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Anaerobic digestion of coffee grounds soluble fraction at laboratory scale: Evaluation of the biomethane potential

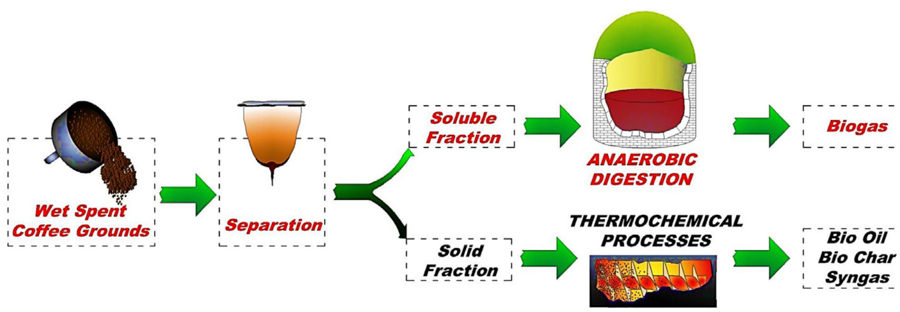
Fábio Codignole Luz *, Stefano Cordiner, Alessandro Manni, Vincenzo Mulone, Vittorio Rocco

Dpt of Industrial Engineering, University of Rome Tor Vergata, Via Del Politecnico 1, 00133 Rome, Italy

HIGHLIGHTS

- The Anaerobic digestion of spent coffee grounds soluble fraction has been studied.
- Residual spent coffee liquid fraction, represent an interesting unexploited source.
- Results encourage the use of such liquid fractions for biogas production in an integrated chain.

GRAPHICAL ABSTRACT



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ABSTRACT

The biochemical conversion of residual biomass may give a significant contribution to the flexible and programmable production of renewable electric and thermal power. In this perspective the use of residuals from coffee chain, which is one of the most popular beverage in the world, is of utmost importance due to the large quantity produced. Over 90% of this mass is discarded after use, becoming a significant waste source known as spent coffee grounds SCG. SCG use as a raw material for biogas production emerges with great potential. SCG is a biomass that does not need pre-treatment, rich in lipids which can be easily recovered in bars and restaurants where it is properly separated. Lipids, which concentrations in SCG can reach more than 25% of its dry weight, have a good biogas production behavior, producing over 1 liter of CH_4/g-VS. In this paper, the analysis of biogas yield potential of SCG recovery is presented using a laboratory scale batch anaerobic reactor, fed with the liquid fraction obtained by spent coffee filtration. The use of SCG liquid fraction in conjunction with cow manure has been monitored for 22 days at a temperature of 37 °C showing a specific SCG production contribution up to 254 ml CH_4/gVS. An increase of ≅ 10% in the methane fraction in Biogas production has been observed with an average LHV of about 28.24 MJ/kg. This result shows the SCG liquid fraction energy recovery potential using an anaerobic digestion process.

1. Introduction

The sustainability of the existing energy model as well as its vulnerability to environmental changes, are currently considered critical issues for the human development. Accordingly, research activities have focused on renewable sources with reduced environmental emissions [1,2], clean generation of electric [3–5] and thermal power [6] and the Distributed Generation concept [7]. In this perspective, biomasses represent an effective contribution which may be affected by low energy density issues. The intermediate conversion through biochemical or thermochemical mechanisms is then one of the possible approaches to address this problem. Several works may be found in recent literature as pro-

* Corresponding author.
E-mail address: fabio.codignole.luz@uniroma2.it (F.C. Luz).

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Nomenclature

Parameter	Unit		
$B(t)$	Methane production over time, $mlCH_4/gVS$	μ_m	microorganisms growth parameter, –
B_0	Ultimate methane production, $mlCH_4/gVS$	*RM*	reactor manure, –
$C^a\ H^b\ O^c$	Elemental molar composition, molar fraction	*SCG*	Spent Coffee Grounds, –
GC	Gas chromatograph, –	*SCW*	spent coffee water, –
ICO	International Coffee Organization,–	*t*	hydraulic retention time, days
K	Chen model kinetic parameter, –	*TCD*	Thermal conductivity detector, –
k	Methane production rate, ml/d·gVS	*TS*	Total Solids, Mass fraction
λ	Lag phase, days	*VFA*	Volatile fatty acids, –
		VS	Volatile Solids, Mass fraction

duction patterns for alternative fuels as gasification [8], pyrolysis [9,10], hydrothermal carbonization [11] or biochemical processes. Given this background, biochemical conversion processes are so far the most established solution with still unexploited applications. Anaerobic microorganisms in fact digest the organic material producing carbon dioxide and methane (biogas) that can be collected and used as a fuel. More recently, the interest in the Wastes-to-Biogas conversion has been growing which requires the design of highly integrated system concepts. Interesting concepts based on submerged anaerobic membrane bioreactors [12,13] have been intensively studied for pulp, paper sludge and real sewage treatment. This wastes exploitation is unfortunately limited by the substrates recalcitrance which requires specific pretreatments [14] to enhance the efficiency of anaerobic digestion, as:

