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Microwave-assisted pyrolysis for production of sustainable biodiesel from waste sludges

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THE PROBLEM:

Safe disposal of sewage sludge is one of the most important issues in the wastewater treatment cycle

In the European Union, the 2005 sludge production was estimated in 9.4 million tons dry weight, up 54% in ten years

Sludge disposal costs may constitute up, and sometimes above, 30-50% of the total cost of operation of a WWTP

Most common disposal options at the moment are: landfilling, disposal in agriculture (about 40% EU-wide), incineration /co-incineration, use in industrial production (bricks, asphalts, concrete.)

Landfilling: less applicable due to recent EU legislation mandates recovery of still-exploitable resources from waste streams (sewage sludge still contains resources that may be put to beneficial use: among the others, nutrients and energy)

Agricultural disposal: limited by local regulations preoccupied by the effects on the food chain of the accumulation of heavy metals in soils

Demand of sludge as an “ingredient” in production of construction materials: greatly reduced due to the ongoing economic downturn in most of Europe, creating a weaker market demand for these products.

The exploitation of sludge-embedded resources is becoming a viable and sensible option:

-reduction of final waste quantities,

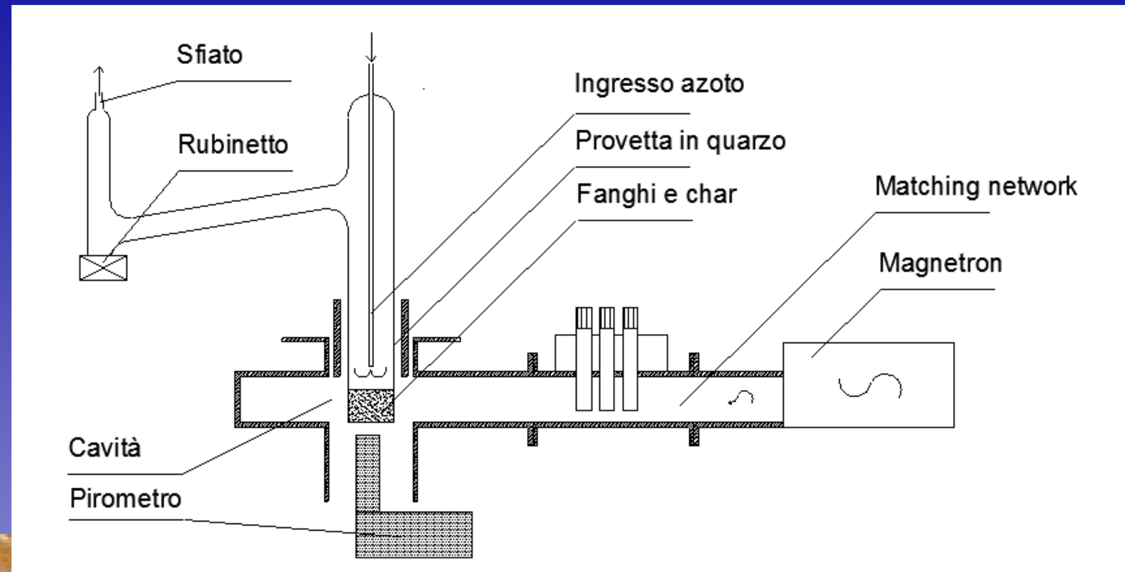
-economic benefit from recovery of resources, either in form of residual nutrients or energy content.

