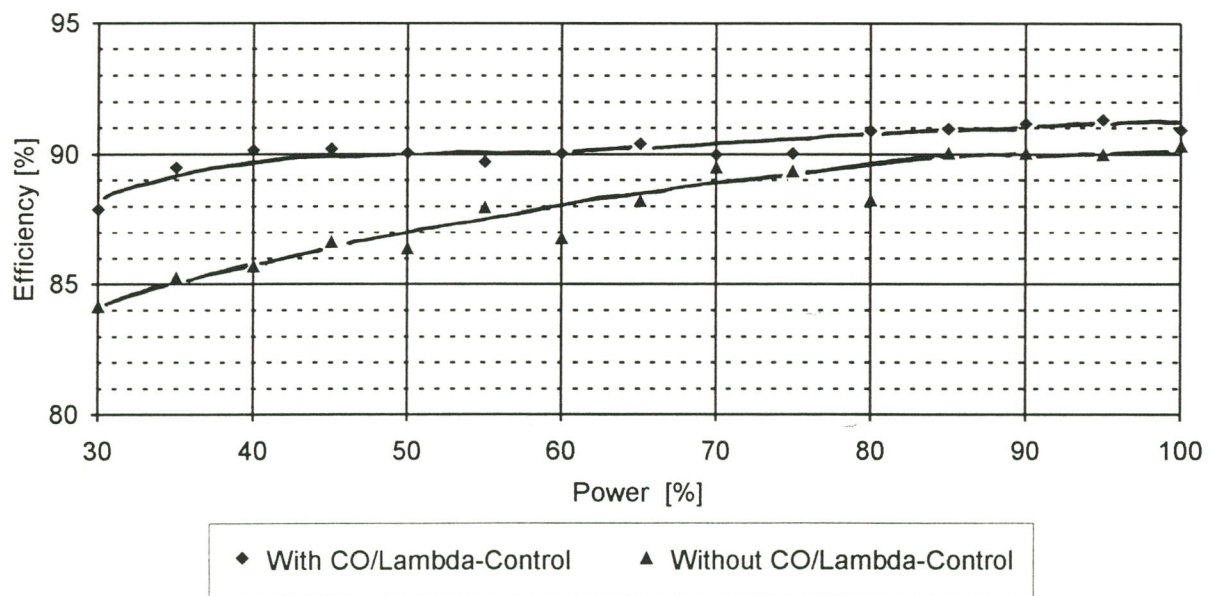


Fig. 5 Efficiency in function of percentage of nominal power.

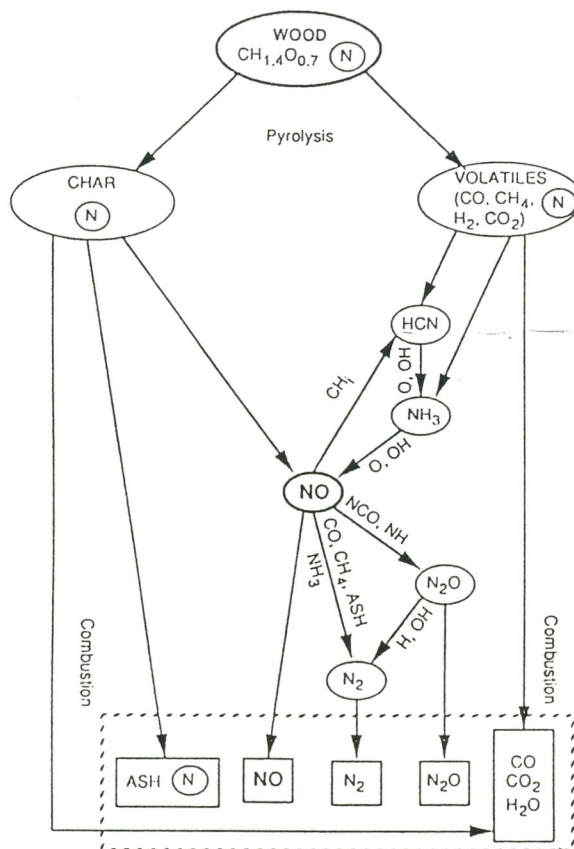


Fig. 6 Conversion of fuel nitrogen during combustion of wood [Keller et al. 1993].

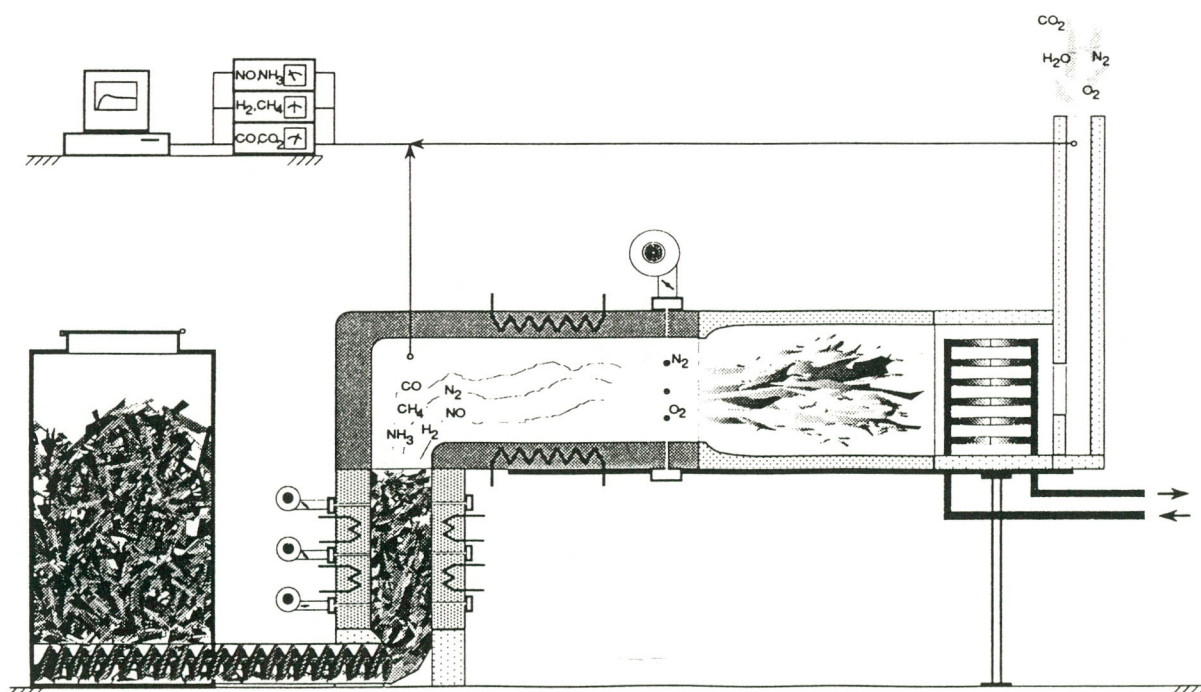


fig. 7 25 kW-test rig for staged combustion of wood chips with electrically heated reduction chamber.

