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"Renewable energy obtained applying torrefaction in pellets of sewage sludge and urban pruning blend"

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Introduction

Waste – Brazilian Norm 10,004/2004

Solid wastes are wastes in the solid or semi-solid states resultant from human activity

- Sewage Sludge
- Urban pruning

Federal Law nº 12,305/10 - National Solid Waste Policy

- Reuse, recycling, composting and **energy recovery** from wastes.

Source:
NBR 10,004 (2004)
Brazil (2010)

Production and disposal of sewage sludge

	Production thousand tons of dry mass/year
Australia	250
Brazil	220
China	3,700
France	1.2
Germany	2.8
Spain	1.1

Disposal:
Landfill, Agricultural, Incineration, Ocean

The costs for disposal of sludge are very expensive
$$$$$

Sewage sludge is no problem, it's solution!

Source:
Saito, M. L. (2007)
Gao, N. et al. (2014)
Pedroza, M. M. et. al. (2010)

Energy Matrix

Energy source	World	Brazil
Petroleum	39.7%	37.3%
Mineral coal	29.1%	5.9%
Natural gas	17.8%	13.7%
Hydroelectric	1.8%	11.3%
Biomass	9.5%	16.9%
Nuclear energy	1.2%	1.3%
Other renewable energies	0.9%	4.7%

Brazil
Tropical and Continental country

Hot, humid and large area for biomass crops

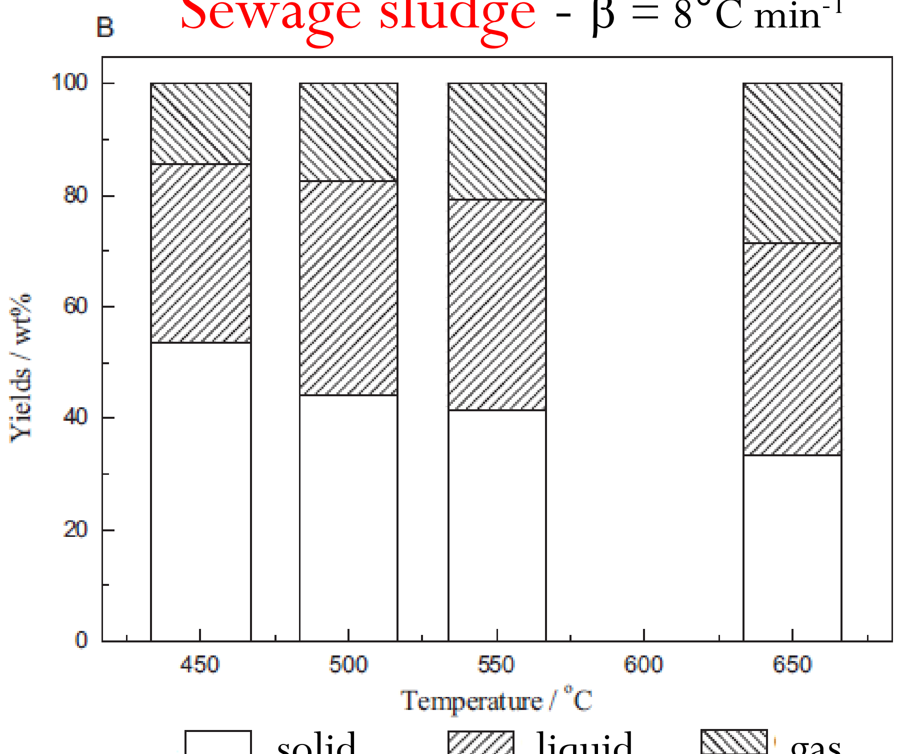
Biomass is the organic matter from plants, animals and microorganisms

Source:
International Energy Agency (2014)
Energy Research Company (2016)
Basu, P. (2010)

Energy recovery of waste: Pyrolysis

Pyrolysis: Thermochemical conversion process in absence of oxygen at low temperature (300 – 700°C)

