Pyroliq 2019: Pyrolysis and Liquefaction of Biomass and Wastes

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Hydrothermal liquefaction of organic waste streams on a continuous pilot scale reactor

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HYDROTHERMAL LIQUEFACTION OF ORGANIC WASTE STREAMS ON A CONTINUOUS PILOT SCALE REACTOR

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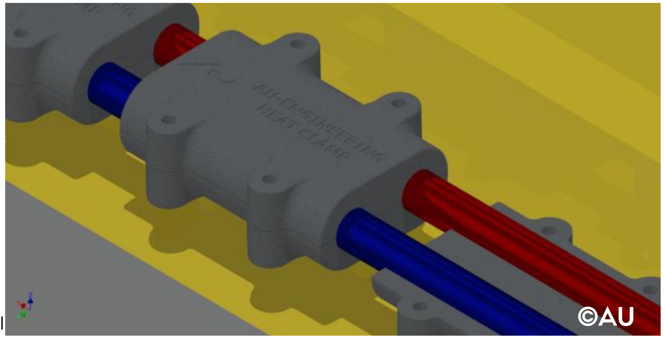
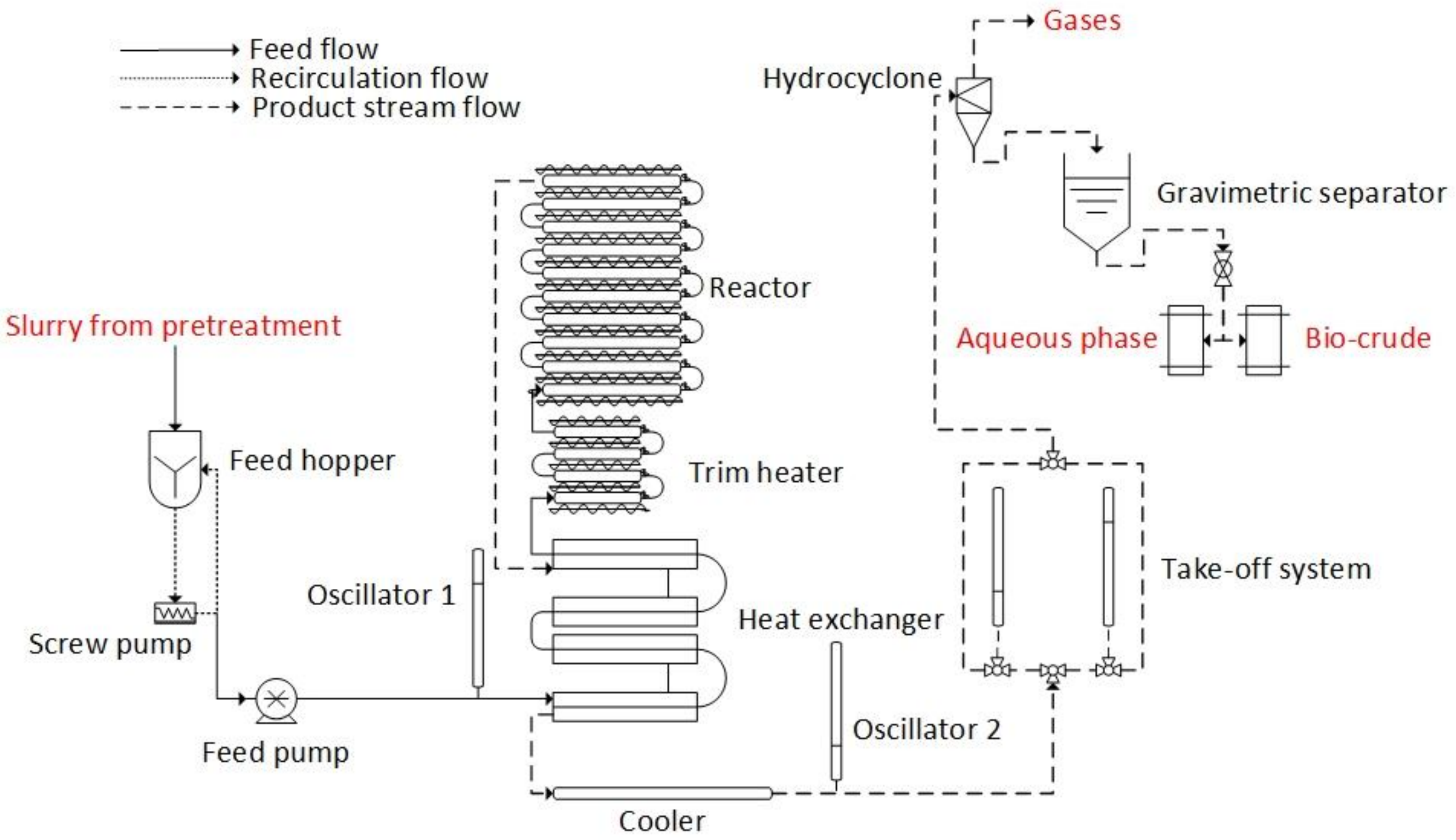
AARHUS HTL PILOT REACTOR