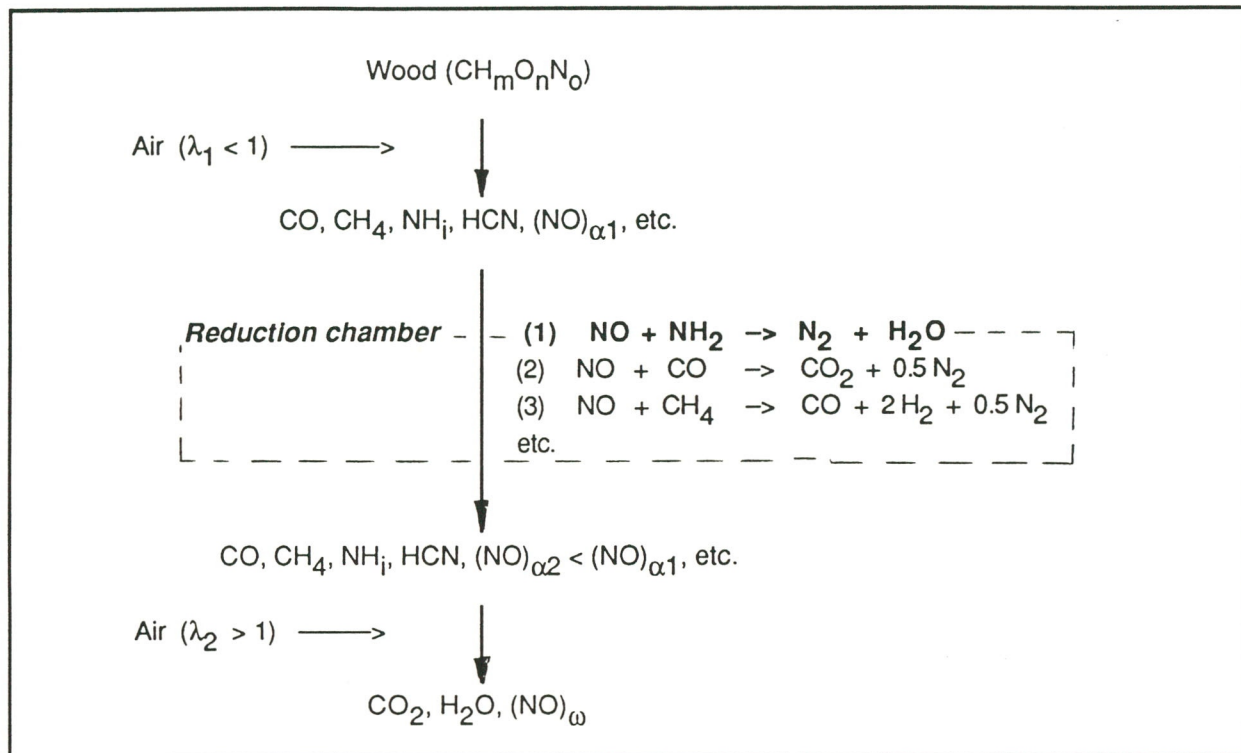


Fig. 8 Reactions for the reduction of nitric oxides with *two-staged combustion with separate reduction chamber*.

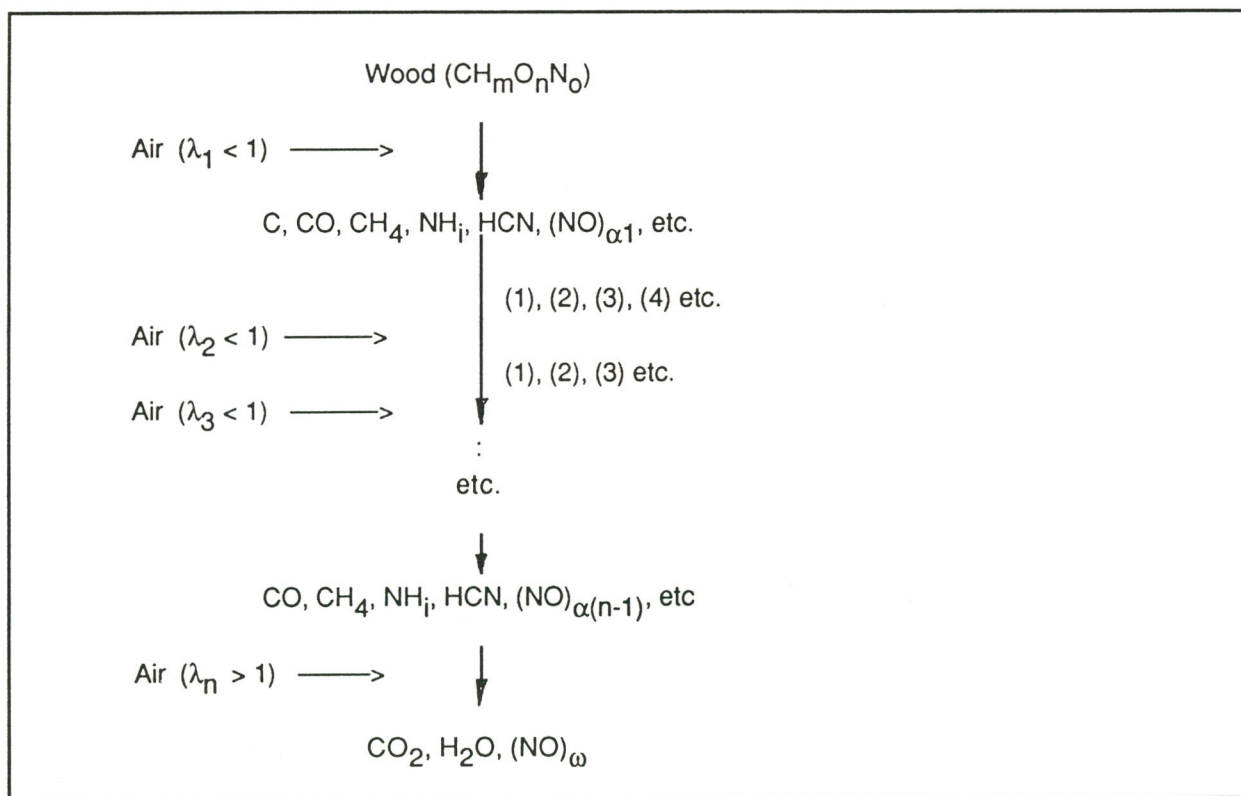


Fig. 9 Supposed reactions for the reduction of nitric oxides with *air-staged combustion*.

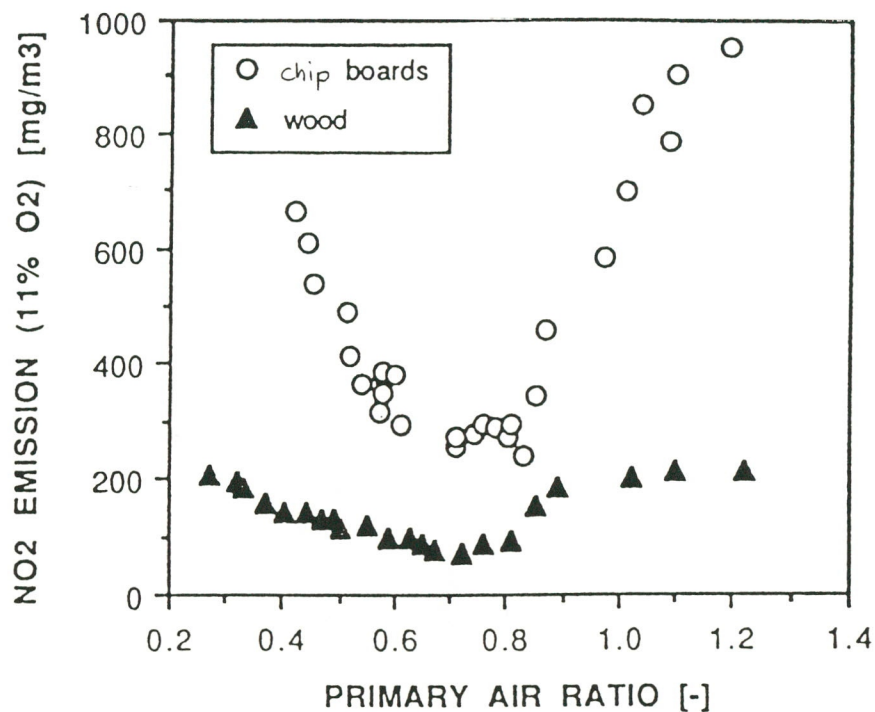


Fig. 10 NO_x emissions from the combustion of wood and chip boards in function of the primary excess air ratio. Temperature in the reduction chamber = 1'173°C, residence time = 0.3 – 0.6 s). [Keller et al. 1993].

