Characterization and anaerobic treatability study of pre-hydrolysis liquor (PHL) from dissolving pulp mill

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ABSTRACT

Anaerobic degradation showed potential as the disposal solution for pre-hydrolysis liquor (PHL) from the dissolving pulp industries. This PHL contained pentose and hexose carbohydrates as monomeric (14.5 g/L) and oligomeric (39.7 g/L) forms along with acetic acid (10.38 g/L), furfural (1.14 g/L) and lignin (11.08 g/L). The average chemical oxygen demand (COD) value of the PHL was around 100 g/L with a biochemical oxygen demand (BOD5) value of 55 g/L. Respirometric studies at 35 °C showed a decrease in methane production with increasing concentration of PHL in the feed. Presence of slowly biodegradable substrates (furfural and lignin) in the feed was suspected to cause such behavior. Therefore, PHL was introduced to a master culture reactor to acclimatize the seed sludge to PHL as substrate. The seed microbes were able to adapt to furfural, but not to the entire lignin present in PHL feed. Lignin concentration going over a threshold value (approximately 7 g/L) was suspected to cause reactor failure. This anaerobic treatability study reflects on the potential of applying anaerobic digestion for PHL waste stream disposal and biogas production.

Key words | anaerobic treatability, lignin, pre-hydrolysis liquor (PHL), specific methane production (SMP)

INTRODUCTION

Kraft pulping has been widely used for the production of dissolving pulp. A hydrolysis step is added to the typical Kraft pulping procedure, for the production of dissolving pulp, prior to the main cooking process. In that step, wood chips are pre-hydrolyzed with steam at 150–170 °C. Treated wood chips leaving this pre-hydrolysis process are sent to the main Kraft pulping process. Thus, the majority of the hemicelluloses from the wood chips are removed prior to the main cooking process. The waste stream exiting this pre-hydrolysis stage is called pre-hydrolysis liquor (PHL) (Fischer & Schmidt 2008; Li et al. 2010).

This PHL waste stream, with total chemical oxygen demand (COD) of approximately 100 g/L, is causing a major disposal problem for the mills that are producing Kraft dissolving pulp. This anaerobic treatability study was carried out on PHL, obtained from a Kraft dissolving pulp mill, situated in New Brunswick, Canada. In the current disposal process, the PHL stream is mixed with the ‘black liquor’ from Kraft cooking, and then concentrated by means of evaporation, and subsequently burned in the recovery boiler. Evaporation itself is an energy consuming process, and burning the condensed PHL in the recovery boiler does not compensate for the energy value put into it. Thus, more energy is required to deal with the PHL waste stream disposal problem, at present. The PHL contains different kinds of pentose and hexose carbohydrates as monomeric and oligomeric form, along with acetic acid, furfural and lignin (Saeed et al. 2012). Some of these materials are considered amenable to biodegradation under anaerobic condition. Hence, anaerobic digestion of PHL could provide an alternative means of waste management and cost reduction for the dissolving pulp mills. Recovery of methane gas during anaerobic digestion could provide a substitute energy source as well. The constituents and the composition of PHL can vary with the types of wood used for pulping.
Therefore, PHL constituents from different places are very likely to change based on the source environment. PHL from Atlantic Canadian sources might be different to PHL from other parts of the world. Although a few studies (Bhattacharya et al. 2005; Rath et al. 2005; Rao & Bapat 2006) have been conducted on anaerobic treatment of PHL from other parts of the world, PHL from Atlantic Canadian sources has yet to be examined.

Therefore, a treatability study was conducted to evaluate the potential of PHL as substrate for anaerobic microbes. In these studies, specific methane production (SMP) analyses were conducted on PHL as substrate. Subsequently, a master culture study was also carried out to observe the effect of seed sludge acclimatization with PHL as substrate.

**MATERIALS AND METHODS**

**Characterization**

To perform the treatability study, the PHL sample had to be characterized properly. The PHL waste stream was characterized in various categories. Samples were collected from the mill in large quantity and then preserved in containers at below 4°C. Analyses were conducted for conventional wastewater parameters like COD, biochemical oxygen demand (BOD$_5$), solids content and carbon content. Analysis was also conducted for the major constituents as monomeric and oligomeric carbohydrates, along with acetic acid, furfural and lignin.

