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Hochschule für Technik und Wirtschaft
Fakultät Maschinenbau

„Microwave-assisted Plasma-Generation for Thermal Treatment of Gases"

- Resonator Design, First Results

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1 Motivation

Exhaust gas aftertreatment by microwaves in a flow reactor is principally an alternative to conventional systems like particle filters.
Key advantages of this method are

- Simple design
- Constant emission reduction
- No regeneration
- No mechanical wear and tear
- No increased exhaust back pressure as with filters, therefore, lower fuel consumption
- Only the combustible particles in the exhaust are heated under certain conditions in contrast to thermal post-combustion.
- Affordability and good availability of the components used.
- Disadvantage: High amount of electric power of approximately 1 kW necessary, which may be used in heat exchangers downstream in industrial furnaces domestic heating etc. Other applications include the treatment of highly toxic gases and particles, such as biological and chemical war materials in air. A further designated use would be the treatment of waste and emissions, such as from chemical industry.

2 Operation

The application examined is the generation of high-pressure plasma, which is produced by a velocity modulated tube in a waveguide. Electromagnetic energy is brought to resonance after a taper where plasma is generated with the help of a spark gap (Fig. 1).

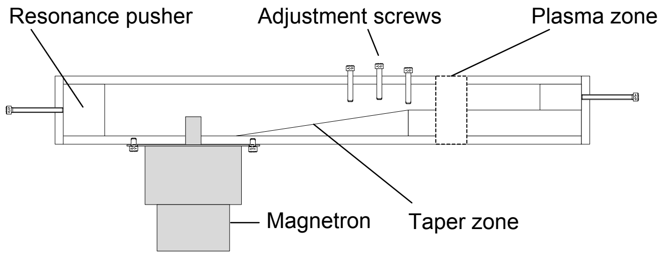

Fig. 1 Schematic of the microwave resonator

3 Test setup

For safety reasons, the tests take place in an anechoic and shielded chamber. An electromagnetic shielding around the plasma zone is mounted (Figs. 3 and 4). To gain plasma ignition at low energy density level and of reasonable volume a spark gap is applied. Soot particles are generated by an under-stoichiometric burning flame. The treated soot concentration was approximately 5.8 g*m^{-3}.The exhaust gas is aspirated by a carrier gas in a venturi nozzle. The soot content with and without the micro wave treatment is measured by PIERBURG BOSCH smoke degree-meter (filter based).

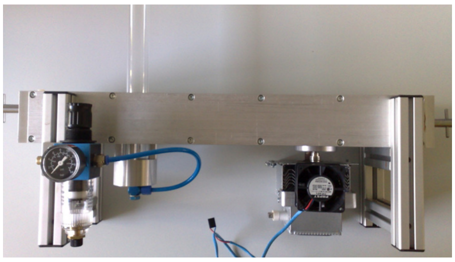

Fig. 2 Microwave resonator

Fig. 3 Test setup

4 Results

The existing designs of similar resonators could be simplified strongly. Only a little and a harmless amount of microwave energy was emitted from the resonator. The soot content could be reduced up to 69 % (Fig. 4). The plasma is carried away at high volume flows of the exhaust gas. This problem could be solved by magnetic retention of the plasma. The induced microwave energy could be increased dramatically by concentration through magnetic fields in the plasma zone. Waste energy could be recuperated in heat exchangers downstream, thus, the disadvantage of the necessary high energy is partly compensated.

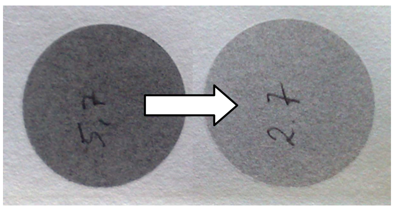

Fig. 4 Blackened filter

Microwave-assisted Plasma-Generation for Thermal Treatment of Gases - Resonator Design, First Results

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Introduction

Exhaust gas aftertreatment by microwaves in a flow reactor is principally an alternative to conventional systems like particle filters.

Key advantages of the microwave technique are:
- Simple design.
- Constant emission reduction.
- No regeneration.
- No mechanical wear and tear.
- Only the combustible particles in the exhaust are heated under certain conditions in contrast to thermal post-combustion.
- No increased exhaust back pressure as with filters, therefore, lower fuel consumption.
- Good affordability and availability of used parts.