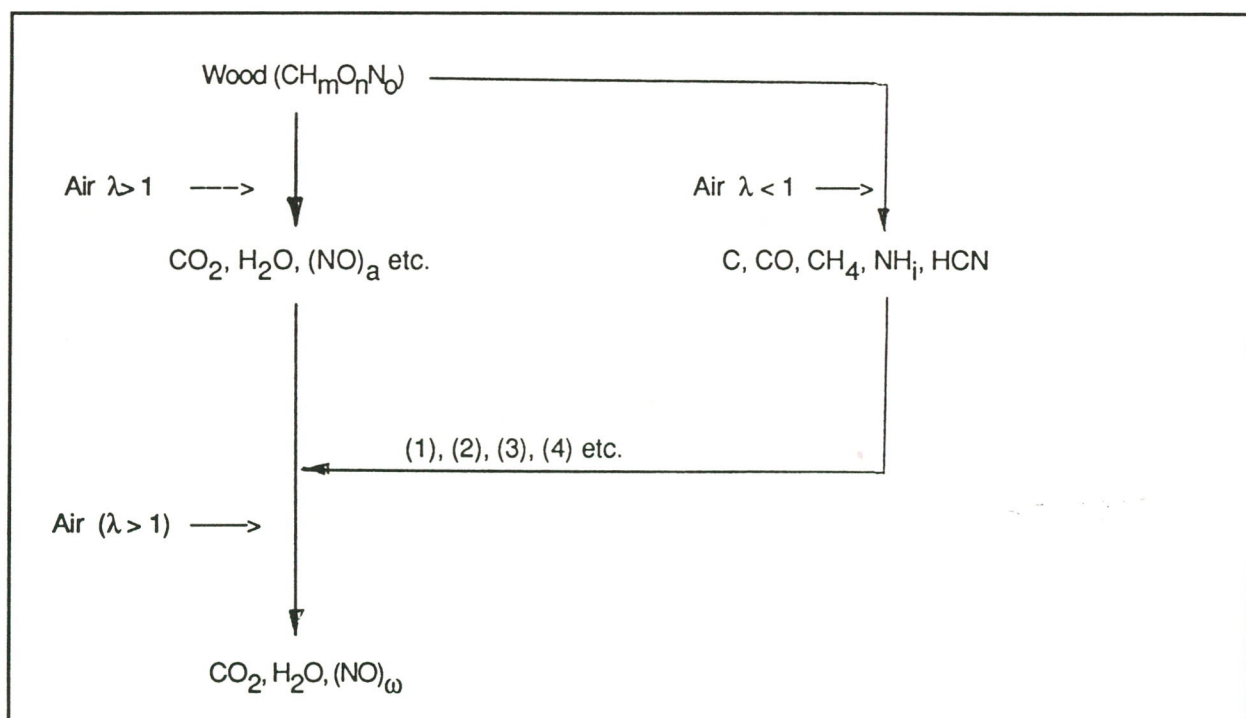


Fig. 11 Supposed reactions for the reduction of nitric oxides with *process internal fuel staging*. A part of the wood is gasified ($\lambda < 1$) and mixed with the flue gas from the combusted wood ($\lambda > 1$) to reduce the NO_x formed during combustion.

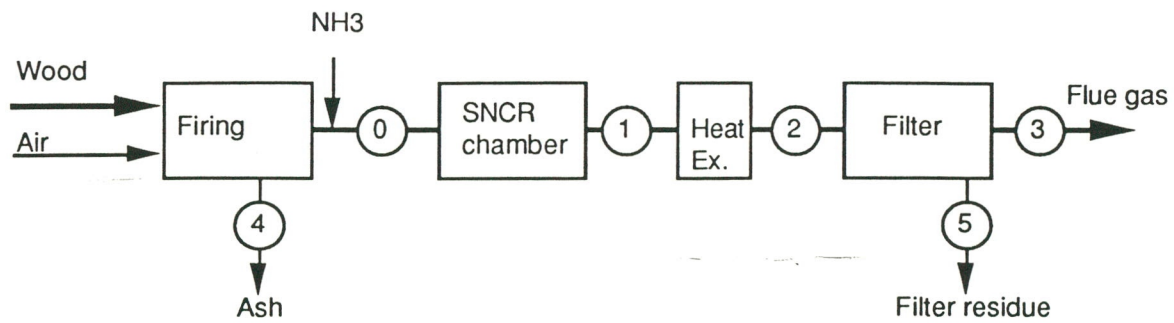


Fig. 12 Wood firing system with NO_x reduction by SNCR.

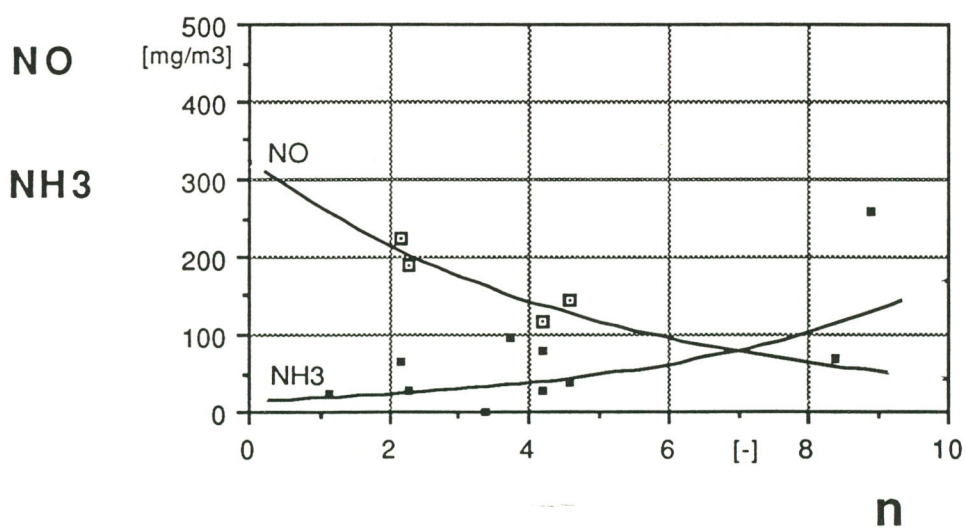
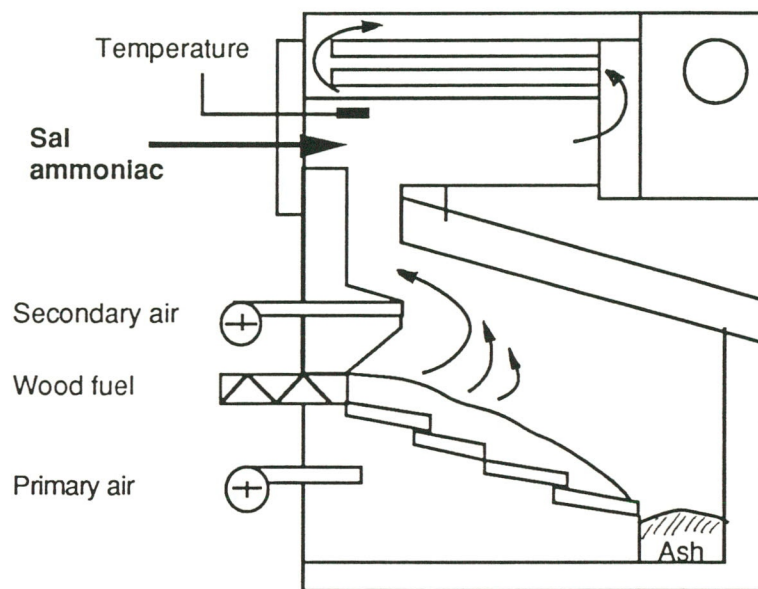
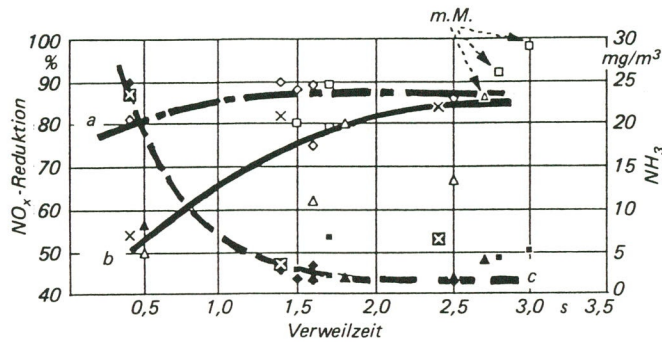
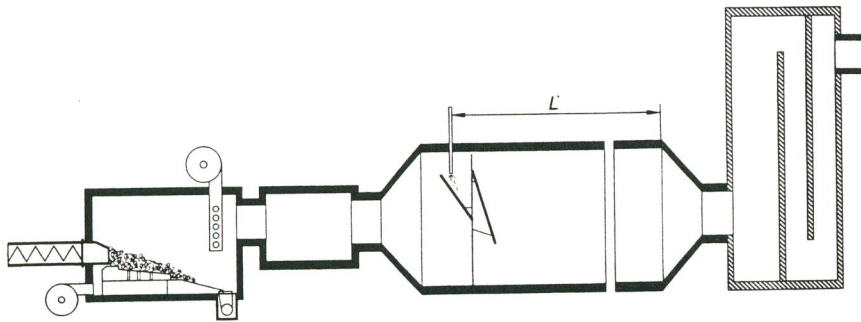