- Capacity of up to 100 L/h
- Cast steel heat clamps used as heat exchangers
- Uniform diameter (14 mm) throughout entire reactor, no size restrictions
- Individual control and monitoring of 32 x 0.5 kW heaters (trim heater) and 5 x 1 kW heaters (reactor)
- 54 thermocouples and 20 pressure transducers



PROCESS FLOW DIAGRAM



7 sections:

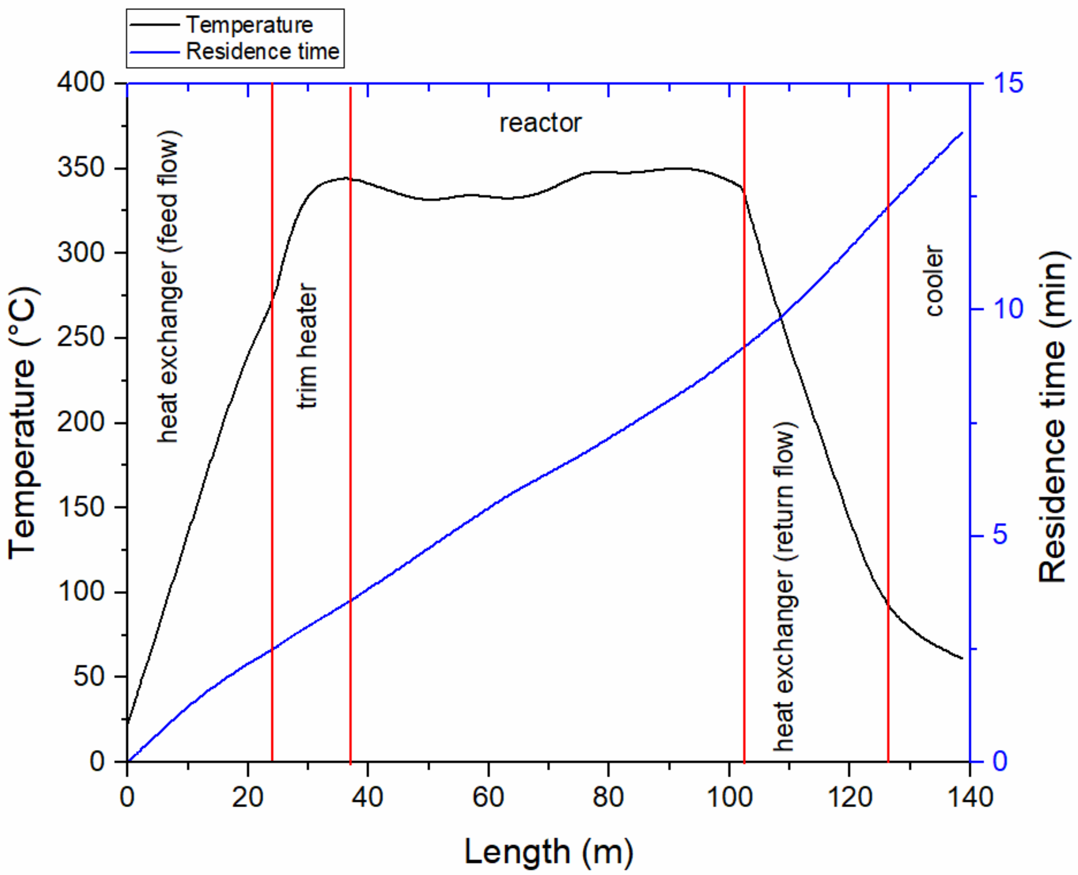
- Feed introduction system
- Heat exchanger
- Trim heater
- Reactor
- Oscillation system
- Take-off system
- Product collection zone

Typical conditions:

- 60 L/h
- ~20% dry matter
- P=220 bar
- T=350°C

Total Volume of the system ~20 L

TEMPERATURE AND RESIDENCE TIME DISTRIBUTION

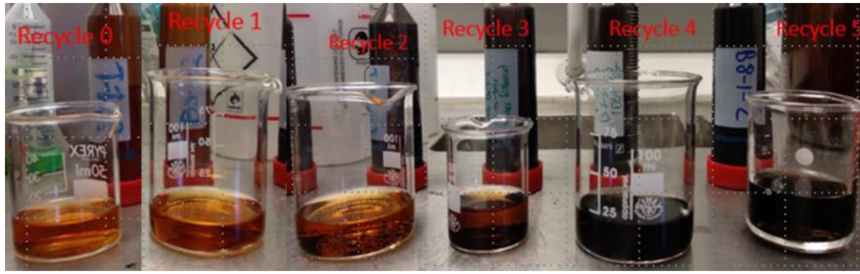


- Incoming feed is heated from ~20°C to ~270°C in the heat exchanger in ~2.5 min
- Heated to reaction temperature (350°C) in the trim heater in 1 min
- Temperature is maintained (330-355°C) for 6 min
- Product is directed to the heat exchanger, where it is cooled to ~80°C in 3 min
- cooling section to 60°C in 1.5 min

