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Microbial and Chemical Enhancement of In-Situ Carbon Mineralization in Geologic Formations DE-FE0002389

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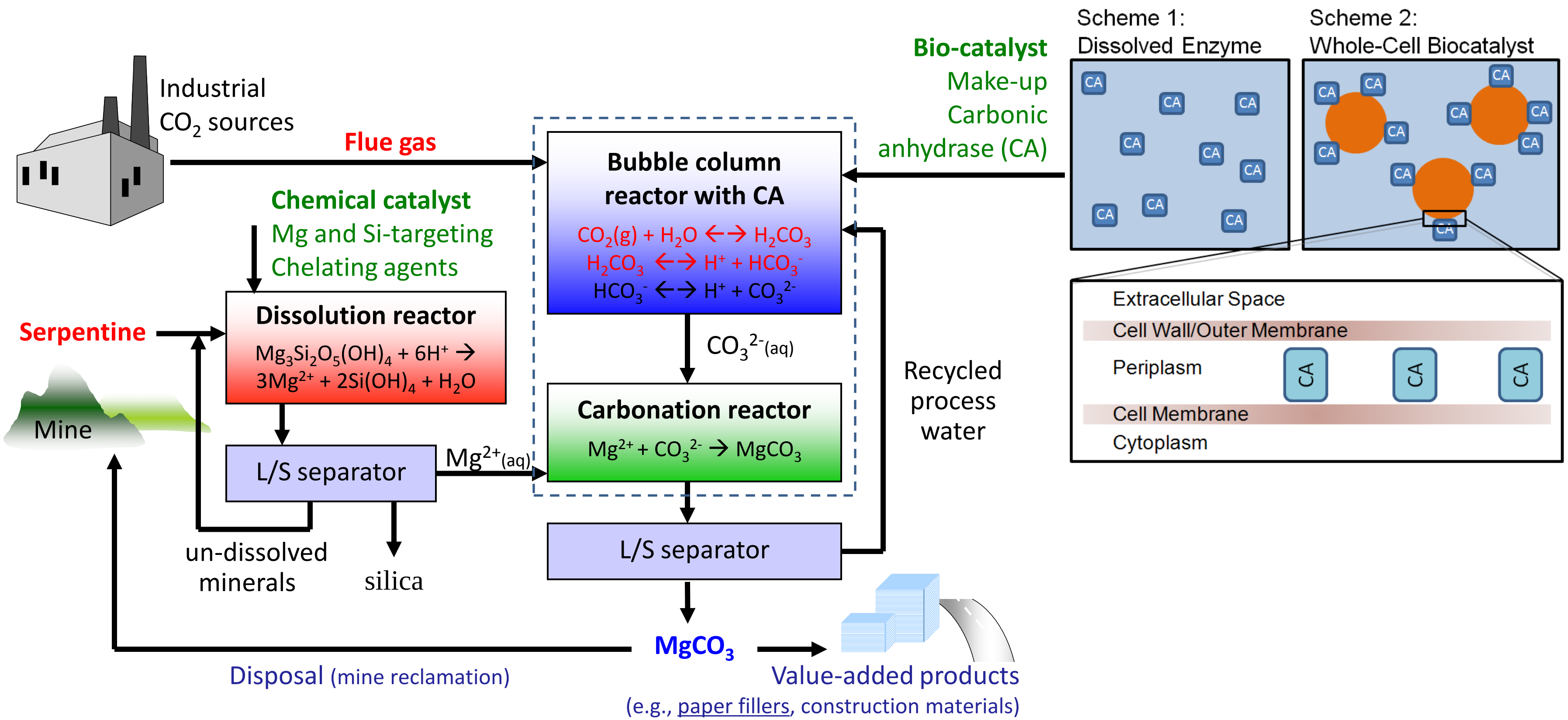
U.S. Department of Energy
National Energy Technology Laboratory
Carbon Storage R&D Project Review Meeting
Developing the Technologies and Building the Infrastructure for CO_2 Storage
August 21-23, 2012

Park Group

Presentation Outline

- **Benefit and Overview**
- **Results and Accomplishments**
  - Characterization of Antigorite
  - Anaerobic Digestion
  - Chemically Enhanced Mineral Dissolution
  - Controlled Precipitation of $MgCO_3$
  - In-Situ Mineral Carbonation
- **Summary**

Chemical and Biological Catalytic Enhancement of Weathering of Silicate Minerals as Novel Carbon Capture and Storage Technology



- ❑ No need for the solvent regeneration and CO_2 compression, straightforward MVA
- ❑ Alternative CO_2 utilization option with improved economic feasibility

Benefit of the Program

- Identify the Program goals being addressed.

  This technology contributes to the Carbon Storage Program's effort of ensuring 99% CO_2 storage permanence in the injection zones.

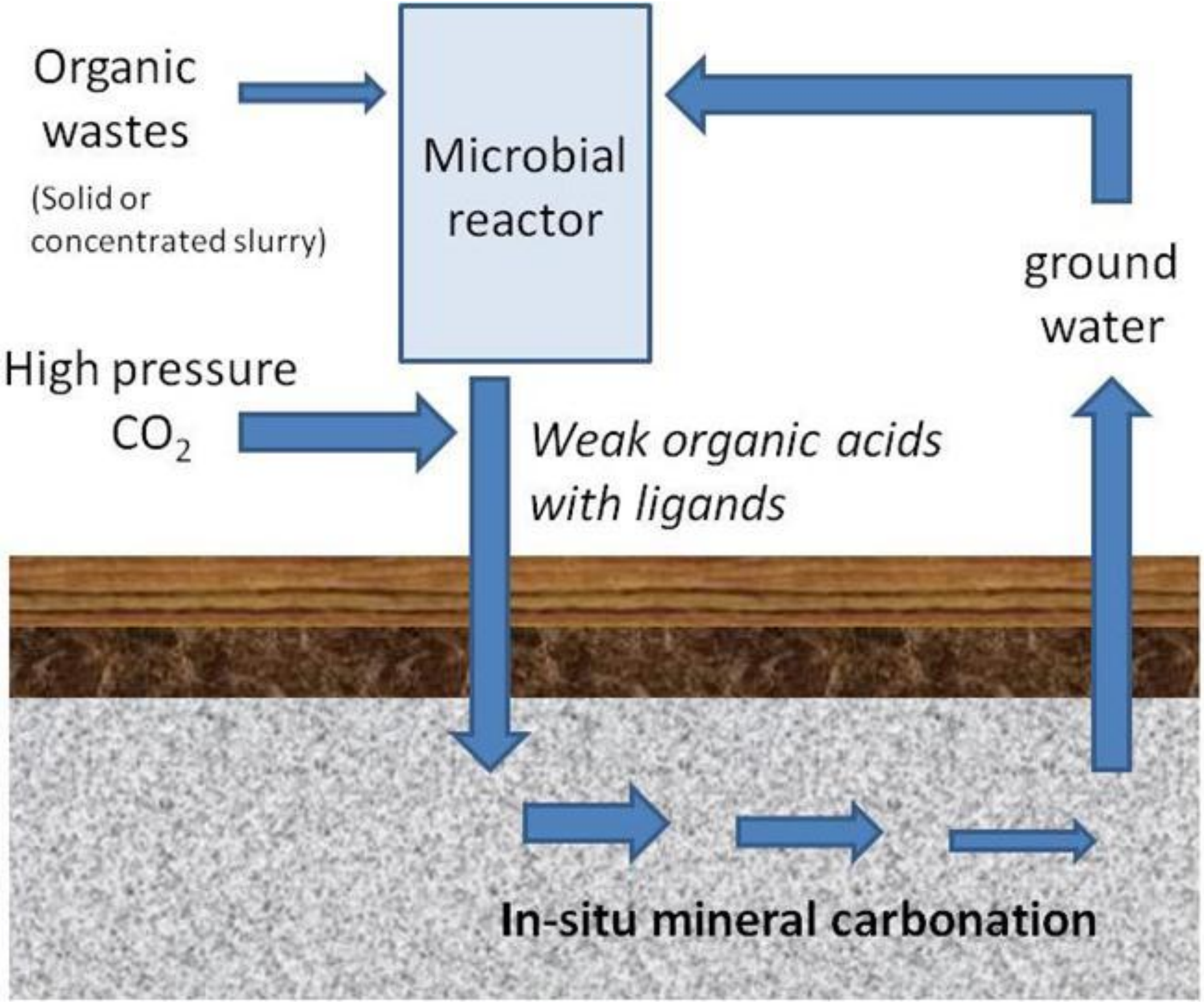
- Project benefits

  The research project is developing chemically enhanced in-situ mineral carbonation system to increase the mineral trapping of injected CO_2. The technology, when successfully demonstrated, will increase the stability of the CO_2 geological storage. This technology contributes to the Carbon Storage Program's effort of ensuring 99 percent CO_2 storage permanence in the injection zone(s).

Project Overview: Goals and Objectives

- This project aims to provide the knowledge basis for in-situ CO_2-mineral-brine interaction for geologic sequestration.
- A microbial system that produces weak acids will be developed in order to chemically enhance the in-situ mineral dissolution and, in turn, to achieve faster carbon mineralization kinetics.
- The proposed project will provide important research experience for both graduate and undergraduate students who will be faced with the challenge of implementing and deploying CCS technologies.

