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Review on research achievements of biogas from anaerobic digestion

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ABSTRACT

With the rising demand for renewable energy and environmental protection, anaerobic digestion of biogas technology has attracted considerable attention within the scientific community. This paper presents a comprehensive review of research achievements on anaerobic digestion developments for biogas production. The review includes a discussion of factors affecting efficiency (temperature, pH, C/N ratio, OLR and retention time), accelerants (greenery biomass, biological pure culture and inorganic additives), reactors (conventional anaerobic reactors, sludge retention reactors and anaerobic membrane reactors) and biogas AD processes (lignocellulose waste, municipal solid waste, food waste, livestock manure and waste activated sludge) based on substrate characteristics and discusses the application of each forementioned aspect. The factors affecting efficiency are crucial to anaerobic digestion, because they play a major role in biogas production and determine the metabolic conditions for microorganism growth. As an additive, an accelerant is not only regarded as a nutrient resource, but can also improve biodegradability. The focus of reactor design is the sufficient utilization of a substrate by changing the feeding method and enhancing the attachment to biomass. The optimal digestion process balances the optimal digest conditions with the cost-optimal input/output ratio. Additionally, establishment of theoretical and technological studies should emphasize practicality based on laboratory-scale experiments because further development of biogas plants would allow for a transition from household to medium- and large-scale projects; therefore, improving stability and efficiency are recommended for advancing AD research.

Contents

Abbreviations: AD, anaerobic digestion; GHG, greenhouse gas; VFA, volatile fatty acid; TAN, total ammonia nitrogen; AN, free ammonia; OLR, organic loading rate; SRT, solid retention time; HRT, hydraulic retention time; WAS, waste activated sludge; FW, food waste; OMSR, olive mill solid residue; COD, chemical oxygen demand; ASBR, anaerobic sequencing batch reactor; CSTR, anaerobic sequencing batch reactor; MBR, membrane bioreactor; APFR, anaerobic plug-flow reactor; ACR, anaerobic contact reactor; UASB, up-flow anaerobic sludge bed reactor; UASS, up-flow anaerobic solid-state reactor; ABR, anaerobic baffled reactor; CRT, cell retention time; IC, internal circulation reactor; BOD, biological oxygen demand; ITS, inclined tube settlers; FFFB, fixed bed fixed film; AFBR, anaerobic fluidized bed reactor; AnMBR, anaerobic membrane bioreactor; AFBMR, anaerobic fluidized bed membrane reactor; GAC, granular activated carbon; PAC, powder activated carbon; EGSB, expanded granular sludge blanket; MSW, municipal solid waste; FW, food waste; WAS, waste activated sludge

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1. Introduction

The consumption of renewable energy is dramatically increasing, along with energy security concerns, efforts to mitigate the environmental impact of conventional fuels, and improvements in living standards and renewable technologies. Bioenergy can play a central role in promoting renewable alternatives. In fact, bioenergy is estimated to be the fourth largest energy resource in the world [1], and is a nearly GHG-neutral replacement for fossil fuels [2] due to its renewable and widely applicable characteristics and its abundance. Forestry resources, agricultural resources, sewage and industrial organic wastewater, municipal solid wastes, livestock and poultry dung and biogas are major categories for use.

Biogas, which is generally referring to gas from anaerobic digestion units, is a promising means of addressing global energy needs and providing multiple environmental benefits, as shown in Table 1 [3–7]. Examples include EU policy estimates that at least 25% of all bioenergy can be derived from biogas [8]; in Italy, 3405 GW h of electricity was produced from biogas in 2011 [9]; in Germany, approximately 4000 agricultural biogas production units were operated on German farms at the end of 2008, which is beneficial for farmer living-environment [10]; in China, 26.5 million biogas plants were built by 2007 with an output of 10.5 billion m^3, and it was increased to 248 billion m^3 (annually) by 2010 [11]. Furthermore, from a socio-economic point of view, biogas not only significantly reduces the costs of treating waste [8] but also has a relatively low feedstock cost. In addition, biogas has a lower sale price compared with diesel and petrol. These examples illustrate that biogas is utilized widely as a renewable source.

Biogas is generated from a digestion process under anaerobic conditions whose application is rapidly emerging as a viable means for providing continuous power generation. The AD cycle represents an integrated system of a physiological process of microbial and energy metabolism, as well as raw materials processing under specific conditions (Fig. 1) [12]. However, the microbial community is sensitive to variations in the operating conditions applied. Thus, the AD process, if improperly managed, would become unstable and result in reduced biogas production. Although previous studies have discussed AD development, most focused on only one aspect (such as technology, mechanism, factors affecting efficiency, etc.) to minimize this instability (Table 2) [13–15] or on one substrate (such as livestock manure, urban solid waste, food waste, crop straw, etc.). An overall

Table 1
Biogas environmental benefits analysis.

Biogas	Corresponding contents	References
Green energy production	Electricity	[5]
	Heat	
	Vehicle fuel	
	Tri-generation	
Organic waste disposal	Agricultural residues	
	Industrial wastes	
	Municipal solid wastes	
	Household wastes	
	Organic waste mixtures	
Environmental protection	Pathogen reduction through sanitation	
	Less nuisance from insect flies	
	Air & water pollution reduction	
	Eutrophication and acidification reduction	[3]
	Forest vegetation conservation	
	Replacing inorganic fertilizer	[4]
Biogas-linked agrosystem	Livestock-biogas-fruit system	
	Pig-biogas-vegetable greenhouse system	[6]
	Biogas-livestock and poultry farms system	[7]
GHG emission reduction	Substituting conventional energy sources	[3]