

# Co-pyrolysis of Chrome Tanned Buffing Dust and Low Density Polyethylene Wastes and Analysis of Products for Energy Recovery

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**Abstract**—Chrome tanned buffing dust (CTBD) leather solid waste and low density polyethylene (LDPE) waste though it contains higher energy value are normally considered as most harmful and hazardous waste materials due to its non-biodegradability. In this paper CTBD and LDPE are pyrolysed separately and the pyrolysis results are compared with the results of co-pyrolysis of the mixed wastes in different ratios (i.e. 1:1 and 1:2). The products i.e., residual ash, condensate liquid and combustible gas are characterized using i) Scanning Electron Microscopy (SEM), Fourier transform infrared (FTIR) spectroscopy, and Gas Chromatography Mass Spectrometry (GCMS). It was observed that liquid condensate i) contains mostly carboxylic acid with strong smell of ammonia ii) alcohol, esters and iii) longer chain hydrocarbons. SEM analysis of co-pyrolysed residual ash and residual ash of LDPE shows the presence of nano carbon with the particle size in the range 70.9 nm – 129 nm. It was also observed that co-pyrolysis of CTBD with LDPE yielded energy enriched combustible gas having 5181kcal when mixed at a ratio of 1:2. The co-pyrolysis yielded reduction in carbon monoxide (CO) and increase in hydrogen (H<sub>2</sub>) as well as hydrocarbon (C<sub>x</sub>H<sub>y</sub>) gas content.

**Index Terms**— Chromium tanned proteinaceous leather waste, Carbon residue, Liquid condensate, Polyethylene, Pyrolysis.

## 1 INTRODUCTION

Disposal of chrome tanned buffing dust (CTBD) and low density polyethylene (LDPE) waste into fuel and value added products are not a simple task in the present scenario of waste disposals due to its non-biodegradability. They demand more eco-friendly disposal rather than recovering fuels and products. These wastes contain hydrocarbons and have high energy values may be used as a potential source for fuel generation if properly treated. The process by which these wastes are to be treated must get an environmental clearance in order to make sure that the adopted process follows the environmental guidelines, eco-friendly and doesn't produce any unwanted secondary emissions during the time of waste treatment.

It is obviously an added advantage if fuels and products are produced while disposing it in an eco-friendly manner. Researchers have been trying for many years to convert these

low-valued wastes into high-valued energy enriched fuels and value added chemical products such as syngas, gasoline or diesel fuel, activated carbon etc. but the device and methods are not eco-friendly and also demands more energy and tedious maintenance work which causes major setback on attempting waste to energy conversion. Double pyrolysis of chrome tanned leather solid waste alone for safe disposal and products recovery was attempted [1].

### 1.1 Leather Waste

Leather manufacturing industries are considered to be most polluting industries because of the generation of large quantity of solid and liquid wastes. Leather industry processes 6.8 million tons of wet salted hides and skins worldwide in a year. It generates about 80% of solid wastes during the processes, in which, variety of chemicals used to convert putrescible collagen fibers into non putrescible leather matrix. One ton of wet hide yields only 150 to 200 kg of finished leather with 800 to 850 kg of solid wastes as by product in the form of wastes such as fleshing, blue sheetings, chrome shavings, cuttings, trimmings and buffing dust [2]. These leather wastes contain more than half of the energy value of coal, at nominally 20 MJ/kg as dry material. The quantity of chemicals applied for leather processing is 0.45 ton per ton of raw skin or hide [3]. Basic chromium sulfate (BCS) is the most widely used mineral tanning agent in leather processing. Only 60% of chromium salts applied in the tanning process is absorbed by the raw materials and the rest is discharged along with the solid waste into the wastewater [4]. The chromium content in solid leather waste (wet blue leather), was approximately 30 g kg<sup>-1</sup> (w/w) [5]. This chromium containing waste material is classified by the Brazilian Environmental Council (CONAMA) as a category-one waste, one of the most dangerous and harmful wastes if discarded into the

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environment without treatment [6].

Chrome containing leather buffing dust is carcinogenic in nature and it causes clinical problems like respiratory tract ailments, ulcers, perforated nasal septum, kidney malfunction [7] and lung cancer [8] and needs special disposal, which is very expensive [9]. In the absence of any economically viable technology to dispose the solid leather waste, land co-disposal, thermal incineration and anaerobic digestion methods are currently being practiced [10]. The demerits of currently practising disposing methods are follows:

The available landfill sites rapidly reach their total capacity and the authorization of new sites becomes difficult [11]. The improper manual handling and transfer of leather waste in open vehicles create unhygienic conditions. Disposal of waste in low-lying areas without proper liners allow leachate to mix with ground water causing water contamination.

