SmartCHP
COGENERATING A RENEWABLE FUTURE

Verbrennung von Pyrolyseöl mit Abgas aus einem BHKW

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4. Aachener Ofenbau- und Thermoprozess-Kolloquium 17. – 18. October 2023

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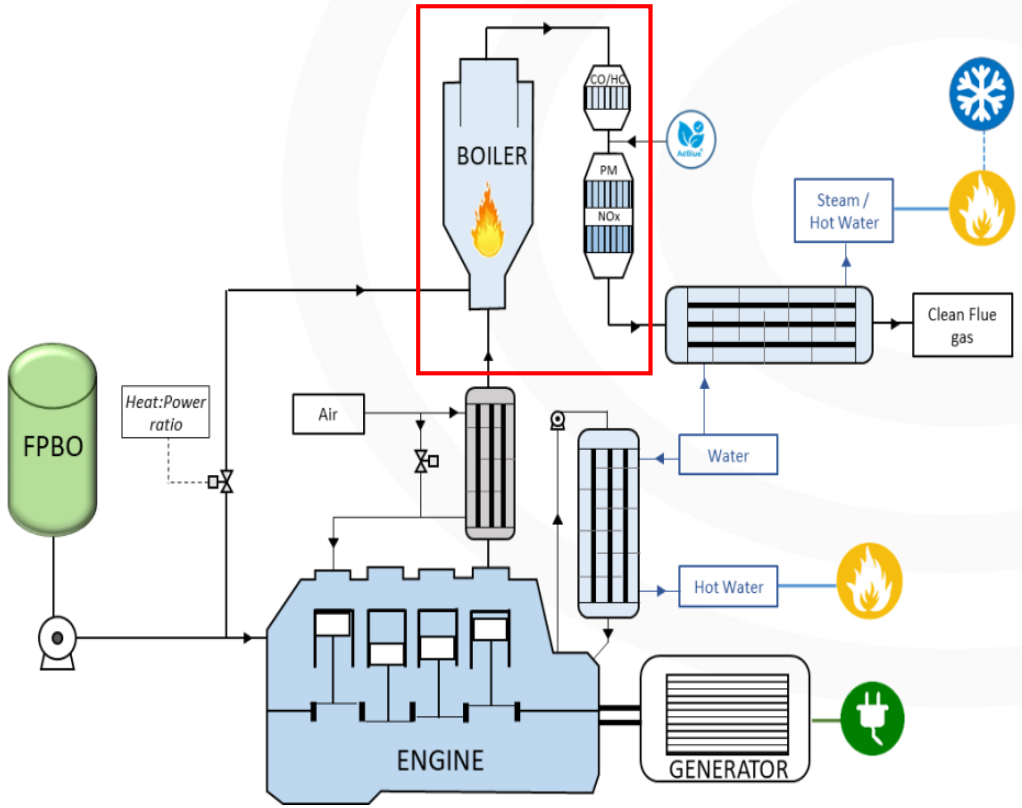
Task objectives

- To develop a boiler (approx. 100 kW_{th}) to operate with FPBO under various conditions of the flue gas of the engine (temperature, mass-flows, composition), depending on the load of the engine.
- Properties of the flue gas from the engine

Properties flue gas	Minimum	Maximum	Unit
Oxygen - O_2	4	18	v %
Carbon dioxide - CO_2	2	16	v %
Flow rate	140	250	Nm^3/hr
Temperature	175	550	°C



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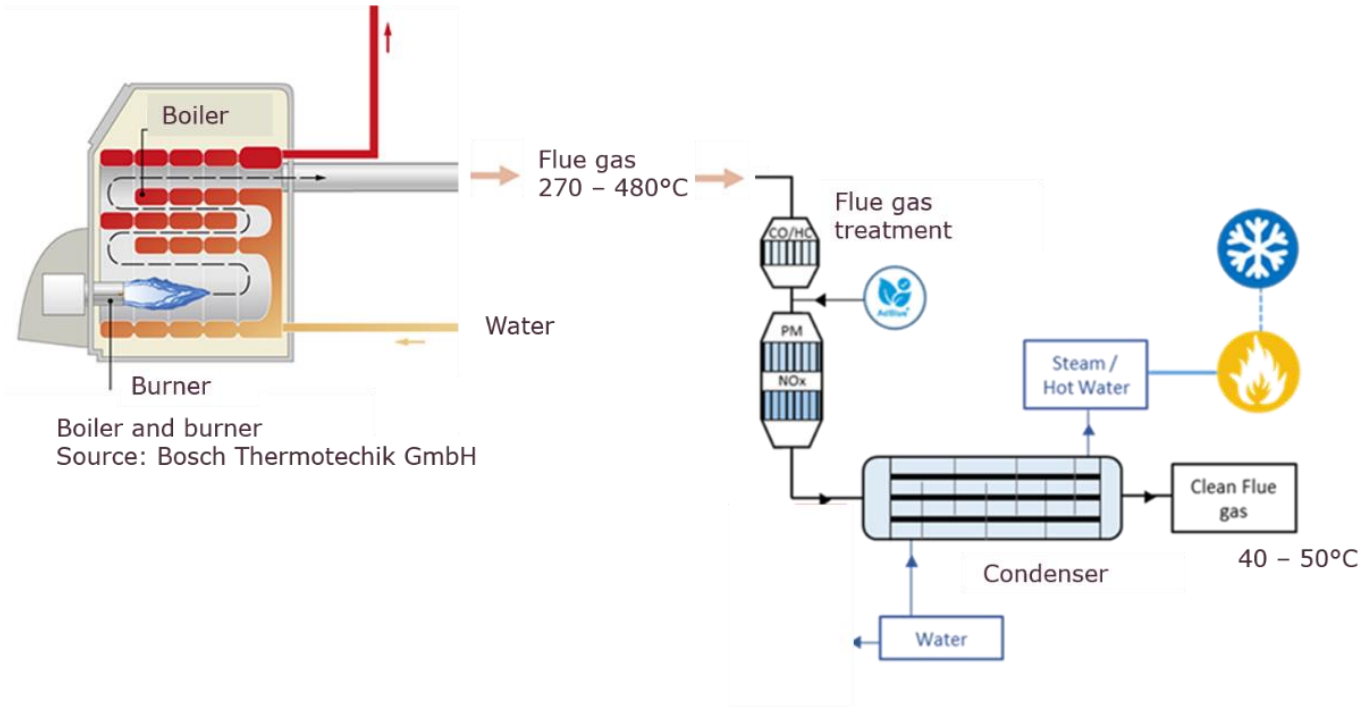
Properties engine flue gas / flame speed

