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Life Cycle Assessment of Intermediate Pyrolysis of Wheat Straw for Sustainable Energy Alternate and Emission Mitigation

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Abstract

Various reports have expressed concerns about the emissions caused due to wheat straw burning in the open fields by farmers. Additionally, it is reported that the use of diesel for off grid power generation is causing large amounts of pollution, mainly due to the addition of green house gases in the atmosphere. Pyrolysis, especially Intermediate Pyrolysis (IP), is a process in which biomasses are thermo chemically decomposed in the absence of oxygen to generate bio-oil, which is a substitution of Diesel. Additionally, this process generates bio char that can be used as a fertilizer and flue gases, which could be used for heat generation.

The paper discusses Life Cycle Assessment of Intermediate Pyrolysis process, showing that this process can be regarded as a method that is carbon neutral and also supports carbon sequestration, thus sustainable. The process is compared against two reference systems, conventional diesel assisted power generation and, open field burning of the straw residue for energy and environmental impact assessment. The result indicates that large Intermediate Pyrolysis system when used, gives surplus energy, and it has excellent environmental benefits. The emission factor for such process is –1.18 (negative) compared to 1.22 kg of CO_2/kWh in case of Diesel.

Keywords: Carbon sequestration; intermediate Pyrolysis; life cycle assessment; power generation; wheat straw.

1. Introduction

It is observed that the growth of a country leads to a corresponding increase in the energy demand. The use of diesel for off grid electricity generation leads to significant emission generation. Emission is also a concern, the way agro residues are currently burning in the open fields after a combined harvesting. Emission due to open field burning of agricultural residue comprise of approximately 61% for Asia, and 39% for the rest of the world (Garg, 2008).

2. Intermediate Pyrolysis Process

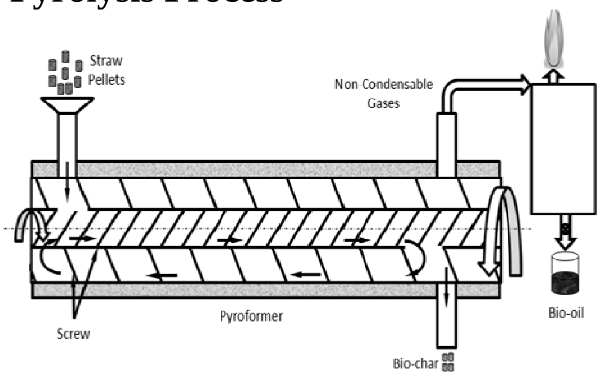

Fig. 1: Pyroformer schematic adapted from (Hornung, 2011).

Pyrolysis is a technology which uses agro residue and can generate off grid electricity. Besides, it offers a range of advantages, for instances, it can solve the problem of waste management by offering an alternate value chain for the straw, it can offset the diesel consumption and reduces emission, and it can also use to get a renewable energy through clean and efficient energy generation option using a carbon neutral source. Pyrolysis is a thermo-chemical process in which feedstock is heated in the absence of oxygen to obtain vapour and char (Evans and Milne, 1987). Vapour fractions are condensed in a condenser (Bridgwater et al., 1999), while char can be use for thermal application or as a fertiliser in the field (Woolf et al., 2010) and (Major, 2009) .

The intermediate pyrolysis (IP) technology developed at Aston University, Birmingham, U.K. by Dr. Hornung is an improved process compared to conventional pyrolysis. It helps in reducing formation of higher molecular tars and offers dry and brittle chars. IP works with a new reactor system "Pyroformer" which is specially designed to separate the ash rich residues from the fuel (Hornung, 2011). The products of the process are pyrolysis liquids (condensed vapours), gas (non-condensed vapours) and char. Schematic of the Pyroformer is as shown in the Fig. 1.

3. Life Cycle Assessment

The aim of the present work is to have a complete "cradle-to-grave" lifecycle assessment of IP process that includes an industrial scale operation. In the present study, the goal of the study is to quantify the power produced as well as emission generated in converting the agro residue into useful energy using IP. Management of 1 ton of straw is chosen as a functional unit for the study. System boundary of the study includes biological absorption of carbon and growth of the biomass, due to photosynthesis, inside the system boundary, i.e. biological emission ($CO_{2,\ biological}$) resulting from combustion of biomass to be treated as carbon neutral to the environment, and char generated from the pyrolysis can be used as a fertilizer or a carbon sequestration option, as shown in Fig. 2. The laboratory scale pyrolyser system is scaled up by employing industrial scaled pelletiser, scaled up from 10 kg/hr to 1000 kg/h and engine, scaled up from 10 kWh to 100 kWh, keeping the capacity of the pyrolyser, 20 kg/h as same. The miss match in the capacity and the processing time at each station (i.e. pelletiser, pyrolyser and at the engine) will lead to differential usage time of individual station. This will give different duty factor for each unit. Such duty factor is obtained based on the processing time and the capacity of the unit. Duty factor for pelletiser will be 2% pyrolyser will be 100% and engine 80%. Overall generation is based on the duty factor of each unit.

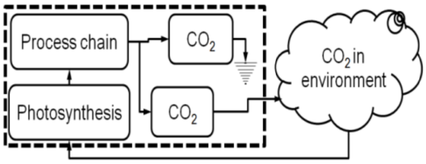

Fig. 2: System boundary for IP of wheat straw.

3.1 Reference System

The partial replacement of diesel is an effective way to reduce emission. Therefore the use of diesel for power generation is an ideal reference system for the present scope of work. Looking to widespread burning in agrarian countries like India, the overall emission is certainly a concern, suggesting open field burning as another reference system.