It has been reported [12] that during thermal incineration at 800 °C, 40% of Cr<sup>3+</sup> was converted to Cr<sup>6+</sup>. Thermal incineration causes serious air pollution problems due to emission of toxic hexavalent chromium (Cr<sup>6+</sup>), halogenated organic compounds, poly aromatic hydrocarbons etc. into environment. The major species formed from Cr<sup>3+</sup> during thermal incineration of solid wastes are Cr<sub>2</sub>(SO<sub>4</sub>)<sub>3(s)</sub>, CrOCl<sub>2(g)</sub> and Cr<sub>2</sub>O<sub>3(s)</sub> which later transformed into Cr<sup>6+</sup> [13]. Hexavalent chromium (Cr<sup>6+</sup>) is mobile in the environment and is highly toxic. It can penetrate the cell wall and exert its noxious influence in the cell itself, being also a source of various cancer diseases [14]. At short-term exposure levels above the maximum contaminant level, Cr<sup>6+</sup> causes skin and stomach irritation or ulceration. Long-term exposure at levels above the maximum contaminant can cause dermatitis, damage to liver, kidney circulation, nerve tissue damage and death [15, 16]. Air pollution is created by odor nuisances and the generation of green house gases from most of the landfill sites. Investments cost on anaerobic digestion plant is very high and also it does not provide a solution for zero waste disposal.

## 1.2 Plastics Waste

In the Municipal Solid Waste (MSW), the quantum of plastic waste is ever increasing due to increase in population, changes in life style and changes in socio-economic conditions. The consumption of plastics in developed countries has increased a lot in recent years. The plastics consumption in 1970 was 13 million ton/year and it was exceeded 70 million ton /year in 2007 [17]. The plastics waste constitutes two major categories: i) Thermoplastics which are recyclable and ii) Thermosets which are not easily recyclable. Thermoplastics, which include Low Density Poly Ethylene (LDPE), High Density Poly Ethylene (HDPE), Poly Vinyl Chloride (PVC), Polypropylene (PP), Polystyrene (PS) etc, constitute 80% of the total plastics. Plastics wastes are not biodegradable and have energy content 38.94 MJ/kg, which shows the great potential to be used as some raw material or energy source [18]. Hence the disposal of waste plastics and at the same time recovering energy from it is an important concern for the society. The most common

method to dispose the plastic waste is landfill and incineration. Acceptance of these methods is decreasing due to limitation on free land and air pollution. Chemical recycling processes such as pyrolysis, hydrogenation, and gasification are also followed to dispose the plastic wastes. Pyrolysis is the thermal cleavage in the absence air with simultaneous generation of pyrolysis oils and gases suited chemical utilization or generation of energy. When plastics are processed in modern waste-to-energy facilities, they can help other waste combust more completely, leaving less ash for disposal in landfills.

Zevenhoven et al [19] studied the behavior of the most-common plastics (PE, PP, PS, PVS) in combustion and gasification process and compared them with conventional fuels such as coal, peat, and wood. They found that co-firing with plastic-derived fuels significantly increased the amount of volatiles in the freeboard of a bubbling fluidized bed.

A literature review on co-pyrolysis of polyethylene with i) saw dust; reveals that it can increase the heating value of the gas then the gas obtained with biomass alone, the hydrocarbon in the gas increased from 14% (saw dust) to 36% (mixed) and CO has got reduced from 53.5% (saw dust) to 33.3% (mixed) [20] ii) wood; reveals that gas yield increase with the increase in temperature, production of ethanol by fermentation of producer gas and the maximum CO and H<sub>2</sub> production were identified at a temperature of 900°C at feed 0.11 g of plastic/g of wood [21], iii) woodchips; reveals that higher yield of syngas and hydrogen can be obtained when 20-40% of woodchips mixed with 80-60% polyethylene and gasified using steam as gasifying agent [22] iv) coal; peak value of energy content and LHV was obtained when 60% coal and 40% plastic mixture was gasified [23].

The earlier studies conducted on co-pyrolysis uncovered some characteristics of biomass and LDPE such as TGA, SEM analysis, Elemental Analysis of residual and FTIR and GC-MS of high fraction condensate. The present study emphasizes, characterization of co-pyrolysed materials composing of CTBD and LDPE with different mix ratio using the instrumental techniques such as proximate and elemental (CHNS) analysis, mass balance, SEM, liquid FTIR and liquid GC-MS so that to bring out the merits of co-pyrolysis of LDPE with CTBD leather solid waste.