Fig. 13 Grate firing (500 kW) with injection of sal ammoniac (SNCR) and NO reduction and NH_3 slippage in function of the molar ration n (NH_3/NO). NO calculated as NO_2 at 11 Vol.-% O_2 .



a: NO_x -Reduktion für $NH_{3, gas}$
b: NO_x -Reduktion für $NH_{3, aq}$ und Harnstoff
c: NH_3 -Schlupf

m.M.: Versuche mit Mischer

Reduktionsmittel:	$NH_{3, gas}$	NH_3 flüssig	NH_3 flüssig	Harnstoff
Molverhältnis:	$n=1,5$	$n=1,6$	$n=2,2$	$n=1,9$
	◇ NO_x -Redukt.	△ NO_x -Redukt.	□ NO_x -Redukt.	× NO_x -Redukt.
	◆ NH_3 -Schlupf	▲ NH_3 -Schlupf	■ NH_3 -Schlupf	⊠ NH_3 -Schlupf

Fig 14 Pre oven firing with separate reduction chamber for SNCR (above).
NOx reduction in function of the residence time in the reduction chamber (below).

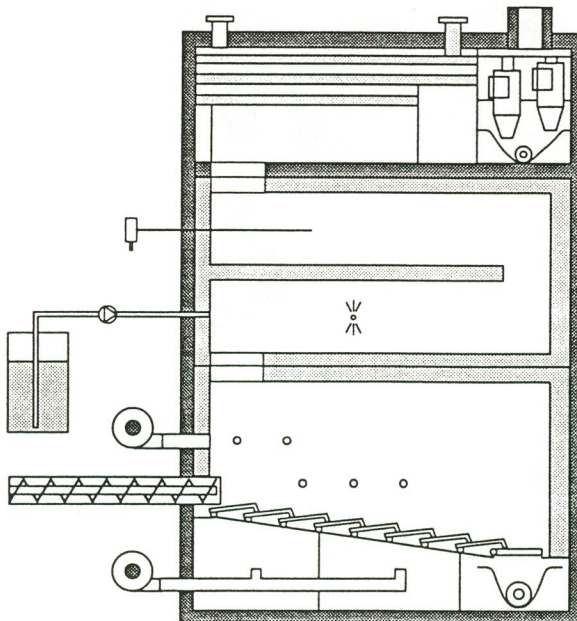


Fig 15 Grate firing with reduction chamber for SNCR.

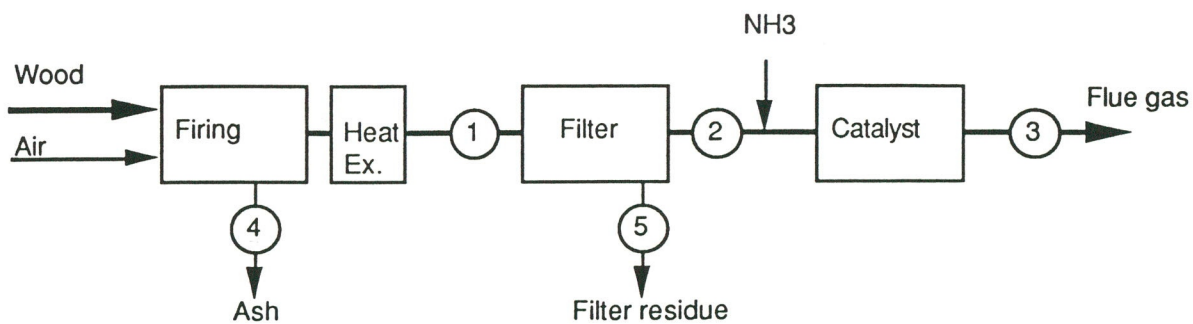


Fig. 12 Wood firing system with NO_x reduction by SCR low dust process.

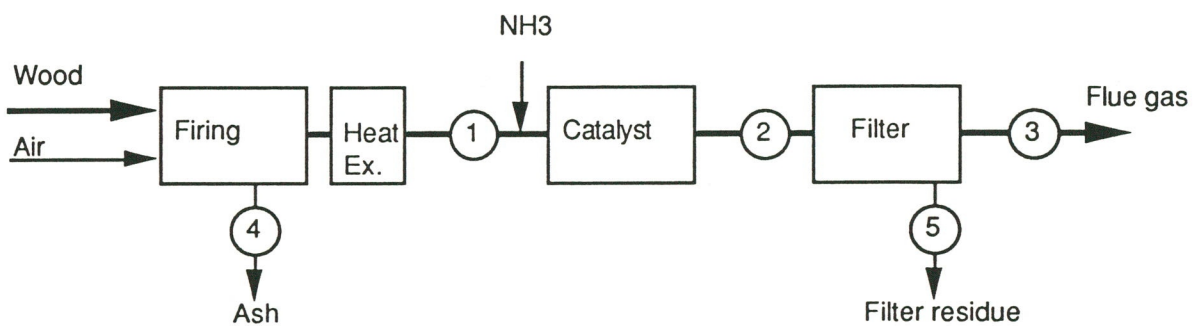


Fig. 17 Wood firing system with NO_x reduction by SCR high dust process.

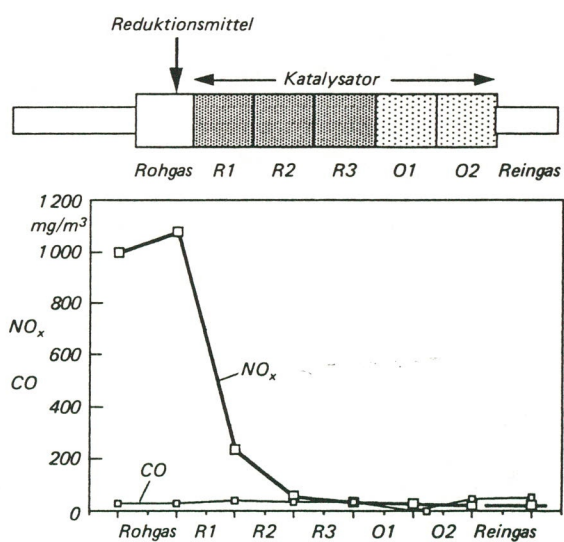
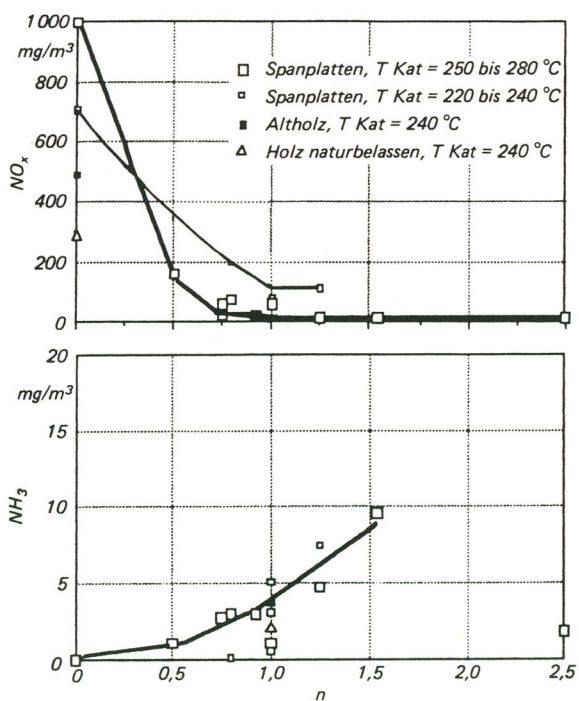


Fig. 18 Emission of NO (above) and NH₃ slippage in function of the molar ratio n (NH₃/NO) for SCR process with sal ammoniac.

