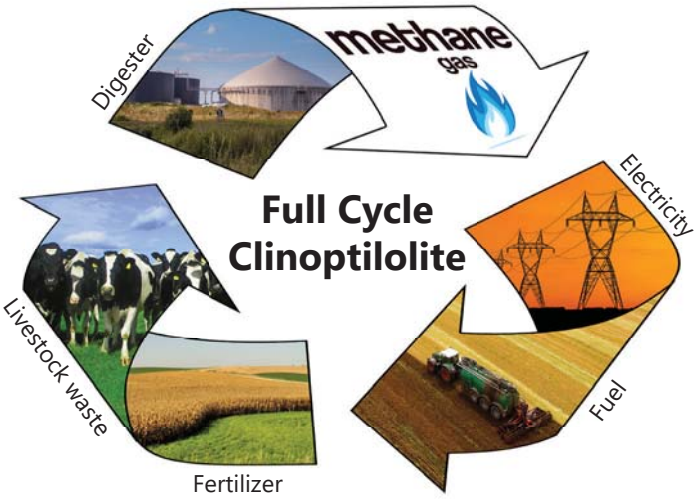
BEAR RIVER ZEOLITE

ANAEROBIC DIGESTION RESEARCH REVIEW

The benefits of clinoptilolite, a volcanic mineral

Clinoptilolite is one of the most useful naturally occurring zeolites, but remains relatively unknown. Recent studies have uncovered benefits that resulted from the addition of clinoptilolite in the anaerobic digestion process.

This document was prepared to provide a compilation of data from world-wide clinoptilolite studies to be used as an informational resource. Some of the benefits from studies cannot be claimed by Bear River Zeolite, Co. due to U.S. and Canadian government restrictions.



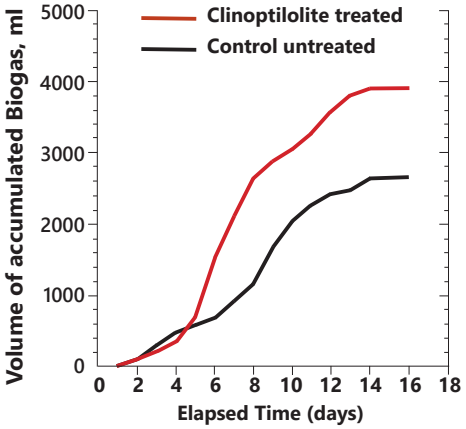
Clinoptilolite Benefits

METHANE PRODUCTION

(Kougias, P.G., et al., 2013) (Kotsopoulos, T.A., et al., 2008) (Meisinger, J.J., et al., 2001) (Montalvo, S., et al., 2012)

- Higher organic matter degradation, resulting in higher methane yield
- 46% increase in methane production (*Fig.1*)
- 78% methane content of biogas
- 59% volatile solid (VS) conversion to methane
- Higher methane production when clinoptilolite is present to hold ammonium nitrogen
- Mitigated ammonium levels to balance the C/N ratio for a higher methane yield

Fig.1: Pig waste treated with 8 grams per liter of clinoptilolite increased methane production 46% when compared with control. *(Kotsopoulos, T.A., 2008)*



MICROORGANISM DEVELOPMENT

(Montalvo, S., et al., 2012) (Kotsopoulos, T.A., et al., 2008)

- Increases the population of anaerobic digesting microorganisms for higher methane yield
- Immobilizes microorganisms on its large surface area to prevent washout and provide a surface for colonization
- Micronutrients and nitrogen are held in the colonization zone
- Hydrolitic and methanogenic microorganisms increased 100 times and the population of hydrolytic microorganisms was 10 times higher

ODOR AND VOC CONTROL

(Meisinger, J.J., et al., 2001) (Montalvo, S., et al., 2012) (Kotsopoulos, T.A., et al., 2008) (Kougias, P.G., et al., 2013)

- Odor and VOC (volatile organic compound) reduction
- The high cation exchange capacity (CEC) of clinoptilolite exchanges the ammonium nitrogen (NH_4^{+1}) into the crystal lattice before it vaporizes to ammonia gas (NH_3), the aerosol of odors

DIGESTATE PRODUCTION*

- Odor reduction during field application
- High fertilizer value from nitrogen (ammonium) and potash (potassium) held in the clinoptilolite lattice
- Higher methane production reduces the carbon content - digestate is lighter and less costly to handle

GROUNDWATER POLLUTION*

- Ammonium is held in the clinoptilolite lattice and doesn't oxidize into nitrates and nitrites
- Reduction in ground water contamination

BEAR RIVER ZEOLITE, PO Box 643, 47 Cox Gulch Road, Thompson Falls, MT 59873
406-827-3523 • FAX: 406-827-3543 • www.bearriverzeolite.com • tfl3543@blackfoot.net

Anaerobic Digestion Stages

1. HYDROLYSIS
Carbohydrates/cellulose, fats and proteins are broken down into monosaccharides, fatty acids and amino acids.

