Introduction

This paper describes a process for the separation and recovery of non-structural phenolic compounds from switchgrass. This process is proposed as a preliminary step of a biorefinery incorporating the organosolv process for biomass fractionation. The economics of such an addition to separate and recover phenolic compounds is then investigated.

Switchgrass has been selected as a dedicated feedstock for bioprocesses producing liquid fuels such as ethanol and advanced fuels. The University of Tennessee has been heavily involved in the development of switchgrass as one of the feedstocks for bioenergy production in the southeast (Tiller 2011). Biofuels have the potential to address problems related to fossil fuels such as carbon emissions, as long as they are produced sustainably while reducing risks to food security, wildlife, land, water, and air resources. Switchgrass can be grown on underutilized or marginal land where there is no or minimal competition with land that is used for food crop production. In addition, switchgrass does not require irrigation due to its inherent drought tolerance, and is a low input crop for producing bioenergy from farmland. With an extensive root system, switchgrass provides significant positive environmental benefits, prevents erosion, improves soil structure, and sequesters carbon in the soils.

As shown in Figure 1 the total extractable materials from switchgrass is quite variable, but averages approximately 11.4% among the switchgrass samples collected from eight farms in Tennessee. However, the phenolic compounds are only a fraction of the extractables.
For a biorefinery to be economically complete and environmentally sustainable, processes need to be implemented to obtain several product streams from the raw material. An integrated biorefinery has the potential to produce biofuels, chemicals and value-added products through fractionation, refinement and upgrading. Fractionation of the biomass into its major components makes this process feasible. While many technologies focus on pretreatments to increase the accessibility of cellulose to facilitate enzymatic hydrolysis (Mosier et al. 2005), fractionation is based on biomass component separation. The “Clean Fractionation Process”, developed and patented by the National Renewable Energy Laboratory (Black et al. 1998), is an organic solvent-based fractionation system that selectively separates the three major components of biomass (i.e. cellulose, hemicellulose and lignin) with a high degree of purity. The organosolv process uses a ternary mixture of methyl isobutyl ketone (MIBK), ethanol, and water, in the presence of sulfuric acid as an acid promoter.

Including both an extractives removal step and the organosolv process as shown in Figure 2 facilitates the utilization and transformation of not only the polymeric components, but also the non-structural components of switchgrass. If the extractives portion, which is currently treated as waste,

![Figure 2. Schematic drawing of phenolic compound and recovery process linked to organosolve process.](image-url)
could be made usable, this fraction would help switchgrass become a more competitive, sustainable, and valuable feedstock.

The extractives from switchgrass, such as phenolic compounds, are a potential source of valuable co-products (Uppugundla et al., 2009; Kline et al., 2013). The nature of the extracted phenolic compounds is likely to vary with extractant, conditions and the biomass type and quality. Phenolic compounds from plants can be used in the pharmaceutical, cosmetic and nutritional industries. They are also known to have antioxidant and anti-inflammatory properties; switchgrass extracts have recently been shown to reduce inflammation in fat tissue (Garrison et al., 2015; Labbé et al. 2012). This paper, discusses the recovery and production of these value-added chemicals from switchgrass. Recovery of co-products such as phenolic compounds may assist the biofuels industry by potentially providing an additional income stream for facilities producing biofuel from switchgrass; such a process producing multiple products from biomass is often referred to as a “phase-III biorefinery (Michels and Wagemann, 2010).

The analysis presented here is focused on the feasibility of a process addition to enhance biofuel production from switchgrass that combines an extraction step and a biomass fractionation process (i.e. organosolv process). Extraction is used here for a solid–liquid process that is commonly referred to as leaching. In addition to producing an additional marketable product, this approach will benefit biofuel production by 1) producing clean cellulose and hemicellulose fractions; 2) decreasing contamination of the solvent used for the organosolv process; increasing its recyclability 3) generating a new stream that has potential to add value to the process, and 4) designing a more sustainable system with minimum waste.

The activity presented in this paper proceeds through several hierarchical levels of a process design, each level having unique decisions and economic analysis (Douglas, 1985). These levels are presented below:

Level 1: Background Information Acquisition and Analysis
Level 2: Input-Output Structure of Flowsheet
Level 3: Reaction/Recycle Structure of Flowsheet
Level 4: Separation System Structure of Flowsheet.

At each level > 1 a flowsheet is produced and economic potential estimated.

Figure 3. Schematic of Process to Remove and Recovery Polyphenolic Compounds from Switchgrass
The target phenolic compound product is to be reasonably free of sugars. A tentative flowsheet for producing a co-product steam of phenolic compounds in a switchgrass-based refinery producing ethanol is presented in Figure 3. The selected switchgrass feed rate is 588,000 ton/yr with a water content of 8%. Experimental information from Lehmann et al. (2015) as well as other literature information is utilized. The extractor contacts preprocessed (chopped) switchgrass with water. The effluent streams from the extractor are wet switchgrass with water-soluble extractables removed. The wet switchgrass effluent is directed to the organosolv process while the aqueous discharge is directed to the absorption system. The absorption system is shown as 2 absorber columns; this system operates with one column being sorbed (loaded) with phenolic compounds while a second column is desorbed (stripped) to produce the ethanol-phenolic compound product stream. By alternatively sorbing and desorbing a continuous operation may be achieved. In actual practice this may involve more than 2 columns. The conceptual design task is to design the Extractor and Adsorber Columns so that the installed costs of these major equipment items may be estimated along with major operating costs. These estimates allow the production cost of producing phenolic compounds to be estimated and feasibility determined.

References