References

- Beér, J.:* Advanced combustion methods for low grade coal utilization, in: Korhonen (Ed.), Low-grade fuels, Vol. 1, VTT Symposium 108, Espoo (SF) 1990, 83-112
- Folsom, B.; Bartok, W.:* Gas reburning-sorbent injection for simultaneous NO_x and SO_x control, Energy Technol. XVI; Conf. 1989, Wash., DC. – Rockville: Gl (1989), 513-527 0-86587-429-8
- Good, J. 1993:* Verbrennungsregelung bei automatischen Holzschnitzelfeuerungen, Diss ETH Nr. 9771, Zürich 1992
- Good, J. 1994:* Combustion control for automatic wood firings, in: Bridgwater (Ed.), Advances in thermochemical biomass conversion, Vol. 1, 1994
- Good, J.; Nussbaumer, Th.:* Regelung einer Stückholzfeuerung mit unterem Abbrand, Bundesamt für Energiewirtschaft, 1993
- Jansohn, P.; Kolb, Th.; Leuckel, W.:* Bildung von Stickstoffoxiden aus Brennstoff-Stickstoff in turbulenten Diffusionsflammen und deren Reduktion durch feuerungstechnische Massnahmen, Chem.-Ing.-Tech. **61** 1989, Nr. 11, MS 1801/89
- Kilpinen, P.; Hupa, M.:* Homogenous N_2O chemistry at fluidized bed combustion conditions: a kinetic modelling study, Combustion and Flame, **85**, 94-105
- Keller, R.; Nussbaumer, Th.; Suter, P.:* Untersuchung der Luftstufung mit Reduktionskammer als Primärmassnahmen zur NO_x -Minderung bei der Holzverbrennung, VDI-Bericht Nr. 1090, 167-174, 1993
- Keller, R. 1994:* Diss ETH 1994 (in preparation)
- Kolb, Th.:* Experimentelle und theoretische Untersuchungen zur Minderung der NO_x -Emissionen technischer Feuerungen durch gestufte Verbrennungsführung, Diss TU Karlsruhe 1990
- Levy, J.; Longwell, J.; Sarofim, A.; Corley, T.; Heap, M.; Tyson, T.:* NO_x abatement in fossil fuel combustion, chemical kinetic considerations, Proc. 3rd Stationary Source Combustion Symposium, Vol IV, EPA 600-79-050d, San Francisco, 3-44
- Nussbaumer, Th. 1988:* Stickoxide bei der Holzverbrennung, Heizung Klima **12** 1988, 51-62
- Nussbaumer, Th. 1989:* Schadstoffbildung bei der Verbrennung von Holz, Diss ETH Nr. 8838, Zürich 1989
- Nussbaumer, Th. 1990:* Grundlagen der Holzverbrennung. In: Nussbaumer, Th. (Ed.): Energetische Nutzung von Holz, Holzreststoffen und Altholz, Bundesamt für Energiewirtschaft, Bern 1992, 7-30
- Nussbaumer, Th. 1992:* Entstickungsverfahren für Holzfeuerungen. In: Nussbaumer, Th. (Ed.): Neue Konzepte zur schadstoffarmen Holzenergie-Nutzung, Bundesamt für Energiewirtschaft, Bern 1992, 123-152
- Nussbaumer, Th. 1993:* Verbrennung und Vergasung von Energiegras, Jahresbericht 1993, Bundesamt für Energiewirtschaft, Bern 1993

- Nussbaumer, Th.* 1993: Sekundärmaßnahmen zur Stickstoffoxidminderung bei Holzfeuerungen, BWK Bd. 45 (1993) Nr. 11, 483–488
- Schu, G.*: Experimentelle Untersuchungen zur selektiven nichtkatalytischen Reduktion von Stickoxiden in einem Flammrohrkessel, Diss Universität München 1989
- Spliethoff, H.*: NOX-Minderung durch Brennstoffstufung mit kohlestämmigen Reduktionsgasen, VDI-Berichte Nr. 765 1989, 217-230

Wood Combustion and Oxidation of Wet Biomass – IEA – TASK X
(Technical Committee Meeting VTT Jyväskylä, Finland, 25-27 mei 1994)
Bezoekverslag

Bijlage 2 Technical Committee meeting

Agenda

Deelnemerslijst

Energy from Contaminated Wood Waste

Presentatie Sulilatu

Excursies

IEA BIOMASS AGREEMENT - TASK X

***WOOD COMBUSTION AND
OXIDATION OF WET BIOMASS***

TECHNICAL COMMITTEE MEETING

VTT

JYVÄSKYLÄ, FINLAND

1994-05-26

TECHNICAL COMMITTEE MEETING

AGENDA

DATE: 26 MAY 1994
TIME: 0830 - 1500
PLACE: VTT, JYVÄSKYLÄ, FINLAND

TIME	ACTIVITY
0815	Bus transportation from Hotel Laajavuori to VTT
0830	Opening by O. K. Sønju
0845	Minutes of meeting - Borås, November 1993 (distributed earlier)
0900	Project status
0900	- Round robin test of a wood stove - E. Karlsvik
0920	- Energy from contaminated wood waste combustion - F. Sulilatu
0940	- Wood chip cogeneration - H.H. Jacobsen
1000	- Condensing systems - H. Oravainen - Catalytic combustion in small wood burning appliances
1020	- Characterization of biomass fuels and ashes - H. Hofbauer
1040	Coffee break
1050	- Emissions from biomass combustion - T. Nussbaumer / J. Good
1110	- Pollutant formation and the behaviour of inorganic material during combustion of biomass-derived fuels - D. Hardesty - Combustion study of pyrolysis oils and chars
1130	- Oxidation of wet biomass - Fred Dumbleton - Cofiring biomass and coal (New project)
1150	- Measurement techniques (FTIR) - M.L. Karlsson
1210	- Lunch
1320	- Combustion of wet biomass feedstocks, ash reinjection and carbon burnout - J. Robert / J.E. Hustad - Indirectly fired gas turbines for electricity production (New project)
1340	Comments and discussion
1400	Plans for further work in 1994 and the next programme: 1995-97
1440	Next meeting
1500	End of meeting
	Presentation of VTT Energy's research activities on biomass combustion. Round tour in the laboratory.
1630	Visit to Rauhalahti Power Plant
1930	Dinner hosted by IEA Bioenergy Agreement - Hotel Laajavuori

LIST OF PARTICIPANTS

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UK

Wood Combustion and Oxidation of Wet Biomass – IEA – TASK X
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Presentatie Sulilatu 'Energy from Contaminated Wood Waste'

1. Gasification of Waste Preserved Wood Waste

Sources of Waste Wood

1. Off-cuts from new building activities and manufacture of wooden components
2. Waste timber arising at the end of a products serviceable life or at the end of the structures life.

Important uses:

- construction and building 55%;
- railway networks 10%;
- power/telephone/telegraph networks 15%;
- agricultural works 20%.

Total Production of Impregnated Wood in Western Europe:
6,150,000 m³

Impregnated with:

- salts 65%;
- creosote 15%;
- organic solvents 20%.