Operating mode

The present application is a high pressure plasma which is generated by a velocity modulated tube.

Calculation of the resonator

Background of the design is the standard-waveguide WR-340 with measures a = 90,42 mm and b = 47,24 mm
In this case , the lower cut-off frequency of the fundamental mode H_{10} is

$$f_{10} = \frac{c}{2a} = \frac{3 \cdot 10^8 m}{2 \cdot 0{,}09 m \cdot s} = 1{,}66\overline{7}\, GHz$$

The wavelength of the mode H_{10} results in

$$\lambda_{10} = \frac{c}{f_{10}} = \frac{3 \cdot 10^8 m \cdot s}{1{,}66\overline{7}\, GHz \cdot s} = 0{,}180\, m$$

The wavelength in the waveguide is

$$\lambda_H = \frac{\frac{c}{f}}{\left(1 - \left(\frac{c \cdot \lambda_{10}}{c \cdot \lambda}\right)^2\right)^{0,5}} = \frac{\frac{3 \cdot 10^8 m}{2{,}45\, GHz \cdot s}}{\left(1 - \left(\frac{3 \cdot 10^8 m \cdot s \cdot 1{,}66\overline{7}\, GHz}{3 \cdot 10^8 m \cdot s \cdot 2{,}45\, GHz}\right)^2\right)^{0,5}} = 0{,}1671\, m$$

An inner length of $2\lambda_H$ is chosen to gain a resonance within the plasma zone. Adjustment of the resonance is achieved with the pushers on both sides (Figs. 1 and 2).
Approximately 800 W are applied in these investigations.

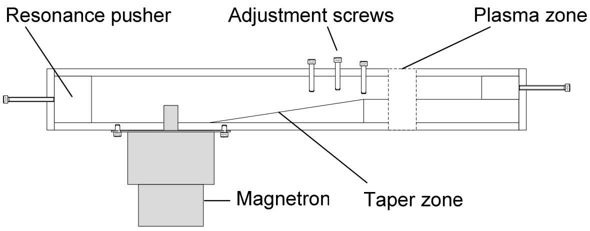

Fig. 1: Schematic of microwave resonator

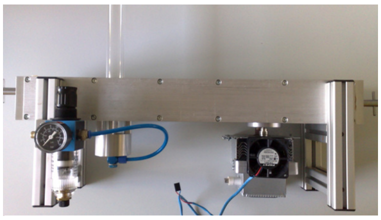

Fig. 2: Microwave resonator

Test setup

- Tests took place in an anechoic chamber.
- A 25 kV spark gap is applied for reliable plasma ignition.
- For safety reasons, an electromagnetic shielding around the plasma zone is mounted.
- Soot particles are generated by an under-stoichiometric burning flame. The exhaust gas is aspirated by a carrier gas in a venturi nozzle.
- The soot content with and without the micro wave treatment is measured by PIERBURG BOSCH smoke degree-meter (filter based).
- The treated soot concentration was approximately 5.8 $g*m^{-3}$.

Fig. 3 shows the laboratory setup

Fig. 3: Test setup

Results

- Existing designs of similar resonators could be simplified strongly.
- Only a little and a harmless amount of microwave energy was emitted from the resonator.
- The soot content could be reduced up to 69 % (Figs. 4 and 5).
- Plasma is carried away at high volume flows of the exhaust gas. This problem could be solved by magnetic retention of the plasma.
- The induced microwave energy could be increased dramatically by concentration through magnetic fields in the plasma zone.
- The waste energy could be recuperated in heat exchangers downstream – thus, the disadvantage of the necessary high energy is partly compensated.
- The micro wave gas treatment offers several applications apart of the diesel exhaust. For example, treatment of toxic gases etc.

	Magnetron	
	Off	On
Bosch numbers BN	5.9	2.2
	5.7	2.7
	5.8	2.3
	5.8	2.2
Average value BN	5.8	2.35
Concentration $g*m^{-3}$	0.5044	0.1557

Fig. 4: Test results

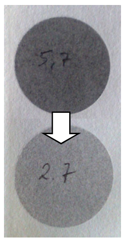

Fig. 5: Blackened filter

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