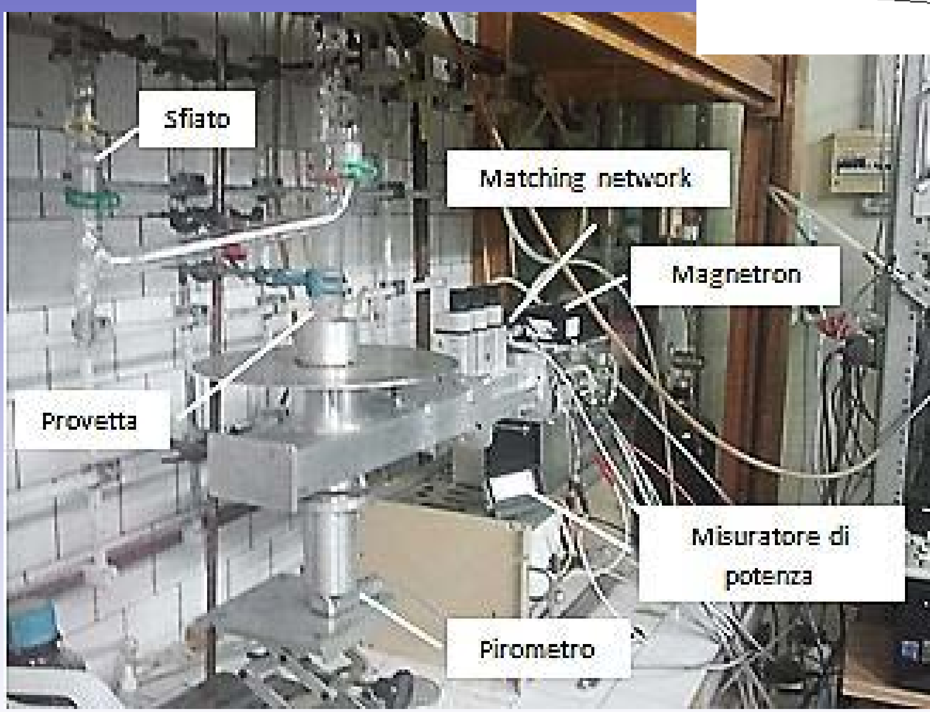
microwave-assisted pyrolysis of urban waste sludge was applied for production of SSPO (Sewage Sludge Pyrolysis Oil) and Syngas. Oil was analytically characterized and compared to mainstream alternative fuels (biodiesel)

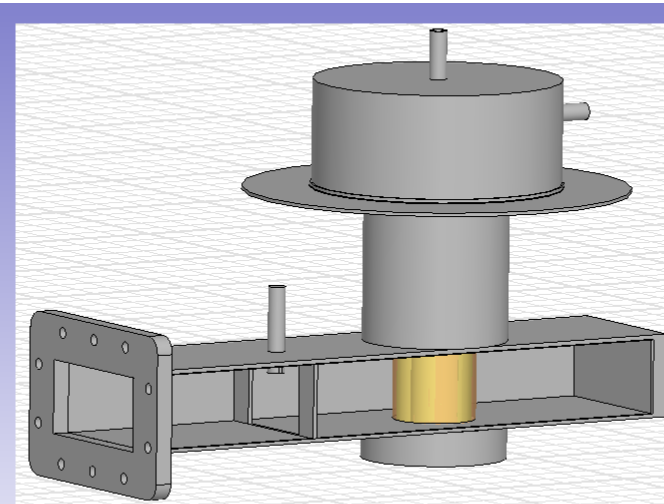
pyrolysis is sometimes applied to dry treatment of sewage sludge from urban Wastewater Treatment Plants (WWTPs). From the process, a solid, a gaseous and an oil fractions are produced in variable quantities, either one can be used as a fuel or, in the case of the oil fraction, as a prime material for new chemicals' production

final products of a pyrolysis process are influenced by its operating conditions (heating rate, final temperature and HART of volatiles) therefore process can be optimized to maximize the production of the most desirable fractions. It has been observed that combining pyrolysis and microwave heating, the production of more desirable oil and gas fractions is increased, and residual solid fraction decreases.

