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Design and analysis of a biomass gasification facility integrated with methanol production system[#]

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ABSTRACT

In this study, methanol has been produced from biomass feedstocks using Aspen Plus simulation tool. The proposed system is a combination of gasification plant, syngas cleaning facility and methanol generation plant. Hydrogen rich syngas was generated using steam biomass gasification facility. After extensive gas cleaning the syngas was fed to the methanol generator system. Five different biomass feedstocks, viz. wheat, barley, rice husk, food waste and date pits were used for the analysis. Among all the feedstocks, date pits yielded the highest amounts of hydrogen (52.52%) and carbon monoxide (34.29%). It was observed that the methanol yield for date pits was the highest (0.82 kg/kg of biomass).

Keywords: biomass gasification, methanol, syngas, renewable energy resources, Aspen Plus

NONMENCLATURE

Abbreviations	
FC	Advances in Applied Energy
MS	Moisture
VM	Volatile matter

1. INTRODUCTION

Biomass is considered a carbon-neutral fuel as long as replanting takes place, and it is a promising choice for replacing conventional fuels in the near future, potentially leading to a decrease in greenhouse gas emissions. Biomass can be used in producing liquid fuels such as methanol through the chemical processes [1]. Methanol is an excellent energy carrier as it remains liquid under normal condition, making it easy to transport and store using the available infrastructure [2]. Methanol production from carbon neutral source such as biomass makes it an attractive green fuel for transport application.

Research on the hydrogenation of CO_2 for methanol production has attracted the attention of several researchers in the last few years [3,4]. However, current literature lacks data regarding potential for various biomass feedstocks for methanol production from syngas generated from steam-biomass gasification.

In this study an attempt has been made to produce methanol from different biomass feedstocks. Firstly, hydrogen rich syngas was generated using biomass feedstocks where steam has been used as gasification medium. After post treatment of syngas, it was used to produce methanol using hydrogenation of CO_2 and CO present in the syngas.

2. MATERIAL AND METHODS

2.1 Feedstocks and their characteristics

In the present study five different biomass feedstocks, viz. wheat, barley, rice husk, food waste and date pits were considered. The proximate and ultimate analysis of selected biomass feedstocks are provided in **Table 1.**

2.2 System modelling and assumptions

In the property selection method Peng-Robinson state equation with Boston-Mathias modifications has been considered in the Aspen Plus simulation environment. Firstly, biomass feedstocks were fed to the gasification plant, where steam has been used as gasifying agent. Furthermore, syngas was cleaned and treated using gas cleaning treatment plant. The cleaned syngas was fed to the methanol production system to produce methanol. The assumptions employed for the modelling are listed below.

- Steady sate condition was considered in running the modelling.
- No tar formation was considered in the gasifier model.

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- Gases are considered as ideal gases.
- Uniform pressure and temperature in the gasification model.
- Isothermal situation is considered in the gasifier model.

2.3 *Gasifier*

The drying process was modelled employing RSTOIC reactor model for the biomass feed stocks in which moisture is removed at 100°C and 1 bar. The dried biomass is fed to the gasification block which is modelled employing combination of RYIELD and RGIBBS reactor.

Table 1: Proximate and ultimate analysis of feedstocks

Parameters	Wheat	Barley	Rice husk	Food waste	Date pits
Proximate analysis					
MS (%)	7	12	9.95	6.95	5
FC (%)	9	9	14.99	20.75	17.20
VM (%)	82	74	55.54	70.90	81.80
Ash (%)	2	3	19.52	3.35	1
Ultimate analysis					
Carbon (%)	41.3	42.4	38.43	45.62	49.80
Hydrogen(%)	5.5	5.59	2.97	6.17	6.80
Oxygen (%)	50.6	48.54	36.36	42.81	37.90
Nitrogen (%)	0.57	0.47	0.49	2.04	4.5
Sulfur (%	0.15	0.3	0.07	0.04	0
Ash (%)	2	3	21.68	3.35	1

