COMPARISON OF CARBOHYDRATE DIGESTION IN THE LARGE INTESTINE OF MONOGASTRIC SPECIES AND IN THE RUMEN – IMPLICATIONS FOR ANIMALS AND HUMANS

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8th ECVCN Residency Class – Sept 18th 2013 – Ghent, Belgium

MICROBIAL POPULATIONS INVOLVED IN CARBOHYDRATE DIGESTION

- Cellulolytic bacteria (digest fibres)
  - pH optimum at 6-7
  - Produce acetate, propionate, little butyrate, CO_2
  - Predominant with high-fibre diets
- Amylolytic bacteria (digest starch and sugars)
  - pH optimum at 5-6
  - Produce propionate, butyrate, acetate, sometimes lactate
  - Predominant with high-starch diets
- Pectinolytic, sugar-utilising, hemicellulolytic, acid-utilising species
- Methanogenic microorganisms (Archaea)
  - keep H_2-concentration low to promote growth of other bacteria and for a more efficient fermentation
  - higher yielding metabolism pathways in bacteria possible

References: Annison and Bryden, 1998; Colorado State University, 2013; Gasteiner, 2012; Pennsylvania State University, 1996

MICROBIAL POPULATIONS IN FORE- AND HINDGUT

- Microbial species similar in fore- and hindgut
- Differences in proportions of the respective microbial populations

References: Bergman, 1990; Immig, 1996; Santos et al., 2011

MAJOR FERMENTATION PATHWAYS

- Two major final pathways of fermentation processes:
  - Methanogenesis (prevalent in the rumen)

$$CO_2 + 4\ H_2 \rightarrow CH_4 + 2\ H_2O$$

  - Reductive acidogenesis (prevalent in the hindgut), mainly acetogenesis

$$2\ CO_2 + 4\ H_2 \rightarrow CH_3COOH + 2\ H_2O$$

In the rumen acetogenesis mainly via pyruvate and acetyl-CoA with a net release of CO_2 and H_2!

References: Bergman, 1990; Immig, 1996; Kienzle and Zeyner, 2010

PRODUCTS OF CARBOHYDRATE FERMENTATION IN MONOGASTRIC SPECIES

- Mainly volatile fatty acids (short chained fatty acids)
  - Usually rather fixed amounts of acetate (around 70%)
  - Less influence of diet composition than in ruminants
  - Small amounts of other VFA

- Energy contribution of VFA from 5-7% (rat, dog, man) to ~ 30% (rabbit, guinea pig) to 30-75% (horse, pig)

References: Bergman, 1990

PRODUCTS OF CARBOHYDRATE FERMENTATION IN THE RUMEN

- Mainly volatile fatty acids (short chained fatty acids)
  - Acetate (60-75%)* => energy, main precursor of lipogenesis (acetyl-CoA)
  - Propionate (15-25%)* => energy, gluconeogenesis, (lipogenesis)
  - Butyrate (10-15%)* => energy, ketone body formation (80% β-hydroxybutyrate ➔ fatty acid synthesis)
  - Smaller amounts of lactate, isobutyrate, valerate, isovalerate

➢ Proportions depending on diet type

VFA contribute more than 70% to ruminant's energy supply

References: Bergman, 1990; Bugaut, 1987; Stevens and Hume, 1995

* on conventional diets

Main endproducts of carbohydrate fermentation not utilisable by the host

- Methane
- H_2
- CO_2

Individual concentrations depending on species

References: Immig, 1996; Jensen, 1996; Williams et al., 2001

CONSEQUENCES OF CARBOHYDRATE FERMENTATION

- Ruminants ~ **0.46** l CH_4/kg BW/d
  - losses of ~6-10% (1.7-14.9 %) of the total energy intake
- Horses ~ 0.16 l CH_4/kg BW/d
  - losses of ~2% of the total energy intake
- Pigs ~ 0.10 l CH_4/kg BW/d
- Humans ~ 0.05 l CH_4/kg BW/d