MATERIALS AND METHODS







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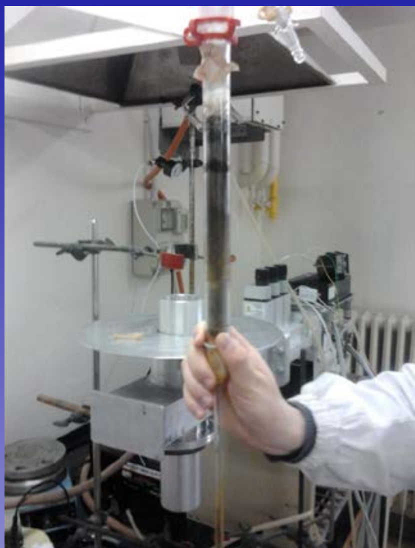
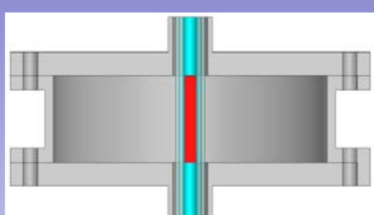
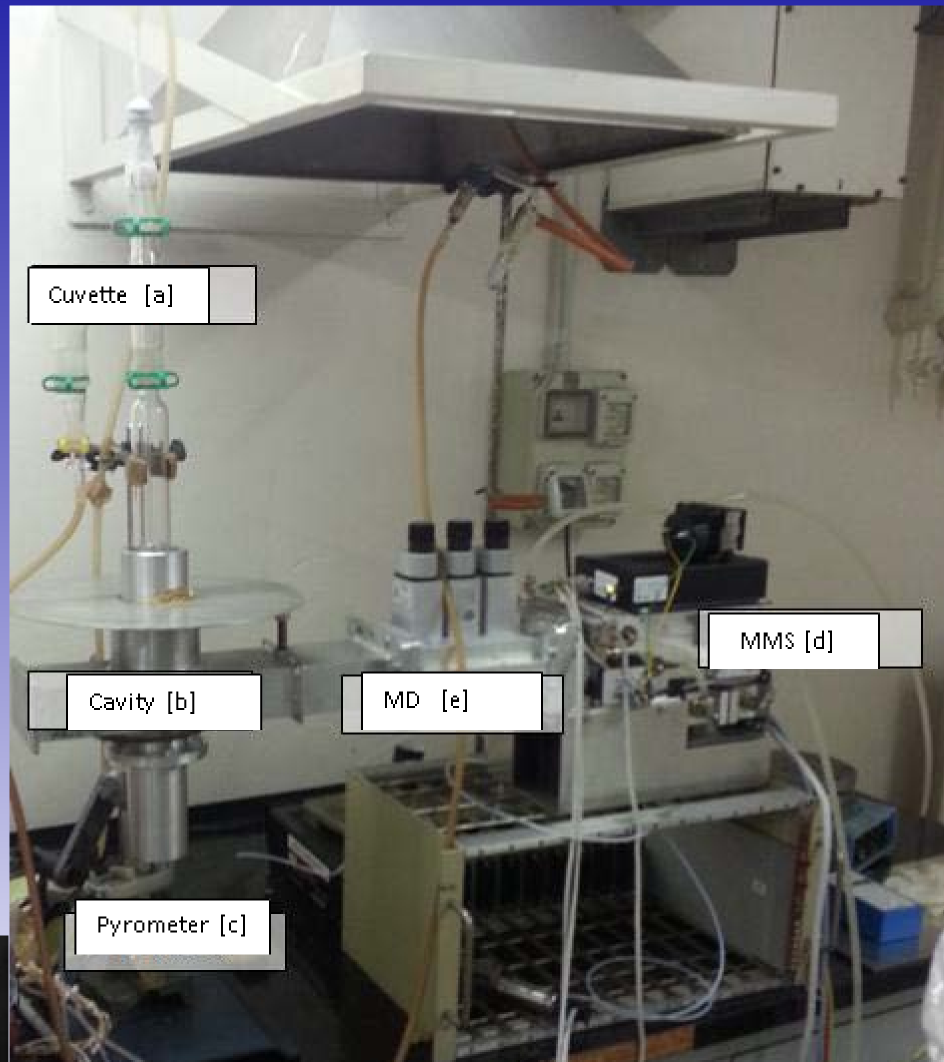
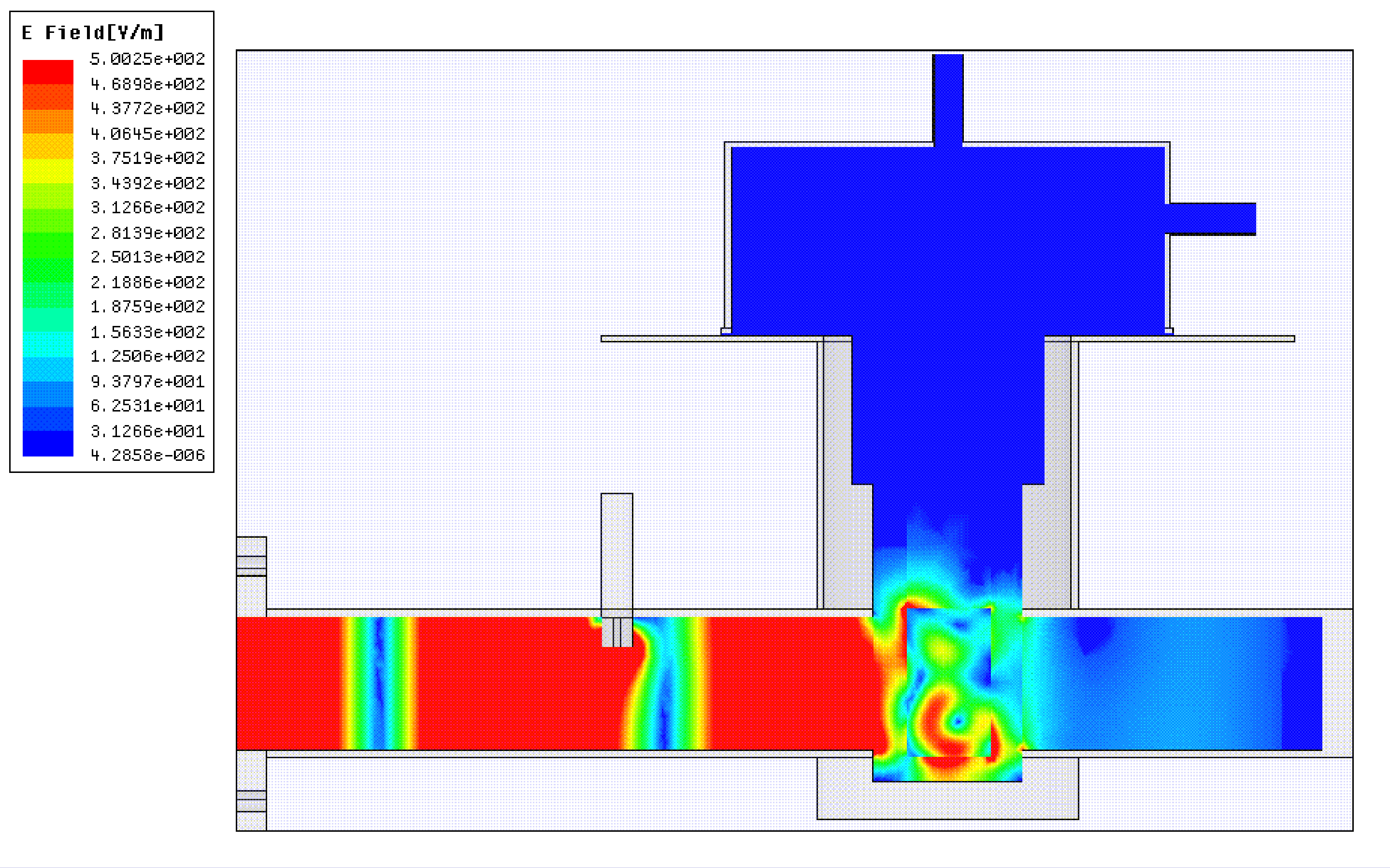






