detritus | Multidisciplinary Journal for Circular Economy and Sustainable Management of Residues

INNOVATIVE BIOENERGY SOLUTIONS FOR DEVELOPING NATIONS: DARK FERMENTATION AND ANAEROBIC DIGESTION OF ABATTOIR WASTE

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APPENDIX

Table A1. Hydrolysis reactions (Amado et al., 2021; Rajendran et al., 2014; Ramasamy et al., 2022; Serrano & Knud, 2011)

No.	Compound	Hydrolysis reaction	Extent of reaction
1	Starch	$(C_6H_{12}O_6)_n + H_2O \rightarrow nC_6H_{12}O_6$	0.6 ± 0.2
2	Cellulose	$(C_6H_{12}O_6)_n + H_2O \rightarrow 2C_2H_6O + 2CO_2$	0.3 ± 0.1
3	Hemicellulose	$C_5H_8O_4 + H_2O \rightarrow 2.5C_2H_4O_2$	0.5 ± 0.2
4	Hemicellulose	$C_5H_8O_4 + H_2O \rightarrow C_5H_{10}O_5$	0.1 ± 0.1
5	Xylose	$C_5H_{10}O_5 \rightarrow C_5H_4O_2 + 3H_2O$	0.6 ± 0.1
6	Protein	$C_{13}H_{25}O_7N_3S + 6H_2O \rightarrow 6.5CO_2 + 6.5CH_4 + 3NH_3 + H_2S$	0.6 ± 0.3
7	Insoluble protein	$C_{4.39}H_8NO_{2.1} + 0.3337H_2O \rightarrow 0.045\,C_6H_{14}N_4O_2 + 0.048\,C_4H_7NO_4 + 0.047C_4H_9NO_3 + 0.172C_3H_7NO_3 + 0.074C_5H_9NO_4 + 0.111C_5H_9NO_2 + 0.25C_2H_5NO_2 + 0.047C_3H_7NO_2 + 0.067C_3H_6NO_2S + 0.074C_5H_{11}NO_2 + 0.07C_6H_{13}NO_2 + 0.036C_9H_{11}NO_2$	0.6 ± 0.3
8	Triolein	$C_{57}H_{104}O_6 + 3H_2O \rightarrow C_3H_8O_3 + 3C_{18}H_{34}O_2$	0.6 ± 0.3
9	Tripalmate	$C_{51}H_{98}O_6 + 8.436H_2O \rightarrow 4C_3H_8O_3 + 2.43C_{16}H_{34}O$	0.6 ± 0.3
10	Palmito-olein	$C_{37}H_{70}O_5 + 4.1H_2O \rightarrow 2.1C_3H_8O_3 + 0.9C_{16}H_{34}O + 0.9C_{18}H_{34}O_2$	0.6 ± 0.2
11	Palmito-linolein	$C_{37}H_{68}O_5 + 4.3H_2O \rightarrow 2.2C_3H_8O_3 + 0.9C_{16}H_{34}O + 0.9C_{18}H_{32}O_2$	0.6 ± 0.2

Table A2. Reactions for Amino-acid degradation, acidogenesis, acetogenesis, methanogenesis and dark fermentation used in the simulations. (Amado et al., 2021; Rajendran et al., 2014; Serrano & Knud, 2011)