## 2 MATERIALS AND METHODS

### 2.1 Proximate Analysis

The non-biodegradable waste materials (leather waste CTBD contains fibers; 30-1200 µm length and 10-30 µm in diameter, grains < 10 µm in diameter powdered in cake form and LDPE with 35 to 50microns size). The proximate analysis of CTBD and LDPE is given in Table-1.

TABLE-1  
PROXIMATE ANALYSIS OF CTBD AND LDPE

Parameters	CTBD (%)	LDPE (%)
Moisture content	5.50	0.035
Ash content	6.58 <sup>a</sup>	0.73
Volatile compound	59.86 <sup>a</sup>	98.28
Fixed carbon <sup>a</sup>	33.56 <sup>a</sup>	0.955

<sup>a</sup>By difference on 'dry basis

## 2.2 Co-pyrolysis system

The co-pyrolysis system consists of pyrolytic reactor, induction furnace, microprocessor based temperature indicator controller, condenser, high fraction liquid receiver, gas chamber, blower, scrubber, water pump, pressure indicators, flow meter.

## 2.3 Pyrolytic reactor

The electrically heated cylindrical reactor still was made up of SS 316 grade with internal diameter, 150 mm; height, 300 mm; with wall thickness, 5mm; empty weight 15 kg. The reactor still was kept inside the single phase inductive furnace.

## 2.4 Inductive furnace

The single phase inductive furnace was fully insulated with glass wool to arrest the heat loss with an outer dimension of 0.65 L x 0.65 B x 0.45 H in meters. There are twelve heating elements, 1.6 mm diameter and resistance 2 Ω each. Out of 12 elements, 8 elements were connected in series to get 16 Ω so that to enable the furnace to deliver 3.5 kW power at full load and raise the maximum temperature to 900 °C in 2 hours. The remaining 4 elements were kept as standby. Varying the input voltage from 0 to 230 V controlled the raising temperature during the process.

## 2.5 Process

The non-biodegradable waste materials CTBD and LDPE were mixed with different ratio i.e. i) 1.5 kg CTBD alone ii) 0.75 kg CTBD mixed with 0.75 kg LDPE iii) 0.50 kg CTBD mixed with 1.0 kg LDPE and iv) 1.5 kg LDPE alone were co-pyrolysed. The microprocessor based temperature indicator controller was set in such a manner to reach the temperature in four segments up to 300 °C, 300-500 °C, 500-700 °C and 700-900°C each in one hour, total in 4hours time.

The co-pyrolysis system is shown in Fig.1. The volatile matters consisting of both condensed and non-condensed gas leaves the reactor still when the temperature reaches to 350°C, liquid portion of syngas gets separated in the condenser. Non-condensed gases leaves the condenser gets cleaned in the scrubber.

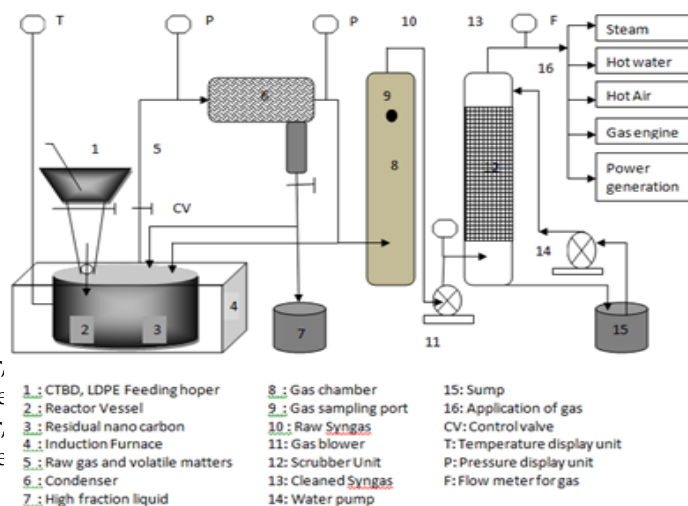


Fig. 1 Co-pyrolysis system

## 2.6 Instrumental Analysis

### 2.6.1 Elemental analysis

The elemental composition of the carbon residue was carried out using Elementar Type Vario Micro Cube. About 2 mg of samples were weighed accurately with a microbalance. The samples were introduced into the combustion chamber and burned at high temperature above 500°C under pure oxygen. The resulting gas mixture and helium carrier gas were passed through various reductive and catalytic zones to convert the gas mixture into CO<sub>2</sub>, H<sub>2</sub>O, N<sub>2</sub>, and SO<sub>2</sub>. Signals of thermal conductivities of those gases were separated by gas chromatography are used to quantify CHNS.