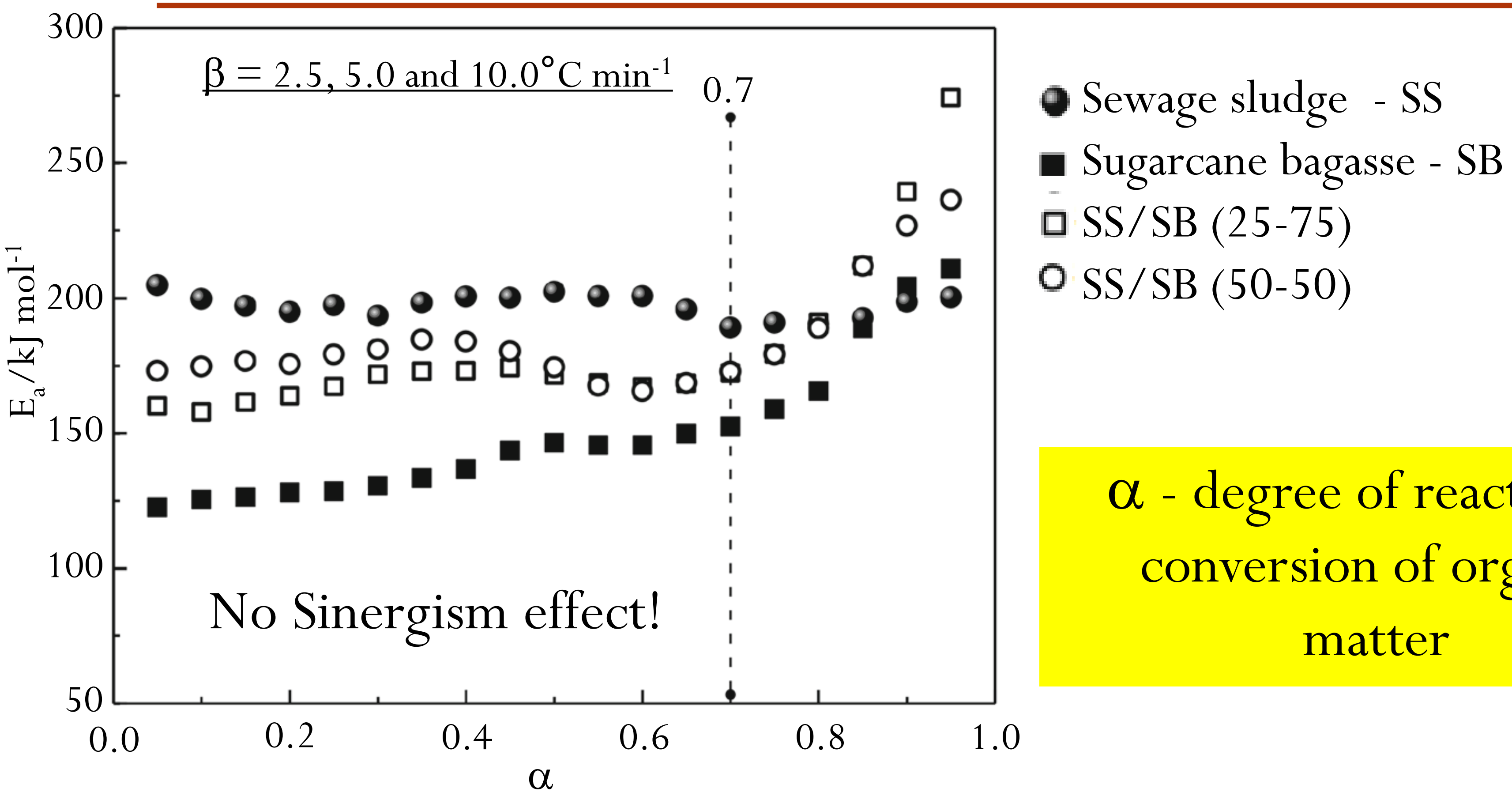
Sewage sludge - $\beta = 8°C\ min^{-1}$



- The solid fuel yield decreased from 53.6% to 33.2%.
- The liquid fuel yield increased from 32.2% to 38.3%.
- The gaseous fuel yield increased from 14.2% to 28.5%.