O_2 content engine flue gas, dry [vol%]	Temperature engine flue gas [°C]	Flame speed [cm/s]	Volume flow increase [%]
17.5	219	41	105
17.1	233	40.01	117
16.2	256	37.29	142
15	290	33.79	182
13.7	328	29.68	234
11.7	376	21.74	331
10.5	414	18.14	414
9.25	448	14.17	520
8.3	478	11.72	627
7.16	515	9.26	793
6.47	542	8.35	928

- Properties engine flue gas - experiments BTG, 80% FPBO & 20% Ethanol
- Flame speed of FPBO with flue gas at $\lambda = 1.1$
- Calculation Cantera
- Skeletal version of FPBO-mechanism by Pelucci et. al
- Volume flow increase of engine flue gas compared to reference point: 21% O_2, T = 20° C, $\lambda = 1.1$, p = 1 atm

Boiler concept



Boiler and burner
Source: Bosch Thermotechik GmbH

- Integration of burner into low-temperature boiler for oil
- Considering requirements of flue gas treatment
- Reduction of heat exchanger surface

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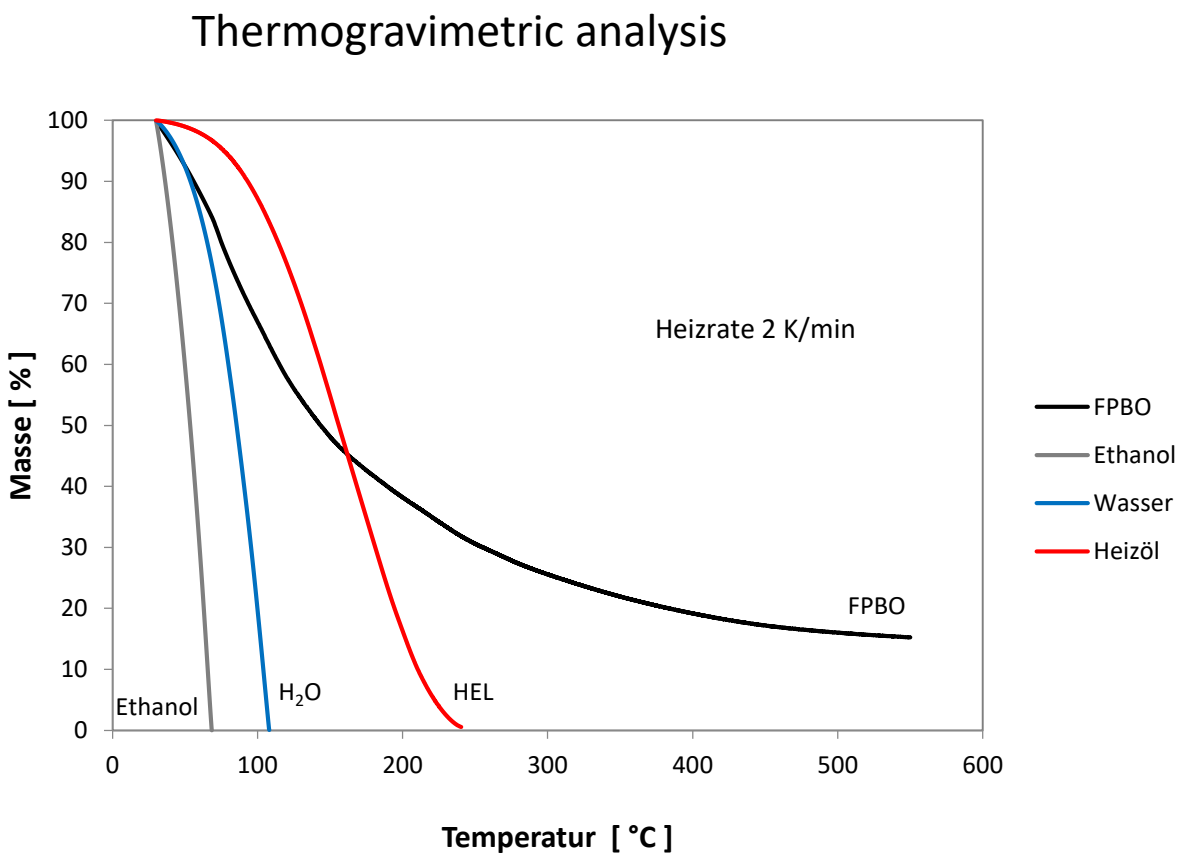
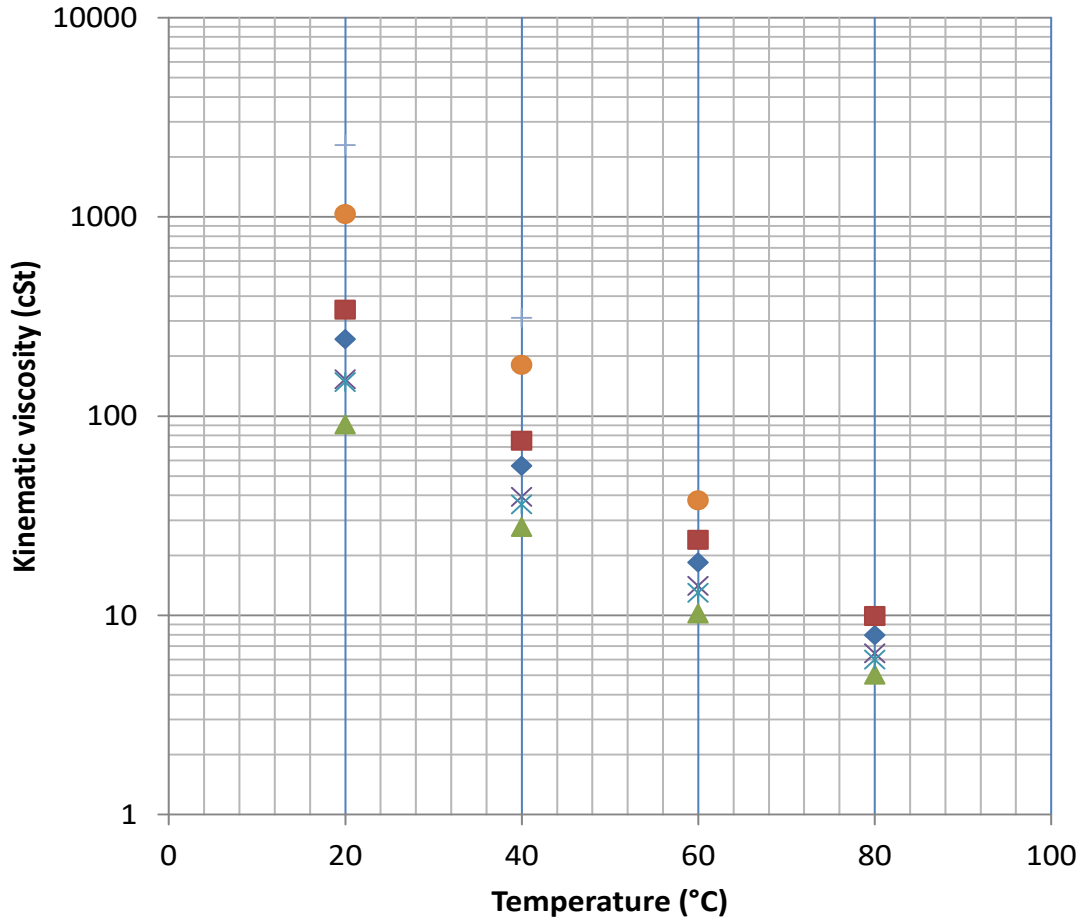
Fuel properties