Overall Schematic

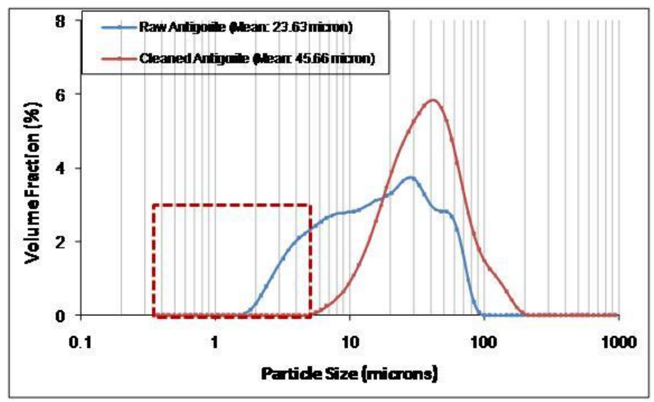


Characterization of Antigorite

Chemical Composition

Mineral Description	Element/Oxide [wt%] Raw Antigorite
Al_2O_3	0.166
CaO	0.217
Cr_2O_3	0.032
FeO	3.664
Fe_2O_3	3.415
MgO	43.342
NiO	0.254
K_2O	0.003
SiO_2	36.429
Na_2O	0.005
Volatiles C, CO_2	0.810
C, fixed	0.025
Water	0.600
Water, bonded	12.065
Total	101.028

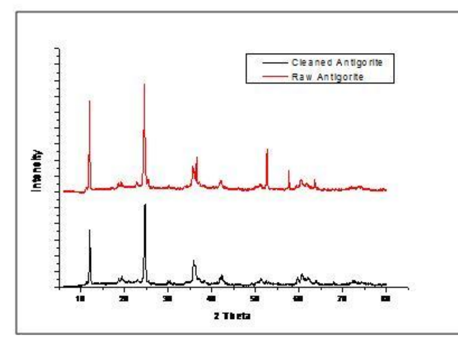
Removal of Fines (< 5μm)



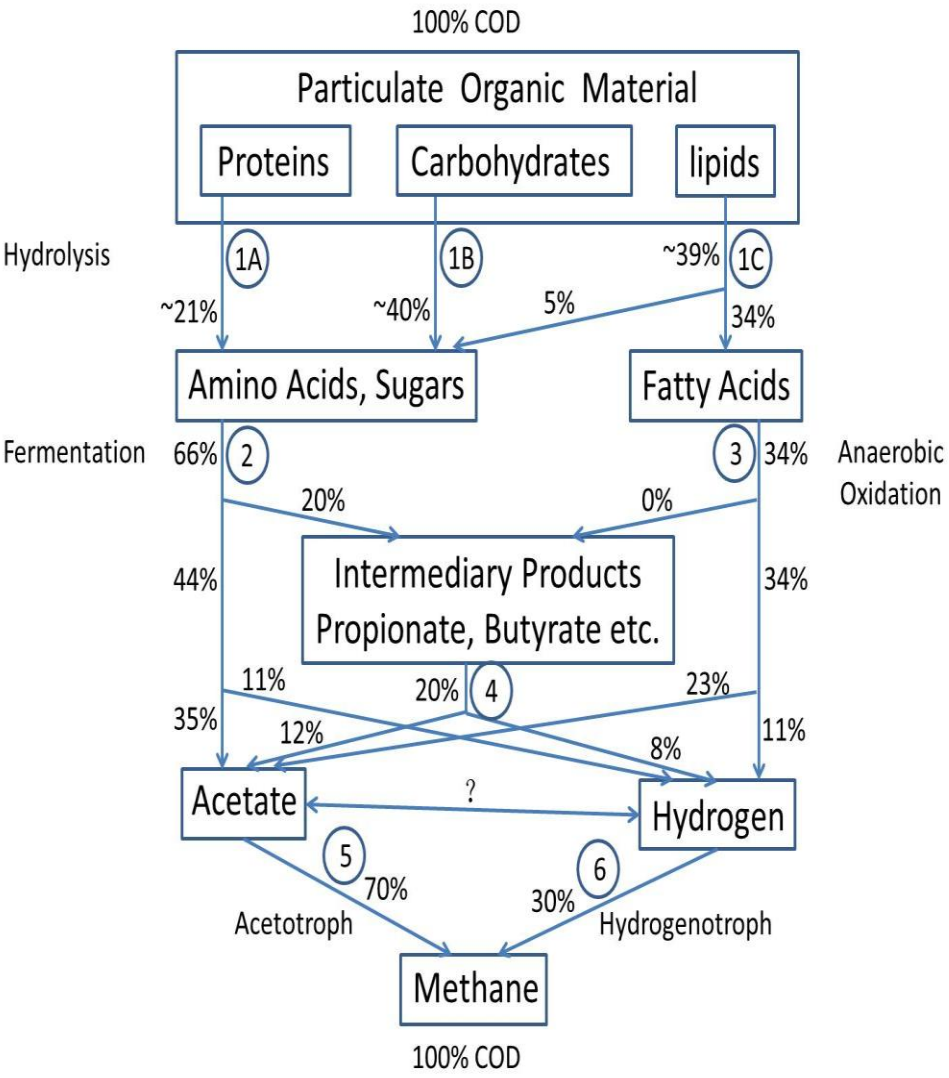
Sample	Surface Area m^2/g	Average m^2/g
Raw Antigorite_A	6.61	6.44
Raw Antigorite_B	6.27	

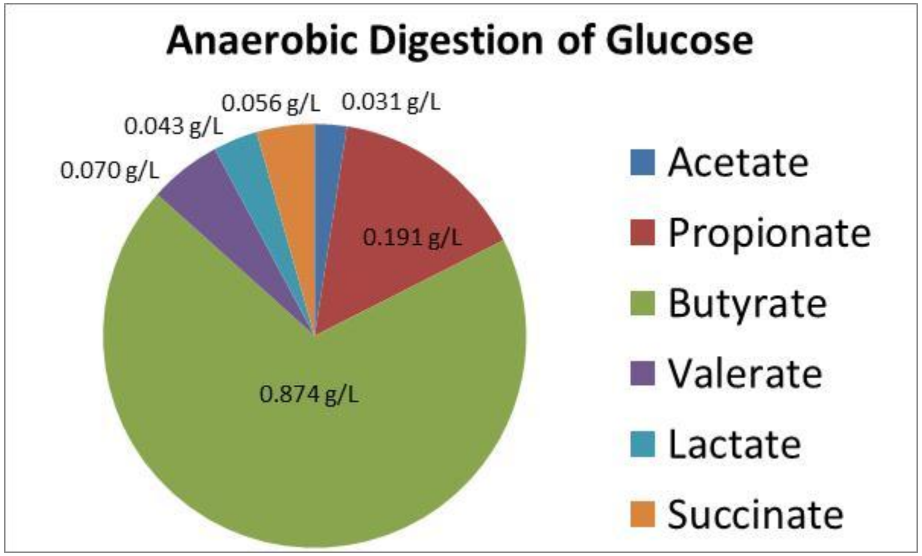
Cleaning

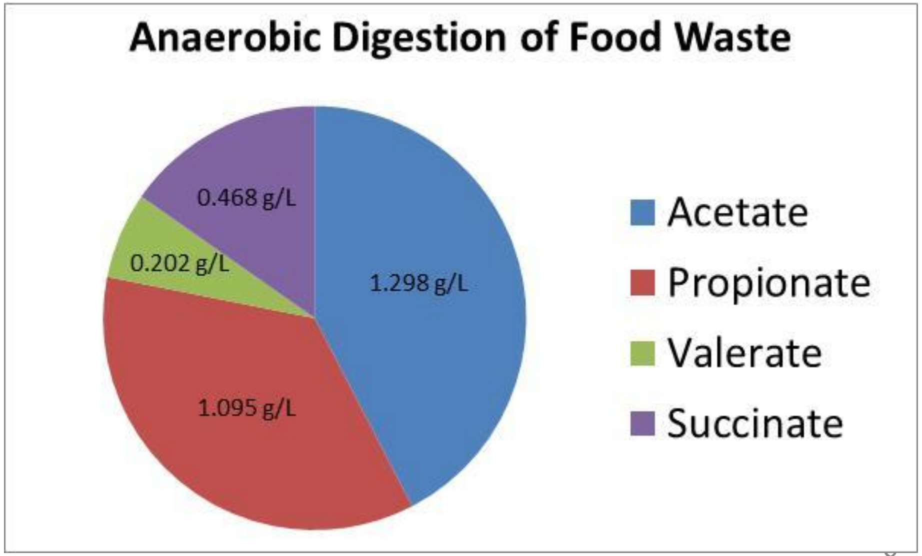
Sample	Surface Area m^2/g	Average m^2/g
Cleaned_Antigorite_A	2.96	3.01
Cleaned_Antigorite_B	3.05	