Rxn No.	Compound	Stoichiometry	Pre-exponential factor s^{-1}
Amino acid degradation reactions			
1	Glycine	$C_2H_5NO_2 + H_2 \rightarrow C_2H_4O_2 + NH_3$	$1.28 * 10^{-02}$
2	Threonine	$C_4H_9NO_3 + H_2 \rightarrow C_2H_4O_2 + 0.5\ C_4H_8O_2 + NH_3$	$1.28 * 10^{-02}$
3	Histidine	$C_6H_8N_3O_2 + 4\ H_2O + 0.5\ H_2 \rightarrow CH_3NO + C_2H_4O_2 + 0.5\ C_4H_8O_2 + 2\ NH_3 + CO_2$	$1.28 * 10^{-02}$
4	Arginine	$C_6H_{14}N_4O + 3\ H_2O + H_2 \rightarrow 0.5\ C_2H_4O_2 + 0.5\ C_3H_6O_2 + 0.5\ C_5H_{10}O_2 + 4\ NH_3 + CO_2$	$1.28 * 10^{-02}$
5	Proline	$C_5H_9NO_2 + H_2O + H_2 \rightarrow 0.5\ C_2H_4O + 0.5\ C_3H_6O_2 + 0.5\ C_5H_{10}O_2 + NH_3$	$1.28 * 10^{-02}$
6	Methionine	$C_5H_{11}NO_2S + 2\ H_2O \rightarrow C_3H_6O_2 + CO_2 + NH_3 + H_2 + CH_4S$	$1.28 * 10^{-02}$
7	Serine	$C_3H_7NO_3 + H_2O \rightarrow C_2H_4O_2 + NH_3 + CO_2 + H_2$	$1.28 * 10^{-02}$
8	Threonine	$C_4H_9NO_3 + H_2O \rightarrow C_3H_6O_2 + NH_3 + H_2 + CO_2$	$1.28 * 10^{-02}$
9	Aspartic acid	$C_4H_7NO_4 + 2\ H_2O \rightarrow C_2H_4O_2 + NH_3 + 2\ CO_2 + 2\ H_2$	$1.28 * 10^{-02}$
10	Glutamic acid	$C_5H_9NO_4 + H_2O \rightarrow C_2H_4O_2 + 0.5\ C_4H_8O_2 + NH_3 + CO_2$	$1.28 * 10^{-02}$
11	Glutamic acid	$C_5H_9NO_4 + 2\ H_2O \rightarrow 2\ C_2H_4O_2 + NH_3 + CO_2 + H_2$	$1.28 * 10^{-02}$
12	Histidine	$C_6H_8N_3O_2 + 5\ H_2O \rightarrow CH_3NO + 2\ C_2H_4O_2 + 2\ NH_3 + CO_2 + 0.5\ H_2$	$1.28 * 10^{-02}$
13	Arginine	$C_6H_{14}N_4O_2 + 6\ H_2O \rightarrow 2\ C_2H_4O_2 + 4\ NH_3 + 2\ CO_2 + 3H_2$	$1.28 * 10^{-02}$
14	Lysine	$C_6H_{14}N_2O_2 + 2\ H_2O \rightarrow C_2H_4O_2 + C_4H_8O_2 + 2\ NH_3$	$1.28 * 10^{-02}$
15	Leucine	$C_6H_{13}NO_2 + 2\ H_2O \rightarrow C_5H_{10}O_2 + NH_3 + CO_2 + 2\ H_2$	$1.28 * 10^{-02}$
16	Isoleucine	$C_6H_{13}NO_2 + 2\ H_2O \rightarrow C_5H_{10}O_2 + NH_3 + CO_2 + 2\ H_2$	$1.28 * 10^{-02}$
17	Valine	$C_5H_{11}NO_2 + 2\ H_2O \rightarrow C_4H_8O_2 + NH_3 + CO_2 + 2\ H_2$	$1.28 * 10^{-02}$
18	Phenyalanine	$C_9H_{11}NO_2 + 2\ H_2O \rightarrow C_6H_6 + C_2H_4O_2 + NH_3 + CO_2 + H_2$	$1.28 * 10^{-02}$
19	Tyrosine	$C_9H_{11}NO_3 + 2\ H_2O \rightarrow C_6H_6O + C_2H_4O_2 + NH_3 + CO_2 + H_2$	$1.28 * 10^{-02}$