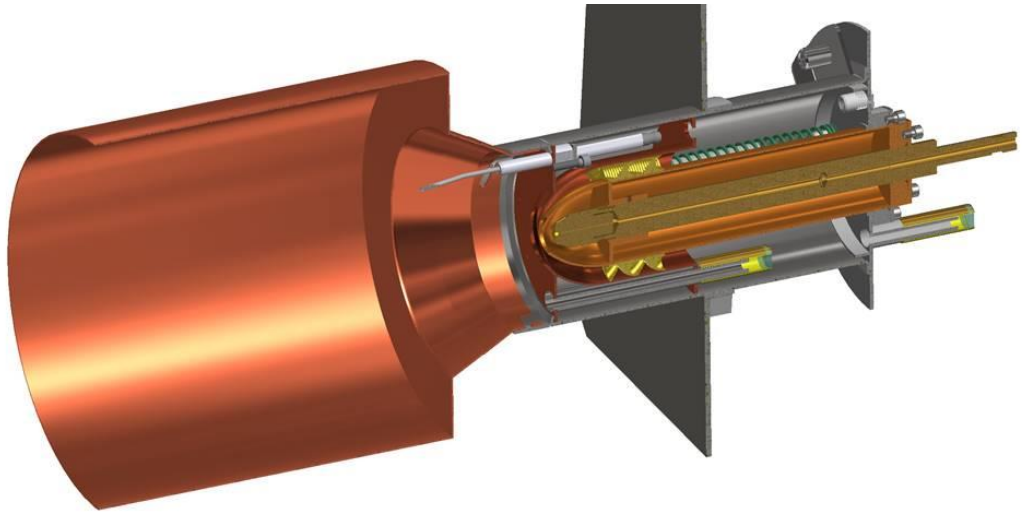
Physical property	Ethanol	FPBO	Diesel / LFO
Water content [wt.%]	< 0.1	25	~ 0
pH [-]	-	2.5	-
Density [kg/dm3 (15°C)]	0.78	1.1 – 1.3	0.82 - 0.85
Nitrogen content [wt.%]	-	0 – 1[a]	0.005 – 0.05
Lower Heating Value (LHV) [MJ/kg]	28.9	16	42.6
Kinematic Viscosity [cSt] (40°C)	1.1	20 – 100	2.0 – 4.5
Solids [wt.%]	-	0.02 – 0.25	Water + sediment < 0.02
Surface tension [mN/m]	20	30	26
Acid Number [mg KOH/g]	-	80 – 100	< 0,08
Cetane number	10	0 - 20	45 - 55
	[a] strongly depends on biomass resource the FPBO is originating from		