Energy Field simulation in the apparatus



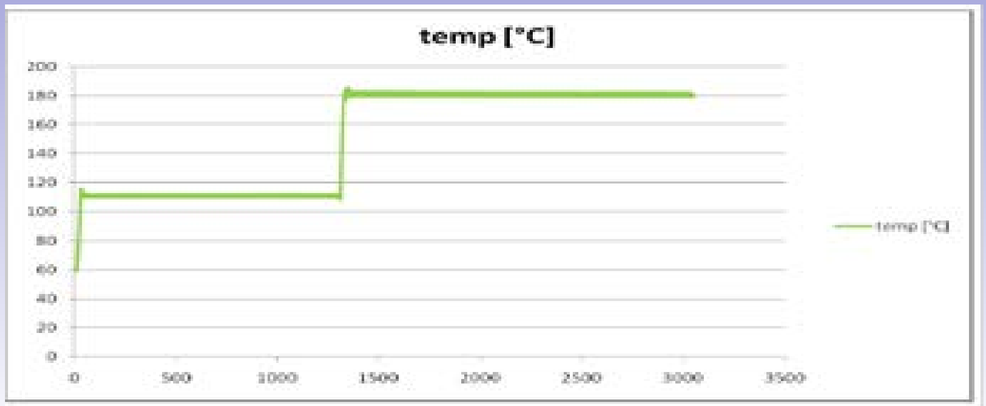
Sludge samples from waste sludge from the municipal WWTP, already subject to anaerobic digestion process, from which biogas (methane and CO_2) had already been produced.

Samples were desiccated at 60°C for 24 hours.

Dry sludge was ground to fine powder.

Sample	Dry fraction	Humidity	Volatile fraction
Desiccated sludge at 60°C/24 hrs	26.10%	73.87%	
Dried sludge at 105°C/24 hrs	85.38%	14.62%	
Dried sludge at 600°C/3 hrs	53.60%		46.40%