Anaerobic Digestion

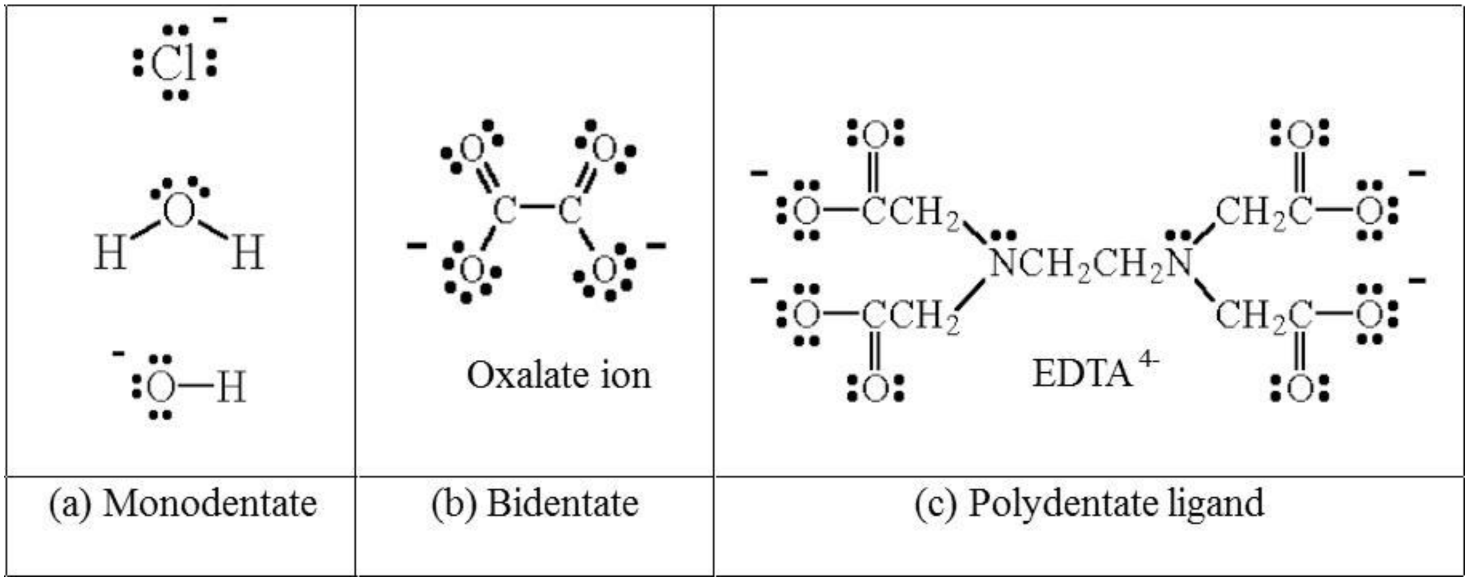


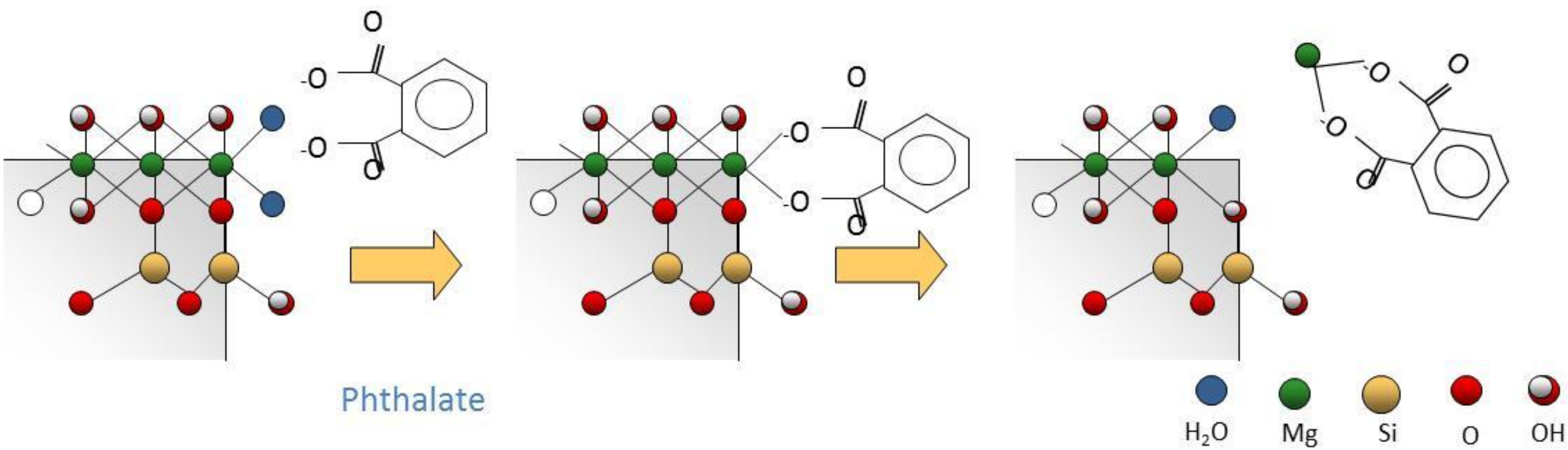




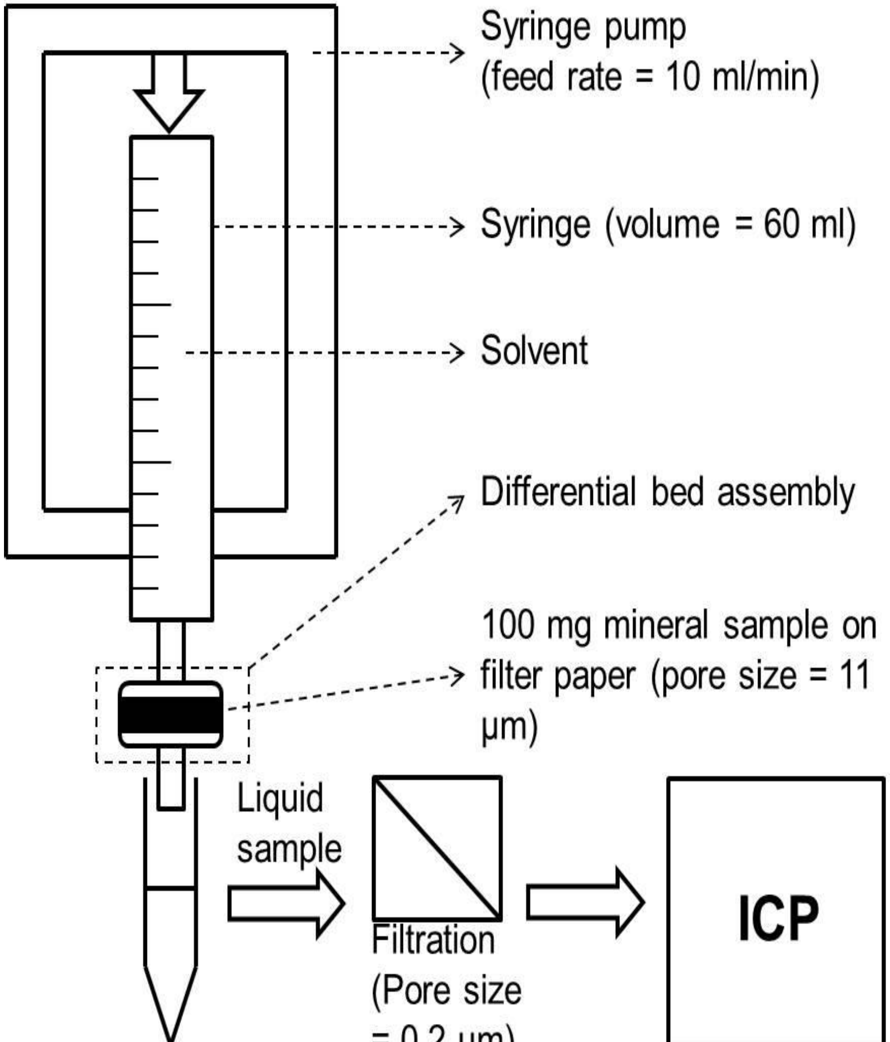
W. Gujer and A. J. B. Zehnder. 1983, Conversion process in anaerobic digestion, Water Science and Technology, Vol. 15, pp. 127-167.