Industrial Roundwood (in 1000 m³) 1989

Country	Production	Import-exports	Consumption
The Netherlands	1,035	374	1,209
Belgium	4,185	391	4,576
France	34,781	-1,624	33,157
Spain	15,009	1,374	16,383
Portugal	9,602	724	10,326
Italy	4,656	49,631	54,287
Greece	4,185	433	5,618

Wood Combustion and Oxidation of Wet Biomass – IEA – TASK X
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Sawnwood and Sleepers (in 1000³ m³) 1989

Country	Production	Import-exports	Consumption
The Netherlands	400	4,048	4,448
Belgium	1,114	17,302	18,416
France	10,769	1,913	12,682
Spain	2,724	1,507	4,231
Portugal	1,650	-741	909
Italy	1,998	7,841	9,839
Greece	1,114	650	1,764

Emissions

Wood impregnated with salts contains:

- copper 1950-3250 mg/kg dry wood;
- chromium 3250-6000 mg/kg „ ;
- arsenic 3200-5500 mg/kg „ .

2 Firing experiments with powderwood/powdercoal in 1 MWth pilot combustion installation

Sheet 1

Firing experiments with powderwood/powdercoal in a 1 MWth pilot combustion installation

Executed by KEMA, Arnhem, The Netherlands

(May 1993)

Sheet 2

Objective

Co-firing of contaminated wood waste in existing coal-fired power installation

Wood Combustion and Oxidation of Wet Biomass – IEA – TASK X
(Technical Committee Meeting VTT Jyväskylä, Finland, 25-27 mei 1994)
Bezoekverslag

Sheet 3

Analyses of Drayton Coal and fine and coarse wood waste (on ash received base)

Parameter	Units	Fine crushed wood waste	Coarse crushed wood waste	Drayton Coal
Tot water	% (m/m)	6.0	~6	~2
Ash	%	2.13	1.87	9.63
Volatiles	%	75.2	75.18	34.55
Cal. Value Upper Lower	MJ/kg	18.54 17.10	18.63 17.28	30.09 29.08
C	%	48.61	18.63	75.1
N	%	0.44		1.53
S	%	0.02		0.81
H	%	6.33		4.94
As	ug/g	9.5		10.9
Cd	ug/g	1.13		0.07
Pb	ug/g	980		14.0
Sb	ug/g	9.1		<1
Sn	ug/g	2.2		<2
Cr	ug/g	10.9		25
Cu	ug/g	37.6		23
Zn	ug/g	870		19.8
Hg	ug/g	0.07		0.23

Wood Combustion and Oxidation of Wet Biomass – IEA – TASK X
(Technical Committee Meeting VTT Jyväskylä, Finland, 25-27 mei 1994)
Bezoekverslag

Sheet 4

Used Coal- and Wood dimensions

Drayton Coal 90% < 60 μ m.

Wood analyses

Screen width [mm]	Fine crushed wood % in range	Screen width [mm]	Coarse crushed wood % in range
< 0.5	62	<0.21	6.4
0.5-0.85	27.9	0.21-0.50	9.6
0.85-1.00	4.1	0.50-1.00	13.7
1.00-1.25	3.4	1.00-3.00	13
1.25-1.60	1.7	3.00-4.00	53.8
> 1.60	0.9	4.00-5.00	2.5
		5.00-8.00	0.45
		>8.00	0.55

Wood Combustion and Oxidation of Wet Biomass – IEA – TASK X
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Sheet 4 a

Figuur B2.1 Pilot Installation 1 MWth

Wood Combustion and Oxidation of Wet Biomass – IEA – TASK X
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Sheet 5

Analyses of the flue gas components

	100% coal	5% fine wood waste	10% wood waste	15% wood waste	10% coarse wood waste
(ug/m ³) Cd	1.2	1.3	2.2	6.2	0.8
Pb	8.5	30	36	63	87
Zn	24	53	62	100	93
Hg	16.4	2.9	<2.5	<2.8	<3.1
(mg/m ³) Partic.	121	74	78	115	117
(V%) O ₂	5.0	4.7	5.1	5.2	8.7
CO ₂	12.4	13.2	13.1	13.2	13.1
(mg/m ³) CO	40	260	179	173	39
C _x H _y	<2	16	8	10	<2
NO _x	483	320	569	368	587
SO ₂	1420	1400	1440	1390	1450

Wood Combustion and Oxidation of Wet Biomass – IEA – TASK X
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Sheet 6

Temperature measurements in the kiln

	100% coal	5% fine wood waste	10% fine wood waste	15% fine wood waste	10% coarse wood waste
pos. 4	1284	1296	1284	1290	1265
pos. 7	1164	1197	1180	1131	1123
pos. 10	1094	1060	1044	1064	1021

Dioxin emissions in the flue gases (duplo results)

	100% coal	10% fine wood waste
Dioxin (ng TEQ/m ³)	<0.01	0.01
” ”	<0.01	<0.01

Wood Combustion and Oxidation of Wet Biomass – IEA – TASK X
(Technical Committee Meeting VTT Jyväskylä, Finland, 25-27 mei 1994)
Bezoekverslag

Sheet 7

Analyses of the fly-ash

	100% coal	5% fine wood	10% fine wood	15% fine wood	10% coarse wood
unburnt [%]	18.3	33.4	26.9	28.4	17.6
Cd [ug/g]	1.1	2.2	2.4	2.8	3.1
As	90	120	120	100	90
Zn	200	990	990	1340	1400
Pb	151	930	970	1300	1740
Sn	7	12	15	12	14
Sb	8.3	17.4	17.6	22.2	25.5

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Main Conclusions

- Co-firing of crushed contaminated wood waste (size <1 mm) is technical feasible.

Co-firing of coal and wood can be realised with separate wood burners or with combined (coal/wood) burners. The selection criterion depends on operating aspects and economic considerations.

Coarse crushed wood waste (> 1 mm) results in high percentages unburnt and is unsuitable for co-firing.

Application of powder coal fly-ash in industrial products required a low percentage of unburnt (< 5%). The experiments show an increase in the percentage of unburnt with a factor of about 1.6 by co-firing fine waste wood. This can be attributed to the low excess air factor of the combustion installation. It is expected that a higher excess air factor leads to lower percentages of unburnt and a better combustion performance.

Due to the higher contaminants in the wood fuel, an increase in the metal concentrations (Cd, Pb, Zn) in the flue gases are measured during co-firing compared to 100% coal firing. The concentration of Hg drops.

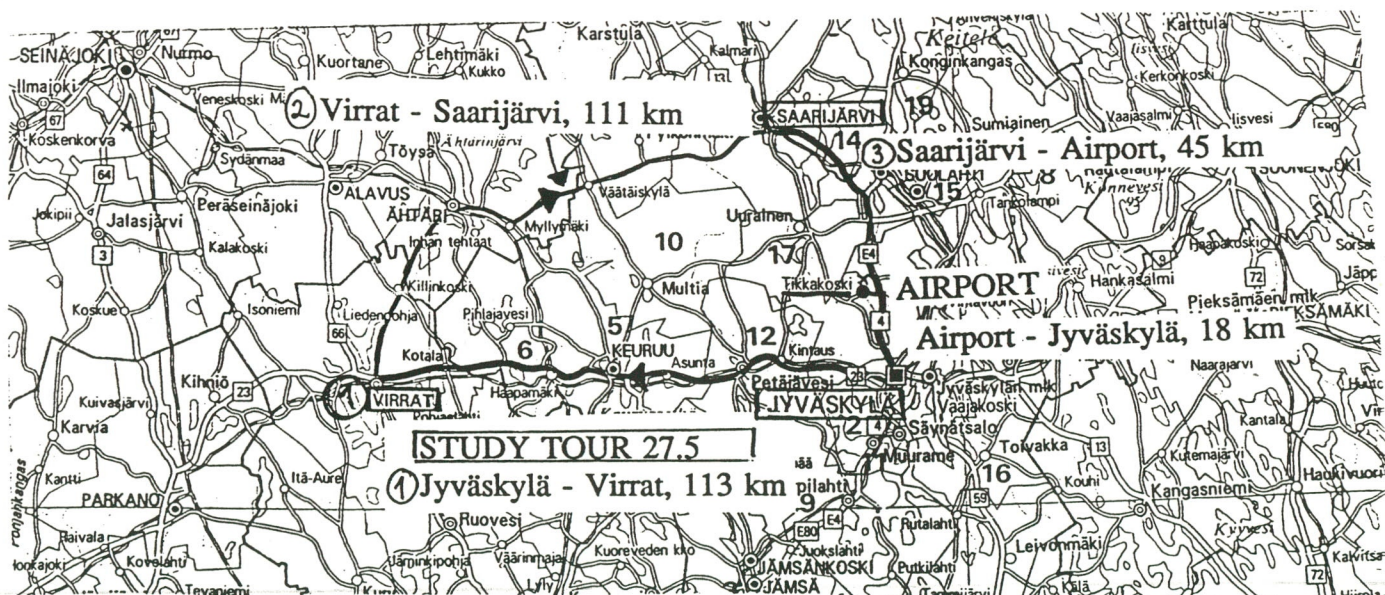
Because of the application of advanced flue gas cleaning systems an increase in the net emission to the environment is not expected.