a controlled temperature profile was adopted for experiments in He atmosphere

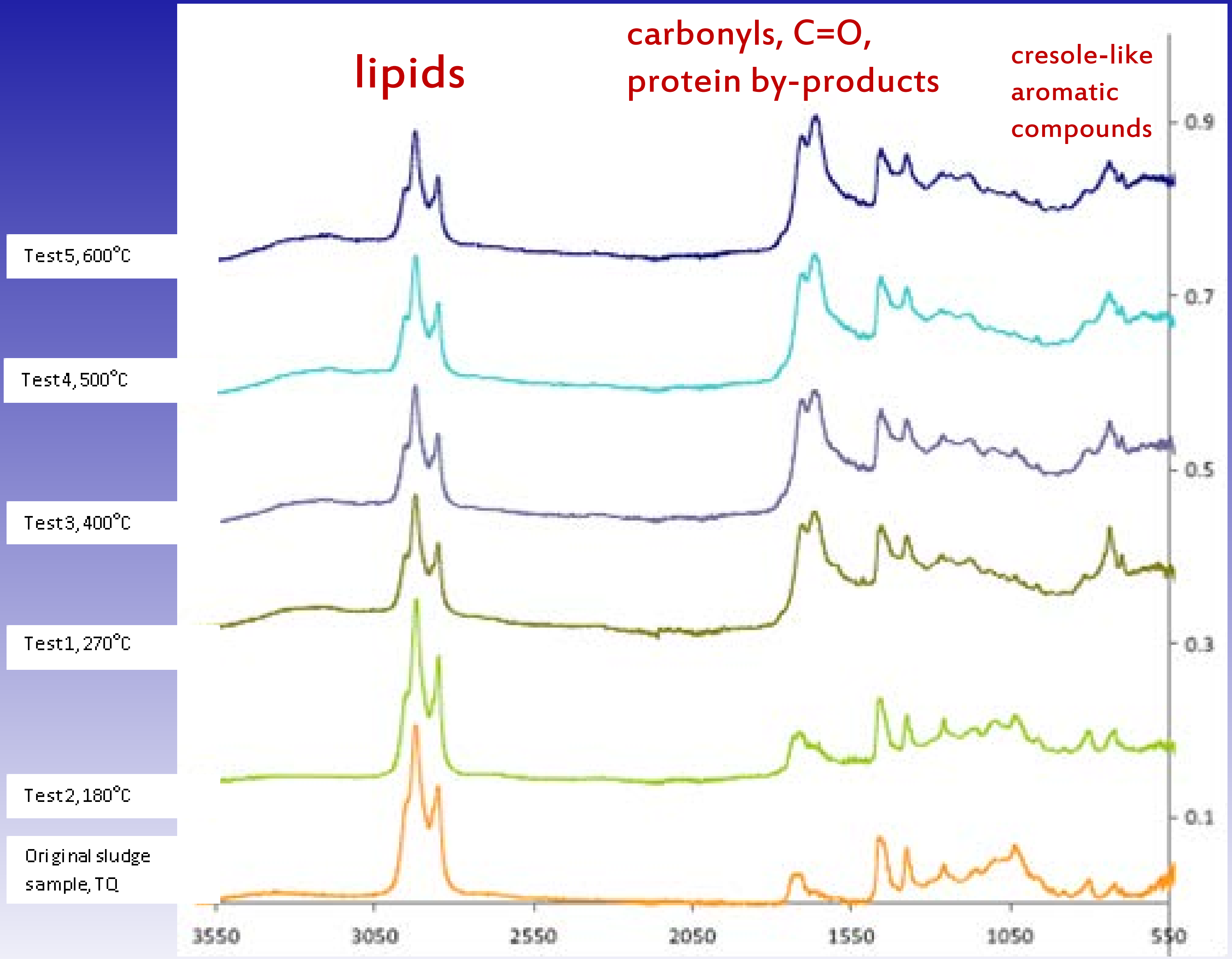


oils were extracted with solvent using a Soxhlet extractor, desiccating the extract with a vacuum rotating evaporator (rotavapor)

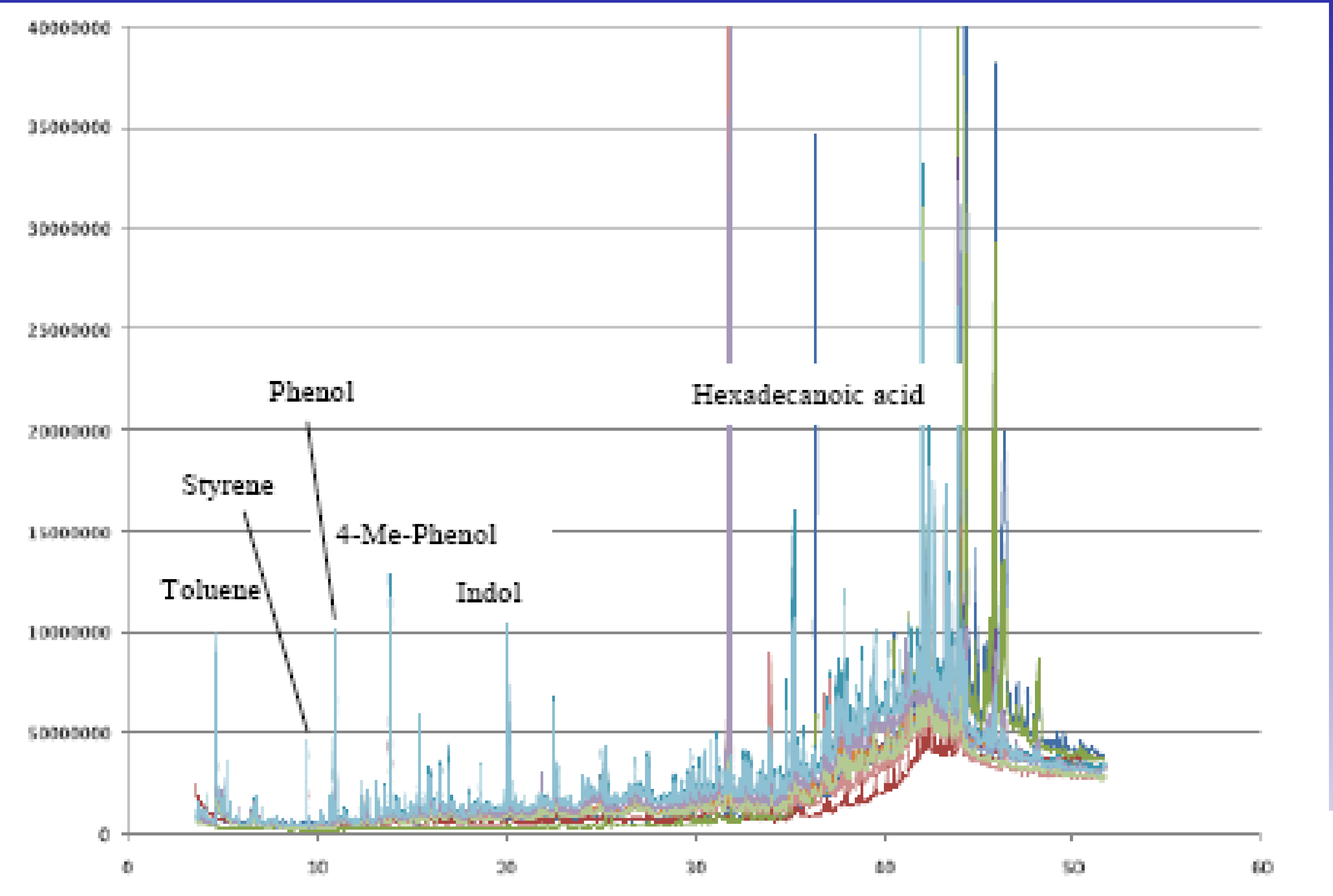
	Max Temp. ^{o}C	Time at T_{MAX} [min]	Total process Time [min]	% oil to total sludge	% oil to sludge org. fraction
TQ	60	=	=	3.57*	7*
TEST 1	270	20	55	9.68	19
TEST 2	180	28	50	3.30	7
TEST 3	400	5	55	8.64	17
TEST 4	490	1	54	10.25	21
TEST 5	600	3	56	8.71	17
TEST 6	400	6	46	11.79	24
TEST 7	500	9	51	7.63	15
TEST 8	650	-	60	7.38	15
TEST 9	280	2	8	12.52	25
TEST 10	400	2	18	10.77	22