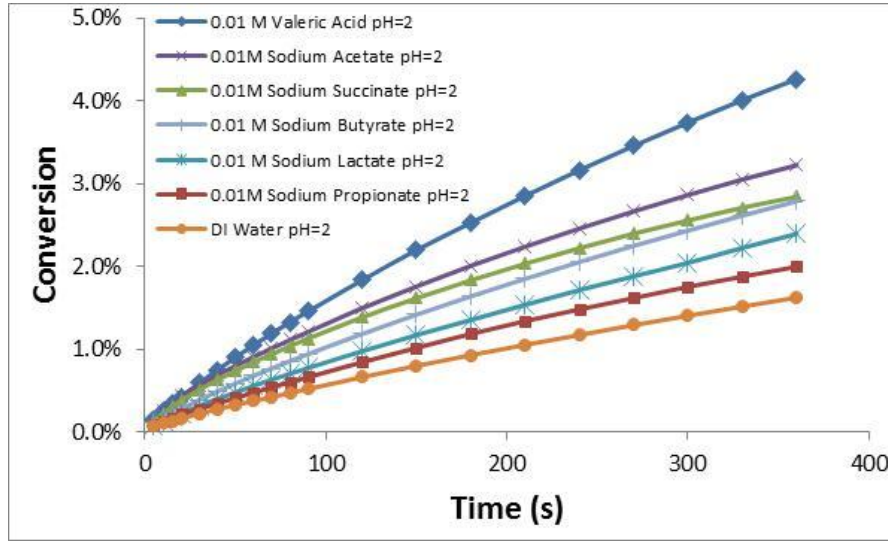
Chemically Enhanced Mineral Dissolution

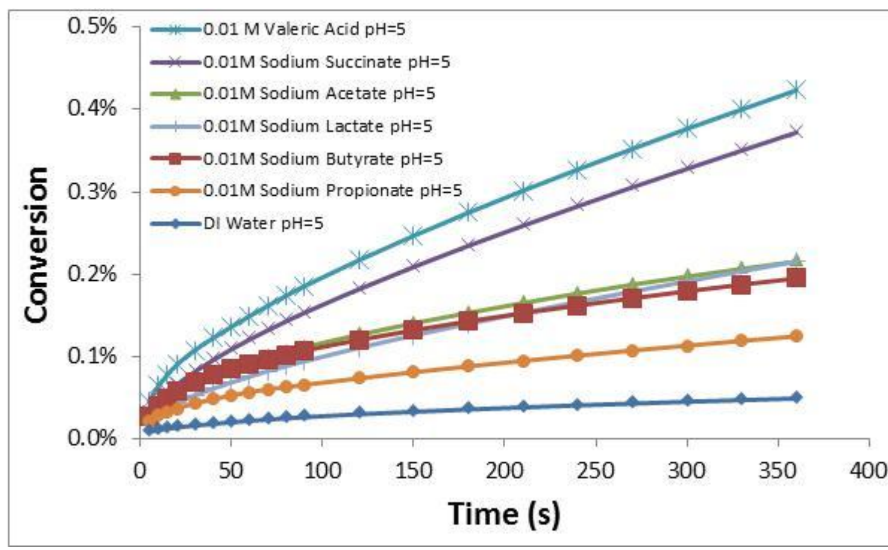




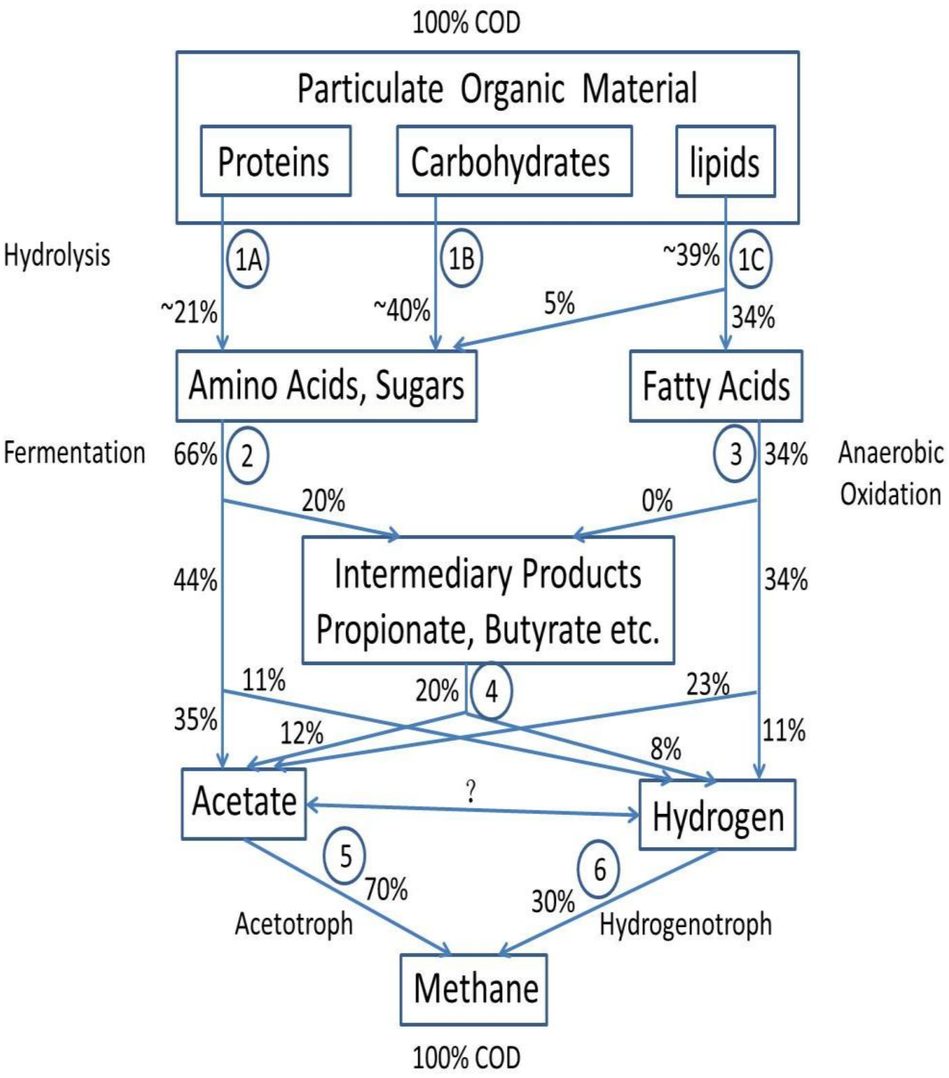
Effect of Chelating Agents on Antigorite Dissolution