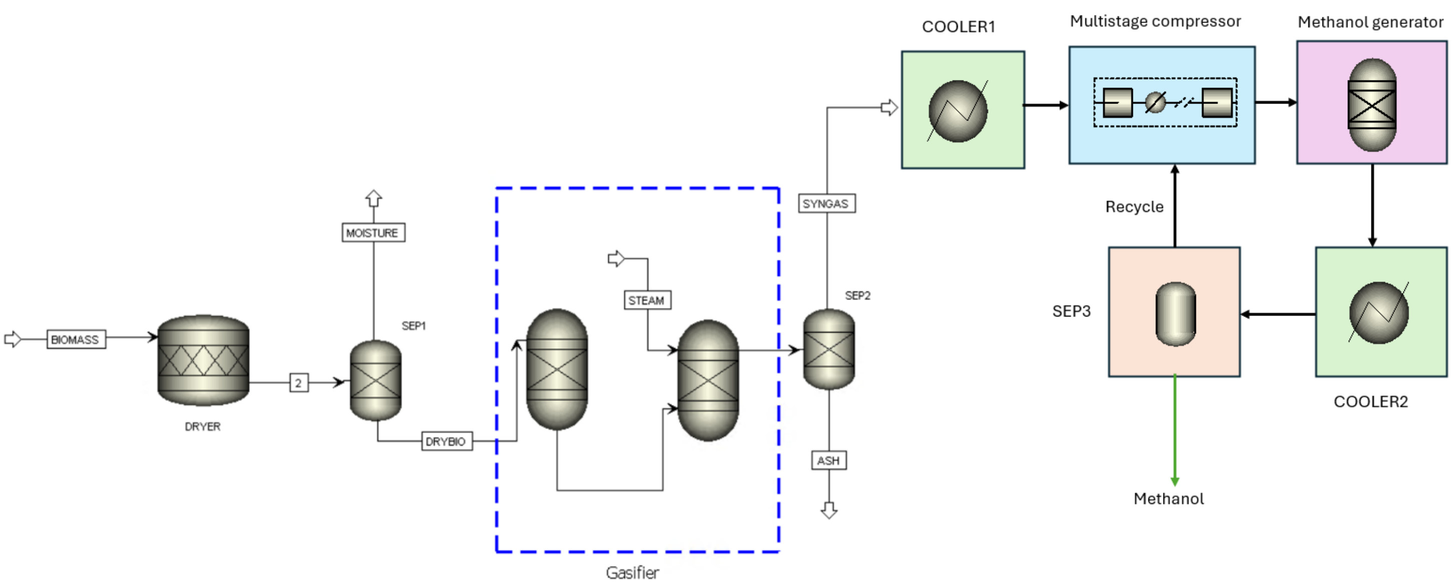

***Fig. 1** Schematic of the proposed biomass to methanol system*

The dried biomass feedstocks get decomposed into conventional components comprising C, H_2, O_2, N_2, S, ash and H2O by stating the yield distribution at the RYEILD block. RGIBBS reactor has employed for the steam biomass gasification reaction, where steam is fed at 100°C and 1 bar. The temperature and pressure at RYELD and RGIBBS reactors are maintained at 800°C and 1 bar respectively. The steam to biomass ratio is maintained at 0.5 for all the biomass feedstocks. For steam biomass gasification process the employed chemical reactions are listed below [5].

$$C + O_2 \rightarrow CO_2 \ \ (Carbon\ combustion) \tag{1}$$

$$C + \frac{1}{2}O_2 \rightarrow CO\ (Carbon\ partial\ oxidation) \tag{2}$$

$$C + CO_2 \rightarrow 2CO\ (Boudouard\ reaction) \tag{3}$$

$$C + H_2O \rightarrow CO + H_2\ (Water\ gas\ reaction) \tag{4}$$

$$CO + H_2O \rightarrow CO_2 + H_2\ (Water\ gas\ shift\ reaction) \tag{5}$$

$$C + 2H_2 \rightarrow CH_4 (Methanation\ of\ carbon) \tag{6}$$

$$H_2 + \frac{1}{2}O_2 \rightarrow H_2O\ \ (Hydrogen\ partial\ combustion) \tag{7}$$

$$H_2 + S \rightarrow H_2S\ (H_2S\ formation) \tag{8}$$

2.4 Methanol generator

The syngas obtained from the steam biomass gasification is treated and cleaned using a cyclone separator (SEP2). Furthermore, cooling of syngas was done by COOLER1 and then compressed employing a multistage compressor. After the treatment of syngas, it was supplied to a methanol generator, where hydrogenation of CO_2 and CO occurs over a Cu/ZnO catalyst [6]. The chemical reactions considered for methanol generation are listed below.