- mechanical [15] in high liquid slurries to enhance the solid fraction
- chemical for the occurrence of hydrolysis of lignocellulosic materials [16]
- hydrothermal pretreatment in two phase systems [17]
- microwave one for microalgae [18] etc.

To support energy and material flows required for pretreatments, the integration among different processes and substrates is an effective solution as well as an opportunity to cut GHG emissions from the waste cycle. In Table 1 as an example, positive effects of co-digestion on biogas yield have been shown in many different application from wastewater to lignocellulosic biomasses, food wastes.

In this perspective, the usage of solid [16] and liquid [19] residuals from coffee chain is interesting. Coffee in fact, is one of the world's most popular beverages and the second largest traded commodity after petroleum [20]. According to the International Coffee Organization (ICO) [21], the average world consumption is approaching the $8\text{x}10^6$ tons in the last 4 years. About 90% of this mass is discarded after use and becomes a waste source known as spent coffee grounds (SCG).

In 2005 approximately 6 mln tons of SCG wastes were generated all over the planet, as reported in [27], with continuously increasing demand as registered by the ICO. In addition SCG containing large amounts of organic compounds [28,29], may be reused as raw material for ethanol production [30] and appear as an interesting substrate for biodiesel, activated carbon production, and last but not least for anaerobic digestion purposes [31,32]. The high content in lipids represents a high biogas production potential. Fats can produce up to more than one liter of CH_4/g-VS [33,34] even if, on the other hand, they can cause inhibition of the anaerobic digestion process [35,14]. The good performance of biogas conversion of high lipid content wastewater is reported in literature [36,37]. As a further benefit, biogas produced from lipids can present more than 60% methane in composition [38,39] which improves its conversion potential. Biomasses with high lipid content as waste kitchen, food wastes, palm oil, meat-cooked have proved to produce between 245 and 500 ml.CH_4/g-VS [40–42] up to 800 Nml.CH_4/g-VS in some specific cases [43]. According to the previous observations, the use of spent coffee grounds as raw material for biogas production emerges with interesting potential. In fact, SCG is a biomass that does not need pre-treatment, is rich in lipids, and may have a simplified logistic through its separation in bar and restaurants. In the given background, this paper aims at studying the biogas yield potential offered by SCG in a laboratory scale anaerobic digestion system. In particular the study is focused at the evaluation of the energy recovery from the liquid fraction obtained by filtration of the spent coffee water soluble fraction here on called SCW. The residual solid part after filtration process, with similar moisture content, can be still used in thermochemical process such as pyrolysis, contributing to the total conversion of the SCG. In Fig. 1 the trend in world toasted coffee consumption is reported of which, as estimated before, about 90% is discarded as waste. As will be seen later in the article, about ten percent of the energy related to such waste can be recovered by means of a simple water filtration. Of that quantity 50% of the energy can be recovered by anaerobic digestion as a conservative assumption. Such energy evaluation is reported in Fig. 1, showing a global

Table 1
Comparison of Co-digestion biogas yields.

Ref.	Global inoculum	Substrate	TS% Sludge	TS% substrate	VS% (%TS) sludge	VS% (%TS) substrate	$mlCH_4/gVS$
[22]	Ref. Cow manure		13.75–25.19		80.09–83.71		133–172
[23]	Municipal wastewater	Poultry industries residues	5.6	11.9	76.9	88.1	390–880
[24]	Pig Manure & inoculum	Pre-treated lignocellulosic biomass	21.4	38	71.9	90.3	353
[25]	Municipal wastewater & inoculum	Food wastes	5.3	18	79.5	89	450
[26]	Low organic content sludge	High solid biomasses	15.4		47.5		189
[18]	Wastewater	Pre-treated microalgae	–	1.65	–	60	172–307
[16]	Cow/chicken manure domestic wastewater	Coffee Waste untreated-pretreated	5.4	10.1	54.8	90.3	45.63–327.5

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