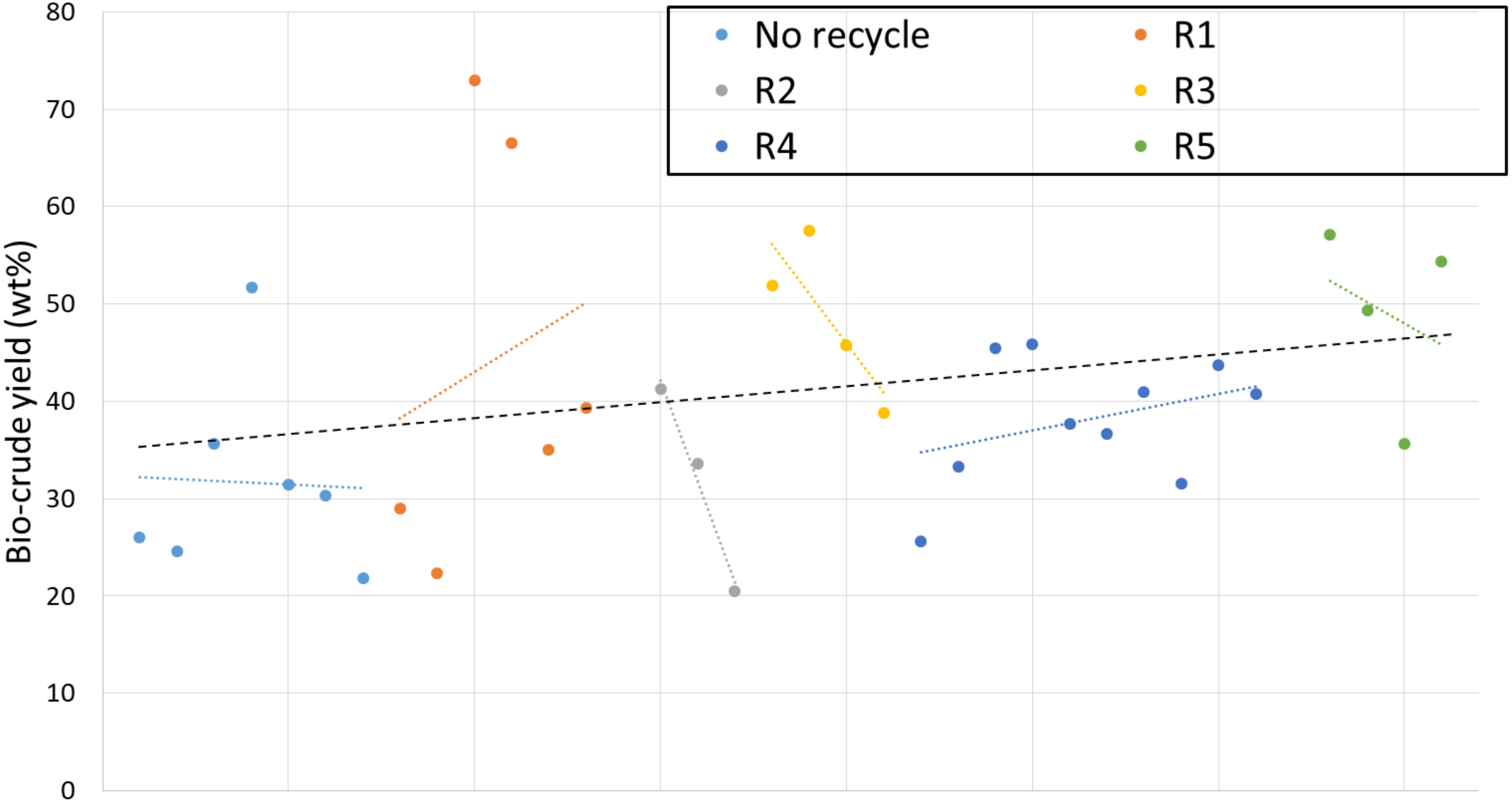
WATER PHASE RECYCLING

- An increase in total organic carbon in the process water was observed with each run
- Full recycling was not achieved due to moisture content of feedstock and water use in extruder
- Recycling water allowed higher DM content slurries to be processed

➢ Max DM fresh 16%
➢ R1 max DM 17.5
➢ R2 max M 18%
➢ R3 max DM 21.3%



BIO-CRUDE YIELDS



We have a large variability in bio-crude yields, mainly due to

- sampling procedure
- varing take off cylinder size
- temperature in take-off

Overall average yield 40.3 %

PROCESS EFFICIENCY

	Pine
Flow rate (l/h)	100
DM content	0.20
Time (h)	1
Feedstock consumed (kg, dry)	20
Energy in feedstock (kW, dry)	113.8 (HHV=20.5MJ/kg)
Bio-crude yield (wt.%)	38.2
Energy in bio-crude (kW, dry)	62.4 (HHV=29.4 MJ/kg)
Chemical energy recovery (%)	**54.8**
Trim heater energy requirement (kW)	9.2
Reactor energy requirement (kW)	2
Main pump energy requirement (kW)	1.3
n_{tot} (%)	**49.4**
EROI	**5**

- Data used for the calculations were from the last recycle run and energy consumption data for the trim heater and the reactor were during the last hour of operation

