Supporting Information

Utilizing agricultural residue for the cleaner bio-fuel production and simultaneous air pollution mitigation due to stubble burning: A net energy balance and total emission assessment

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Description of the Experimental Setup and Procedure

The experimental setup can be divided into three different units: Devolatilization and heating, Condensing and finally the Condenser fluid cooling unit, schematically shown in Figure 1. Overall the process is semi-continuous with a constant weight (50 gm) batch of the sample fed in the tubular fixed bed reactor. The alumina tube (ID = 70 mm, OD = 75 mm and Length = 800 mm) was placed horizontally in an electrically heated furnace (Sonalite, India). The inert conditions were maintained by a continuous flow of N_2 gas with an arrangement of rotameter (0-1 LPM) to control the sweeping gas flow rate. The hot volatiles released from the end of the tube goes to the condensing unit to get the desired product. The stainless steel double pipe cylindrical condenser is continuously supplied with cold circulating water to maintain the surface temperature ~10 ℃. At the bottom, a ¼" ball valve is provided with a screw-threaded container connected in series to collect the liquid product. A similar valve with an exit gas line arrangement is made at the top to collect the uncondensed gas. The most critical parameter that directly influences the quality of the product and the system's overall efficiency is the condensing fluid temperature. In this study, a Peltier effect based thermoelectric cooling system was used to supply cold water to the condenser. Further, a copper tube condenser with a fan is provided to increase the system's cooling efficiency. This is an electrically run continuous cooling unit that fed cold inlet water to the condenser and then recirculates the hot water to maintain the constant lower temperature of the condensing fluid.

Each run was carried out by taking 50 gm of PS sample placed in a crucible inside the alumina tube. The heating tube was carefully sealed at both ends and then N_2 gas was purged initially for 5 mins to prevent any oxidation of the sample. The desired pyrolysis temperature was

attained at a fixed heating rate and then the sample was kept isothermally at this temperature for 1 h with continuously collecting the bio-oil. Further, the heated reactor was allowed to cool at an ambient rate along with a supply of N_2 gas till the temperature reaches ≤ 125 ℃. Finally, the products were collected and stored for further analysis. The pyrolysis temperature (T), heating rate (β), particle size (d_p) and sweeping gas flow rate (v) can be adjusted to get an optimum yield of products. In this present study, one parameter at a time optimizing strategy was followed. The product yield was calculated based on wt. % of each component obtained by using the following equation:

$$Bio-oil\ (wt.\%) = \left[\frac{Total\ weight\ of\ liquid\ product\ collected}{Initial\ weight\ of\ biomass\ feedstock\ taken}\right] \times 100 \quad \text{(S1)}$$

$$Bio-char\ (wt.\%) = \left[\frac{Total\ weight\ of\ char\ left\ after\ experiment}{Initial\ weight\ of\ biomass\ feedstock\ taken}\right] \times 100 \quad \text{(S2)}$$

$$Fuel\ gas\ (wt.\%) = 100 - [(\%\ Bio-oil) + (\%\ Bio-char)] \quad \text{(S3)}$$

Table S1. Physiochemical properties of the PS feedstock biomass and its residual Bio-char.

Physiochemical Properties	Biomass PS	Bio-char
Proximate analysis (wt. %)		
Fixed carbon†	16.07 ± 0.18	65.37 ± 0.75
Volatile matter	73.30 ± 0.64	13.93 ± 0.24
Ash content	4.53 ± 0.32	17.60 ± 0.67
Moisture content	6.10 ± 0.93	3.10 ± 0.17
Physical property and Heating value		
Bulk density (g cm^{-3})	0.32 ± 0.01	1.16 ± 0.03
HHV (MJ kg^{-1})	15.10 ± 0.26	28.13 ± 0.38
Ultimate analysis (wt. %)		
C	49.5	71.6
H	5.5	3.20
N	0.68	1.05
S	0.31	0.44
O†	44.01	23.81
H/C	1.34	0.53
O/C	0.67	0.25
Lignocellulosic composition (wt. %)		
Hemicellulose	34.27 ± 0.56	-
Cellulose	28.50 ± 0.61	-
Lignin	32.70 ± 0.26	-
Extractive analysis (wt. %)		
DI water	7.73 ± 0.22	-
Ethanol	1.87 ± 0.12	-
Total content	9.61 ± 0.32	-

† Calculated by difference

Table S2. Properties and characteristics of the obtained Bio-oil.

	Ultimate Analysis (wt. %)				
	C	**H**	**N**	**S**	**O†**
Bio-oil	50.8	7.4	0.95	0.72	40.13
	HHV (MJ kg^{-1})	**pH**	**Density (g cm^{-3})**	**Kinematic Viscosity @ 45 ℃ (cm^2 s^{-1})**	**Solid Content (wt. %)**
Bio-oil	18.85 ± 0.22	3.80 ± 0.16	1.06 ± 0.03	34.63 ± 1.07	1.14 ± 0.14

† Calculated by difference