2. ACIDOGENESIS
Monosaccharides, fatty acids and amino acids are converted into volatile fatty acids, alcohols, ketones, hydrogen and carbon dioxide.

3. ACETOGENESIS
Volatile fatty acids, alcohols, ketones, hydrogen and carbon dioxide are converted into hydrogen, CO_2 and acetic acid.

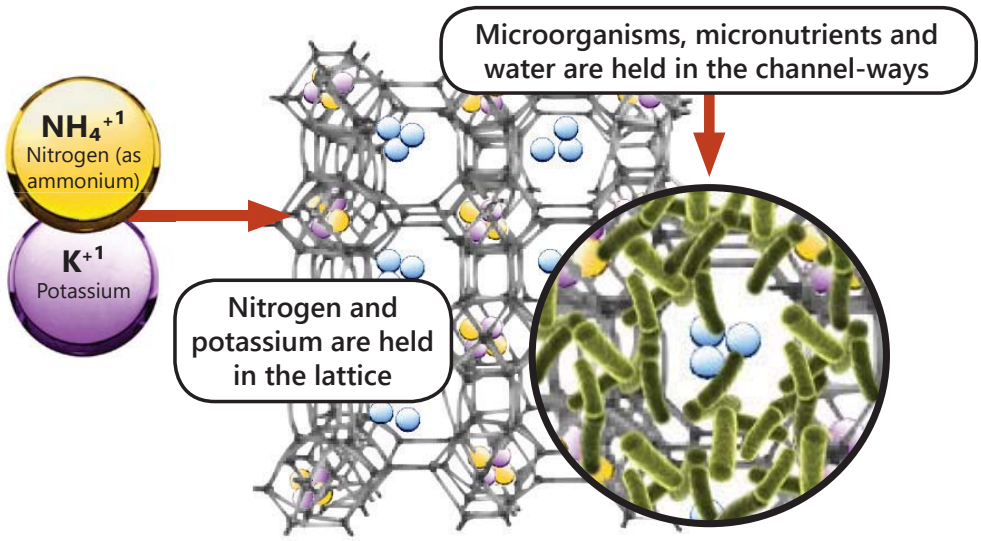
4. METHANOGENESIS
Hydrogen, CO_2 and acetic acid are converted into methane, CO2 and effluents (fertilizer, bedding, and waste water).

Specific microorganisms are needed for each stage in the anaerobic digestion process. Clinoptilolite increases the populations required for each stage. *(Montalvo, S., et al., 2012) (Kotsopoulos, T.A., et al., 2008)*

How Clinoptilolite Works

Clinoptilolite has the ability to capture ammonium (NH_4^{+1}) through its cation exchange capacity (CEC).*

The clinoptilolite lattices are negatively charged and are able to hold positively charged ammonium (NH_4^{+1}) and potassium (K^{+1}), which are accessible to microorganisms as needed for growth but not water soluble.



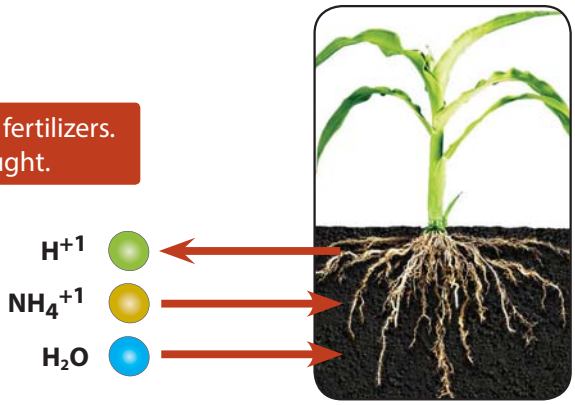
Clinoptilolite lattice and channel-ways

CLINOPTILOLITE IN DIGESTATE FERTILIZER*

BRZ™ contains approximately 3.47% potassium, which is an important nutrient in fertilizers.
BRZ™ holds at least 55% of its weight in water that protects the plant against drought.

The plant releases hydrogen (H^{+1}) during growth, which exchanges with nitrogen (NH_4^{+1}) held in the clinoptilolite lattice, which is plant accessible but not water soluble.

Available water (H_2O) is held in the open pore spaces of the clinoptilolite near the root zone.



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*Additional information on file at Bear River Zeolite Co.