Fuel properties

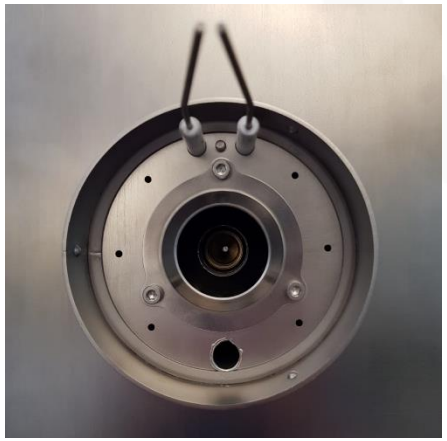




Burner design 100 kW

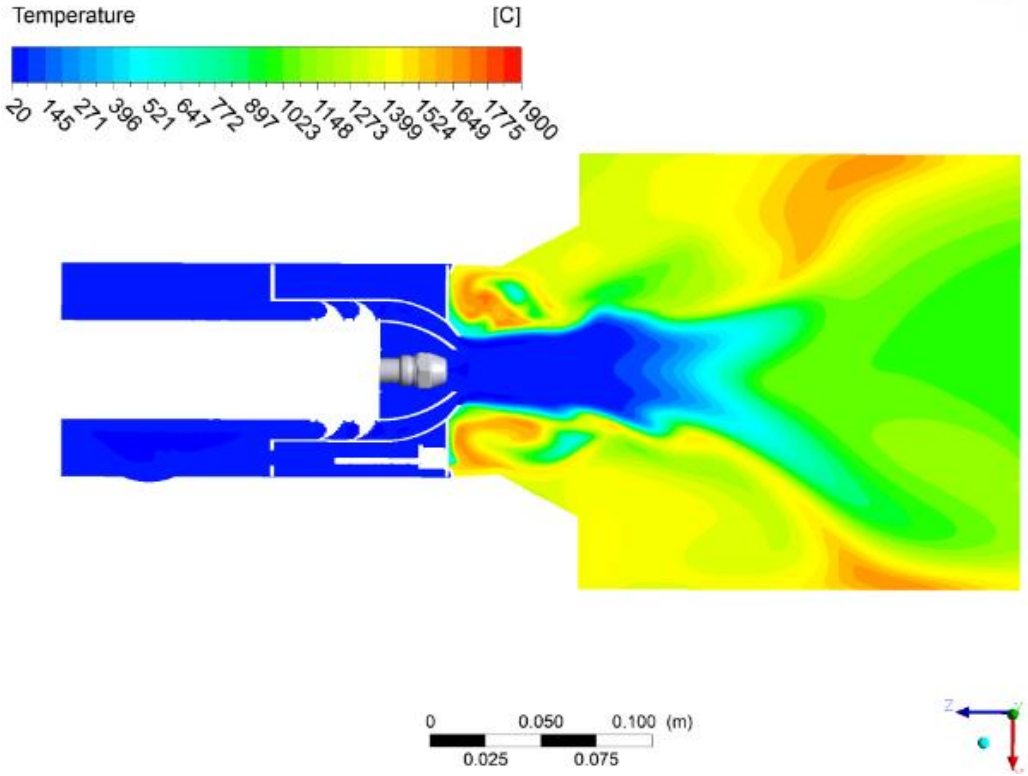


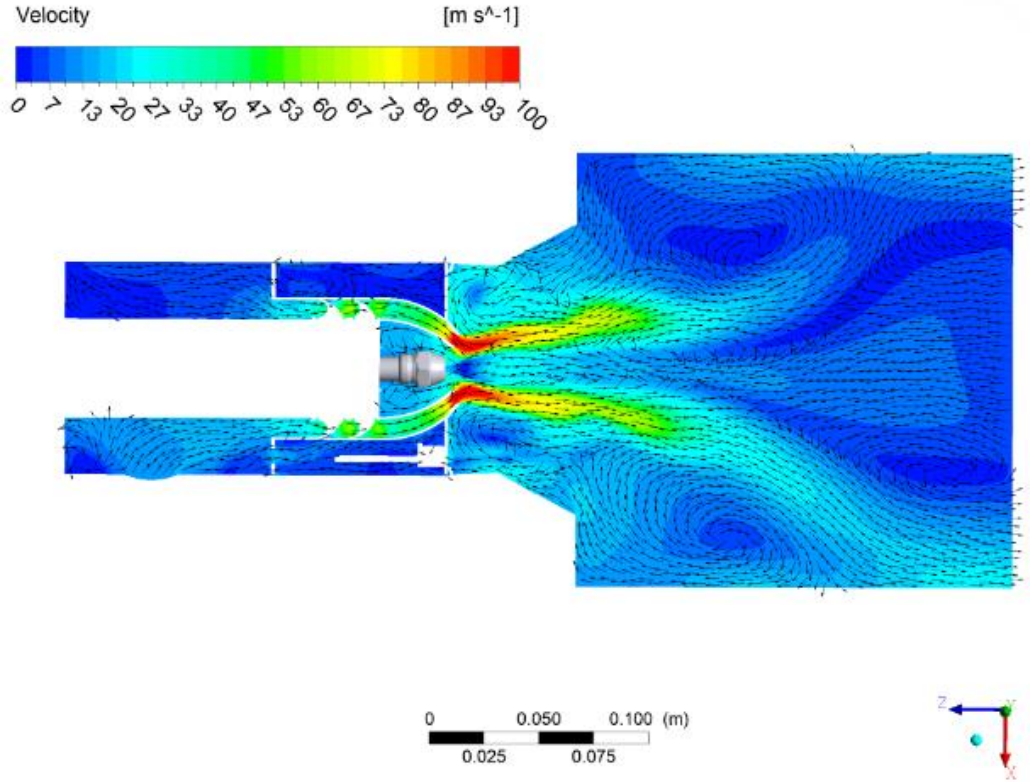
CAD drawing burner 100 kW for FPBO constructed by MEKU Metall Processing GmbH



- Adjustable fuel nozzle position
- Annular gap around nozzle for thermal protection
- Suitable for up to 500°C

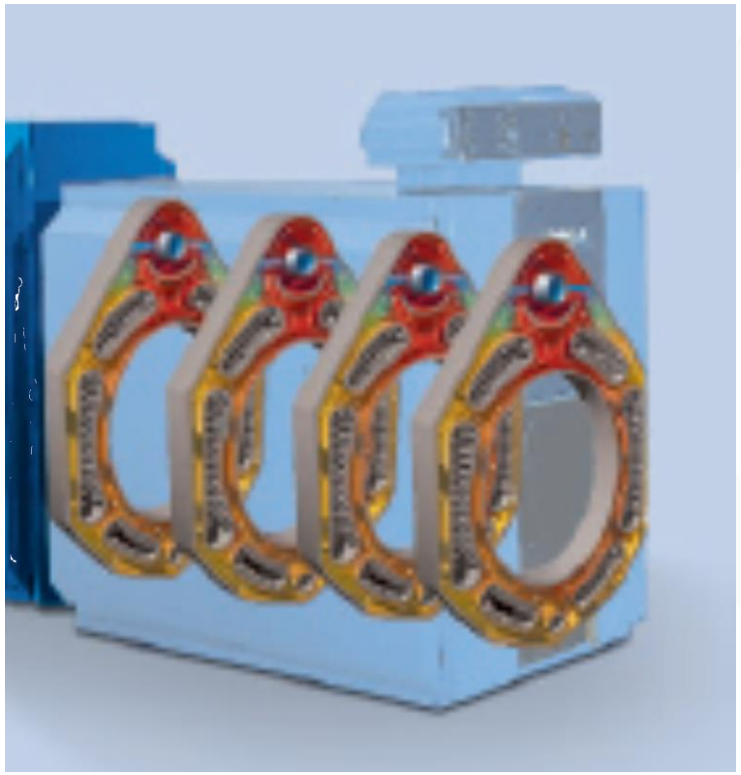
Burner design 100 kW





100 kW, FBPO 80% and 20% ethanol, non-preheated air, lambda 1.5, insulation of flame tube, temperatures (left), velocities (right)

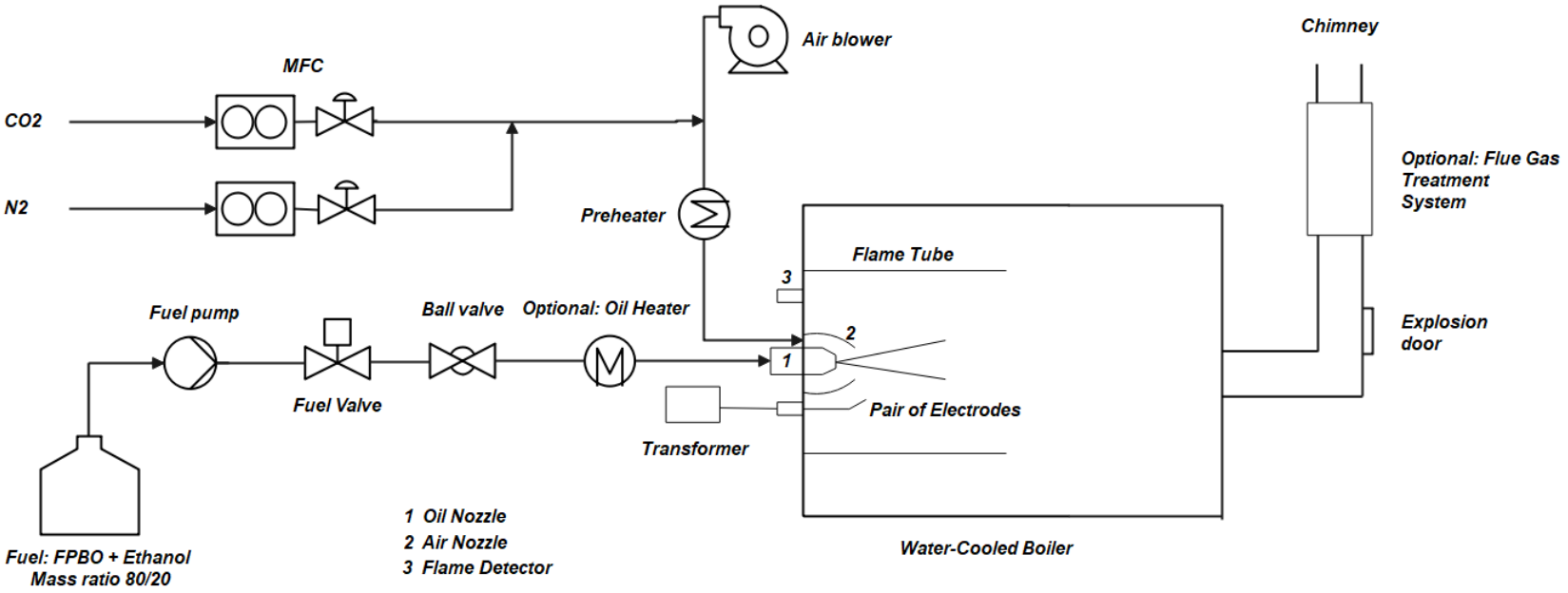
Boiler design 100 kW



- Boiler Logano plus GE515 (195 kW) without condenser form Bosch Buderus GmbH
- Boiler with insulation and covering (left)
- Principle sketch openings to the heat exchanger (right)