**Wastewater analyses**

Samples of the PHL waste stream were analyzed for COD, BOD$_5$, solids contents and total organic carbon (TOC), during the study period following the standard method (APHA (American Public Health Association) et al. 2005). TOC and total nitrogen (TN) were analyzed using a SHIMADZU TOC-VcpH TOC analyzer mounted with a TNM-1 TN measuring unit (Shimadzu Corporation, Japan).

**Constituent analyses**

The sugar (hemicelluloses) concentrations were determined by using an ion chromatography (IC) unit mounted with a CarboPac™ PA1 column (Dionex-300, Dionex Corporation, Canada) and a pulsed amperometric detector (PAD) (Liu et al. 2011; Saeed et al. 2012). The PAD settings were $E_1 = 0.1$ V, $E_2 = 0.6$ V and $E_3 = -0.8$ V. This equipment can determine only the mono-sugar concentration. Therefore, the oligo-carbohydrates were converted to mono-carbohydrates by acid hydrolysis with 4% sulfuric acid added to PHL sample with a mass ratio of 5:1. The mixtures were heated at 121°C in an oil bath (Neslab Instruments Inc., Portsmouth, NH, USA) for 1 hour. The oligo-carbohydrate concentrations were obtained from the difference between mono-carbohydrate concentrations with and without acid hydrolysis (Li et al. 2010). The concentrations of furfural and acetic acid were analyzed by a nuclear magnetic resonance (NMR) method using a Varian 300 NMR-spectrometer. Concentrations were obtained by comparing NMR data for the sample with respect to those for standard solutions of acetic acid and furfural. The method of solvent suppression was used with D$_2$O to a sample ratio of 1:4 (Li et al. 2010; Saeed et al. 2012). The dissolved portion of lignin present in the PHL was determined by the UV spectrometric method using a Genesy 6 UV spectrophotometer (Thermo Electron Corporation, Madison, WI, USA) at a wavelength of 205 nm (TAPPI UM 250).

**Respirometric batch studies**

On the basis of initial characterization, anaerobic treatability studies were carried out in batch reactors, to observe the microbial activity with PHL as substrate. SMP tests were carried out at 35°C using a Challenge AER-208 Aerobic/Aerobic Respirometer System (Challenge Environmental System Inc., Arkansas, USA). The biogas composition and the volatile fatty acid (VFA) concentrations were analyzed by gas chromatography (Varian GC CP-3800, Varian Inc., CA) using thermal conductivity and a flame ionization detector, respectively. The kinds of respirometric batch studies that were carried out can be categorized as follows:
(a) SMP studies, to select the best available seed sludge.
(b) SMP studies, to observe effect of organic loading on methane production.

Seed sludge collection and substrate preparation

Anaerobic granular seed sludge was obtained from two different sources. One was from a high-rate extended granular sludge bed (EGSB) reactor treating effluent of a local food processing plant in Grand Falls, NB. The other one was from an anaerobic digester (AD) treating the municipal wastewater in Oromocto, NB. The seed sludge samples were kept in tight containers and preserved at room temperature (∼22°C) for approximately 3 weeks. Different volume percentages of PHL were used as substrates for the batch reactors with glucose (COD = 20 g/L) as control. For seed sludge comparison studies, 20, 60 and 100% (v/v) of PHL were fed to reactors in triplicates. To study the effect of different organic loading rates, 20, 40, 60, 80 and 100% (v/v) of PHL were fed to the reactors in duplicates. For all the respirometric experiments, the volumes of the reactor were maintained as 500 mL. The reactors were fed 30 mL of feed, three times in total. The first feedings were at the beginning of the tests. Each of the later two feedings was introduced only when the gas production rate due to the previous feed, had become zero. In each case, the VSS (volatile suspended solids) of the sludge in the reactor was maintained in the range of 8,000–10,000 mg/L (Young & Cowan 2004).

Micro-nutrients and buffer

The micro-nutrients and buffer used are listed in four categories in Table 1 (Young & Cowan 2004). For every 20 g/L of feed as COD, 10 mL/L each of mineral base 1, mineral base 2, and nutrient base, and 100 mL/L of buffer base were added to each reactor (Young & Cowan 2004).