References: Crutzen et al., 1986; Holter and Young, 1992; Jensen, 1996

Fermentation efficiency

- Reductive acidogenesis yields more energy in form of VFA
  - The hindgut yields ~15% more energy from fermented dry matter than the rumen
- Methanogenic pathway ferments higher percentage of fibre
  - Higher energy yield from higher fermentation percentage
  - Ruminants are more effective on low-quality forage diets until dry matter intake capacity is limiting factor

References: Immig, 1996; Kienzle and Zeyner, 2010

WHY ARE THERE SUCH HUGE DIFFERENCES BETWEEN RUMINANTS AND MONOGASTRICS?

- Monogastrics have other major pathways to dispose of H_2 due to other carbohydrate compositions entering the hindgut than the rumen
  - **Reduction of CO_2 to acetate** (suggested major pathway e.g. in the horse)
  - Saturation of unsaturated fatty acids
  - Reduction of nitrate to ammonia
  - Reduction of sulphate to sulphide
  - Reduction of O_2 to H_2O
  - Microbial synthesis of lipids and amino acids
  - Absorption by the blood (as well as CH_4) and exhalation
- Some species have limited growth of methanogenic archaea due to rapid ingesta passage

References: Immig, 1996; Jensen, 1996

Consequences of defaunation in the ruminant

- Defaunation of the rumen used to reduce methane output
- The rumen can work without methanogenic archaea
- Works with high-grain diets
- Impaired fermentation capacity with high-forage diets

References: Kienzle, 2013 personal communication; Wolin, 1981

Implications for humans: Biogas Plant

- Use of the same principle as in the rumen

- Substrates:
  - Renewable primary products (energy plants, mainly corn)
  - Production waste from food and feed industry
  - Manure from livestock farming
  - Table scraps, contents of organic waste collection bin

→ Anaerobic process (only small energy losses through heat production compared to aerobic processes)

References: Landesanstalt fuer Landwirtschaft, 2007; Weichgrebe et al., 2012

PHASES OF BIOGAS PRODUCTION

- Hydrolysis (fragmentation of long-chained organic compounds into simple organic compounds (AA, sugars)) hydrolytic bacteria
- Acidogenesis (Degradation of smaller molecular entities to acetate, propionate, butyrate, lactate, alcohols, CO_2, H_2) acidogenic bacteria
- Acetogenesis (Conversion of organic acids and alcohols into acetate, CO_2 and H_2) acetogenic bacteria
- Methanogenesis (Products of all other phases converted to CH_4 by microorganisms) methanogenic archaea