- greatest oil yields were observed between 270 and 500C
- oil yield increases in inverse proportionality to test duration

ATR-IR spectroscopy analysis of oil samples



GC-MC analyses on diluted samples



Energetic balance summary of tests conducted

Test no./ Temp. ^{o}C	Emitted Energy [kJ]	Reflected energy [kJ]	Absorbed Energy [kJ]	Oil yield [g]	Recoverable Energy [kJ]	Process Efficiency Gross [%]	Process Efficiency Net [%]
1/ 270	49.36	13.96	35.40	1.7164	56.6	114.67	159.89
2/ 180	65.94	23.82	42.11	1.7894	59.1	89.63	140.35
3/ 400	47.22	25.08	22.14	1.5621	51.5	109.06	232.61
4/ 490	76.07	31.85	44.22	1.0775	35.6	46.80	82.54
5/ 600	44.09	21.53	22.56	1.1365	37.5	85.05	166.22
6/ 400	90.64	62.7	27.94	1.8413	60.8	67.09	217.61
7/ 500	60.19	18.79	41.40	1.022	33.7	55.99	81.40
8/ 650	94.51	33.31	61.20	0.86221	28.4	30.05	46.40
9/ 280	92.99	19.17	73.82	1.4137	46.7	50.22	63.26
10/ 400	134.62	33.34	101.28	1.4077	46.6	34.61	46.01

Gross Efficiency incorporates energy losses due to reflected energy in the irradiation system, indicating that a process overall efficiency was achieved "as was" during the experiments if its value is greater than 100