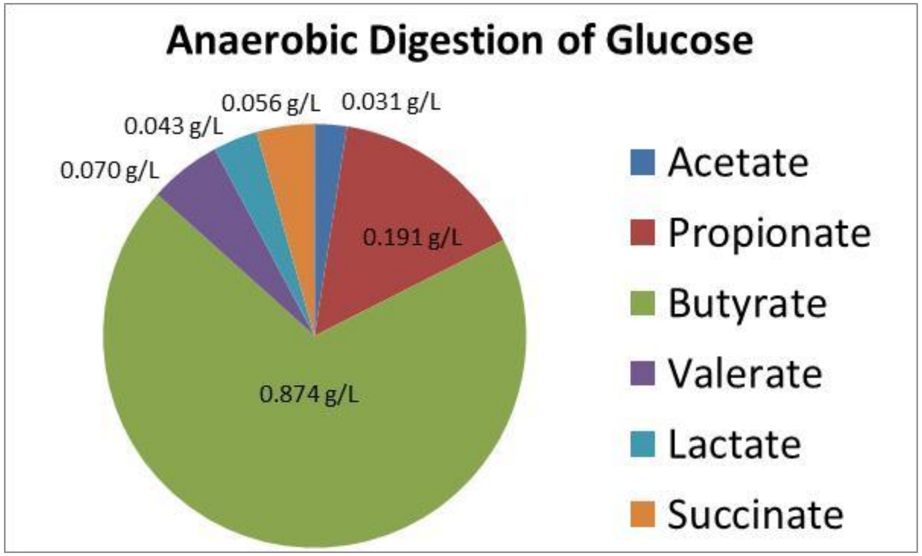


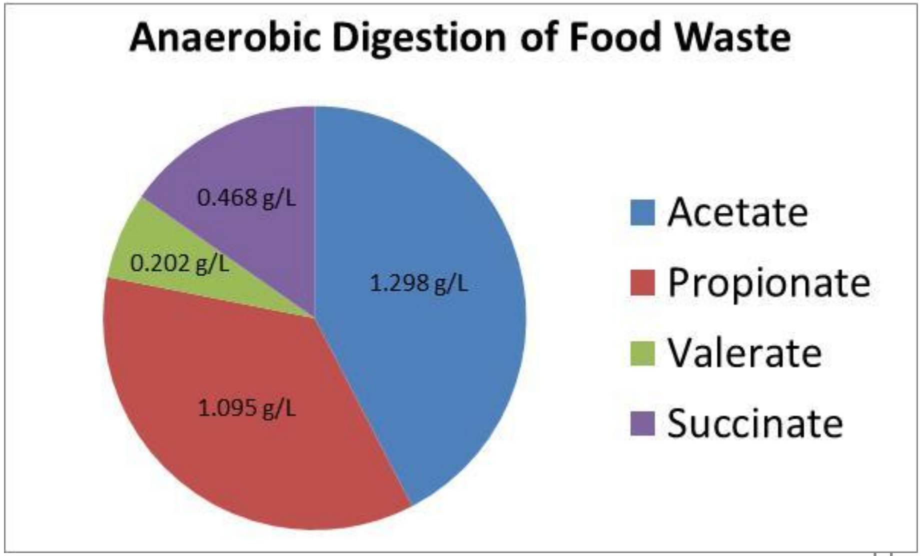




Anaerobic Digestion

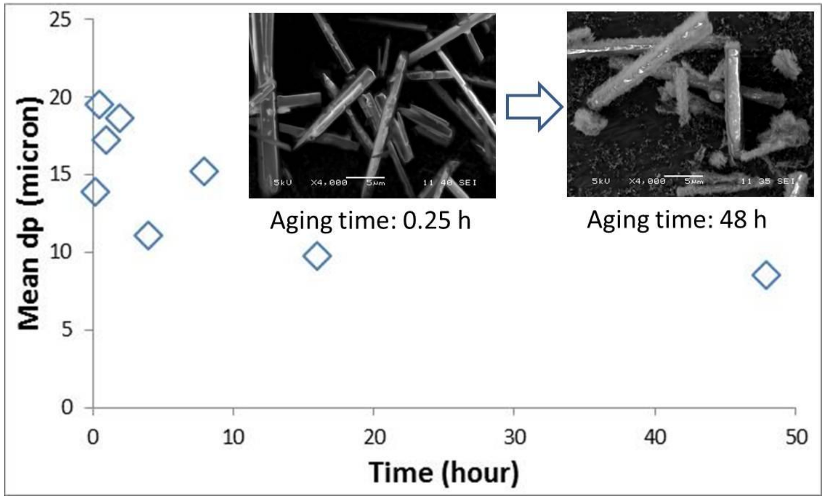


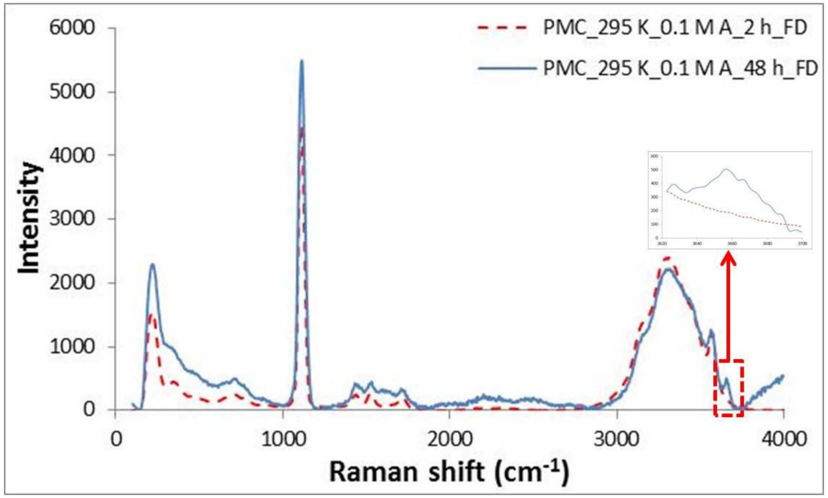


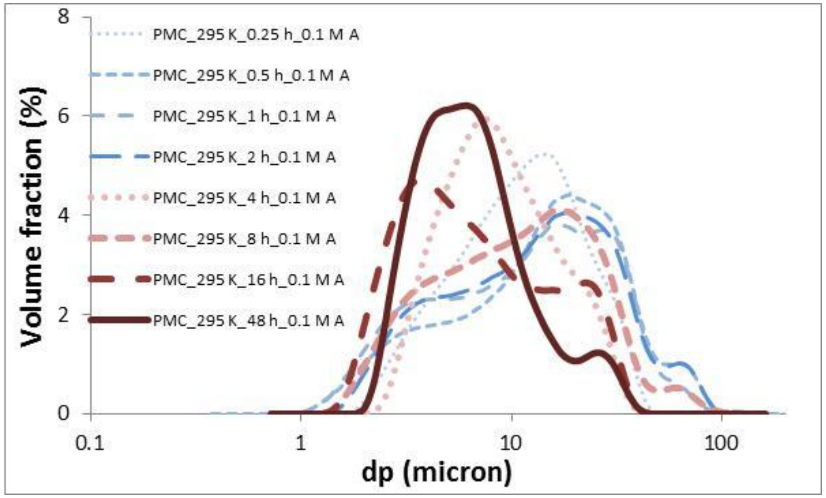


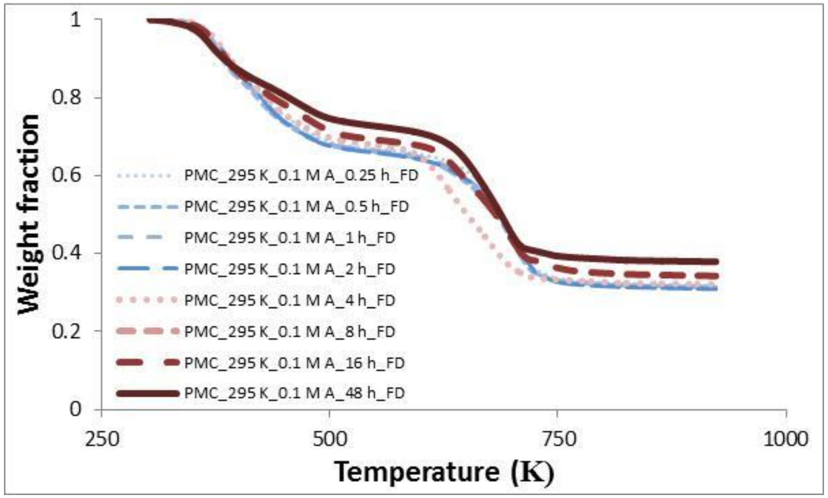
W. Gujer and A. J. B. Zehnder. 1983, Conversion process in anaerobic digestion, Water Science and Technology, Vol. 15, pp. 127-167.