20	Typtophan	$C_{11}H_{12}N_2O_2 + 2\ H_2O \rightarrow C_8H_7N + C_2H_4O_2 + NH_3 + CO_2 + H_2$	$1.28 * 10^{-02}$
21	Glycine	$C_2H_5NO_2 + 0{,}5\ H_2O \rightarrow 0.75\ C_2H_4O_2 + NH_3 + 0.5\ CO_2$	$1.28 * 10^{-02}$
22	Alanine	$C_3H_7NO_2 + 2\ H_2O \rightarrow C_2H_4O_2 + NH_3 + CO_2 + 2\ H_2$	$1.28 * 10^{-02}$
23	Cysteine	$C_3H_6NO_2S + 2\ H_2O \rightarrow C_2H_4O_2 + NH_3 + CO_2 + 0.5\ H_2 + H_2S$	$1.28 * 10^{-02}$
Acidogenic reactions			
1	Dextrose	$C_6H_{12}O_6 + 0.1115\ NH_3 \rightarrow 0.1115\ C_5H_7NO_2 + 0.744\ C_2H_4O_2 + 0.5\ C_3H_6O_2 + 0.4409\ C_4H_8O_2 + 0.6909\ CO_2 + 1.0254\ H_2O$	$9.54 * 10^{-03}$
2	Glycerol	$C_3H_8O_3 + 0.4071\ NH_3 + 0.0291\ CO_2 + 0.0005\ H_2 \rightarrow 0.04071\ C_5H_7NO_2 + 0.94185\ C_3H_6O_2 + 1.09308\ H_2O$	$1.01 * 10^{-02}$
Acetogenic reactions			
1	Propionic acid	$C_3H_6O_2 + 0.06198\ NH_3 + 0.314336\ H_2O \rightarrow 0.06198\ C_5H_7NO_2 + 0.9345\ C_2H_4O_2 + 0.660412\ CH_4 + 0.160688\ CO_2 + 0.00055\ H_2$	$1.95 * 10^{-07}$
2	Isobutyric acid	$4H_8O_2 + 0.0653\ NH_3 + 0.8038\ H_2O + 0.0006\ H_2 + 0.5543\ CO_2 \rightarrow 0.0653\ C_5H_7NO_2 + 1.8909\ C_2H_4O_2 + 0.446\ CH_4$	$5.88 * 10^{-06}$
3	Isovaleric acid	$C_5H_{10}O_2 + 0.0653\ NH_3 + 0.5543\ CO_2 + 0.8044\ H_2O \rightarrow 0.0653\ C_5H_7NO_2 + 0.8912\ C_2H_4O_2 + C_3H_6O_2 + 0.4454\ CH_4 + 0.0006\ H_2$	$3.01 * 10^{-08}$
4	Linoleic acid	$C_{18}H_{32}O_2 + 15.356\ H_2O + 0.482\ CO_2 + 0.1701\ NH_3 \rightarrow 0.1701\ C_5H_7NO_2 + 9.02\ C_2H_4O_2 + 10.0723\ H_2$	$3.64 * 10^{-12}$
Methanogenic reactions			
1	Acetic acid	$C_2H_4O_2 + 0.022\ NH_3 \rightarrow 0.022\ C_5H_7NO_2 + 0.945\ CH_4 + 0.066\ H_2O + 0.945\ CO_2$	$2.39 * 10^{-03}$
2	Hydrogen	$14.4976\ H_2 + 3.8334\ CO_2 + 0.0836\ NH_3 \rightarrow 0.0836\ C_5H_7NO_2 + 3.4154\ CH_4 + 7.4996\ H_2O$	$2.39 * 10^{-03}$
Dark Fermentation reactions			
1	Dextrose	$C_6H_{12}O_6 + 2H_2O \rightarrow 2CH_3\ COOH + 4H_2 + 2CO_2$	$2 * 10^{-02}$
2	Dextrose	$C_6H_{12}O_6 \rightarrow CH_3CH_2CH_2COOH + 2H_2 + 2CO_2$	$2 * 10^{-02}$

3	Dextrose	$C_6H_{12}O_6 \rightarrow 2CH_3CH_2OH + 2CO_2$	$2 * 10^{-02}$

Table A3: Charaterisation of abattoir waste

	Cattle Manure g/100g	Blood %	Fat %	Meat	Cattle manure	Cattle rumen g/kg	Pig stomach g/kg
	(Al-Rubaye et al., 2019)	(Hejnfelt & Angelidaki, 2009; Palatsi et al., 2011)			(Budiyono et al., 2011)	(Palatsi et al., 2011)	
Protein		94,4		61,6	0,70	73	6,7
Lipids		0,3	100	17,2	0,08	10,8	8,64
Carbohydrates		5,3		21,2	0,02	16,2	
Glycine	0,083						
Cellulose	0,204						
hemicellulose	0,086						
Glucose	0,257						
Triolein	0,015						
Inerts	0,355				0,20		
	Confiscate (lung, kidney, liver) g/kg	Pig meat + fat	Goat rumen %	Poultry feathers	Poultry wastewater		
	(Palatsi et al., 2011)			(Mozhiarasi & Natarajan, 2022)	(Baker et al., 2021)		
Protein	15,5	8,38	3	80	16,4		
Lipids	46,6	46,7	2,6	3	15,1		
Carbohydrates			7,6				