Master culture reactor

A 4.0 L master culture reactor (MCR) with CO2 scrubber and a gas counter, was set up at 35°C for substrate acclimatization of the seed biomass (Young & Tabak 1993; Kim et al. 1994). The reactor was fed initially with glucose (COD = 20 g/L) and subsequently with 20, 40, 60, 80 and 100% (v/v) of PHL. Each higher concentration of PHL was introduced only after the effluent COD of each feed concentration, reached a steady low value. The reactor was operated semi-continuously with daily feeding and effluent extraction of 310 mL. In the feed, micro-nutrients were added with similar proportion as stated in the previous section, balancing with PHL solution. Characterization studies of the feed and effluent were carried out in similar ways as for the original PHL. Daily gas production, effluent oxidation reduction potential (ORP), and pH were monitored.

Statistical analysis

Throughout the study period, each sample was analyzed in duplicates or triplicates. For every type of analysis conducted, the average of the values and standard deviation were calculated. The percent relative standard deviation (%RSD) values were found to be within 6% for all measurements except the COD and BOD5 values with higher %RSD values. This deviation is attributable to the nature of the analytical processes and the sampling procedures for COD and BOD5 determination tests.

RESULTS AND DISCUSSION

PHL characterization study

Characteristics of the waste stream are some of the attributing factors affecting anaerobic treatment processes. The
physical and chemical characteristics of the waste stream are important factors affecting the biogas production, methane percentage and process stability (Zhang et al. 2007). The characteristics of the PHL waste stream are presented in Table 2. These characterization studies showed that PHL had a very high total COD value, the majority of which was present in a soluble form. The ratio of soluble COD to total COD was approximately 91% and the ratio of soluble BOD₅ to total BOD₅ was 84%. The ratio of total BOD₅ to total COD is an indicator of biodegradability of a waste stream (Speece 1996). The BOD₅/COD value for PHL was found to be approximately 0.52. Considering that most of the constituents of PHL are organics and that the total carbon (TC) is mostly comprised of organic carbon, this is a low value of BOD₅/COD. The COD value of a waste stream could include the refractory components of the wastewater, where BOD represents only the biodegradable ones.

Hence, the low BOD₅/COD value of PHL can be attributed to the presence of slow biodegrading organics such as lignin, in the PHL waste stream (Kotze et al. 1969; Speece 1996). The pH of the PHL ranged from 3.7 to 4.0. As methanogens prefer pH to be close to neutral condition, alkalinity needed to be added. This low pH was mainly due to the presence of acetic acid in the PHL. The major portion of total solids (TS) was in dissolved form and mostly volatile, and the amounts of suspended solids were negligible. The volatile dissolved solids (VDS) content was 75.5% of the TS. This high quantity of VDS indicated the presence of a high quantity of organics. A high quantity of organics does not guarantee high biodegradability, but surely promises a good potential of that (Kotze et al. 1969; Zhang et al. 2007).

The constituent analysis shows that PHL was mainly comprised of different forms of carbohydrates along with acetic acid, furfural and lignin. The constituents’ concentrations are presented in Table 3. The majority of the carbohydrates found were xylose along with other five- and six-carbons carbohydrates in both monomeric and oligomeric forms. Among the constituents of PHL, acetic acid is one of the major VFAs produced during any anaerobic degradation (Speece 1996). According to previous studies, hemicellulosic carbohydrates are easily degradable by anaerobic microbes (Wang et al. 1994; Chin et al. 1998). Among these hemicellulosic carbohydrates, oligomeric hemicelluloses are converted to monomeric carbohydrates and acetic acid by anaerobic bacteria, and consequently produce methane and carbon dioxide. It has also been found that sludge granulation favors slightly acidified carbohydrates as substrate, compared to VFAs only (Latinga 1995). Hence, hemicelluloses obtained from PHL promises to be a favorable substrate for anaerobic digestion. Furfural, another component of PHL, is believed to be an anaerobically biodegradable substrate (Boopathy & Daniels 1991; Rivard & Grohmann 1991; Boopathy et al. 1993), but is sometimes also recognized as a slow degradable substrate, at higher concentrations (Benjamin et al. 1984). Lignin is the other important constituent of PHL, with an approximate concentration of 11 g/L. The physio-chemical properties of lignin may differ based on the source of lignocellulosic