Effect of Aging Time at 295K

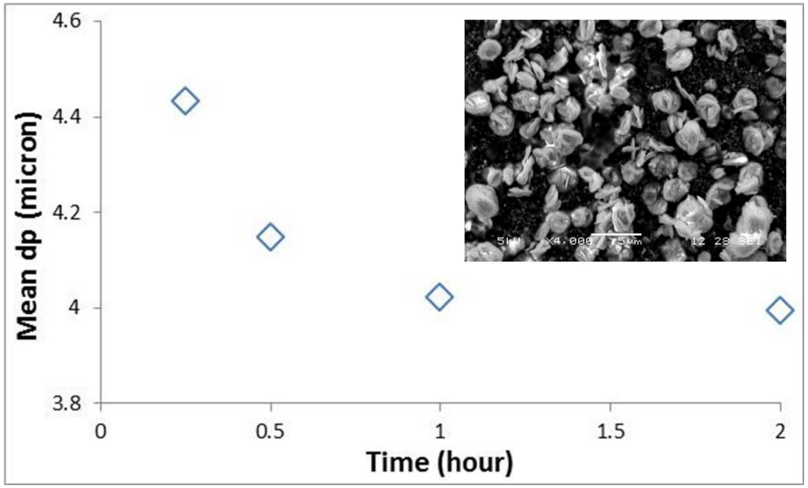


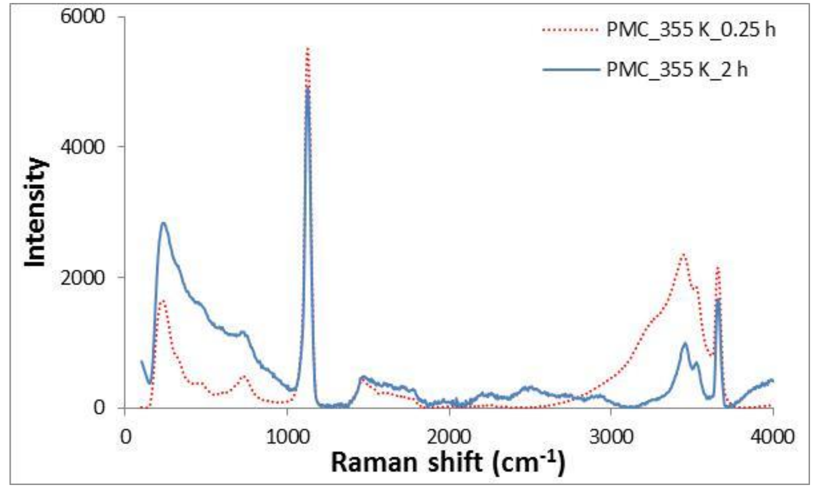


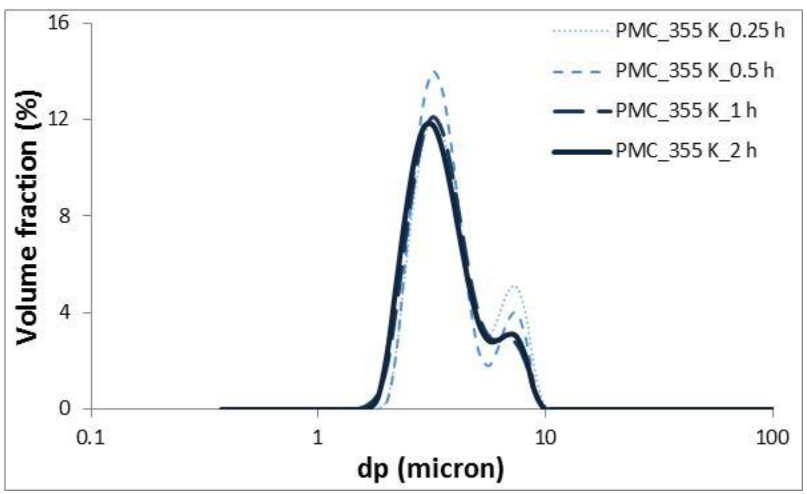


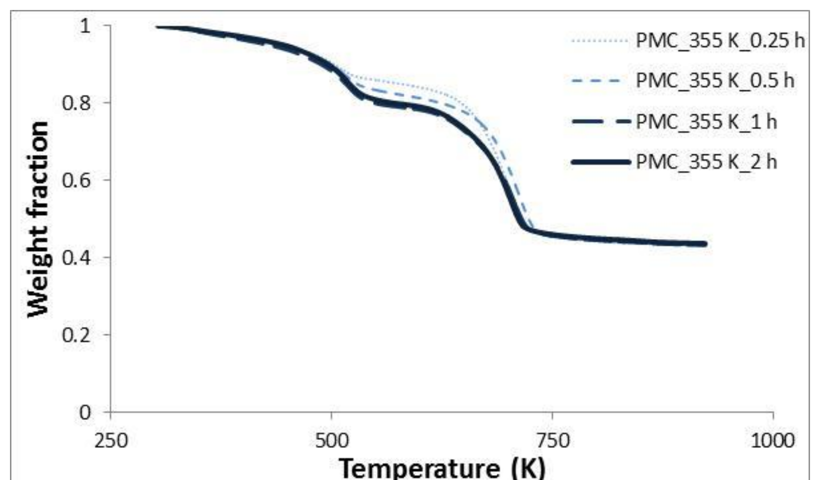


Effect of Aging Time at 335K

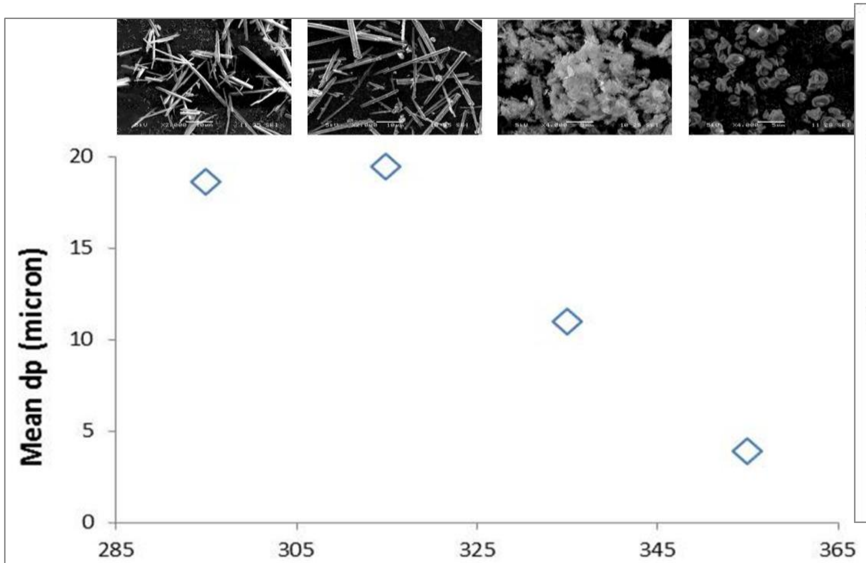


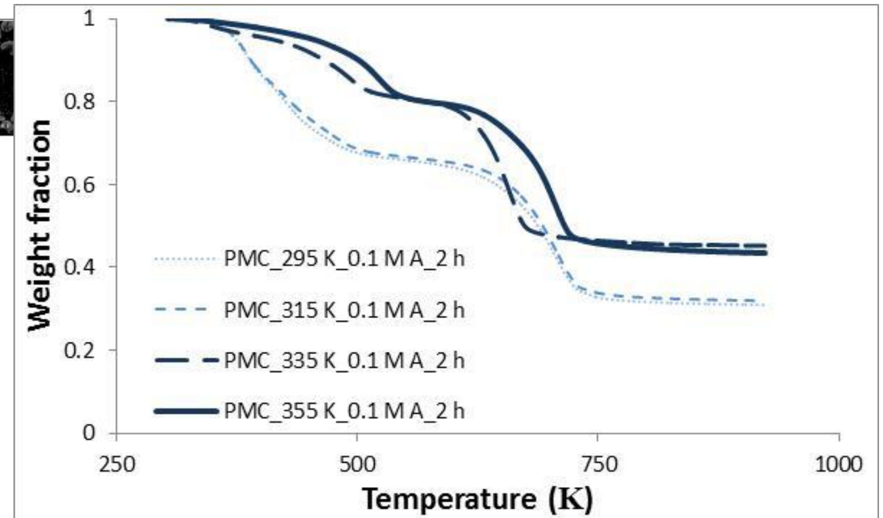


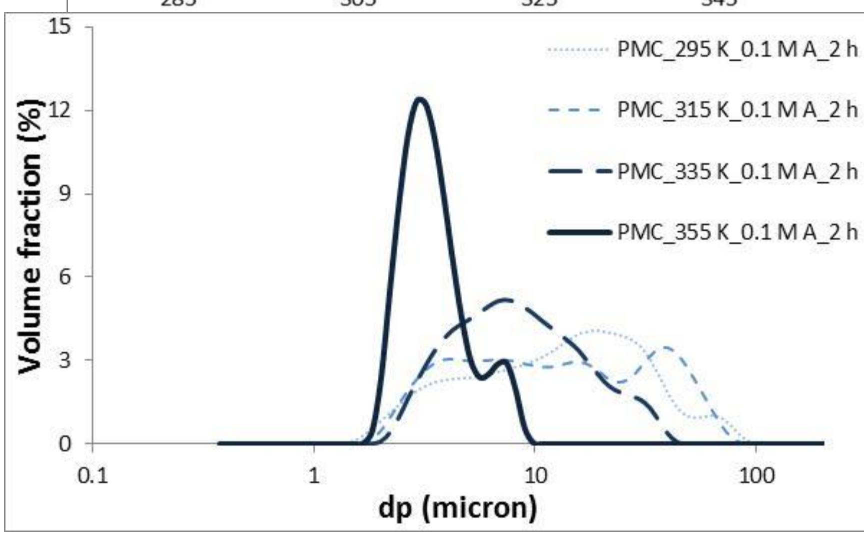


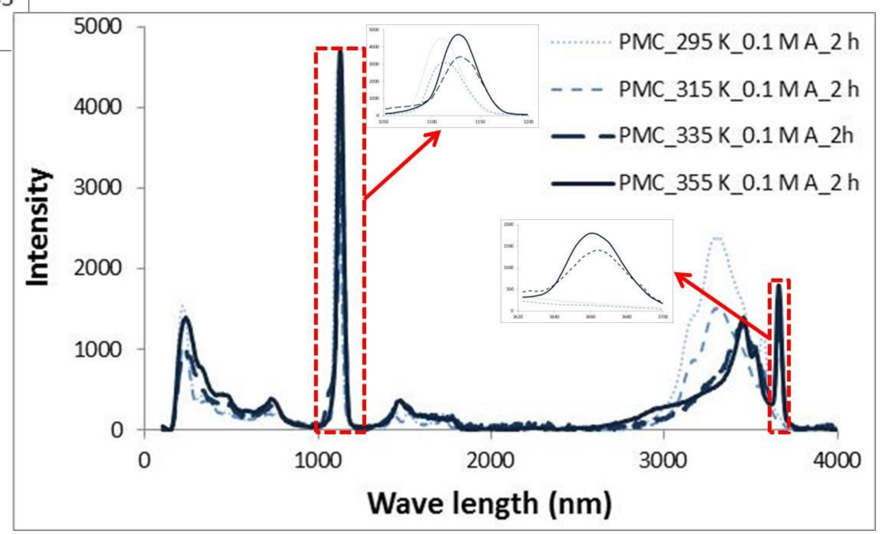


Effect of Reaction Temperature

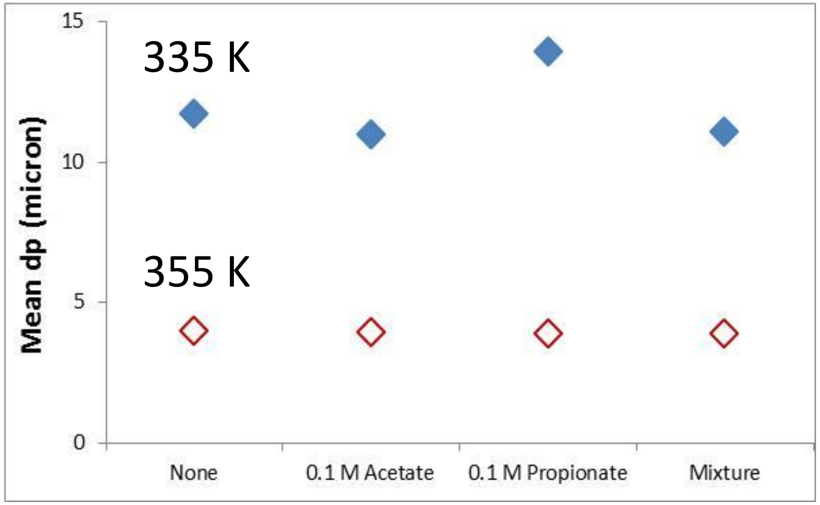


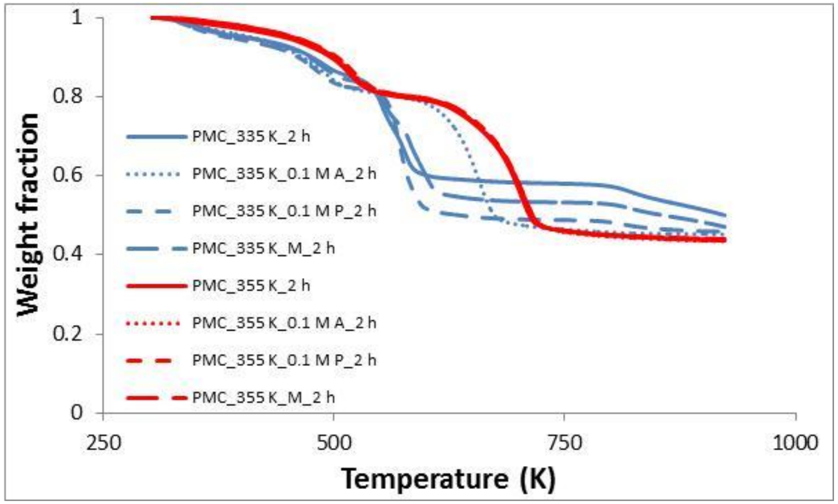


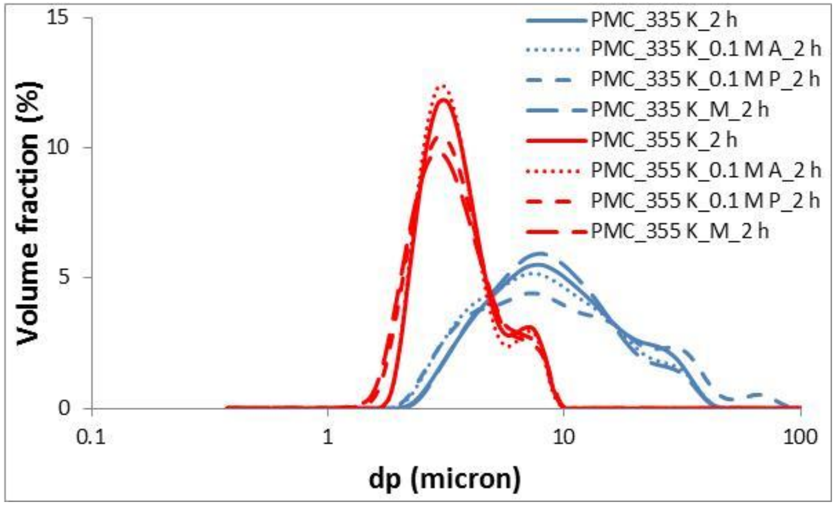


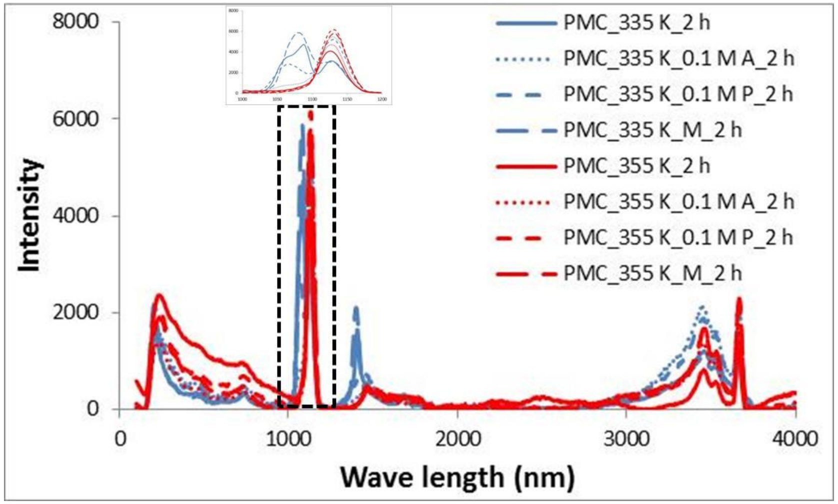


Effect of Chelating Agents

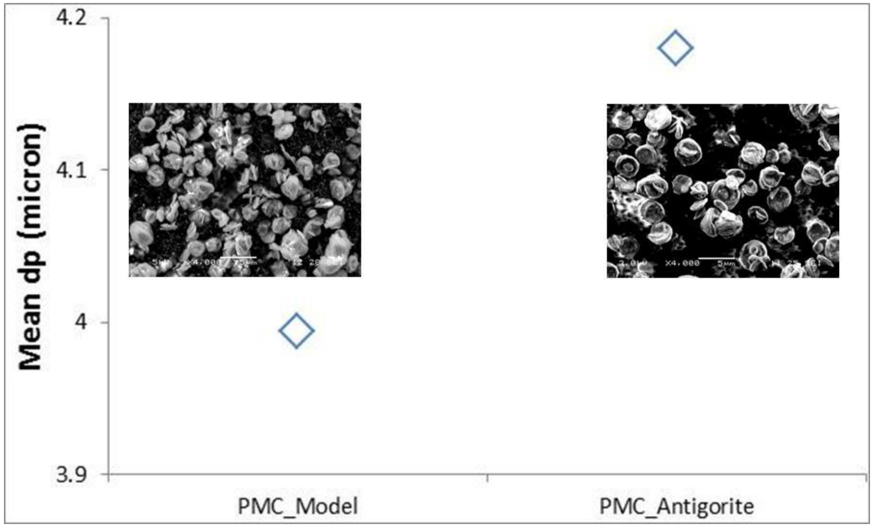


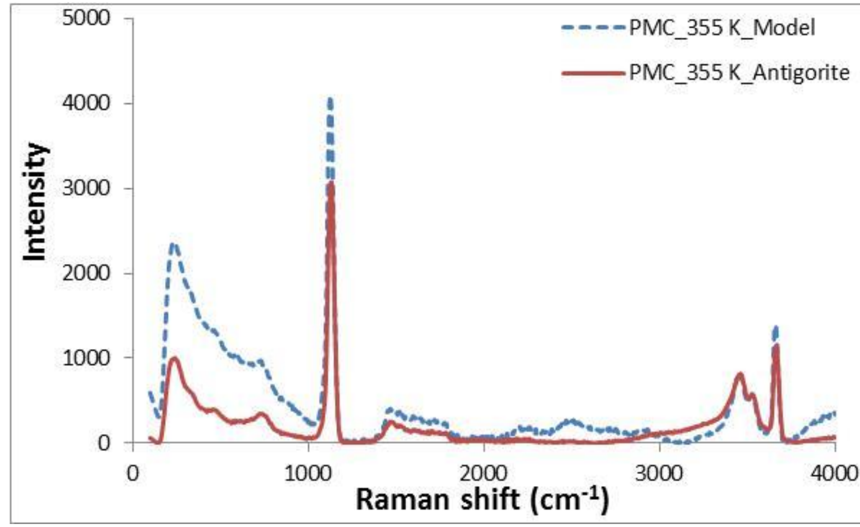


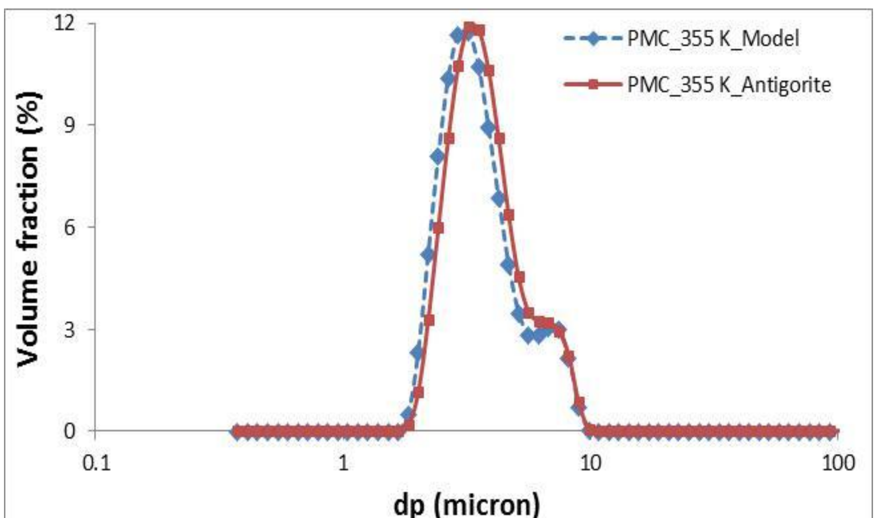


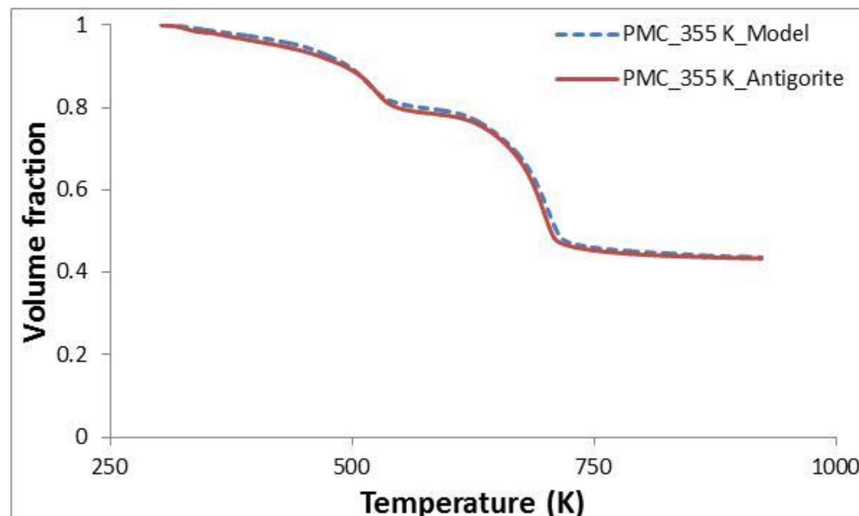


Model System vs. Real System

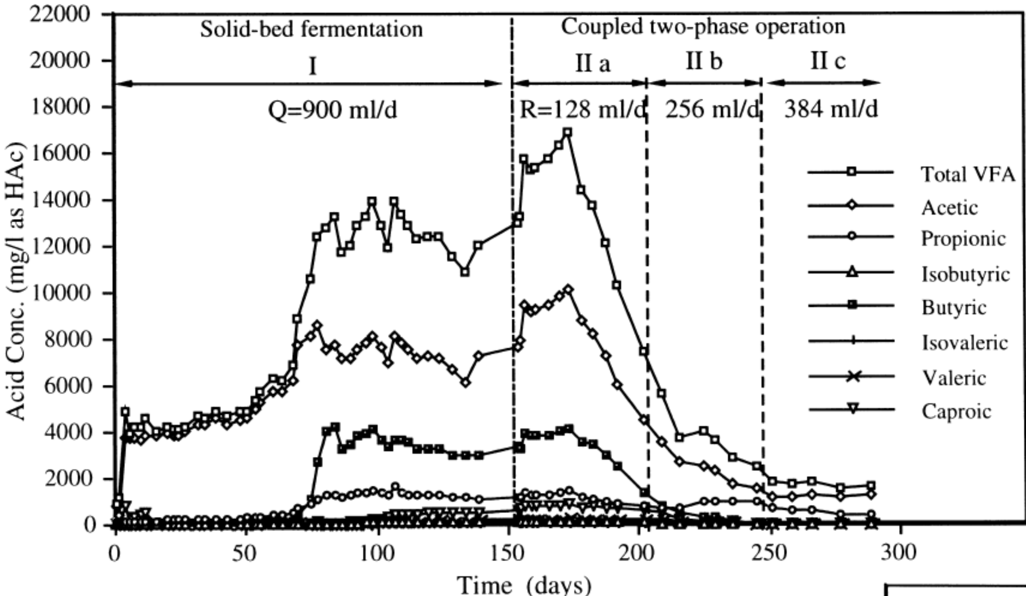




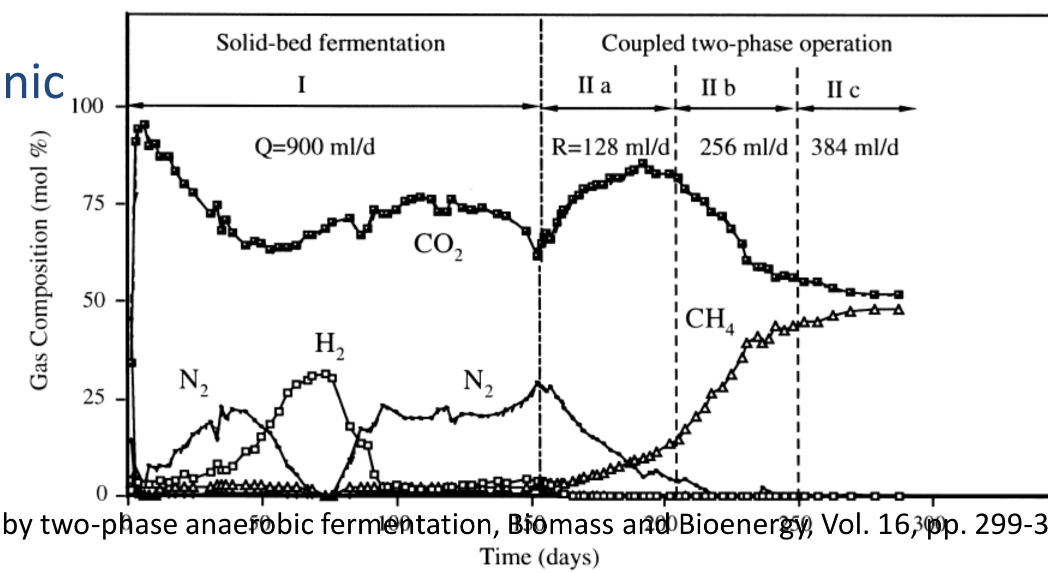




Biogasification of Organic Waste

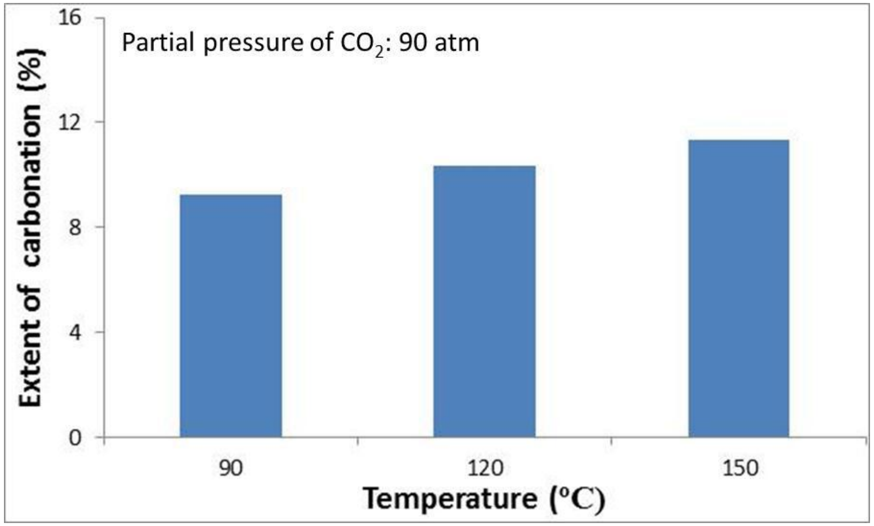


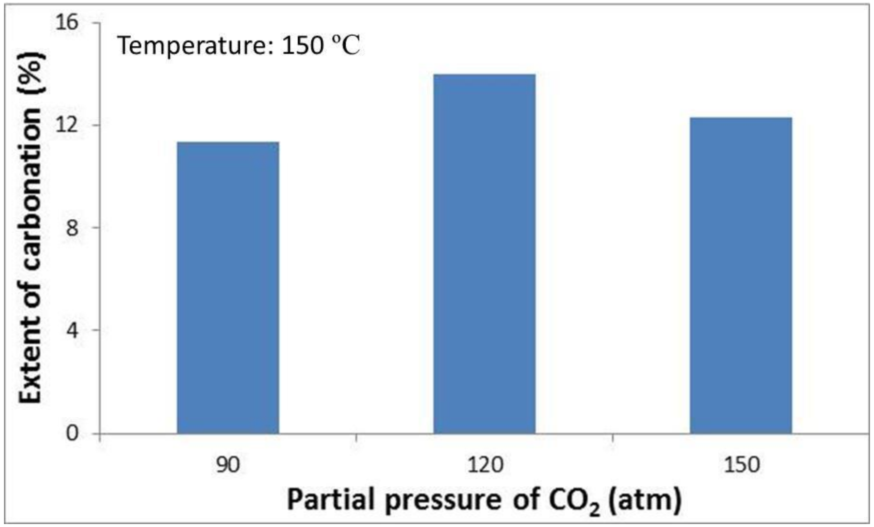
- Organic acids are produced as intermediate products.
- Maximum concentrations of organic acids during the process:
  - Acetic acid: 0.15 M
  - Propionic acid: 0.025 M
  - Butyric acid: 0.05 M
  - Valeric acid: 0.002 M
  - Capeoic acid: 0.01 M

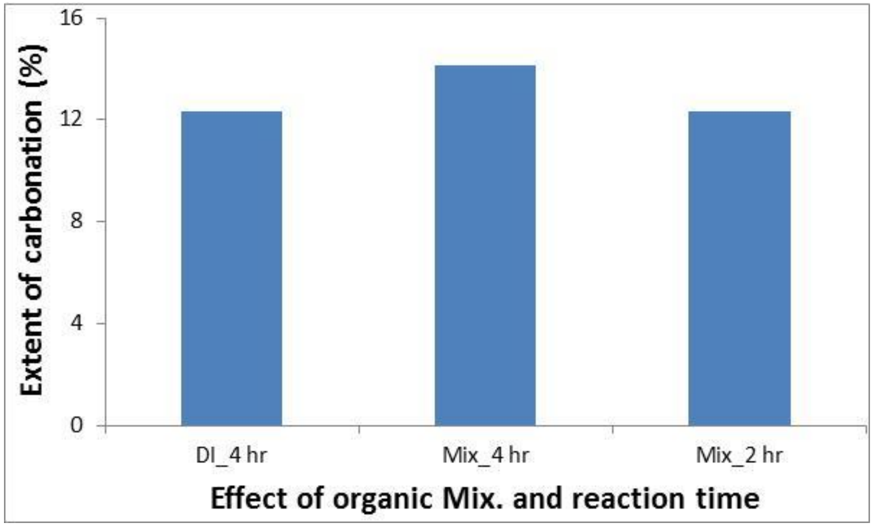


E.R. Vieitez, S. Ghosh. 1999, Biogasification of solid wastes by two-phase anaerobic fermentation, Biomass and Bioenergy, Vol. 16, pp. 299-309.

In-Situ Mineral Carbonation







- Mixture is effective in enhancing antigorite carbonation compared to D.I. water
- Increasing temperature and a longer reaction time result in more carbonation

Accomplishments to Date

- Mineral characterization completed
- Thermodynamic modeling completed