- ~10% of energy in feedstock consumed for process

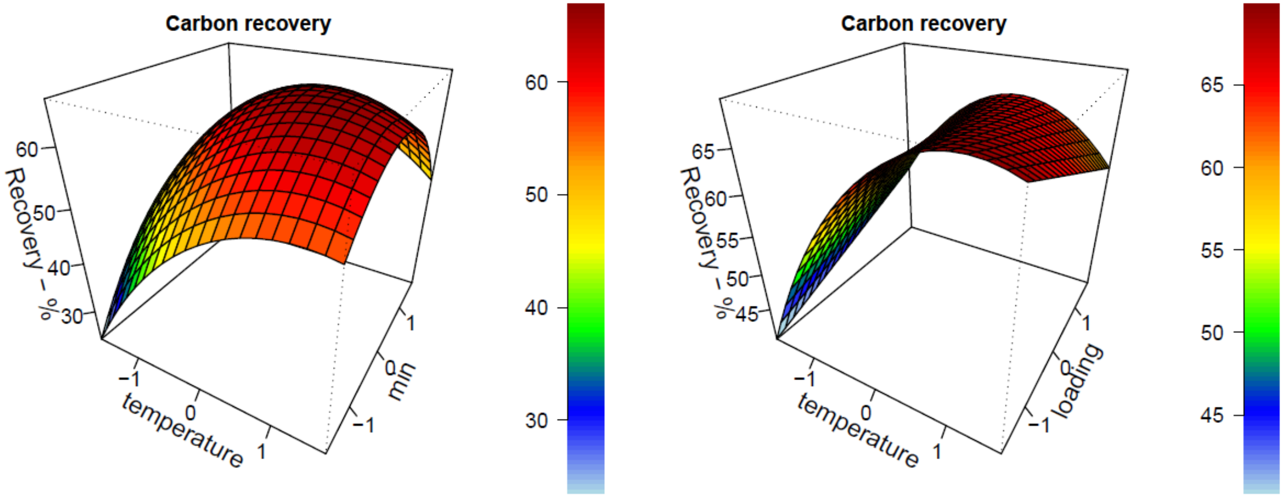
PROCESS EFFICIENCY

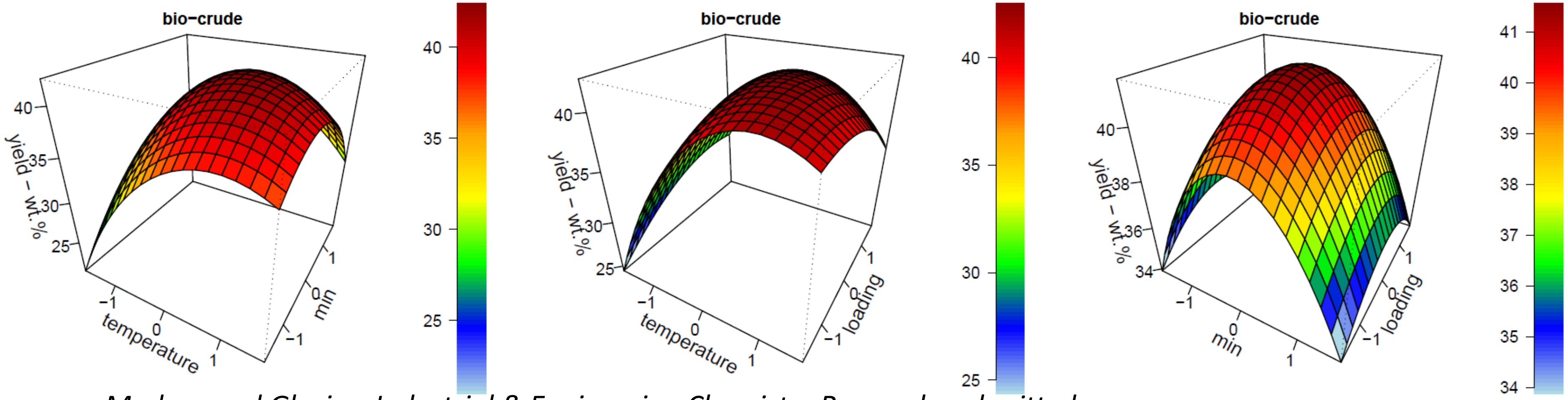
	Miscanthus	Spirulina	Sewage sludge
Flow rate (l/h)	60	60	60
DM content	**0.15**	**0.16**	**0.04**
Time (h)	1	1	1
Feedstock consumed (kg, dry)	9	9.8	2.4
Energy in feedstock (kW, dry)	42.7 (HHV=17.1MJ/kg)	63.1 (HHV=23.1MJ/kg)	13.2 (HHV=19.8MJ/kg)
Bio-crude yield (wt.%)	26.2	32.9	**24.5**
Energy in bio-crude (kW, dry)	19.9 (HHV=30.6 MJ/kg)	32 (HHV=35.6 MJ/kg)	4.4 (HHV=26.8 MJ/kg)
Chemical energy recovery (%)	**46.5**	**50.7**	**33.2**
Trim heater energy requirement (kW)	4.4	5.5	5.4
Reactor energy requirement (kW)	2	2.8	2.5
Main pump energy requirement (kW)	0.7	0.7	0.7
n_{tot} (%)	**39.9**	**44.4**	**20.1**
EROI	**2.8**	**3.5**	**0.5**