Source:
Gao, N. et al. (2014) Basu, P. (2010)

Energy recovery of waste: Pyrolysis



α - degree of reaction
conversion of organic matter

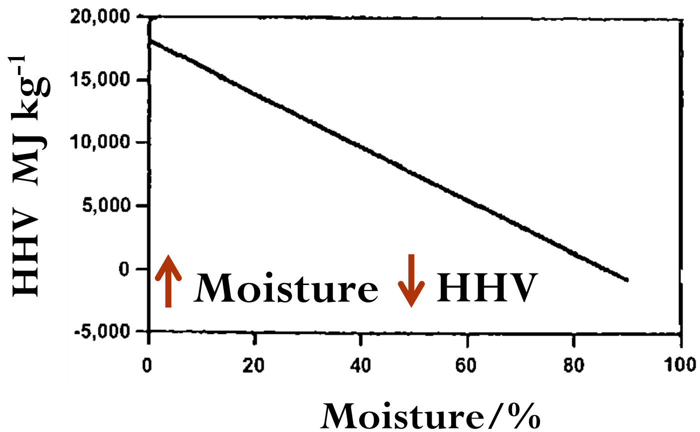
Sinergism effect: interaction between two or more agents, entities, factors, or substances that produces an effect greater than the sum of their individual effects.

Source:
Torquato, L. D. M. et al. (2015)

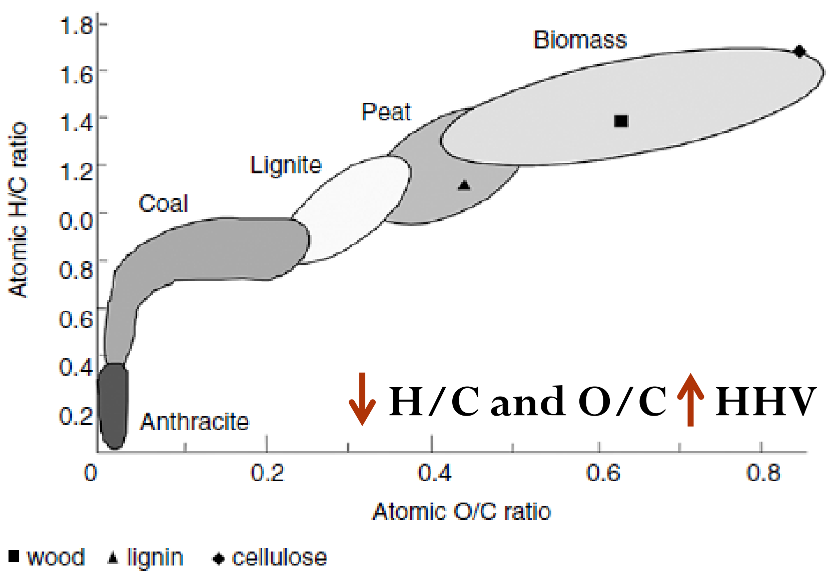
Pelletizing and torrefaction

Torrefaction: is a partial pyrolysis which is carried out in a temperature range of 200-300°C, and under an inert atmosphere

- It removes moisture and oxygen.
- It becomes more hydrophobic.
- It increases the energy density.



van Krevelin Diagram



Source:

Nhuchhen, D. R.; Basu, P.; Acharya, B. (2014)

Zhang, L.; Xu, C.; Champagne, P. (2010)

Objective

The aim of this study was to evaluate the obtaining of renewable energy from urban pruning and sewage sludge wastes, as well as the blend between them, after pelletizing and torrefaction to 260°C.