Table 2 | Characteristics of PHL waste stream

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Average value</th>
<th>%RSD</th>
<th>Parameters</th>
<th>Average value</th>
<th>%RSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>3.7–4.0</td>
<td>2.22</td>
<td>Total solids (TS), g/L</td>
<td>121.9</td>
<td>3.56</td>
</tr>
<tr>
<td>Total COD, g/L</td>
<td>96–120</td>
<td>11.58</td>
<td>Total dissolved solids (TDS), g/L</td>
<td>119.2</td>
<td>2.86</td>
</tr>
<tr>
<td>Soluble COD, g/L</td>
<td>88–110</td>
<td>9.23</td>
<td>Total volatile solids (TVS), g/L</td>
<td>93.94</td>
<td>0.98</td>
</tr>
<tr>
<td>Total BOD₅, g/L</td>
<td>51–60</td>
<td>5.92</td>
<td>Volatile dissolved solids (VDS), g/L</td>
<td>92.04</td>
<td>2.35</td>
</tr>
<tr>
<td>Soluble BOD₅, g/L</td>
<td>42–50</td>
<td>4.78</td>
<td>Suspended solids (SS), g/L</td>
<td>2.7</td>
<td>1.42</td>
</tr>
<tr>
<td>Total carbon (TC), g/L</td>
<td>88.0</td>
<td>2.33</td>
<td>Volatile suspended solids (VSS), g/L</td>
<td>1.9</td>
<td>1.51</td>
</tr>
<tr>
<td>Total organic carbon (TOC), g/L</td>
<td>84.3</td>
<td>1.65</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total inorganic carbon (IC), g/L</td>
<td>3.52</td>
<td>2.18</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: %RSD = % Relative standard deviation – (Standard deviation/Average) × 100%. Samples were taken in triplicates – twice a week for a study period of approximately 5 months.
feedstock and the various processes used for pulp production (Glasser 1980). The difficulty of lignin biodegradation is due to its high molecular weight, inconsistency, and resistance in chemical structure (Zeikus et al. 1982; Kirk & Farrell 1987). It has been reported that lower molecular weight lignins are anaerobically degradable (Colberg & Young 1982, 1985a, b; Chen et al. 1985a, b, 1987), whereas higher molecular weight fractions are not. The reason for the non-biodegradable nature of the higher molecular weight lignins can be attributed to the absence of depolymerizing enzymes or any other oxidizing agent (Zeikus et al. 1982; Benner et al. 1984). Lignin in wastewater showed toxicity (Sierra-Alvarez & Lattinga 1991) and resistance to degradation with higher concentration as well (Op den Camp et al. 1998). Based on its characterization, PHL wastewater seems to be a complex mixture of organics, some of which are anaerobically degradable and two of which (furfural and lignin) may not be. Some treatability studies were conducted to assess anaerobic degradability of PHL.

### Anaerobic treatability studies

#### Comparison of seed sludge

To facilitate stable and efficient COD removal and high methane productivity, it is important to have active and acclimatized seed sludge (Dangcong et al. 1994; Enright et al. 2009; Oz et al. 2012). Batch reactors, having seed sludge from the EGSB reactor treating food processing wastewater and AD-treating municipal wastewater, were fed with identical PHL concentrations, maintaining the same nutrients and reactor VSS concentrations. It was observed from the SMP studies that seed sludge from the EGSB reactor performed better, in terms of methane production, with both glucose and PHL as substrates. The comparison of specific methanogenic activity (SMA) values also indicated that seed sludge from the EGSB reactor showed better methanogenic activity. The SMA values for the EGSB reactor were 234% higher for 20% PHL as feed, and 125% higher for 100% PHL as feed. Table 4 shows the comparative performance of the batch reactors in SMP studies with respect to two different seed sludges.
With increased concentration of PHL in the feed, the difference in seed sludge activity became less distinct. The seed sludge from the EGSB reactor showed superior performance compared to the performance of the AD. The reason for this phenomenon is attributable to the nature of the substrate this seed sludge was previously acclimatized to Gavala & Lyberatos (2001). The EGSB reactor had substrates similar to PHL from food processing plant with more carbohydrates, but the AD-treated municipal wastewater had no significant type of substrate dominance. That was why seed sludge from the EGSB reactor demonstrated better performances, compared to that of the AD reactor. It was decided that, for further studies in batch and continuous reactors, seed sludge from the EGSB reactor would be used.