### 2.6.2 Thermo Gravimetric Analysis

TGA was performed using Universal TGA Q50 V20.6 build 31. The 5-10 mg of the sample was taken in the sample holder and the TGA controller is programmed and the sample holder is kept inside the analyser. The sample temperature was maintained at 50°C for a minute and then increased from 50°C to 800°C at 40 °C/min. The inert atmosphere was maintained with nitrogen flow of 20 mL/min. The TGA for the carbon residue was also carried out in presence of air.

### 2.6.3 Scanning electron microscope (SEM)

The surface morphology of the carbon residue obtained after pyrolysis was studied using SEM. The instrument used for the analysis was of model Hitachi S-3400 N. The coating given to the sample was of gold. The time required for the setting of coating in the sample was 60s.

### 2.6.4 GC-MS of the liquid condensate

The liquid condensate obtained will be a mixture of different organic compounds. So to determine the composition of the liquid, the GC-MS analysis was performed by JEOL GCMATE II GC-MS with Data system is a high resolution, double

focusing instrument. Maximum resolution: 6000 Maximum calibrated mass: 1500 Daltons, with a split-split less injector with fused silica capillary column. Helium was used as a carrier gas at a flow rate of 1.0 mL/ min. The injection port was maintained at 250°C. Oven temperature programming was done from 50°C to 280°C, at 10°C/min, and it was kept at 280°C for 5 min. Interface temperature was kept at 250°C. Ionization mode was electron impact ionization and the scanning range was from 40 amu to 400 amu. Mass spectra were obtained at 0.5 sec. interval. The spectra of the compounds were matched with NIST and Wiley library.

### 3 RESULTS AND DISCUSSION

#### 3.1 Mass Balance

The present study of pyrolysis was carried out by keeping the total amount of the raw material constant and varying the individual composition of CTBD and LDPE. The mass balance of raw input material and products is given in Table 2.

TABLE-2  
MASS BALANCE OF CO-PYROLYSIS PRODUCTS

CTBD (g)	PE (g)	Residual (g)	Liquid condensate (g)			Gas (g) <sup>a</sup>
			Total Condensate (g)	Bottom layer (g)	Top layer (g)	
1500	0	480	600	585	15	420
750	750	300	730	689	41	470
500	1000	180	840	756	84	480
0	1500	26	985	860	125	489

<sup>a</sup>by difference

From the above table; the amount of carbon residue obtained after pyrolysis shows the amount of potent carbon present in the sample mixture. The pyrolysis of CTBD as such gave the maximum residue of 480 g. The amount of the solid residue obtained got decreased on the addition of LDPE. The minimum amount of potent carbon obtained was 26 g after the pyrolysis of LDPE as such. The potent carbon remained as such even when the process time and temperature was increased. The volatile organic compounds in the mixture got removed as gases and were separated as condensable liquid phase (liquid condensate) and non condensable gaseous phase.

The volatile organic compounds in CTBD were less when compared to that of LDPE. This was clarified when there is an increase in amount of the liquid condensate on the addition of LDPE. The minimum amount of the liquid obtained was 600 mL during the pyrolysis of CTBD alone. The maximum amount of liquid obtained was 985mL during the pyrolysis of LDPE as such. The volatile organic compounds got removed, and were segregated as condensable (liquid condensate) and non condensable gases. The amount of gas obtained was

calculated by difference. The amount of non condensable gases also shows the presence of volatile matter in the sample mixture. The maximum amount of gaseous phase obtained was 489 g during the pyrolysis of LDPE and the minimum amount was 420 g during the pyrolysis of CTBD. This also confirms the presence of more volatile compound in PE when compared to CTBD.

#### 3.2 Elemental analysis

The elemental study of the residue and raw material is given in table 3. The potent carbon (carbon content in the residue) decreased on the addition of PE, which shows a decrease in the carbon percentage. When the percentage of CTBD decreased the percentage of nitrogen, sulphur also reduced. The percent of nitrogen and sulphur is nil when PE is pyrolysed. Even though the hydrogen content is more in the case of PE they are not present in the carbon residue.

TABLE-3  
RESULTS OF ELEMENTAL ANALYSIS

Samples	Mass (g)	C%	N%	H%	S%
CTBD	1500	44.20	9.55	4.57	1.44
LDPE	1500	83.41	0.62	5.72	0.25
Residue					
1.5 kg CTBD	480	61.34	4.98	1.72	0.86
0.75 kg CTBD + 0.75 kg LDPE	300	60.26	5.36	1.68	0.50
0.5kg CTBD + 1.0kg LDPE	180	57.50	5.79	1.92	0.78
1.5 kg LDPE	26	19.43	0.00	0.84	0.00

