Environmental Applications of Industrial Microwave Heating and Plasma Technology
MUEGGE GMBH
Hochstrasse 4 – 6
D - 64385 Reichelsheim
Germany

fon +49 6164 - 9307 - 0
fax +49 6164 - 9307 - 93
mail info@muegge.de
web www.muegge.de
web www.applied-microwave.de
web www.meyerburger.com
MUEGGE Business Areas

- **Photovoltaics**
  - Power Supplies
  - Magnetron Heads
  - Measurement Equipment
  - MW Transitions

- **Plasma Technology**
  - Plasma Line
  - Plasma Array
  - RPS Source
  - APS System
  - Plasma Systems

- **Industrial Heating**
  - Power Supplies
  - Magnetron Heads
  - Waveguide Components
  - Measurement Equipment

- **Environmental**
  - Applicators
  - Generators
  - Measurement Equipment
  - Customized Solutions

- **Trading Goods**
  - Magnetrons
  - Waveguide Components
  - Spares

- **Service Consulting**
  - 24 Hour Hotline
  - Service
  - Start up
  - Training

MUEGGE provides innovative products and technology solutions to our customers worldwide and across many applications.
Products

MW-Generators 915/2450/5800MHz
Waveguide Components
Magnetrons
MW-Measurement Devices
Plasma-Components

Plasma Systems
Consulting
Service and Start-Up’s
Workshops and Training
Rental MW-Equipment
Environmental applications of industrial microwave heating in
- renewable energies and industrial microwave heating
- food industry
- construction materials
- recycling and biocompatible materials

Environmental applications of microwave plasma technology in
- pyrolysis and waste gas abatement
- barrier layers on and sterilization of food packaging materials

Summary
Applications of Microwave Heating

Industrial applications at 915 MHz, 2.45 GHz and 5.8 GHz

Industries:
- Chemical
- Ceramics
- Pharmaceutical
- Medical
- Environmental
- Building & Construction Materials
- Rubber & Plastic
- Paper & Wood
- Food
  - Vacuum-Drying
  - Sterilization
  - Pasteurization
...and many more

100 kW / 915 MHz microwave power supply with external magnetron head
Example for application of high-power microwave technology in a customized project

Generator 4 x 100 kW at 915 MHz

- Switch mode technology
- Customized design
- Mounted in a container for off-shore use
Example: heating and drying in pharmacy and rubber industry

Fields of application:

→ drying
→ heating
→ annealing
Example: high-power microwave systems for renewable energies and environmental technology

Microwave systems for bio/environmental technology at 915 MHz and 2.45 GHz

- Renewable energy
  - Biofuel, bio diesel, biogas
- Environmental technology
  - Abatement systems
  - Waste gas purification
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Summary
Example: food processing

Cooking of meatballs
36 kW (12 x 3kW) 2.45 GHz

Combined process of cooking and pasteurisation of food in trays
100 kW (100 x 1kW) in a pressurized tunnel
Example: microwave freeze drying

- 3-20 times shorter drying time
- Maintaining aromas, vitamins, flavors, etc.
- Microwave freeze drying of 100 kg batches of entire fruits within 4-8 h

→ More economical process by microwave technology
Industrial microwave heating for pasteurization and sterilization of food: Coaxial Slot Antenna

- Directed power distribution
- High selectivity due to multiple “heating rows”
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Summary
Example: heating and drying of wood

- MW-Power 300…1000 kW, 915 MHz
- Heating up to 80°C
- LVL veneer billet production
- Microwave shortens the process time in the hydraulic press
Example: selective drying of moisture nests in multilayer sanitary ceramic parts

Flexible microwave transmission line connected to coaxial high-power microwave iso-launcher

→ Flexible microwave transmission line facilitates **targeted positioning of the microwave launcher** for **selective drying** of moisture nests

Targeted microwave heating showing moisture nests with different moisture content by increased temperature
Example: heating and drying glass melting
Example: stabilization of foams used as heat and sound insulation

Microwave heating for foaming and stabilization of polyurethane and melamine foams used as heat and sound insulation

→ Foam with fine bubbles is obtained by homogeneous heating with fan-shaped microwave power splitter
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Summary
Example: pyrolysis and recycling

Recycling of PTFE enriched with microwave susceptor SiC in an eddy current reactor