- Fermentation of organic waste streams for volatile fatty-acid production completed
- Investigation of microbial ecology of acidogenic fermentation completed
- Design and fabrication of a high pressure reactor completed
- Kinetic and mechanistic studies of mineral dissolution and carbonation almost done
- Characterization of mineral carbonates almost done
- Environmental and economic assessments still going on

Summary

- Various organic chelating agents can be produced by the process of anaerobic digestion of organic waste.
- Organic chelating agents can enhance the reaction rate in the mineral dissolution step.
- Effect of organic chelating agents on precipitated magnesium carbonates formation is not significant.
- By controlling the parameters of the crystallization system, the PMC can be synthesized with the crystal structures that are suitable for the filler materials.
- Low concentrated organic chelating agents enhanced the overall reaction rate in the one-step mineral carbonation slightly in short term.
- Kinetic and mechanistic studies of mineral dissolution and characterization of mineral carbonates will be continued.
- Environmental and economic assessments will be continued.

Organization Chart

- Ah-hyung Alissa Park (Co-PI), Department of Earth and Environmental Engineering, Columbia University
  - Kartik Chandran (Co-PI), Department of Earth and Environmental Engineering, Columbia University
    - Edris Taher (GRA), Department of Earth and Environmental Engineering, Columbia University. Project: Anaerobic digestion studies
  - Juerg Matter (Co-PI), Lamont Doherty Earth Observatory (LDEO), Columbia University
  - Huangjing Zhao (GRA), Department of Earth and Environmental Engineering, Columbia University. Project: Carbon mineralization studies

Gantt Chart