#### 3.3 Scanning Electron Microscopy (SEM) Analysis

The carbon residue obtained after pyrolysis was analyzed using SEM. The size and surface morphology was analyzed. The size of the particle in the carbon residue obtained in the presence of CTBD was a mixture of micro and nano sized particle, but it was more towards nano sized when the amount of PE was increased. Fig 2 shows the SEM image of CTBD, carbon residuals of mixture and LDPE. Fig. 2a indicates that the CTBD has long strands and the carbon residue with white

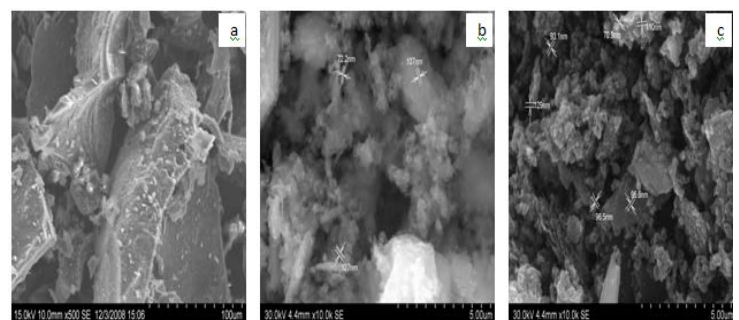




Fig. 2 SEM analysis of a. CTBD, b. residual of (0.75kg CTBD + 0.75kg LDPE), c. residual of LDPE.

spots showing the presence of heavy metal chromium. Fig. 2b and 2c shows potential of producing nano carbon from the coprolysed residual ash since the size of the particles were 70.9 nm, 72.2 nm, 93.1 nm, 96.5 nm, 107 nm, 110 nm and 129 nm.

### 3.4 FTIR analysis

The FTIR of the liquid condensate obtained from 1.5 Kg CTBD (Fig. 3) shows the presence of hydroxyl group as phenol, alcohol or acid which is shown at frequencies 3674, 3746, 3898  $\text{cm}^{-1}$ . The frequencies at 1399 and 3095  $\text{cm}^{-1}$  show the presence of hydrocarbons. The frequency at 1632  $\text{cm}^{-1}$  shows the presence of  $\text{C}=\text{N}=\text{C}$  in the mixture. The frequency at 1720  $\text{cm}^{-1}$  shows the presence of  $\text{C}=\text{O}$  as carbonyl group of acid.

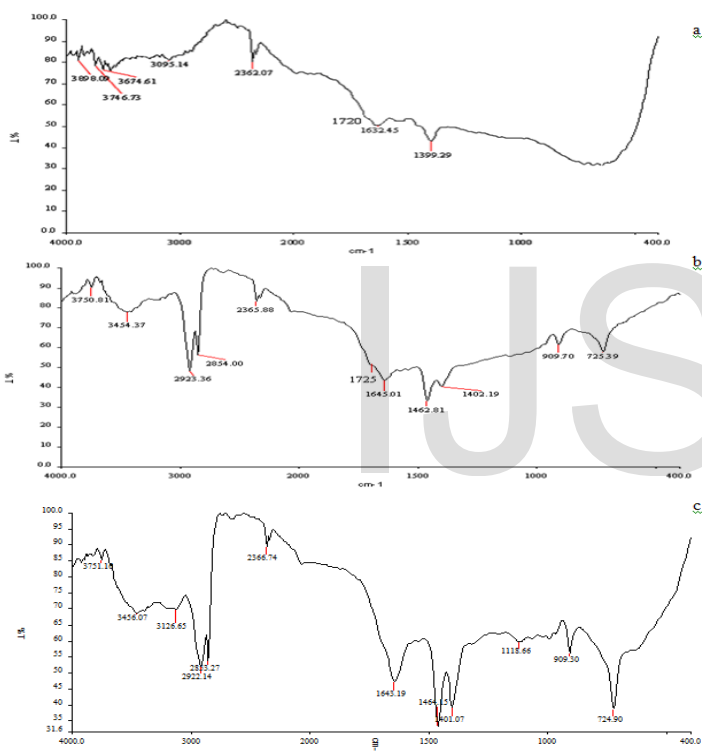


Fig. 3 FTIR analysis of condensate liquid of a. CTBD, b. (0.75kg CTBD + 0.75kg LDPE), c. LDPE.