Co-firing of powder coal and contaminated wood waste will have consequences for fly-ash applications in the industry because of the high concentrations of heavy metals (Pb, Cd, Zn) in the fly-ash.

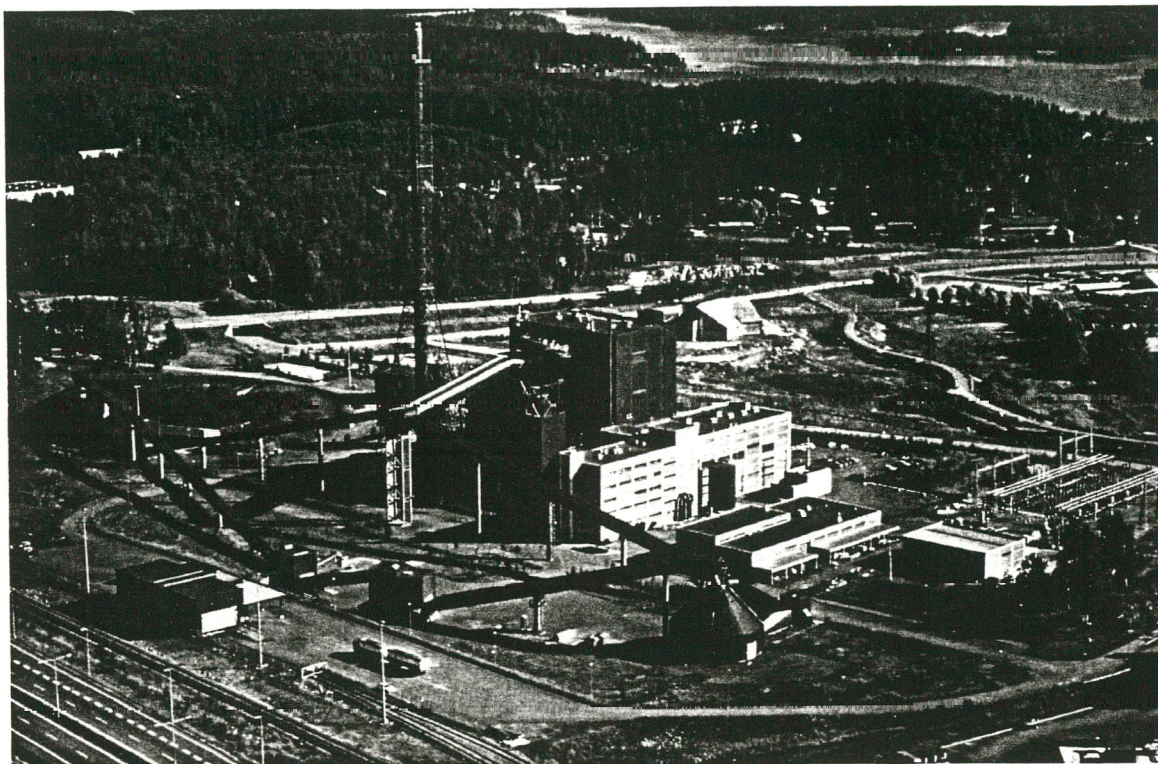
Co-firing of wood up to 15% does not lead to significant alterations in the emissions of particulates, NO_x, SO₂ and dioxines.

EXCURSIONS

8.00 am	Departure for the Virrat district heating plant Check out from hotel
9.30 am	THE VIRRAT DISTRICT HEATING PLANT (1) Power plant design (Markku Ollakka, Jyplan Oy) - Wood chips and sod peat, RDF - Flue gas condensation
11.15 am	Lunch hosted by Jyplan Oy at Virtojen Perinne kylä
1.30 pm	SAARIJÄRVI DISTRICT HEATING PLANT (2) Power plant manager Eero Mykkänen - 5 MW FB boiler - heat storage - biomass fuels
3.00 pm	Departure for airport by bus (3)
4.05 pm	Departure for Helsinki (Flight)



RAUHALAHTI CHP PLANT IN JYVÄSKYLÄ



- * **Owner: IVO**
- * **Design, engineering, project management and O&M: IVO**
- * **District heat supplied to:**
the City of Jyväskylä
Puutarha Tahvoset Oy (greenhouses)
- * **Process steam supplied to:**
Metsä-Serla Oy (paper mill)
- * **Electric power supplied to:**
IVO tariff clients
- * **Electric output max. 87 MW**
- * **District heating output max. 140 MW**
- * **Process steam output max. 65 MW**
- * **Fuels: milled peat, biomass (sawdust, bark, chipped wood), coal (reserve fuel) and oil (startup fuel)**
- * **Commissioned in 1986**
- * **Boiler conversion to bubbling fluidized bed boiler in 1993**

BOILER CONVERSION AT RAUHALAHTI POWER PLANT

<i>Name of Client</i>	<i>Imatran Voima Oy</i>
<i>Project Country</i>	<i>Finland</i>
<i>Project Duration</i>	<i>Oct. 1992 - Nov. 1993</i>
<i>Value of Services</i>	<i>USD 2.3 million (FIM 13 million)</i>
<i>Project Value</i>	<i>USD 8.8 million (FIM 50 million)</i>



The Rauhalahti cogeneration plant, commissioned in 1986, was initially equipped with a pulverized fuel (PF) firing system. Milled peat was used as primary fuel with coal and oil as optional fuels. In 1991-92, IVO International Ltd made a feasibility study which showed advantages in converting the boiler from PF combustion to bubbling fluidized bed combustion. The design phase of the conversion project was started in October 1992, and the project was completed during the latter half of 1993.

IVO International Ltd carried out the boiler conversion as a turnkey delivery, assuming overall responsibility for the project. The fluidized bed system for the boiler was ordered from Tampella Power.

IVO International's services:

- * preliminary design
- * project management
- * construction management
- * preparation of enquiries and evaluation of bids for materials and equipment
- * supervision of deliveries and installations
- * testing of equipment
- * trial run and commissioning.

Advantages achieved:

Fluidized bed combustion enables the use of biomass (sawdust, bark, wood chips) as fuel and also the use of milled peat mixed with biomass. This means easier fuel handling and improved safety in operations. Additionally, other important advantages were achieved through the boiler conversion:

- * enhanced generation capacity
- * improved cost effectiveness
- * reduced particles emissions
- * reduced NO_x emissions
- * reduced SO₂ emissions
- * decreased use of oil
- * improved efficiency of electric filter.

VIRRAT - DISTRICT HEATING PLANT

Design manager Markku Ollakka

Elomatic companies/Jyplan Oy

Kangasvuorentie 10

FIN-40320 JYVÄSKYLÄ, FINLAND

Telephone: + 358 41 676 055

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BACKGROUND

The district heating plant at Virrat started operation in 1979, then mainly wood chips were used as a fuel. The 6 MW boiler of the plant was equipped with mechanical disc-grate in 1984, which enabled the combustion of sod peat.