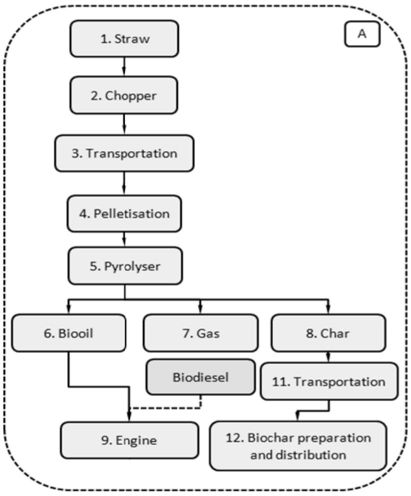

Fig. 3: Process of pyrolysis of wheat straw.

3.2 Process of Pyrolysis

The IP process description is as shown in the Fig. 2. The process starts with the straw fed to pelletiser to make pellets. Pellets will be fed to Pyrolyser which will pyrolyse the pellets and the generated biooil. biooil will be fed to engine for power generation. The char that is leftover is crushed and sieved to be used as a fertilizer in the field. The gas resulting from the pyrolyser will be burned and flare off from the pyroformer.

3.3 Inventory analysis for diesel process

Inventory analysis is carried out for an equivalent quantity of diesel of 207 kg considered in the process. The refining emission of the diesel is considered as, 0.22 kg of CO_2/kg of diesel (UNIDO, 2010). The diesel is transported to the processing unit. Transportation emission for light goods vehicle is considered as 0.097 kg of CO_2/t-km, as per (Ashby, 2012). EF of grid is considered as 0.84 kg of CO_2/kWh, this is an indirect emission generated due to the use of electricity and based on the national grid emission data of 2011 (GoI, 2011). Table 1 summarises the inventory data using diesel as fuel. It is observed from the table that the net power produced is 584 kWh and net emission is 710 kg of CO_2. This gives an emission factor for the diesel option as 1.22 kg of CO_2/kWh.

Table 1: Inventory analysis for diesel.

	Mass kg	Energy kWh	Emission Kg of CO_2
Refining	207	--	45.6
Transportation	207	--	4.22
Engine	--	584	660.6
Net under Diesel option		584	710.4

3.4 Inventory Analysis for IP Process

Inventory analysis for 1 t of straw is carried out in the IP process. Engine will not consume any electricity, unlike pelletiser and pyrolyser. Emission from transportation of char is obtained in line with that of transportation of diesel (Ashby, 2012). The loss of moisture from straw at pellet making (3 % by wt.) is considered as a waste stream. Similarly the gas fractions generated at the pyrolysis are flared to the atmosphere after combustion and flue gases generated as a result of this is considered as a waste stream leads to the emission. The emission from the combustion of the flue gases is considered as neutral to the atmosphere and so this quantity is considered as null in the Table 2. Biological emission is considered as environment neutral and char when crushed and sieve in to fine particles and converted in to biochar is used as a fertiliser in the field. The summary of the analysis is as shown in Table 2. Negative sign indicate the energy consumes or emission absorbs. Emission equivalent to the biochar is considered as negative to the environment since the carbon trapped in the char is locked in the field as biochar and will act as fertiliser for period more than 100 years.

Table 2: Inventory analysis of pyrolysis of wheat straw.

	Mass [kg]	Oper [h]	Energy [kWh]	Emission [Kg of CO_2/t]
1. Transportation	1000	--	--	4.9
2. Pyrolyser (20 kg/h)	970	48.5	- 334	281
3. Gas to flare	330	--	0	503
4. Char	320	--	0	- 751
5. Transportation	320	--	--	1.6
6. Pelletiser (1 t/h)	970	1	- 15	13
7. Engine (100 kWh)	--	38	733	714
Net (1+2-4+6+7)			384	-451

4. Impact Assessment

Impact Assessment phase of an LCA is the evaluation of environmental impacts caused due to resources depletion or consumption and carrying out production of a product or process (*SAIC*, 2006). In the present case impact assessment is a link between product (energy generation) and its environmental impacts (emission of CO_2). Emission and emission intensity or emission factor of the IP process is determined and compared with the reference systems. Such numbers will help in estimating the change a process can bring in due to suggested switch over. Two reference systems considered are, power generation using diesel (Diesel), wherein power generation as well as emission both considered as prime objective. Another is open field burning of the straw (OP), wherein objective is to determine emission only. The emission for the open field burning can be obtained based on the carbon in the straw (47%), mass of the straw under consideration (1000 kg) and the ratio of atomic mass between carbon and CO_2. Energy and emission from 1 ton of wheat straw is presented in Table 3.

Table 3: Emission and EF.

Scenario	Emission Kg of CO_2/t	Reduction		Energy kWh/t	EF Kg of CO_2/kWh
		Diesel	OP		
OP	1723	--	--	--	--
Diesel	710	--	--	584	1.22
IP	-451	-159 %	-126%	384	-1.18

It is observed from Table 3 that IP can reduce emission by 159% and 126% when switched over from Diesel and OP option to IP option and at the same time it offers 384 kWh of electricity. It is worth noting that biochar route can give emission reduction potential greater than 100% due to carbon sequestration effect. Switching from Diesel to IP may leads to emission reduction of almost 150%.

5. Conclusion

The paper discusses the LCA of intermediate pyrolysis process at higher scaled operation. It is observed that pyrolysis process at industrial scale and following biochar route is an excellent renewable energy alternate and is also attractive from the environmental point of view. Compared to diesel option of power generation and open field burning of residual straw, if straw is used by intermediate pyrolysis to generate power and biochar route which can be used for low cost carbon sequestration option, it is possible to achieve a negative emission factor. Hence intermediate pyrolysis is process which gives biooil which can be used for power generation and is a carbon negative fuel alternative.

6. Acknowledges

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