BATCH TESTING OF SLUDGE HTL

- Parametric study of temperature, residence time and solids loading using sludge
- T=250-350°C
- Time=5-35 mins
- Solids loading wt% =5-25

- Optimum condition identified:
- **320 ˚C, 16-18 min, and 12-15 wt.%**





Madsen and Glasius, Industrial & Engineering Chemistry Research, submitted

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PILOT SLUDGE HTL

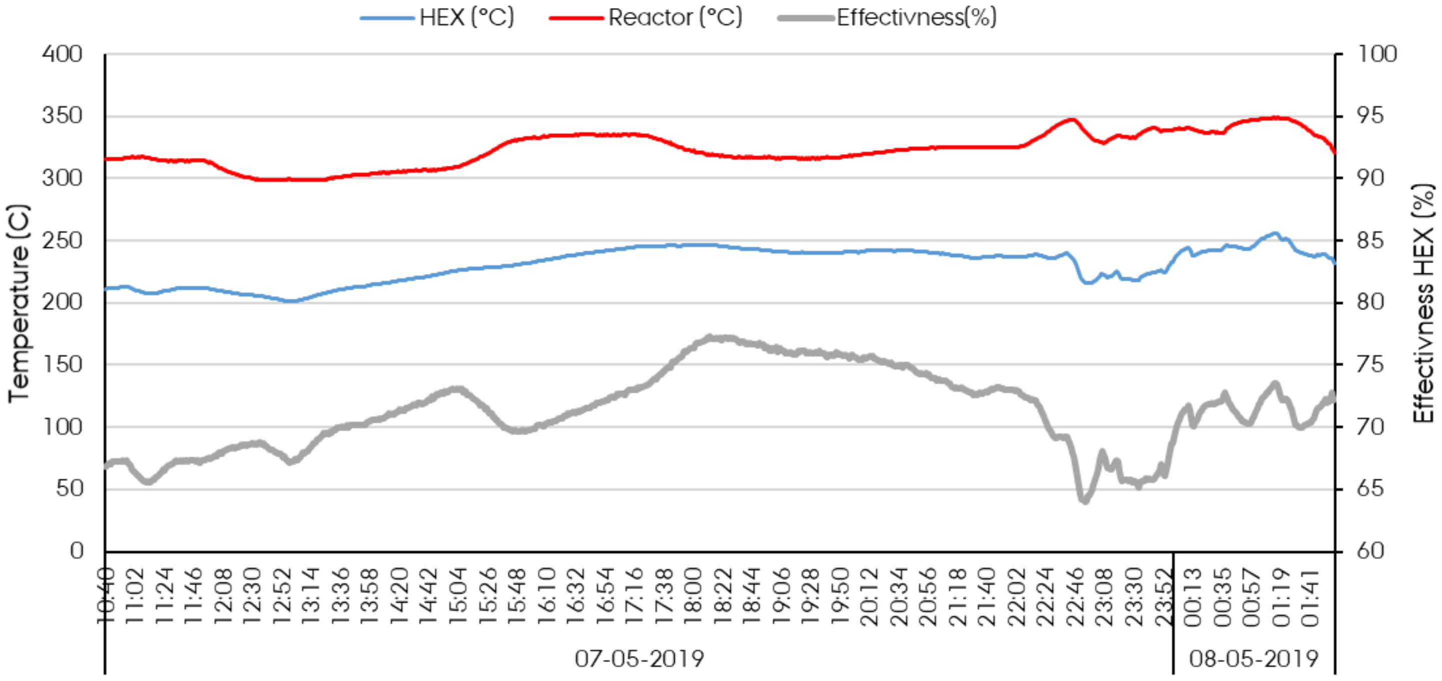
- In order to validate batch results we had to increase the DM content of sludge from 5→15%

- Added benefit of removing some of the ash from the feedstock

	dry matter (%)	Ash(%)	dry matter ash free (%)
Primary Sludge	4,0%	13%	3,1%
Cake	19,3%	7%	18,5%
Water	0,2%	50%	0,1%

PILOT HTL SLUDGE PROCESSING

- Temperatures of 300, 325 and 350°C
- Overall bio-crude yield from 14 hour production campaign 46%
- 60 kg of bio-crude produced
- HEX effectiveness not affected by different reactor temperatures (65-77%)
- Considerable ash content in bio-crude but reduced to 0.3% after filtration



Temperature	C [%]	H [%]	N [%]	S [%]	O [%]	Ash [%]	HHV [MJ/Kg]
300°C	67.1	7.7	3.1	0.7	5.7	15	31.5
325°C	65.6	8.7	2.9	0.6	5.1	16	32.3
350°C	58.0	7.7	2.8	0.6	1.2	27	28.6

PILOT HTL SLUDGE PROCESSING

- Batch processing data confirmed with best results obtained at 325°C
- Pumping accounts for <5% of total energy consumption
- Heating energy affected by flow and temperature
- ~16% of energy in feedstock required for process energy
- Further improvements possible, especially in DM content