### Effect of PHL content in the feed

SMP studies were conducted at mesophilic condition (35°C) with increasing organic loading of PHL from 20 to 100% concentration (v/v). Table 5 presents the average values of the SMA and observed gas production. Reactor efficiency was defined in percentage as the rate of experimental methane production with respect to theoretical methane production, at 35°C. Theoretical methane production was calculated based on the COD equivalence of methane at 35°C (Speece 1996). At 35°C, 1 g of COD consumed is equivalent to 0.395 L of methane production. For example, 20% PHL, with an approximate COD of 20 g/L and feed of 30 mL, theoretically can produce (0.395 L/g × 20 g/L × 30 mL) 237 mL of methane gas. It was found that the methane conversion efficiency of the reactors decreased gradually with increasing concentration of PHL in the feed (Kuşcu & Sponza 2009). The methane conversion efficiency was 92% for 20% PHL, and gradually decreased to a lower value of 55%, with increasing concentration up to 100% PHL. From the SMA values, it was also observed that the activity of the biomass seemed to decrease with increasing concentrations of PHL in the feed. It is rational that with increasing concentration of PHL in the feed, the amounts of slow biodegradable substrates (e.g. lignin and furfural) also increased.

### Table 4 | Comparison of the methanogenic activities of the seed sludges

<table>
<thead>
<tr>
<th>Seed sludge source</th>
<th>Glucose (COD ~ 20 g/L)</th>
<th>PHL (20% v/v) (COD ~ 20 g/L)</th>
<th>PHL (100% v/v) (COD ~ 100 g/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>EGSB</td>
<td>AD</td>
<td>EGSB</td>
</tr>
<tr>
<td>Theoretical methane production (mL)</td>
<td>237</td>
<td>237</td>
<td>237</td>
</tr>
<tr>
<td>Experimental methane production (mL)</td>
<td>219</td>
<td>193</td>
<td>202</td>
</tr>
<tr>
<td>% Reactor efficiency</td>
<td>92</td>
<td>82</td>
<td>85</td>
</tr>
<tr>
<td>SMA (gCOD/gVSS/d)</td>
<td>0.348</td>
<td>0.211</td>
<td>0.125</td>
</tr>
</tbody>
</table>

Note: COD and VSS samples were taken in triplicates. Volumes of the methane production were measured by the Challenge Respirometer System, automatically.

### Table 5 | Effect of PHL loading on the efficiencies of the reactors

<table>
<thead>
<tr>
<th>Feed approximate COD</th>
<th>Glucose</th>
<th>PHL-20%</th>
<th>PHL-40%</th>
<th>PHL-60%</th>
<th>PHL-80%</th>
<th>PHL-100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD ~ 20 g/L</td>
<td>CH₄ 56</td>
<td>CO₂ 43</td>
<td>CH₄ 53</td>
<td>CO₂ 40</td>
<td>CH₄ 57</td>
<td>CO₂ 42</td>
</tr>
<tr>
<td>COD ~ 20 g/L</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>COD ~ 40 g/L</td>
<td>CH₄ 57</td>
<td>CO₂ 42</td>
<td>CH₄ 53</td>
<td>CO₂ 46</td>
<td>CH₄ 52</td>
<td>CO₂ 44</td>
</tr>
<tr>
<td>COD ~ 60 g/L</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>COD ~ 80 g/L</td>
<td>CH₄ 55</td>
<td>CO₂ 42</td>
<td>CH₄ 55</td>
<td>CO₂ 42</td>
<td></td>
<td></td>
</tr>
<tr>
<td>COD ~ 100 g/L</td>
<td></td>
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<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Gas composition (%)</th>
<th>CH₄ 56</th>
<th>CO₂ 43</th>
<th>CH₄ 53</th>
<th>CO₂ 40</th>
<th>CH₄ 57</th>
<th>CO₂ 42</th>
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<tbody>
<tr>
<td>CH₄ 56</td>
<td>CO₂ 43</td>
<td>CH₄ 53</td>
<td>CO₂ 40</td>
<td>CH₄ 57</td>
<td>CO₂ 42</td>
<td>CH₄ 55</td>
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<tr>
<td>CH₄ 55</td>
<td>CO₂ 42</td>
<td>CH₄ 55</td>
<td>CO₂ 42</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CH₄ 55</td>
<td>CO₂ 42</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Theoretical methane production (mL)</th>
<th>237</th>
<th>237</th>
<th>474</th>
<th>711</th>
<th>948</th>
<th>1,185</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental methane production (mL)</td>
<td>230</td>
<td>217</td>
<td>317</td>
<td>399</td>
<td>550</td>
<td>652</td>
</tr>
<tr>
<td>Methane conversion efficiency (%)</td>
<td>97</td>
<td>92</td>
<td>67</td>
<td>56</td>
<td>58</td>
<td>55</td>
</tr>
<tr>
<td>SMA (gCOD/gVSS/d)</td>
<td>0.33–0.45</td>
<td>0.31</td>
<td>0.28</td>
<td>0.26</td>
<td>0.21</td>
<td>0.18</td>
</tr>
</tbody>
</table>