Materials and Methods

Sample collection

City: Araraquara/SP
Brazil
Population: 229,000

Waste Water Treatment Plant

Aerated Lagoons: Suspension mixed lagoons

Sludge: thermal drying process

Dry Sludge **DS** → Landfill

Landfill

Crushing and drying

UP **Urban Pruning**

Preparation of samples

DS and UP

Cryogenic Milling → Blend - **B** { 50% DS, 50% UP }

DS, UP and B → **Pelletizing:**

Pressure of 3 tons in hydraulic press machine

Torrefaction ←

<u>Slow pyrolysis</u> in muffle

Heating rate10 °C min^{-1} to 260°C

60 minutes of isotherm[1] →

DS

UP

B

energy properties were analyzed

Source:
Dias, D. S. et al (2017)

Analytical Techniques	Experimental Condition	Equipment / model
Ultimate Analysis % C, H, N, S and O **H/C and O/C**	Sample mass - 1.5 mg	Elementary Analyzer CHNS/O 2400ii Perkin Elmer
Proximate Analysis[1] **% Moisture,** Volatile Material, Carbon Fixed and Ash	Sample mass - 10.0 mg β = 50.0°C min^{-1} At 110°C Isotherm 15 min. At 600°C Isotherm 30 min. CO_2 and Synthetic air	**TG/DTA Simultaneous** SDT-2960 – TA Instruments
Higher Heating Value **HHV/MJ kg^{-1}**	Sample mass – 400/800 mg	Bomb Calorimeter 2901EB Parr Instrument Company
Ignition temperature **°C**	Sample mass - 7.0 mg β = 20°C min^{-1} 25 untill 400°C N_2 and Synthetic air	**TG/DTA Simultaneous** SDT-2960 – TA Instruments
Kinetics **Ea/kJ mol^{-1}**	Sample mass - 7.0 mg β = 5.0, 10.0, 20.0 °C min^{-1} 25°C untill 700°C/N_2	**TG/DTA Simultaneous** SDT-2960 – TA Instruments

Source:
Torquato, L. D. M. et al. (2015)

Results and discussion

Before Pelletizing and Torrefaction		Sugarcane Bagasse	Miscanthus	Sewage Sludge	DS	UP	B
Proximate	Moisture/%	7.6	9.8	6.2	5.74	6.86	5.93
	Volatile Material/%	79.2	69.4	58.9	40.10	67.69	54.96
	Fixed Carbon/%	9.6	20.4	19.0	11.01	21.55	16.75
	Ash/%	3.5	0.4	15.9	43.15	3.90	22.36
Ultimate	C/%	45.1	53.4	58.5	28.46	44.58	37.46
	H/%	5.6	4.4	9.0	4.57	5.78	5.35
	O/%	38.0	41.3	27.45	16.39	38.88	28.11
	H/C[1]	1.691	1.592	1.163	1.314	1.732	1.560
	O/C	0.843	0.773	0.469	0.576	0.872	0,750
HHV/MJ kg^{-1}		17.5	16.8	20.43	15.63	13.72	**20.36**
Ignition Temperature/°C		240	-	250	250	260	**235**