Temperature	°C	300	325	350
Flow rate	L/h	80	51	84
Dry matter content	(%)	15	17	17
Feedstock consumed	(kg, dry)	12.0	8.7	14.3
Energy in Feedstock	(kW, dry)	66.0	47.7	78.5
Bio-crude yield	(wt%)	37.5	57.3	61.2
Bio-crude ash content	(%)	15.0	16.0	27.0
Bio-crude yield filtered	(%)	**31.9**	**48.1**	**44.7**
HHV bio-crude ash free	(MJ/kg)	31.2	32.3	28.6
Energy in Bio-crude	(kW, dry)	33.1	37.4	50.7
Chemical Energy Recovery	(%)	50.1	78.5	64.5
Trim heater energy requirements	(kW)	8.0	5.0	8.0
Reactor energy requirement	(kW)	2.3	1.9	4.2
Main pump energy requirement	(kW)	0.30	0.24	0.62
Efficiency total	(%)	43.2	67.9	55.4
EROI		3.1	5.2	4.0

MIXING OF FEEDSTOCKS

- Synergistic effects on yields between lignocelluloscis and sludge
- For all three parameters (temp, solids loading, residence time) a higher than expected yield is observed for the mixture of sludge-miscanthus
- Lower O, higher HHV and much higher chemical energy recovery than calculated
- Avoids need for alkali catalyst

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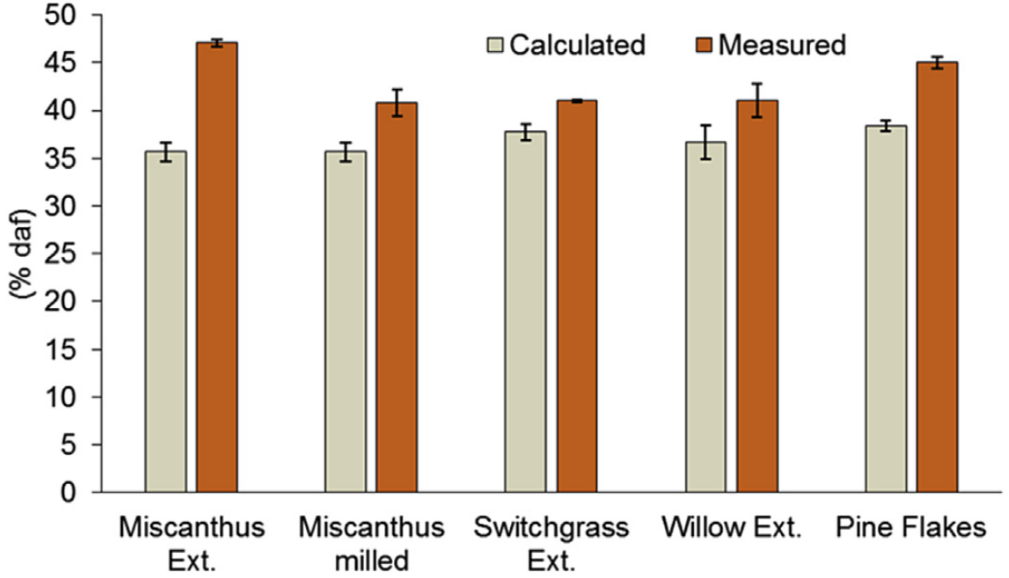
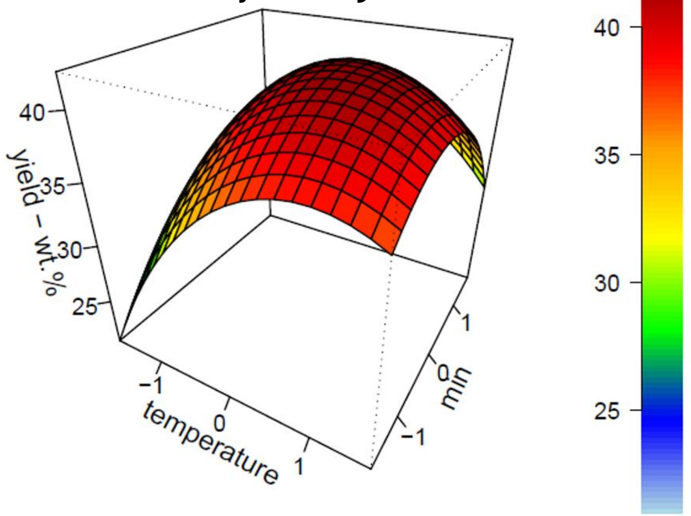
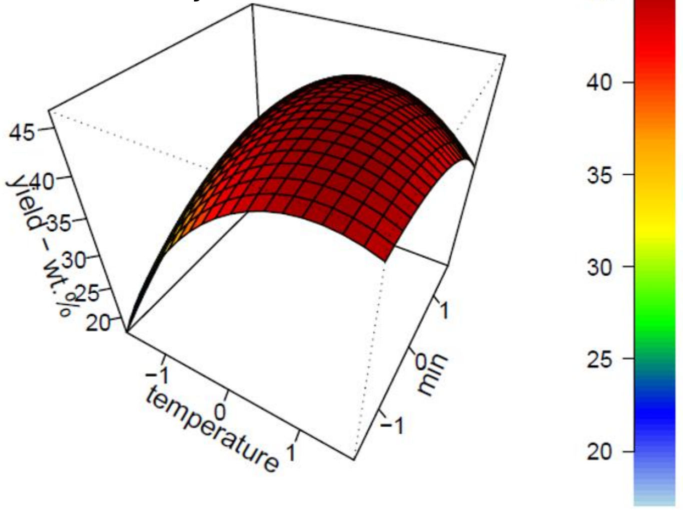