→ Up to 93 wt% yield of monomers tetrafluoroethylene and hexafluoropropylene, used for production of new fluorine-based polymers

Pyrolysis of biomass, domestic waste, scrap tires and used oil to functional bio char, bio fuels (both light and heavy fuels) and volatile compounds

Prototype powered with 60 kW microwave (2.45 GHz), capacity: 100 kg of waste per hour
Example: microwave-assisted reactive extrusion of metal-free polylactic acid (PLA)

Microwave injection system (extruder block)

Extruder block integrated into twin-screw extruder

Faster polymerization with microwave energy

→ increased molecular weight of PLA

Time related temperature profiles directly after microwave injection into the extruder block
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Summary
Atmospheric pressure microwave plasma system at 915 MHz: functional model

- rectangular waveguide
- gas turbulence device
- axial gas injection
- quartz tube

- water-cooled adapter flange
- plasma
- tube acting as electromagnetic shield
- hot gas
Atmospheric pressure microwave plasma system at 915 MHz: functional layout

Functional layout of the 915 MHz / 75 kW microwave plasma system

915 MHz
30 kW
Atmospheric pressure microwave plasma system at 915 MHz: 75 kW system used for pyrolysis

Temperature of air (flow rate of 2000 l/min) at the outlet of the 75 kW microwave plasma system

Achieved operating performance with 2000 l/min compressed air (incl. cooling air) at 75 kW
Decomposition of volatile organic compounds

Gas flow: 75 sl/min, different admixtures of propane to air

$\Rightarrow$ 100% degradation of hydrocarbons easily feasible
Decomposition of perfluorinated volatile organic compounds

Almost 100% DRE achievable for CF$_4$ - air mixtures when being plasma treated with 3.0 kW microwave power @ 2.45 GHz.

DRE: Decomposition Removal Efficiency

Gas flow: 25 sl/min
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Summary
Duo-Plasmaline Technology

The Duo-Plasmaline provides unique possibilities for large area plasma treatment.

Pressure range:
Typical: 10 - 1000 Pa  Pulse mode: < 2000 Pa
ECR: 0.1 - 10 Pa  (Pulse power ≥ 5kW)
Duo-Plasmaline Technology

The length of the plasma column mainly depends on the microwave power.
Duo-Plasmaline XXL

Easy scalability of the Duo-Plasmaline

⇒ Large area plasma systems
Duo-Plasmaline Large Area Plasma Array

- A combination of Duo-Plasmalines can be used to obtain a two dimensional plasma array.
- Single sources as well as 2, 4 and 8 or even more Duo-Plasmalines arranged in parallel are available for plasma assisted surface treatment like
  - surface activating
  - etching and
  - deposition

Array 120 cm x 80 cm
- including gas supply / gas shower
- 8 compact microwave power heads
- 16 kW MW-power
Deposition of gas diffusion layers for polymer food packaging materials

Development of SiO$_x$ gas diffusion barriers for PP food containers:

- Single barrier layer 35 nm in thickness reduces oxygen permeability of polypropylene by already a factor of 100.
Multi-layer barrier films on polymers as barrier against organic solvents

Applications:

Fuel tanks and other containers for (organic) solvents made of polymers

Polymer materials (e.g. food packaging) to protect from diffusion of plasticisers
Plasma sterilisation

Synergy of the inactivation effects of UV light and radicals produced by the plasma leads to short and efficient plasma sterilisation results.

Spore reduction of 4-5 orders of magnitude in < 1 s
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Summary
Snapshot – industrial microwave heating in “food, construction materials, recycling and biocompatible materials”

Microwave technology is the key component for the OEMs who supply machinery and plants for the food, construction materials, renewable energies and environmental industries.

Food

Construction materials

Recycling

Biocompatible Materials
Snapshot – microwave plasma technology in “pyrolysis and waste gas abatement”

Waste gas abatement (e.g. CF₄)

DRE of almost 100 %

Plasma chemistry (e.g. pyrolysis, decomposition of H₂O)

Atmospheric Plasma System (APS)
Snapshot – microwave plasma technology in “barrier layers on and sterilization of polymer food packaging materials”

Duo-Plasmaline

Coatings and …

… Functionalisation
Thank you very much for your attention!

MUEGGE GmbH
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