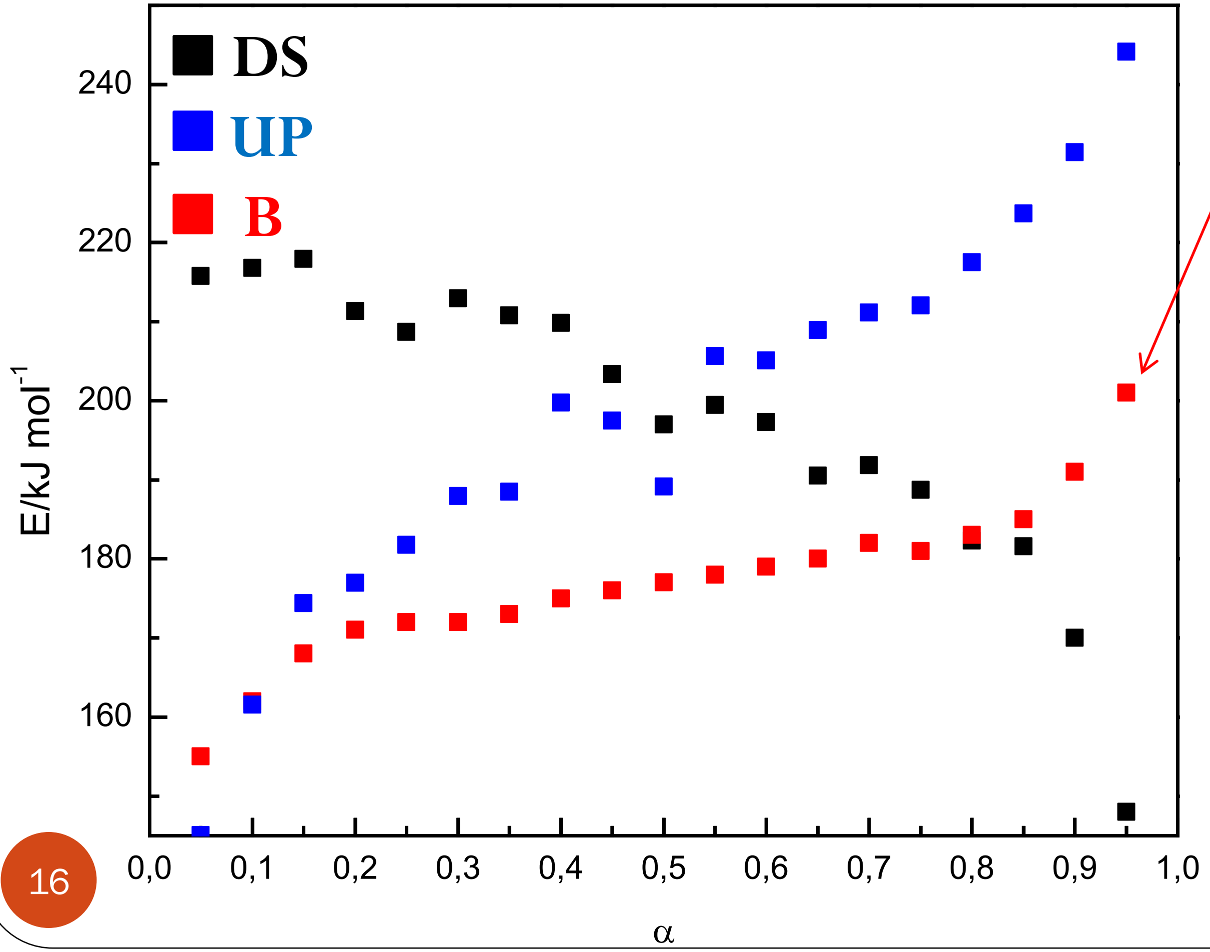
intermediate parameters

[1] $H/C = 1.4125(O/C) + 0.5004$

Source:
Torquato, L. D. M. et al. (2015)
Cruz, G; Crnkovic, P. M. (2016)
Jayaraman, K.; Gokalp, I. (2015)
Basu, P. (2010)

After Pelletizing and Torrefaction: Activation energy

Local Linear Integral Isoconversional Method analogous to the Wanjun-Donghua Method



B needed less energy to start and to keep the reaction

Average activation energy

DS = 198 kJ mol^{-1}

UP = 198 kJ mol^{-1}

B = 177 kJ mol^{-1}

Synergism effect

After pelletizing and torrefaction B sample

Parameters	Before	After
Moisture/%	5.93	3.68
H/C	1.560	1.296
O/C	0.750	0.563
HHV/MJ kg^{-1}	20.36	32.15
Mass Reduction/%	-	31.8%
Volume Reduction/%	-	50.0%
Hygroscopy test[1]	7.43%	4.92%

57.9% ↑

It was more energy in lower volume

[1]Moisture absorption after one week at temperature of 25°C and 70% of relative humidity in a climatic chamber

Pelletizing and torrefaction improved the energetic properties of B sample!

Conclusion

- Blend sample presented higher HHV than the DS and UP samples (20.36 MJ kg^{-1} against 15.63 MJ kg^{-1} and 13.72 MJ kg^{-1}) due to the synergism effect.

- Pelletizing and torrefaction improved the energetic qualities of Blend sample (32.15 MJ kg^{-1} against 20.36 MJ kg^{-1}).

- Blend sample can be applied as a renewable energy souce.
  - Reduction of fuel costs from non-renewable energy sources.
  - Minimization of environmental impacts due to inadequate disposal of wastes
  - Noble end to the wastes.

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