It was decided in 1993 that the whole plant has to be refurbished and equipped with a new flue-gas scrubbing and condensing equipment, which would be common to both the 4.0 MW and 6.0 MW boilers. It is possible to burn sod peat, wood chips, bark, sorted and crushed municipal waste, and crushed plastic waste.

IMPLEMENTATION OF THE REFURBISHMENT

- * Elomatic companies/Jyplan Oy from Jyväskylä has been responsible for the total planning of the investment task, for consultancy and the experts (see brochure attached)
- * The measurements and research work will be carried out by VTT Energy from Jyväskylä
- * The boiler and the conveyors are supplied by Ekopoint Oy from Lahti
- * The flue gas scrubbing and condensing equipment have been supplied by Condens Oy from Hämeenlinna (see brochure attached)
- * The electrification, instrumentation and automation has been supplied by Consor Oy from Tampere
- * The stack was distributed by Livite Oy from Seinäjoki
- * The construction technical work has been carried out by Technical Office of the town Virrat

The total investment costs of the plant refurbishment were 7.6 million FIM. 30 % (2.28 million FIM) of the investments were covered by the new technology support of the Finnish Ministry of Trade and Industry, 10 % (0.76 million FIM) by the employment support of the Ministry of the Labour, and 40 % (3.04 million FIM) by the interest subsidy loan of the Administration of the Housing. Additionally, funding for two year further research and measurements of the efficiencies of the emissions has been acquired from the Ministry of Trade and Industry, in total 0.85 million FIM.

The heating plant of the town Virrat has also been acquired to the research in which the possibilities for power generation from both 4.0 MW and the 6.0 MW

boilers by using the ORC-high speed technology is studied. The electrical power of the plant would then be 2 x 250 kW. The study will be carried out by the Elomatic companies/Jyplan Oy from Jyväskylä and the High Speed Tech Ltd from Tampere.

PRODUCTION AND PROCESS DATA OF THE VIRRAT DISTRICT HEATING PLANT

Annual heat production	24 000 MWh
Annual heat delivery	22 000 MWh
Fuel consumption:	
- chips	9 000 MWh
- sod peat	9 000 MWh
- flue gas scrubbing and condensing plant	4 500 MWh
- sorted municipal waste	1 500 MWh
- heavy fuel oil	500 MWh
Moisture contents of the fuel	30 - 50 %
Wood chip price for the plant	78 FIM/MWh
Sod peat price for the plant	48 FIM/MWh
District heat tariff/	220 FIM/MWh
consumers (incl. turnover tax 22%)	
Personnel	1+4 persons

The plant has been registered for unmanned operation.

Connected building level	500 000 m ³
Peak output demand	9.0 MW (- 32 C)
Minimum output demand	0.8 MW
District heating network	6.0 km
Connected consumers	130

Additional power of about 10 - 30 % is obtained from the flue gas scrubbing and condensing equipment. The amount depends on the moisture content of the fuel, the distribution temperature of the district heating water, the amount of district heating water, etc.

Particles of the plant after the scrubber	10 - 20 mg/m ³
Rate of desulfurization	over 90 %
Rate of chlorine removal in the scrubber	over 95 %

SAARIJÄRVI DISTRICT HEATING PLANT

Power plant manager Eero Mykkänen

P.O. Box 56

FIN- 43101 Saarijärvi, Finland

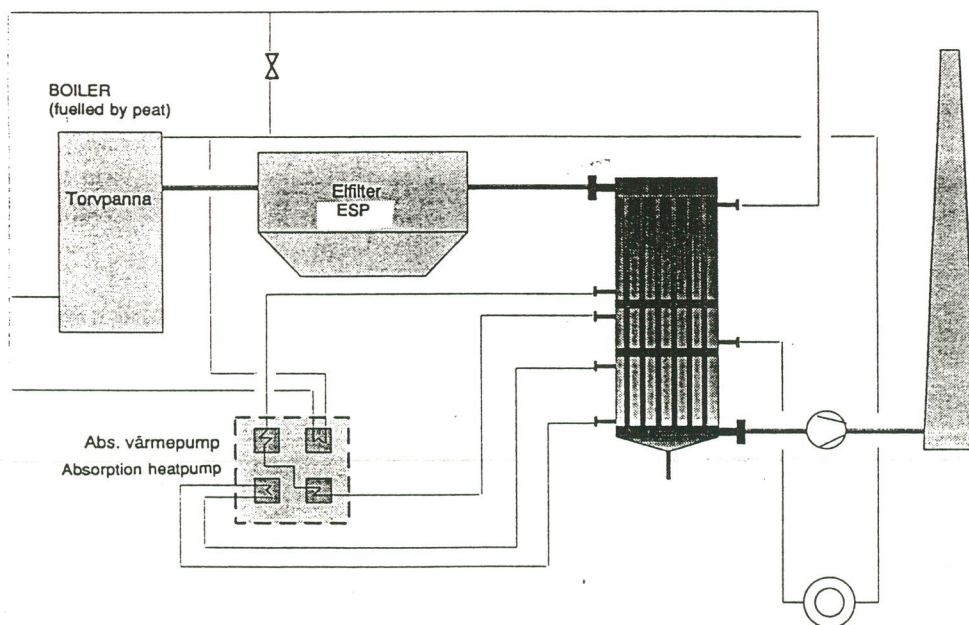
Telephone + 358 44 423 411

Telefax + 358 41 423 413

TECHNICAL DATA

Boiler	4 MW (Fluidized bed combustion, Sermet Oy)
Efficiency	86,7 % (peat boiler)
Heat generation	23 - 25 GWh/a
Heat price	140 - 150 MWh/FIM
Main fuel	Milled peat, moisture 35 - 45 %
Peat consumption	25 000 - 30 000 m ³ /a
Fuel supplier	Vapo Oy
Other fuels	sod peat wood chips, bark municipal wastes (experimental)
Heat accumulator	20 MWh (4 - 5 hours heat production) 350 m ³
ESP	particles less than 50 mg/m ³ⁿ limit 150 mg/m ³ _n
Investment costs of peat plant	10,4 million FIM
District heating network	6700 m

New absorbtion heat pump will increase the heat output of the peat boiler to 6 MW. See above the schematic picture.



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Bijlage 3 New Agreement 1995-1997

Project Proposals

ACTIVITIES PLANNED FOR TASK XIII

1995 - 1997

ACTIVITY:

- 1. BIOMASS COMBUSTION**
- 2. BIOMASS GASIFICATION**
- 3. ANAEROBIC DIGESTION**
- 4. PYROLYSIS OF BIOMASS FOR LIQUID FUELS**
- 5. BIOTECHNOLOGY FOR LIQUID FUELS**
- 6. TECHNOECONOMIC ANALYSIS OF BIOENERGY SYSTEMS**
- 7. INTEGRATED BIOENERGY SYSTEMS ANALYSIS**

PRELIMINARY

**PROPOSED ACTIVITIES FOR THE NEXT
TRIENNium 1995 - 1997**

1. WOOD STOVE TESTING ~~PROCEDURES~~ AND EMISSIONS
2. CATALYTIC CLEANING SYSTEMS (OR OTHER CLEAN. SYST.?)
3. SMALL SCALE POWER GENERATION FROM BIOMASS ✓
4. CHARACTERIZATION OF BIOMASS FUEL AND ASHES
5. EMISSIONS AND ASH DEPOSITION
6. CO-FIRING BIOMASS WITH COAL AND OIL ✓
7. MODELLING OF BIOMASS COMBUSTION
8. MEASUREMENTS TECHNIQUES, FTIR, TGA, DSC
9. MEASURING AND CONTROL SYSTEMS ✓
10. ANALYSIS OF BAT DOMESTIC HEATING SYSTEMS AND 0.5 - 10
MW *(Best available Technology)*
11. OPTIMIZATION OF BIOMASS COMB. SYSTEMS 1kW - 5 MW.
12. COMBUSTION OF WET BIOMASS (GRASS, PLANTS)
13. WOOD PELLET COMBUSTION