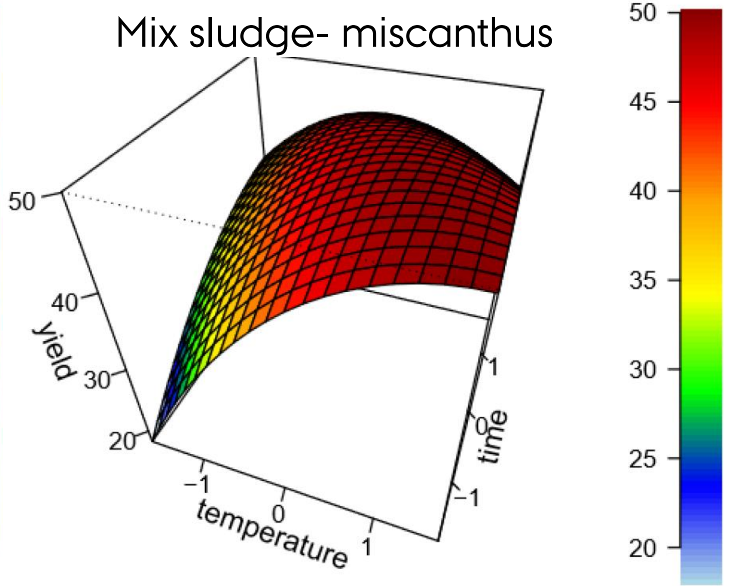
Only sludge



Only Miscanthus



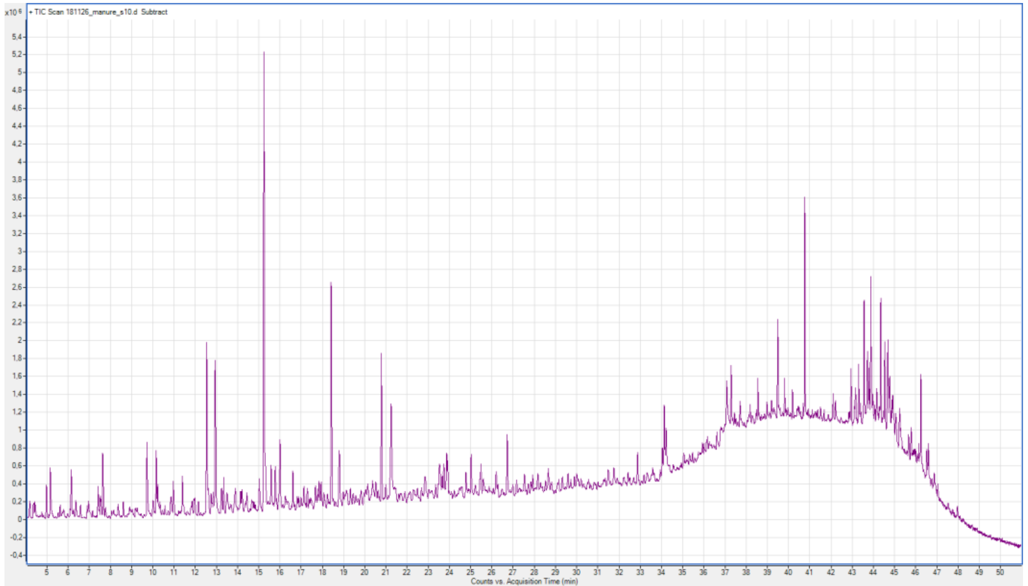
Mix sludge- miscanthus



MANURE

- Manure has been identified as a high impact feedstock in DK
- We performed initial tests with very promising results
- Physical nature of slurry resulted in pump failure after 2 hours
- Composition is favorable with high abundance of alkanes, indoles, fatty acids and fatty acid amides.
- Low dry matter content (9%) makes it a good candidate fro co-liquefaction