The liquid condensate from the pyrolysis of 0.75 Kg CTBD and 0.75 Kg PE is a mixture of compounds having hydrocarbons, acid and alcohols (Fig. 3 b). The presence of hydrocarbon is at the frequencies 725, 909, 1402, 1462 and 1645  $\text{cm}^{-1}$ . The presence of hydroxyl group is at frequencies 2365, 2854, 2923, 3545 and 3750  $\text{cm}^{-1}$ . The signals for acid and ester and hydroxy ester in FTIR were shown at frequencies 1725  $\text{cm}^{-1}$  ( $\text{C}=\text{O}$  of acid and ester), 1402  $\text{cm}^{-1}$  ( $\text{C}-\text{O}$  of acid and ester) and 2923  $\text{cm}^{-1}$  ( $-\text{OH}$  of acid). The presence of alcohol is found only in the liquid condensate obtained when both the solid raw materials were taken in equal composition. The signal for alcohol was seen in FTIR at 3454  $\text{cm}^{-1}$ . The presence of

hydrocarbon must have been along with the functional group as there was no elution of pure hydrocarbon.

The frequencies shown in the FTIR of 1.5 Kg PE (Fig. 3c) shows the presence of unsaturated hydrocarbon. The frequencies at 1643, 2853 and 2922  $\text{cm}^{-1}$  shows the presence of alkane carbon and the frequencies at 909, 1118, 1464 and 3126  $\text{cm}^{-1}$  shows the presence of unsaturation. The presence of hetero atoms may be due to the presence as impurity since the signals were weak.

### 3.5 GCMS Analysis

The FTIR spectra of the liquid condensate show the presence of characteristic functional group in the mixture. The presence of individual component was confirmed using GCMS. The mass spectra were taken for individual compounds that were eluted from the column at respective retention time (RT).

In Fig. 4 a, there were 11 compounds that got eluted from the column between 3 and 23 minute. The compounds were of different intensity. The most abundant compound was eluted at RT 17.89. The mass spectra of the compound were compared with spectra from NIST library. The nature of the compounds that were eluted from the column was acid, phenolic, pyrazine. The maximum abundant compound was acid. The second abundant compound was also acid. The GCMS results when compared with FTIR confirms the presence of acid in the mixture. The third abundant compound in the GCMS spectra belongs to pyrazine family. The  $\text{C}=\text{N}=\text{C}$  bond has the frequency in FTIR at 1632  $\text{cm}^{-1}$ . So the presence of pyrazine compound can also be confirmed. The nature of the compounds that were eluted from the column was acid, phenolic, pyrazine.

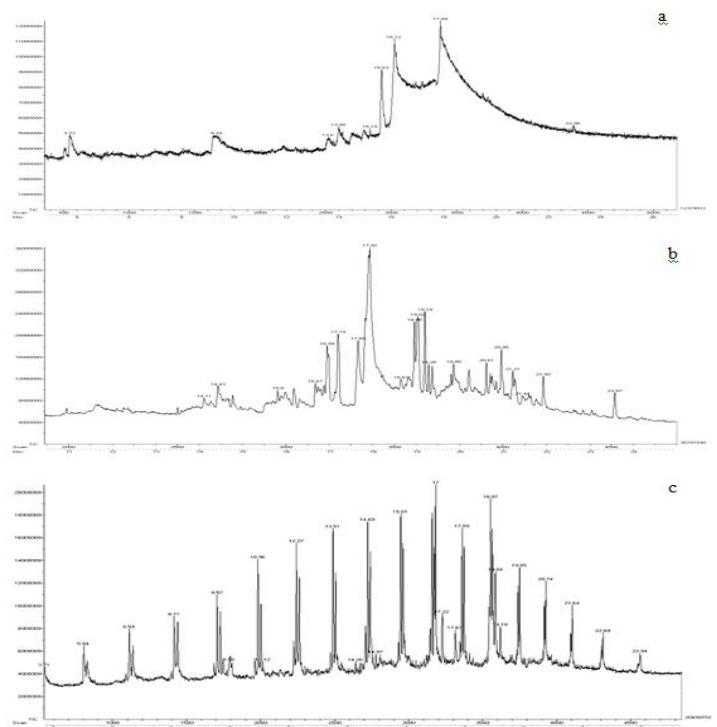


Fig. 4 GCMS spectra of liquid condensate obtained from a. CTBD, b. (0.75kg CTBD + 0.75kg LDPE), c. LDPE.

In Fig. 4 b, there were 20 compounds that got eluted from the column between 14 and 24 minute. The compounds that got eluted were mixed in nature of polyethylene and the leather waste. The nature of the compounds that got eluted was acid, alcohol and hydrocarbons. The compound with highest intensity was eluted at RT 17.92. The nature of the compound was carboxylic acid (n-hexadecanoic acid on comparison with hit list). Even though the compound with higher concentration was acid, remaining 19 compounds were alcohol, ester and hydroxy ester. The compound with second abundance was ester at RT 17.19 and the third was alcohol at RT 16.94. The presence of hydroxy ester in GCMS was found at RT 20.95.