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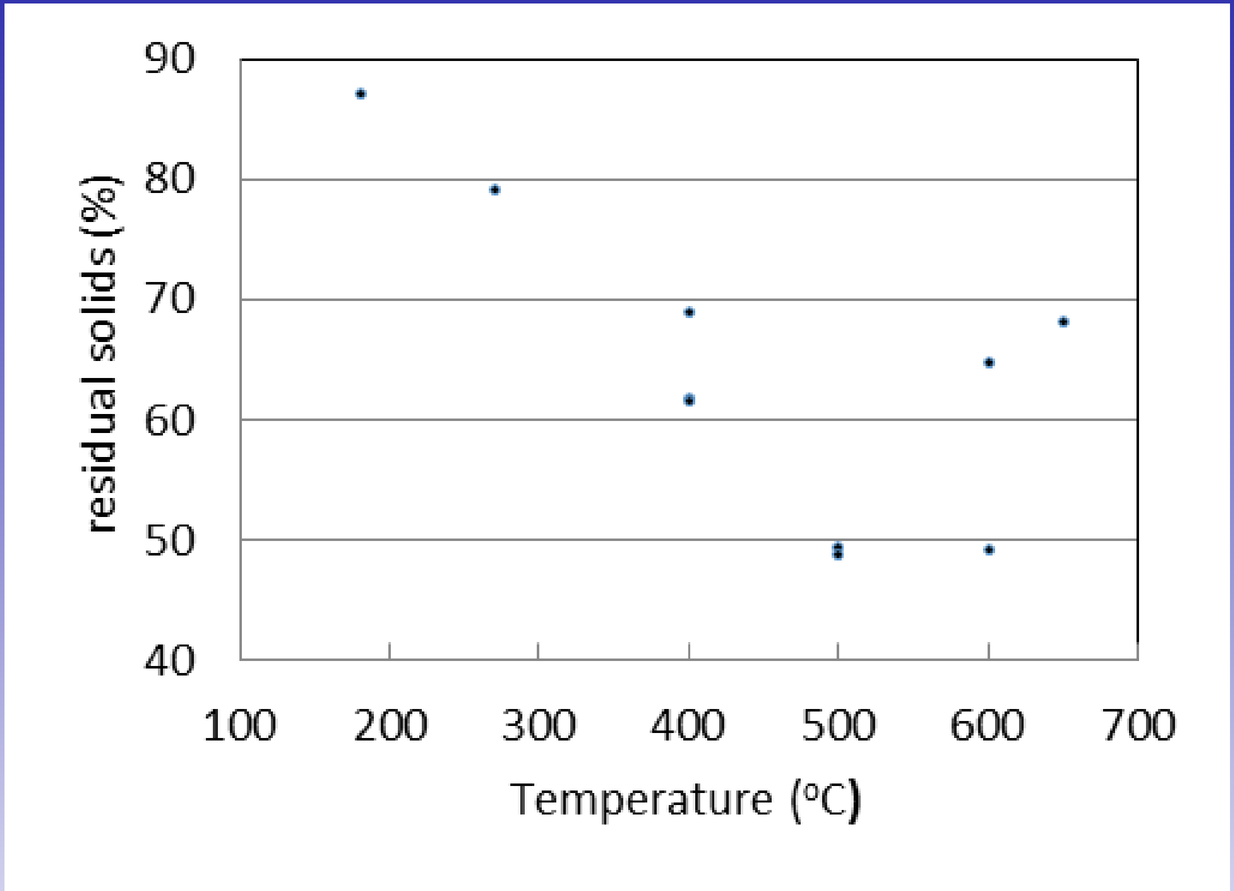
Solids residuals as a function of temperature



CONCLUSIONS

Sewage Sludge Pyrolysis Oils (SSPOs) were produced through microwave-assisted pyrolysis of municipal waste sludges.

Process yield varies according to operating conditions and depends on a good tuning between MMS and sludge samples in order to minimize reflected (non-absorbed) energy in the system that influences its energetic balance.

Obtained oil composition is similar to that reported by other authors and not dissimilar to that of biodiesel obtained from common feedstock crops, with slightly lower calorific value.

CONCLUSIONS - 2

-Based on experiments, the overall energy balance of the process is not always immediately favourable: in just two cases over ten the oil-recoverable energy was higher than the MMS-emitted energy under adopted process conditions.

-In five cases over ten the energy balance turned out to be positive if reflected energy in the system was neglected. With more accurate tuning between wave generator and samples, wave absorption could be improved (reducing the quantity of reflected waves), turning the energy balance positive.

-This could be achieved with more sophisticated equipment capable of tracking the dielectric constant of sludge samples.

CONCLUSIONS - 3

-In the energy balances presented, the positive energy contribution of the pyrolisis-generated gases was neglected for simplicity. (NOTE: the pre-digested sludge had released some of its contained energy during anaerobic bio-gasification: the additional energetic value of the biogas previously generated was also ignored)

Overall, pyrolysis can be an interesting process for production of bio-oils and syngas from a waste component such as sewage sludges, since it may allow energy-positive recovery of resources on one side, and at the same time reduce the original sludge volumes, consequently reducing disposal costs. The process may become more popular should energy and sludge disposal cost continue to rise at the current rates.

Thank you for your attention !