Source: Bosch Buderus GmbH

Boiler and burner test



Process diagram of test bench

- Simulated flue gas: mixture of N_2, (CO_2), air
- Preheating of mixture
- Integration of new fuel pump
- Tests with 80% FPBO and 20% Ethanol

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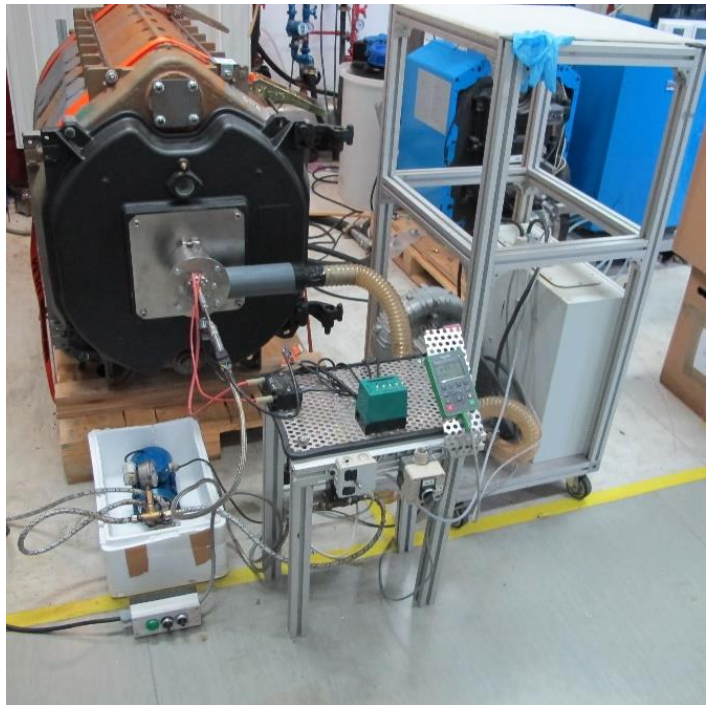
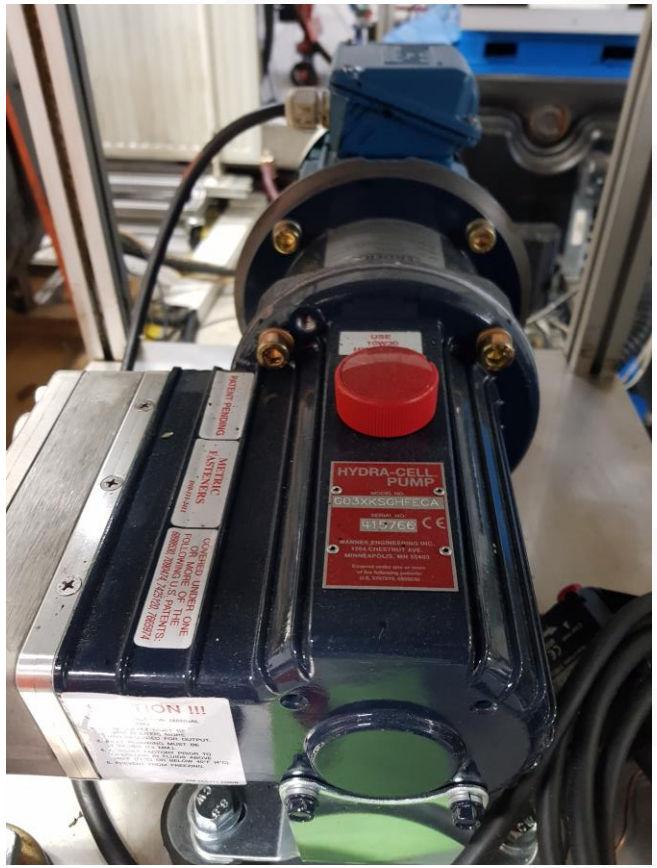
Boiler and burner test