In Fig. 4 c, there were 22 compounds that got eluted from the column. The liquid condensate was mainly composed of unsaturated hydrocarbon and traces of ester. The compound with maximum intensity got eluted at RT 17 (unsaturated hydrocarbon from hit list). The second and third abundant compound eluted at RT 15.81 and RT 14.69 respectively. In FTIR there was no characteristic frequency between 1735 and 1750  $\text{cm}^{-1}$  which shows the absence of C=O of ester compound. So the presence of ester in the mixture may be due to the impurity present in the sample.

### 3.6 Gas analysis

Table 4-8 depicts the analysis of gas recovered during the pyrolysis process. When CTBD alone subjected to pyrolysis, the maximum percentage of gas was shared by carbon monoxide followed by hydrogen in addition to a very low percentage of other gases as shown in table 5. However, when pyrolysis was carried out along with LDPE, interestingly it was observed that the percentage of hydrogen gas was more (16.86% and 23.18%) compared to CO (10.40% and 6.65%), table 6 and 7. The increase in weight percentage of LDPE increases the percentage contribution of hydrogen rather than CO, whereas, when LDPE alone pyrolysed, there was nil CO generation, table 8. The increase in weight percentage of LDPE also increases the percentage of other combustible hydrocarbon gases including methane, ethane, propane, butane etc. was found more. These observations suggested that both CTBD and LDPE if mixed at proper compositions the fuel value of the combustible renewable fuel gas released might substantially be increased.

TABLE-4  
RESULTS OF ELEMENTAL ANALYSIS

Composition	Unit	A	B	C	D
Gas quantity	(g)	420	470	480	489
CO	%	16.66	10.40	6.65	0
H <sub>2</sub>	%	10.54	16.86	23.18	8.43
C <sub>x</sub> H <sub>y</sub>	%	4.416	11.56	22.42	15.17

A = 1.5kg CTBD, B = (0.75 kg CTBD + 0.75 kg LDPE),  
C = (0.50 kg CTBD + 1.0 kg LDPE), D = 1.5kg LDPE

TABLE-5  
GROSS CALORIFIC VALUE OF GAS GENERATED FROM 1.5KG CTBD

Gas composition	%	Mass <sup>#</sup> (g)	Gross calorific value of standard gas (kcal/kg)	Gross calorific value of measured gas (kcal)
CO	16.66	69.97	2427	169.82
H <sub>2</sub>	10.54	44.27	33935	1502.30
^C <sub>x</sub> H <sub>y</sub>	4.35	18.26		
CH <sub>4</sub>	2.07	8.70	13228	115.08
C <sub>2</sub> H <sub>4</sub>	1.46	6.13	12158	74.53
C <sub>2</sub> H <sub>6</sub>	0.10	0.40	12332	4.92
C <sub>2</sub> H <sub>2</sub>	0.15	0.63	11983	7.55
C <sub>3</sub>	0.35	1.47	11820	17.38
C <sub>4</sub>	0.221	0.93	11783	10.95
Total	31.55	132.5		1902.52

# Mass = Individual gas % x 420g

^ C<sub>x</sub>H<sub>y</sub> = Sum of (CH<sub>4</sub>, C<sub>2</sub>H<sub>4</sub>, C<sub>2</sub>H<sub>6</sub>, C<sub>2</sub>H<sub>2</sub>, C<sub>3</sub>, C<sub>4</sub>)

TABLE-6  
GROSS CALORIFIC VALUE OF GAS GENERATED FROM 0.75kg CTBD + 0.75kg LDPE

Gas composition	%	Mass <sup>#</sup> (g)	Gross calorific value of standard gas (kcal/kg)	Gross calorific value of measured gas (kcal)
CO	10.40	48.88	2427	118.63
H <sub>2</sub>	16.86	79.24	33935	2689.01
^C <sub>x</sub> H <sub>y</sub>	11.44	53.77		
CH <sub>4</sub>	3.12	14.66	13228	193.92
C <sub>2</sub> H <sub>4</sub>	6.35	29.85	12158	362.92
C <sub>2</sub> H <sub>6</sub>	0.44	2.07	12332	25.53
C <sub>2</sub> H <sub>2</sub>	0.09	0.42	11983	5.03
C <sub>3</sub>	0.91	4.28	11820	50.59
C <sub>4</sub>	0.53	2.49	11783	29.34
Total	38.70	181.89		3474.97

# Mass = Individual gas % x 470g

^ C<sub>x</sub>H<sub>y</sub> = Sum of (CH<sub>4</sub>, C<sub>2</sub>H<sub>4</sub>, C<sub>2</sub>H<sub>6</sub>, C<sub>2</sub>H<sub>2</sub>, C<sub>3</sub>, C<sub>4</sub>)

