Electronic Supplementary Material (ESI) for Environmental Science: Water Research & Technology.

Supplementary Information (SI)

Encapsulation Technology to Improve Biological Resource Recovery: Recent Advancements and Research Opportunities

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SI Table

Table SI1. Tabulated references of resource recovery by encapsulated bacteria.

Microbial community/culture	**Host Matrix**	**Aqueous waste streams treated**	**Resource recovered**	**Study** [1]
Anaerobic sludge	Cellulose triacetate	Low strength synthetic wastewater (COD: 400 mg L^{-1})	1.64 ± 0.05, 1.58 ± 0.07, 0.96 ± 0.07 L CH_4 d^{-1} at 35, 25 and 15°C (HRT @ 16 hr)	[10]
Photosynthetic bacteria	Modified glass fiber spheres coated with poly(vinylidene) fluoride and polysulfone	High salinity organic wastewater (COD: 3056-3945 mg L^{-1}, salinity: 40 - 80 g NaCl L^{-1})	5.43 mL H_2 h^{-1} L^{-1}	[11]
Bacillus cereus	Ca-alginate	Sludge from wastewater treatment plant (total COD: 10,100 mg L^{-1}, soluble COD: 110 mg L^{-1})	0.055 g CH_4 g^{-1} sludge COD	[12]
Rhodopseudomonas palustris CGA009	Cellulose-based paper	Acetate (20 mM sodium acetate)	4.0 ± 0.28 mmol H_2 m^{-2} h^{-1}	[23]
Hydrogen-producing bacteria cultured from anaerobic sludge	Ca-alginate+chitosan+activated carbon	Pretreated red algae hydrolysate (16.6 g sugar L^{-1})	2.7 L H_2 L^{-1} d^{-1} (HRT @ 24 hr)	[24]
Hydrogen-producing bacteria cultured from anaerobic sludge	Ca-alginate	Potato waste (10-40 g L^{-1})	298.11 mL H_2 g^{-1} total volatile solids	[25]

Pretreated activated sludge	Ca-alginate	Low-strength wastewater from beverage factory (2.9 ± 2.0 g COD L^{-1})	3.20 ± 0.7 and 115.00 ± 42 mL H_2 L^{-1} d^{-1} (for HRT @ 4 hr and 2 hr, respectively)	[26]
Genetically modified *Escherichia coli*	Polyethylene glycol diacrylate hydrogel	Neodymium, gadolinium, NdFeB Magnet waste leachate (Nd, Pr, Dy)	~2.64 mg Nd g^{-1} microbe bead dw [2]	[27]
Saccharomyces cerevisiae	Ca-alginate with or without chitosan; Protanal LF 10/60 with or without chitosan	fermentative medium containing containing 15% dextrose	>90% g ethanol g^{-1} substrate [3]	[28]
Electroactive bacteria cultured from microbial fuel cell effluent	Polydopamine	Acetate (1g L^{-1})	0.20 ± 0.05 Amp m^{-2}	[29]
Anaerobic sludge	Polyvinyl alcohol	Medium strength synthetic wastewater (soluble COD: 565 ± 11 mg L^{-1})	0.28 ± 0.03 L CH_4 d^{-1} (HRT @ 24 hr)	[30]
Protease-secreting bacteria cultured from waste activated sludge	Ca-alginate	Sludge (TCOD: 10,000 ± 250 mg L^{-1}, VSS: 6300 ± 200 mg L^{-1})	135.9 mL CH_4 g^{-1} VS	[31]
Bacillus cereus	Ca-alginate	Sludge from wastewater treatment plant	235.8 mL CH_4 g^{-1} VS	[32]
Cellulase and β-glucosidase	Poly(methacrylamide-co-acrylic acid)	Cellulose	89.1% mg glucose mg^{-1} cellulose [4]	[33]
Clostridium pasteurianum CH5	Alginate+κ-carrageenan+polyvinyl alcohol, supplemented with nano-metal (Fe, Ni) at 100-400 mg L^{-1}	Glucose (5 g L^{-1})	0.97, 1.18, 1.22 and 1.28 mol H_2 mol^{-1} glucose; 1.09, 1.05, 1.19 and 1.19 H_2 mol^{-1} glucose [5]	[34]