Boiler (not insulated) and burner

View into the boiler



Verderbar Hydracell Diaphragm Pump

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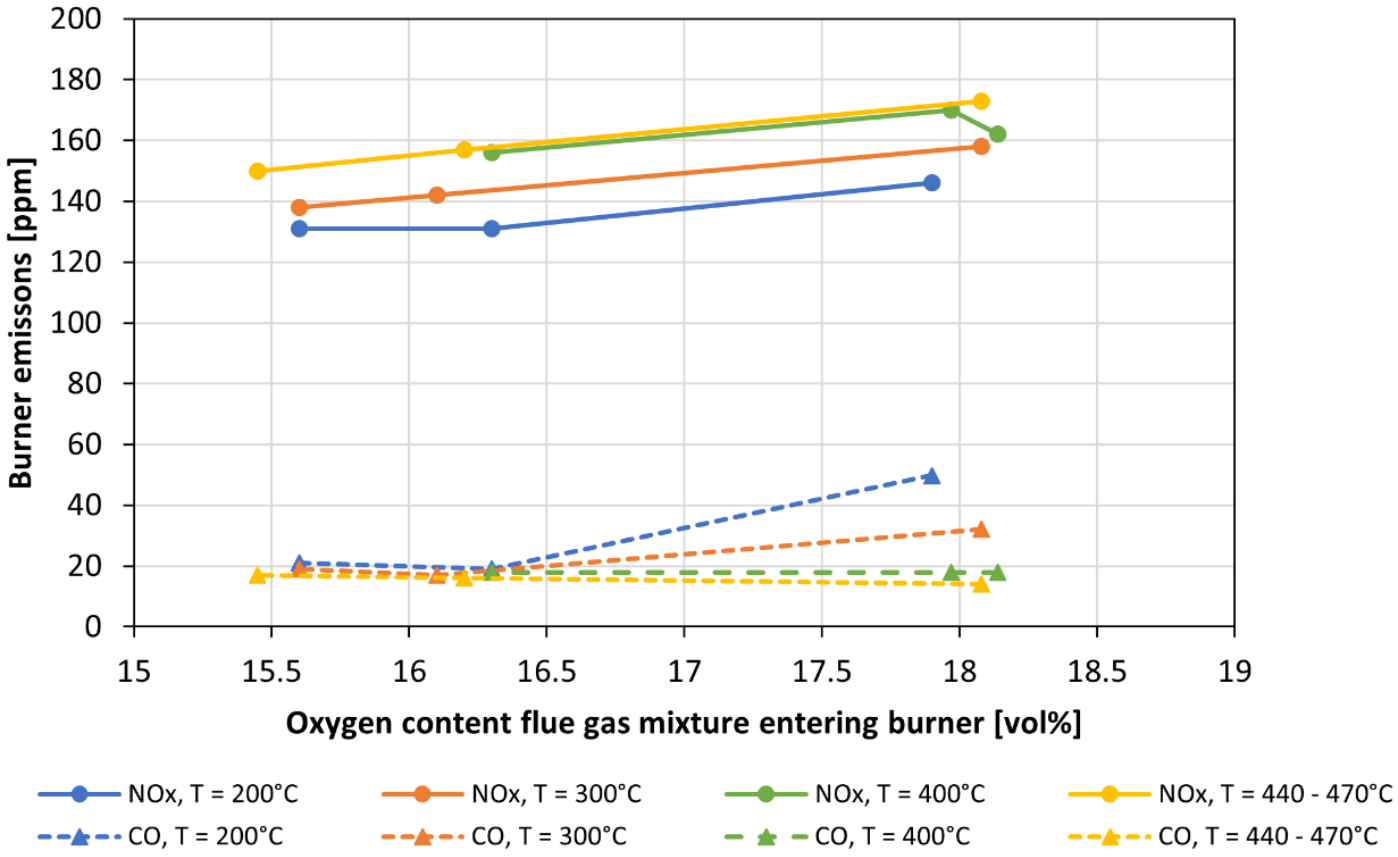
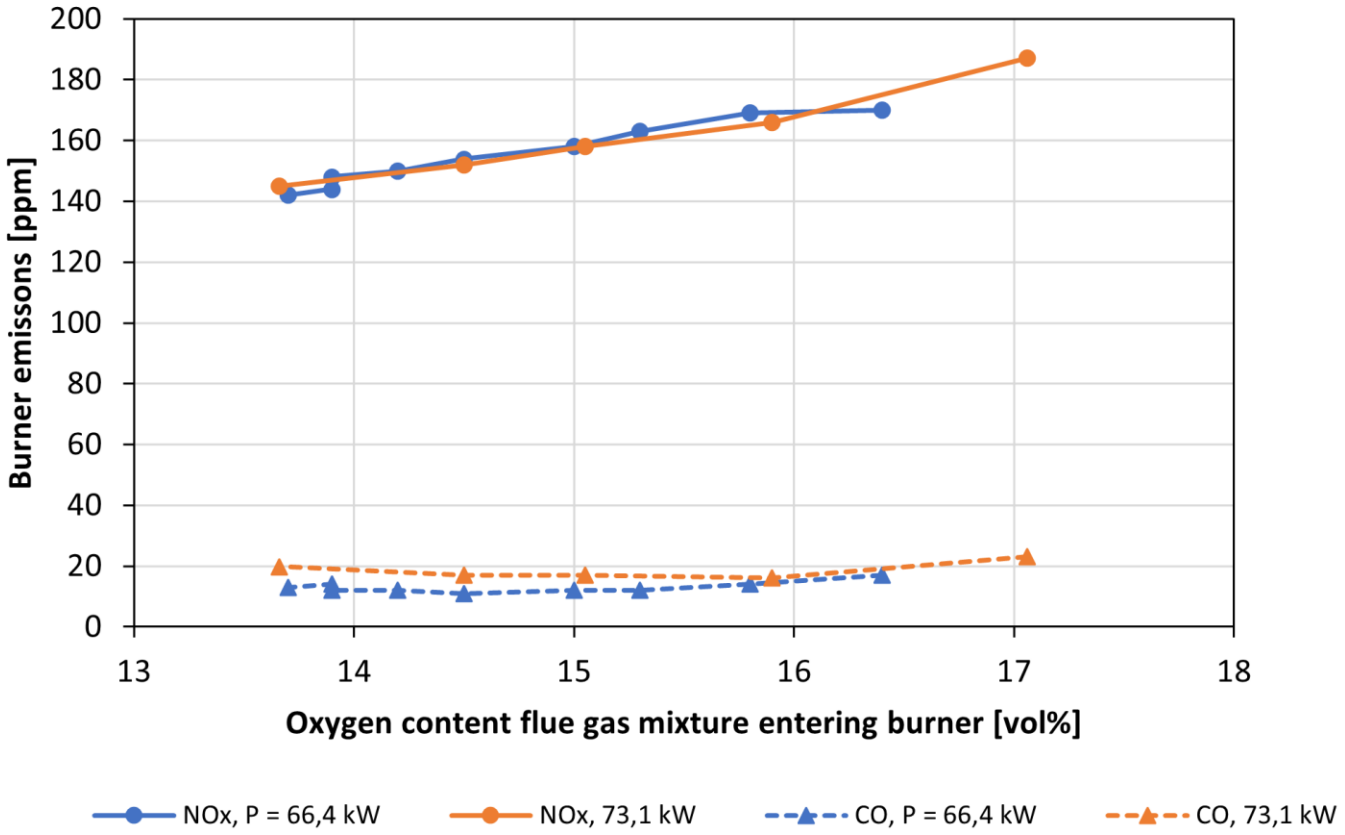
Boiler and burner test



- Burner emissions
- Fuel input: 61.5 – 63.5 kW
- 80% FPBO, 20% Ethanol, T = 40° C
- Oxygen content flue gas entering burner: 18.2 – 15.4%
- Temperature flue gas entering burner: 200 – 470° C
- Air ratio: 1.1 – 1.2
- Hydrocarbon emissions ≤ 5 ppm (CH4 equivalent)

Boiler and burner test



- Burner emissions
- Fuel input: 66.4 & 73.1 kW (10 – 12 bar fuel pressure)
- 80% FPBO, 20% Ethanol, T = 40° C
- Oxygen content flue gas entering burner: 17.1 – 13.6%
- Temperature flue gas entering burner: 416 - 424° C
- Air ratio: 1.05 – 1.1
- No deposits and instabilities