TABLE-7  
GROSS CALORIFIC VALUE OF GAS GENERATED FROM 0.50kg CTBD + 1.0kg LDPE

Gas composition	%	Mass <sup>#</sup> (g)	Gross calorific value of standard gas (kcal/kg)	Gross calorific value of measured gas (kcal)
CO	6.65	31.92	2427	77.47
H <sub>2</sub>	23.18	111.26	33935	3775.61
^C <sub>x</sub> H <sub>y</sub>	22.42	107.62		

CH <sub>4</sub>	4.91	23.57	13228	311.78
C <sub>2</sub> H <sub>4</sub>	12.92	62.02	12158	754.03
C <sub>2</sub> H <sub>6</sub>	0.92	4.42	12332	54.51
C <sub>2</sub> H <sub>2</sub>	0.21	1.01	11983	12.10
C <sub>3</sub>	1.82	8.74	11820	103.31
C <sub>4</sub>	1.64	7.87	11783	92.74
Total	52.25	250.8		5181.55

# Mass = Individual gas % × 480g

^ C<sub>x</sub>H<sub>y</sub> = Sum of (CH<sub>4</sub>, C<sub>2</sub>H<sub>4</sub>, C<sub>2</sub>H<sub>6</sub>, C<sub>2</sub>H<sub>2</sub>, C<sub>3</sub>, C<sub>4</sub>)

TABLE-8  
GROSS CALORIFIC VALUE OF GAS GENERATED FROM  
1.5KG LDPE

Gas composition	%	Mass <sup>#</sup> (g)	Gross calorific value of standard gas (kcal/kg)	Gross calorific value of measured gas (kcal)
CO	0.0	0.0	2427	0.0
H <sub>2</sub>	8.43	41.22	33935	1398.8
^C <sub>x</sub> H <sub>y</sub>	15.03	73.49		
CH <sub>4</sub>	3.35	16.38	13228	216.67
C <sub>2</sub> H <sub>4</sub>	8.90	43.52	12158	529.12
C <sub>2</sub> H <sub>6</sub>	0.55	2.69	12332	33.17
C <sub>2</sub> H <sub>2</sub>	0.0	0.0	11983	0.0
C <sub>3</sub>	1.18	5.77	11820	68.20
C <sub>4</sub>	1.05	5.13	11783	60.45
Total	23.46	114.71		2306.41

# Mass = Individual gas % × 489g

^ C<sub>x</sub>H<sub>y</sub> = Sum of (CH<sub>4</sub>, C<sub>2</sub>H<sub>4</sub>, C<sub>2</sub>H<sub>6</sub>, C<sub>2</sub>H<sub>2</sub>, C<sub>3</sub>, C<sub>4</sub>)

#### 4 CONCLUSION

The solid wastes CTBD and PE were pyrolysed and the products were characterized. The amount of the products obtained depends on the composition of the raw material. The amount of the carbon residual ash was 32% when CTBD alone pyrolysed and the addition of the PE with CTBD at a ratio of 1:1 and 1:2 resulted the reduction in mass of residual ash by 20% and 12% respectively. Co-pyrolysis resulted the generation of more liquid and gaseous products. The liquid condensate was a mixture of various components like hydrocarbons, acids, nitrile compounds, esters etc. The traces of oxygen compounds were seen in the liquid condensate. The products obtained during the individual pyrolysis paved the way for the mixing pyrolysis of these solid wastes in different proportions. The results of the study revealed that the CO% in the gases could be reduced from 16.66% (CTBD alone), 10.4% at 1:1 ratio, 6.65% at 1:2 ratio and nil in the case of LDPE alone. The results also suggested that the increase in weight percentage of LDPE increases the percentage contribution of hydrogen from 10.54% to 23.18% as well as combustible hydrocarbon gases which includes methane, ethane, propane, butane etc from 4.41% to 22.42%. The pyrolysis of PE yielded more gaseous product with higher calorific value compared to CTBD, but the amount of

condensed gas (waxy tar) was more which does not have good application or may be used with further treatment. The co-pyrolysis of CTBD and LDPE 1:2 has given gas yield with more energy content i.e. 5181 kcal. The results of the study suggested an effective method of disposal of hazardous solid wastes with the generation of high energy value gaseous products through co-pyrolysis. The results of the study suggested an effective method of disposal of hazardous solid wastes with the generation of high energy value gaseous products.

#### ACKNOWLEDGMENT

This research was supported by Council of Scientific & Industrial Research, CSIR New Delhi (A clean fuel from hazardous leather solid waste – OLP 0198 & SUSTRANS Net Work Project Code ESC 0106). The authors are thankful to CSIR and the Director- CSIO & Director - CLRI for their active support.

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