Note: COD and VSS samples were taken in triplicates. Samples for gas percentage were taken in triplicates. Volumes of the methane production were measured by the Challenge Respirometer System, automatically.
The amounts of seed sludge added to the reactors were increased with increasing concentration of PHL, keeping the F/M (food to microbial) ratio (with respect to feed COD to reactor VSS) within a constant range of 0.036 to 0.048. Hence, it was very likely that the decrease in reactor efficiency with increasing PHL concentration was because of the increasing concentration of slow anaerobically biodegradable components of PHL.

Development of master culture

It was found that, operational conditions need to be amended to enhance anaerobic treatment of lignocellulosic wastes, which were difficult to degrade (Pfeffer & Khan 1976). In anaerobic digestion, methanogenic microbes showed great ability to adjust to new environments (Jain & Mattiason 1998). The purpose of the master culture study was to acclimatize the seed sludge to the slow biodegradable components of the PHL. The MCR was started up with glucose (COD = 20 g/L) as substrate, followed by different concentrations of PHL (20, 40, 60, 80 and 100%), at different stages, for a total of 196 d. The daily methane production fluctuated with feed PHL concentration. The methane content in the biogas ranged from 50 to 56%, with the rest mostly comprised of CO₂. Figure 1 shows the time-series of daily gas production and Figure 2 presents the trend in effluent COD during the study period.

A previous study reported that, for long chain organics, acclimatization depends more on the concentration of the substrate, rather than on the loading rate (Pereira et al. 2003). In the present study, gas production increased for every increased PHL concentration. But, every time it decreased initially, to compensate for the initial shock absorption due to the increase in feed concentration. The effluent COD values during the study period supported the gas production trend line. With every instance of increasing feed PHL concentration, the effluent COD got higher; with enough time to acclimatize for the microbes, the effluent COD came down to lower values (1–5 g/L). These trends of periodical increases in gas production, and decreases in effluent COD, continued until the reactor was fed with 100% PHL on day 179. With 100% PHL as feed, the gas production initially decreased as in the previous cases, but never recovered back to higher values. Also, the effluent COD value kept on increasing. The reactor operation, eventually, was terminated with a very high effluent COD of 80 g/L. With 20% increase in PHL concentration, this was a very unusual behavior, as this 20% increase should not pose such drastic change in the reactor performance. An explanation could be found from the component analysis of the master culture effluents. The effluents of the master culture were analyzed on regular basis, and it was found that the effluent contained no carbohydrates. Presence of furfural (around 22–28 mg/L) was observed in some early
days of reactor operation, but after that the seed sludge seemed to get acclimatized to furfural. However, lignin remained in the effluent throughout the entire study period as showed in Figure 3.

Until 100% PHL in the feed, the lignin concentration in the effluent showed a decreasing trend at each stage of PHL feeding, but could not be removed completely and started to accumulate inside the reactor. When the lignin concentration in the feed, increased over 10 g/L, with 100% PHL as feed, it became untreatable by the anaerobic microbes. The lignin concentration in the effluent of the master culture was found to be 7.13 g/L. Previous studies have shown lethal effect on microbial activity with concentration of toxic substrate reaching a threshold value (Rinzema et al. 1994). In some other studies, lignin is termed as a toxic material which could have a detrimental effect on microbial growth (Sierra-Alvarez & Lattinga 1991; Hou et al. 2007). Under the enlightenment of these findings, the possible reason for reactor failure was attributed to accumulation of lignin inside the reactor to a threshold value of 7 g/L.
CONCLUSION

The characterization of the PHL waste stream ensured the presence of high organic contents as monomeric and oligomeric carbohydrates, acetic acid, furfural, and lignin. The treatability study concludes that PHL can be considered as a promising substrate for anaerobic biodegradation. But the presence of lignin in the feed, and continuous accumulation inside the reactor, can pose challenges for anaerobic treatment of PHL.

REFERENCES


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