	Yields (%)
Bio-crude	41.7
Char	11.6
Gas	20.6
Water soluble	26.1

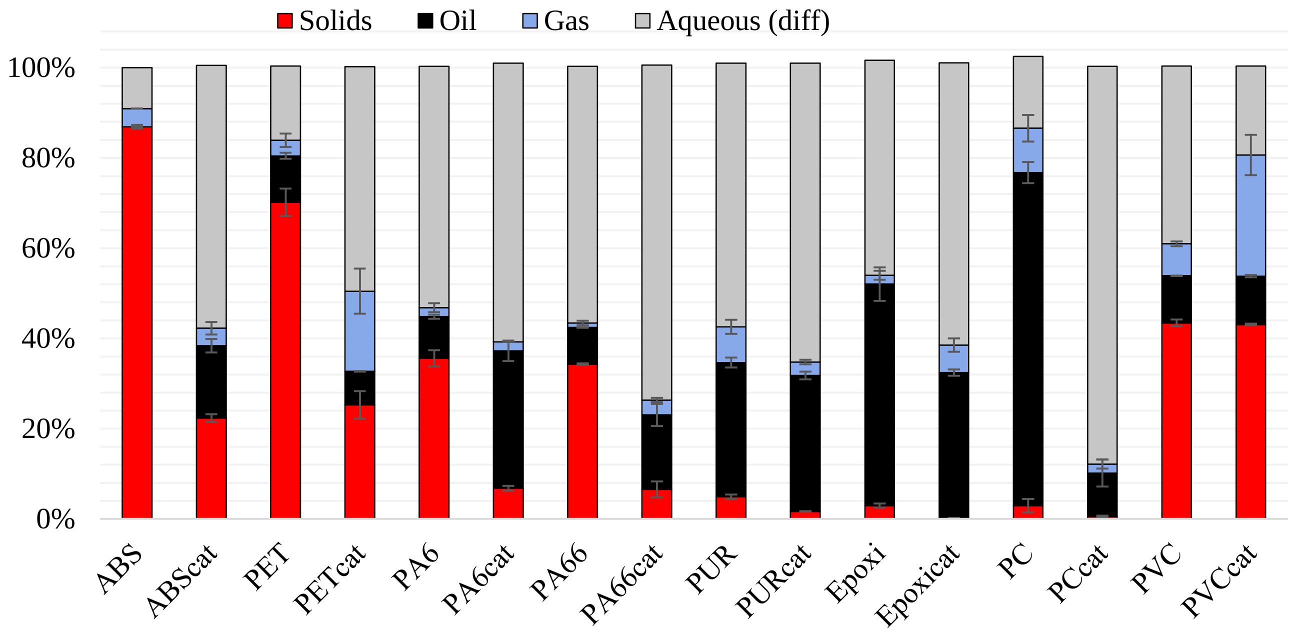


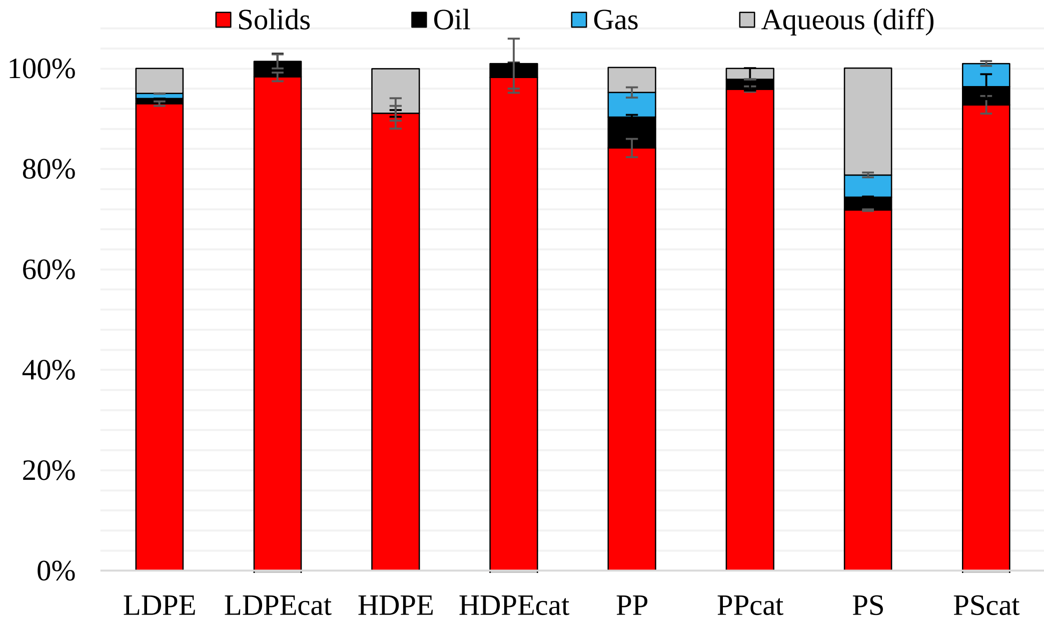
Bio-crude composition

C [%]	H [%]	N [%]	S [%]	O [%]	Ash
67.47	7.222	1.270	0.081	6.587	17.37

HTL OF PLASTICS

- Our new project is investigating end of life plastics for HTL
- Idea is to use mixed and contaminated plastics
- We performed a screening study with/without alkali catalyst
- Poly-ethylene/styrene/propylene are hardly converted
- Focus now on finding synergies and investigating co-liquefaction





CONCLUSIONS

- Continuous operation of diverse feedstocks has been demonstrated with high efficiencies
- Batch reactor studies are very useful to identify feedstock synergies and optimal process conditions for upscaling and validation at pilot scale
- There is a large potential for mixed wastes/biomass applications to exploit synergies for improved process efficiency
- There are still some engineering challenges remaining such as pumping diverse feedstocks, inline filtering and continuous product separation

Thank you for your attention!

Any questions?

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