Task/ Subtask#	Tasks	Year I				Year II				Year III			
		Qt1	Qt2	Qt3	Qt4	Qt1	Qt2	Qt3	Qt4	Qt1	Qt2	Qt3	Qt4
1.0	**Project Management, Planning, and Reporting**												
1.1	Project Management Plan												
1.2	Reporting and Budgets												
1.3	Presentation and Briefings												
	Final Report Preparation												
2.0	**Characterization of minerals and thermodynamic modeling of CO_2-mineral-brine systems with potential organic acids (Phase I)**												
2.1	Mineral characterization												
2.2	Thermodynamic modeling												
3.0	**Development of a microbial system for the production of volatile fatty-acids from organic waste streams (Phase II)**												
3.1	Fermentation of organic waste streams for volatile fatty-acid production												
3.2	Investigation of microbial ecology of acidogenic fermentation												
4.0	**Kinetic and mechanistic studies of chemical enhancement of mineral dissolution and carbonation using organic acids (Phase III)**												
4.1	Design and fabrication of a high pressure reactor												
4.2	Kinetic and mechanistic studies of mineral dissolution and carbonation												
4.3	Characterization of mineral carbonates												
5.0	**Environmental and economic assessments (Phase IV)**												

Bibliography

- Journal papers
  1. Dissolution of serpentine using organic acids produced by microbial reactor (in preparation).
  2. In-situ mineralization using organic chelating agents from food waste treatment (in preparation).
- Presentation
  1. Greeshma Gadikota, Huangjing Zhao, Peter Kelemen and Ah-hyung Alissa Park, 2011, Carbon mineralization via carbonation of Ca and Mg-bearing minerals as permanent storage of anthropogenic CO_2, 28th Annual International Pittsburgh Coal Conference, Pittsburgh, PA.