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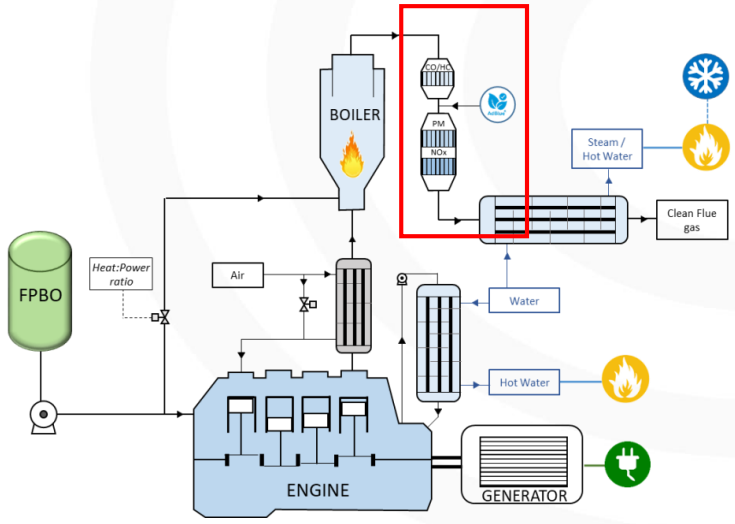
Subtask objectives

- The development a flue gas treatment system for the CHP system respecting emission legislations.
- To set up a test environment to be able to test the flue gas treatment system for their suitability with FPBO
- Emissions limitations after flue gas treatment

Emissions	Maximum	Unit
Carbon monoxide - CO	80	mg/m³
Hydrocarbons - HC	10	ppm
Nitrogen oxides - NO_x	180	mg/m³
Particulate matter - PM	10	mg/m³



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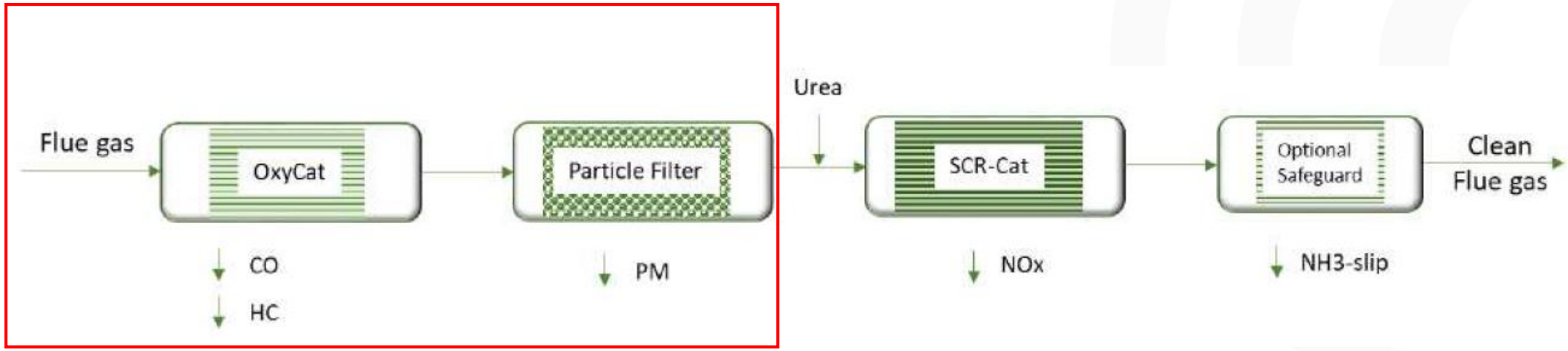
Test of filter at OWI

- Design of compact filter system
  - Filter minimizes CO, HC und PM emissions
  - Construction of filter system for test



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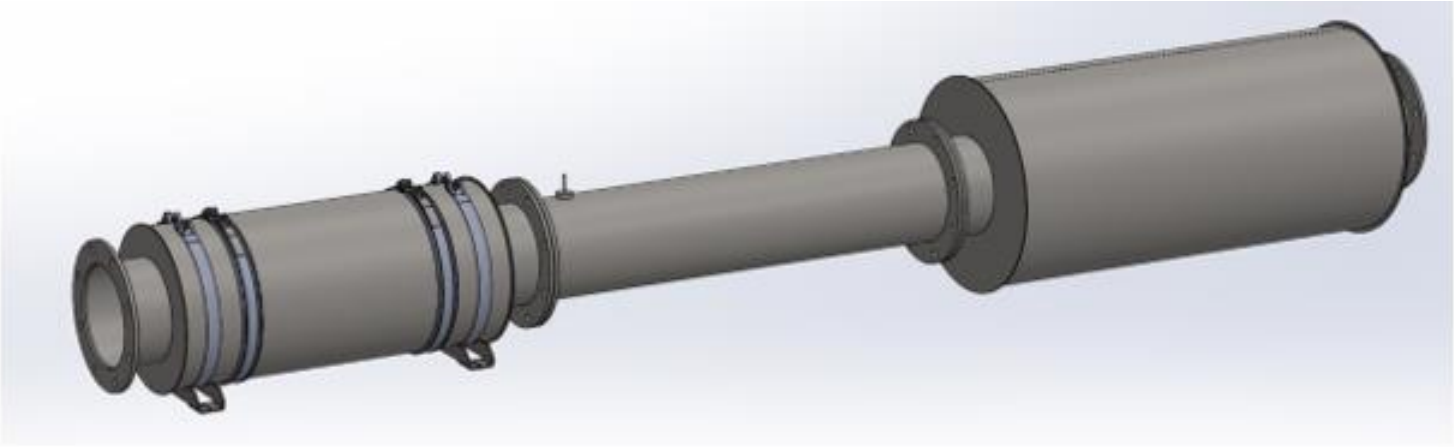
Flue gas treatment design with SCR - THEAG



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Flue gas treatment @ OWI

Time	O2	λ	CO	CO	NOx	NOx	Temp. before cat	Additional air temp.
upstream								
hh:mm	vol%	-	ppm	mg/m^3_N	ppm	mg/m^3_N	°C	°C
16:07	5	1,32	3	4	77	145	336	180
16:18	5,3	1,34	0	0	77	145	338	200
16:29	4,8	1,32	0	0	76	143	368	235
								9 mbar back-pressure
downstream								
16:12	5,2	1,33	0	0	3….5	6…9	336	180
16:19	5,9	1,37	0	0	3,5…4	7…8	338	200
16:31	5,3	1,36	0	0	0…3	0…6	368	235