References: Baerreiter, 2011; Landesanstalt fuer Landwirtschaft, 2007

Composition of rumen gases and biogas

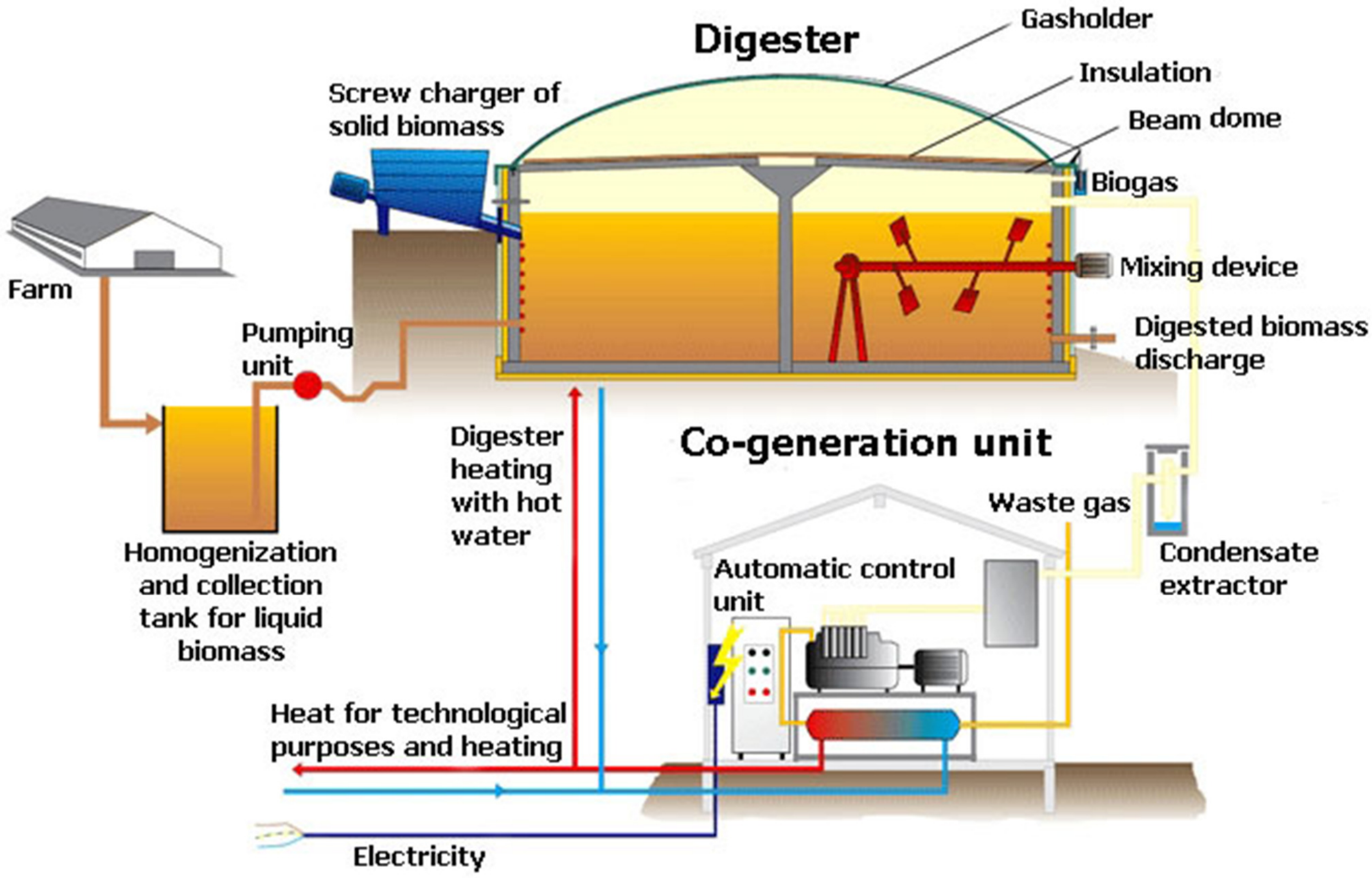
- Rumen gases contain on average

  65.4 % CO_2, 26.8% methane, 7% N_2,0.6% O_2, 0.2% H_2

- Biogas with 50-75% methane, 25-50% CO_2, 0-10% H_2O and other gases (N_2, O_2, H_2, H_2S, NH_3)

- Caloric value 4-7.5 kWh/m^3, depending on methane content

References: Baerreiter, 2011; McArthur and Miltimore, 1961


Digester
Gasholder
Insulation
Beam dome
Screw charger of solid biomass
Biogas
Farm
Mixing device
Pumping unit
Digested biomass discharge
Co-generation unit
Digester heating with hot water
Waste gas
Homogenization and collection tank for liquid biomass
Condensate extractor
Automatic control unit
Heat for technological purposes and heating
Electricity

PROSPECT FOR THE FUTURE

- Already lab-scale/pilot plant tests of more rumen-like biogas plant techniques (Rumen Simulation Technique – RUSITEC)
- Two-step arrangement of hydrolysis/acidogenesis (SCFA) and methanogenesis (biogas) and use of ruminal microbial population instead of „normal“ microbial population ➔ use of substrates rich in cellulose possible
- More cost-effective because of use of high-fibre substrates and increase of substrate-specific methane output

➔ Use of the „demonised“ methane as a renewable energy source

Reference: Weichgrebe et al., 2012

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