Anaerobic sludge	κ-carrageenan+gelatin	Sucrose (COD: 15 g L^{-1})	64.6 mL H_2 L^{-1} d^{-1} and 395 mL CH_4 L^{-1} d^{-1}	[36]
Anaerobic sludge	Polyvinyl alcohol	Lignocellulosic waste (filtered COD: 18.1 ± 0.2 to 83.6 ± 0.2 g L^{-1})	337.8 ± 14.2 mL CH_4 g^{-1} COD [6]	[37]
Micrococcus luteus	Ca-alginate; polyvinylpyrrolidone & poly(vinylidene fluoride)-co-hexafluoropropylene	$CuSO_4$ solution (10 mM)	97% & 95% of copper input [7]	[38]
Chlorella vulgaris	Ca-alginate	Fe(II), Mn(II), and Zn(II)	129.43, 115.90 and 105.29 mg g^{-1}; 25.76, 21.76 and 18.74 mg g^{-1} [8] for Fe(II), Mn(II), and Zn(II) input, respectively	[39]
Thamnidium elegans	p(3-Methoxyprophyl)acrylamide + 2-Akrylamido-2-methyl-1-propane sulfonic acid	Cd(II)	31.80 ± 0.20 mg Cd(II) g^{-1} [9]	[40]
Lysinibacillus sphaericus CBAM5	Ca-alginate	$HAuCl_4 \cdot 3H_2O$ (60 mg L^{-1}), a final volume of 15 mL	97% of Au(III) input [10]	[41]
Synechococcus sp. PCC7002	Polysilicic acid+polydiallyldimethylammonium chloride+polystyrene sulfonate	Cu^{2+}, Pb^{2+} (10 ppm)	70% and 90% of Cu^{2+}, Pb^{2+} input after 1200 mins, respectively	[42]
Anaerobic sludge	Polyvinyl alcohol	Synthetic wastewater (soluble COD: 540±17 mg L^{-1})	0.06 ± 0.01 and 0.07 ± 0.0004 L CH_4 g^{-1} soluble COD removal; 1.79 & 1.85 L H_2O m^{-2} membrane area h^{-1} [11]	[50]

Hydrogen-producing bacteria cultured from anaerobic sludge	Ca-alginate+chitosan+SiO_2	Galactose (20-40 g L^{-1})	9.57 L H_2 L^{-1} d^{-1}	[51]
Hydrogen-producing bacteria cultured from anaerobic sludge	Ca-alginate+chitosan+SiO_2	Galactose (15 g L^{-1})	26.3±9.7 L H_2 L^{-1} d^{-1}	[54]
Hydrogen-producing bacteria cultured from anaerobic sludge	Sodium alginate+activated carbon+chitosan+silicon dioxide	Deoiled jatropha waste (biomass: 100 g L^{-1}; total COD: 11866 ± 1006 mg L^{-1})	785 ± 100 mL H_2 L^{-1} d^{-1} (HRT @ 16 hr)	[55]
Hydrogen-producing bacteria cultured from anaerobic sludge	Ca-alginate	Brewery wastewater (COD: ~ 14 g L^{-1})	240 mL H_2 d^{-1} (HRT @45 min)	[56]
Zymomonas mobilis strain ZM4 (ATCC 31821)	Alginate supplemented with polyethylene oxide	Glucose (100 g L^{-1})	74.7% and 91% of maximum ethanol yield [12]	[57]
Hydrogen-producing bacteria cultured from anaerobic sludge	Ca-alginate	Ground potato waste (39.56 g L^{-1})	292.8 mL H_2 g^{-1} total volatile solids (a cumulative 4986 mL H_2)	[58]
Anaerobic sludge	Hydrophilic poly(vinylidene fluoride) membrane sachets	Citrus waste containing D-limonene (COD: 31.3 g L^{-1})	90 mL CH_4 at an organic loading rate of 3.6 g COD L^{-1}	[60]
Pogostemon cablin	Hydrophilic poly(vinylidene fluoride) membrane sachets	Ground Patchouli oil distillery waste (0.3 g VS)	291 mL CH_4 g^{-1} VS	[61]
Providencia vermicola	Ca-alginate	Pd(II) solution (100 mg L^{-1})	84.32% of Pd(II) input [13]	[66]
Salinivibrio sp.	Ca-alginate	Acetate (2 g L^{-1})	(12± 4) mW m^{-2};	[67]

	120 ± 30 mAmp m^{-2} *14*

Note:

1. Reference numbers are as listed in the main paper.
2. The adsorption is low in the microbe beads since 87% of bead weight is non-adsorptive material
3. Ethanol yield, a percentage of the theoretical maximum yield for the grams of ethanol produced from the grams of dextrose consumed after 12 hours
4. Yield of glucose from hydrolysis of cellulose
5. Hydrogen improvement between encapsulated and free bacteria; with nano-nickel addition (100, 200, 300 and 400 mg L^{-1}); with nano-iron addition (50, 100, 200, and 400 mg L^{-1})
6. Six kinds of lignocellulosic waste at varying concentration were evaluated. The data shown here is Hydrolysate of Jerusalem artichoke stems at 3.0 ± 0.14 g COD L^{-1}
7. Percentage of copper depleted from supernatant of 10 mM $CuSO_4$ by electrospun and sodium alginate fiber with or without bacteria

8. Amount of metals adsorbed per gram of biosorbent at equilibrium

9. pH changed from 3 to 2; mass of Cd(II) per mass of sorbent at equilibrium

10. Gold ions Au(III) captured by the cells in the alginate sphere

11. Methane production and permeate flux with NaCl and $(NH_4)_2SO_4$ as draw solutions in anaerobic forward osmosis membrane process

12. Ethanol yield from substrate normalized by the theoretical maximum ethanol production, horizontal and vertical flow direction

13. Percentage of Pd(II) removed from the aqueous solution

14. Power density