Flue gas treatment system

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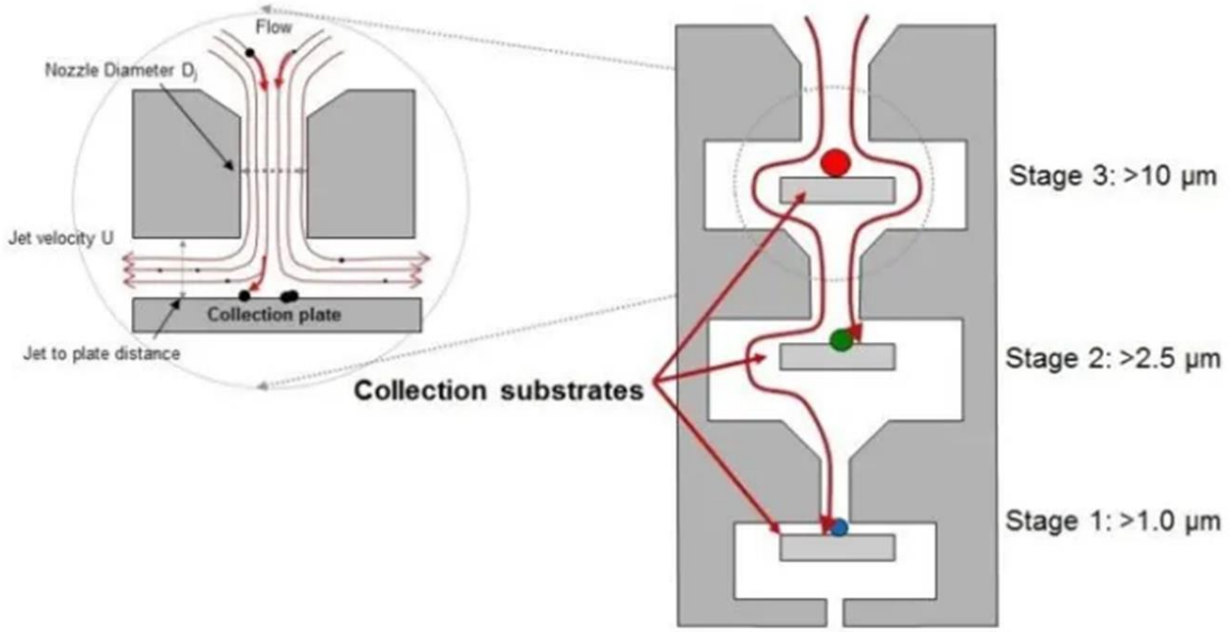
Particulate measurement



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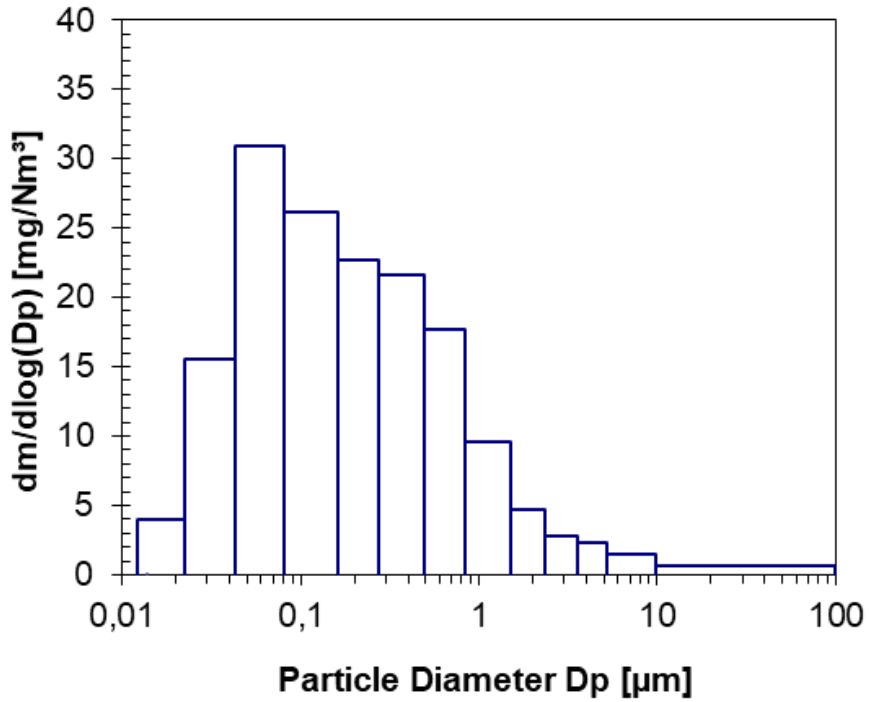
Flue gas treatment @ OWI



PM_1: 5,8 mg/Nm³
$PM_{2.5}$: 22,2 mg/Nm³
PM_{10}: 41,7 mg/Nm³
PM_{Σ}: 42.4 mg/Nm³

PM upstream
FPBO with 20% ethanol
100 kW, λ = 1.3

Impactor / Particle measurement device

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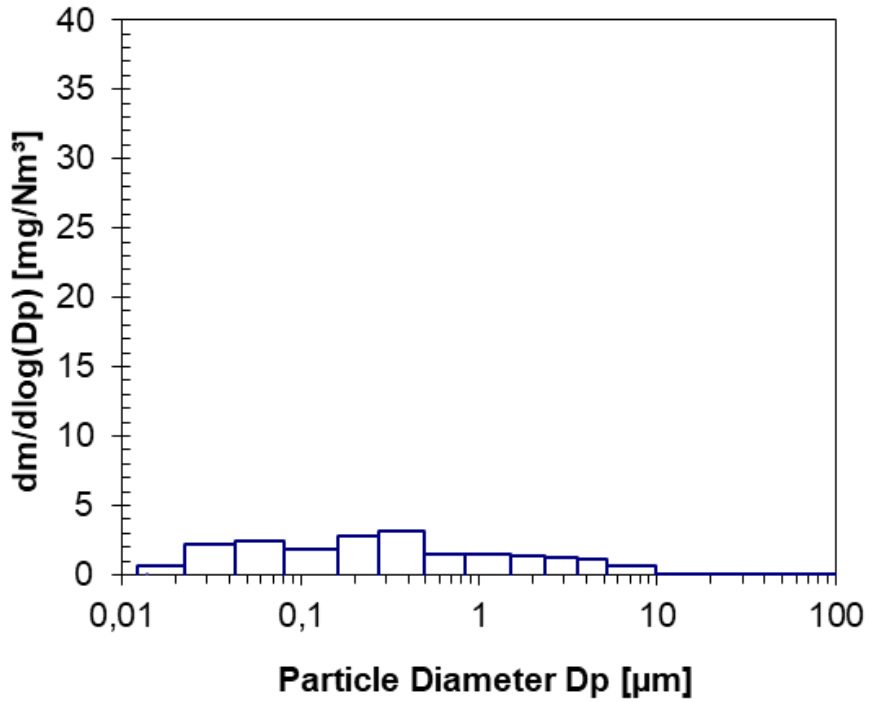
Flue gas treatment @ OWI



PM_1: 3,8 mg/Nm³
$PM_{2.5}$: 4,5 mg/Nm³
PM_{10}: 5,1 mg/Nm³
PM_{Σ}: 5,1 mg/Nm³

PM downstream
FPBO with 20% ethanol
100 kW, λ = 1.3

Impactor / Particle measurement device

Thank you!

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