



Review

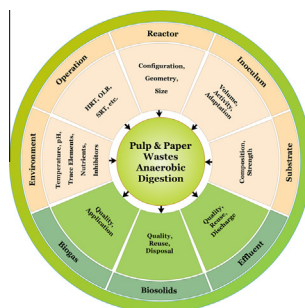
Anaerobic digestion of pulp and paper mill wastes – An overview of the developments and improvement opportunities

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HIGHLIGHTS

- Historical perspective of P&P mill wastes anaerobic digestion is critically reviewed.
- Recent progress in anaerobic digestion of P&P mill wastes is reviewed and discussed.
- Combined methods are proposed as promising technologies for P&P wastes treatment.

GRAPHICAL ABSTRACT



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ABSTRACT

Various organic and inorganic hazardous substances are commonly originated during the processing of virgin or recovered fibers (RCFs), when the pulp and paper (P&P) are produced. Hence, pulp and paper industry (PPI) strongly need to employ advanced waste treatment processes as a powerful tool to comply with the stringent environmental regulations in one hand, and to increase their profitability in the current declining P&P markets, on the other hand. Among the treatment alternatives, anaerobic digestion (AD), is an interesting cost-effective alternative with a small environmental footprint and has been increasingly adopted by the PPI to reach this goal. However, the application of AD to deal with wastes generated in P&P mills has been restricted due to a number of limitations, regarding the anaerobic reactor design and the operating conditions. Hence, the optimization of the AD performance would be a crucial step in order to increase the economic benefits, and also to satisfy the strict environmental protection standards. To this end, this paper presents an overview on the current state of the developments associated with AD treatment of P&P mill wastes to assess the applicability of this treatment process for the management of this type of complex wastes. In this context, suggestions are provided to maximize both biogas production and removal efficiency, focusing on the relationship between waste composition and reactor design and operational conditions, which will enhance methane capture and contribute to prevent global warming.

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Nomenclature

ABR	anaerobic baffled reactor	PPI	pulp and paper industry
AD	anaerobic digestion	PPMW	pulp and paper mill wastewater
AFs	anaerobic filters	PPMS	pulp and paper mill sludge
AOPs	advanced oxidative processes	PPS	pulp and paper sludge
AOXs	adsorbable organic halogens	PVDF	polyvinylidene fluoride
AnMBRs	anaerobic membrane bioreactor	RCF	recovered fiber
BI	biodegradability index	SAnMBRs	submerged anaerobic membrane bioreactors
BOD	biochemical oxygen demand	SBR	sequencing batch reactor
COD	chemical oxygen demand	SCOD	soluble chemical oxygen demand
CP	chemical pulping	SCP	semi-chemical pulping
CTMP	chemical thermo-mechanical pulping	SRT	solids retention time
DCP	dichlorophenol	SGBR	static granular bed reactor
ECF	elemental chlorine free	SPC	sulfonated polycarbonate
ENMs	engineered nanomaterials	TCF	total chlorine free
FBRs	fluidized bed reactors	TCOD	total chemical oxygen demand
HRT	hydraulic retention time	TDS	total dissolved solids
KP	kraft pulp	TSS	total suspended solids
LTAD	low temperature anaerobic digestion	TMP	thermomechanical pulping
MP	mechanical pulping	UASB	upflow anaerobic sludge blanket
NPs	nanoparticles	UAF	upflow anaerobic filter
OLR	organic loading rate	UAPBR	upflow anaerobic packed bed reactor
P&P	pulp and paper	VFAs	volatile fatty acids

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1. Introduction

Various wood or non-wood materials are the main raw materials for the production of pulp and paper (P&P) in many countries through the world (Fig. 1). Moreover, P&P manufacturing from recovered fibers (RCFs) has been increased during recent years [1]. After preparation of stock materials, steps including pulping, bleaching, and P&P making are applied, respectively, to yield pulp or paper as final products (Fig. 2). Based on the raw materials used and the manufacturing process adopted, P&P industry (PPI) produce relatively large amounts of both wastewater and solid wastes [2]. On-site, reuse and recycling, and also modifications in the technology [3] are among the most efficient economic and environmental options dealing with the produced residues. In this regard, measures for minimizing the produced wastes, and recovery of energy and unavoidable wastes have been introduced [4] and adopted by PPI [5]. However, the external waste treatments are still the main ways to deal with the residues from PPIs, especially for small and medium size units which generally do not benefit of infrastructures for the recovery of chemicals [6]. So

far, various types of treatments (primary, secondary, and tertiary) have been developed and applied in order to enhance the treatment efficiency of both pulp and paper mill wastewater (PPMW) and sludge (PPMS) with the aim of reducing the amount of the produced final wastes, and also to prevent the probable subsequent toxic effects induced by the presence of hazardous compounds when released into the receiving environment [7].

Anaerobic digestion (AD), defined as the biological degradation of organic compounds into different end products, including methane (50–75%), carbon dioxide (25–50%), hydrogen (5–10%), and nitrogen (1–2%) [8] by a microbial consortium in the absence of air [9], has been widely employed for primary or secondary treatment of various industrial residues. The development of methods for the AD process control and monitoring [10] as well as the operational conditions set-up has raised a large interest in recent studies. This is mainly due to the advantages of AD over conventional biological P&P waste treatment, such as a significant reduction of the produced wastes and the production of biogas, mainly composed by methane. Despite these advantages, some improvements in the stability of the process, in methane yields,

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