$$CO + 2H_2 \leftrightarrow CH_3OH$$

$$CO_2 + 3H_2 \leftrightarrow CH_3OH$$

3. MATERIAL AND METHODS

3.1 Model validation

The gas compositions obtained from the gasifier model have been validated with the experimental and simulation studies of Loha et al.[7], as depicted in Fig. 2. For validation purposes, rice husk has been used as fuel, the gasification temperature is taken at 750°C, and the steam-to-biomass ratio has been fixed at 0.6. The root mean square error has been obtained as 3.05 with the experimental study and 1.13 with the simulation results.

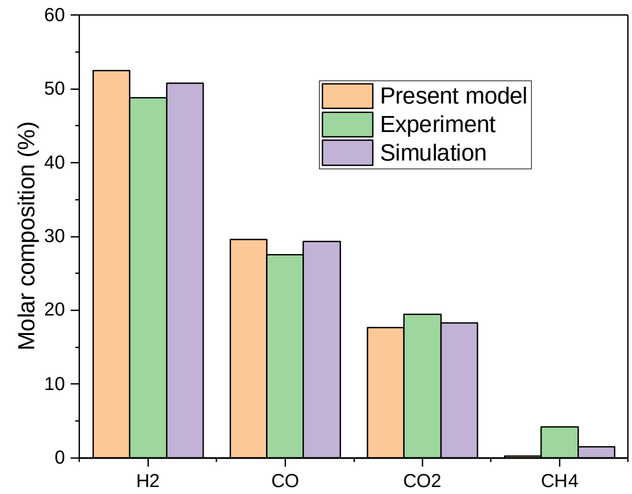

Fig. 2 *Gasifier model validation*

3.2 Effect of biomass feeds on syngas composition

The steam gasification model has been run with five different biomass feedstocks, viz., wheat, barley, rice husk, food waste, and date pits. The gasification temperature and the steam-to-biomass ratio for all the simulations have been kept at 800 °C and 0.5, respectively. The syngas compositions of all the biomass feedstocks are depicted in Fig. 3. It was found that among all the feedstocks, date pits yielded the highest amounts of hydrogen (52.52%) and carbon monoxide (34.29%). The study also revealed that the rice husk yielded the lowest amount of hydrogen among all the biomass feedstocks.

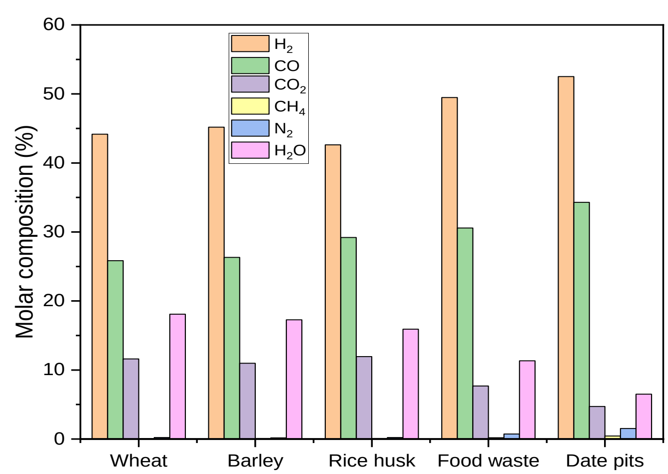

Fig. 3 *Syngas composition using various biomass feedstocks*

3.3 Effect of biomass feeds on methanol yield

The effect of biomass feedstocks on the methanol yield has been calculated and is depicted in **Fig. 4**. It is observed that the methanol yield for the date pits is maximum (0.82 kg/kg of biomass), followed by food waste (0.68 kg/kg of biomass), barley (0.526 kg/kg of biomass), wheat (0.52 kg/kg of biomass), and rice husk (0.44 kg/kg of biomass).

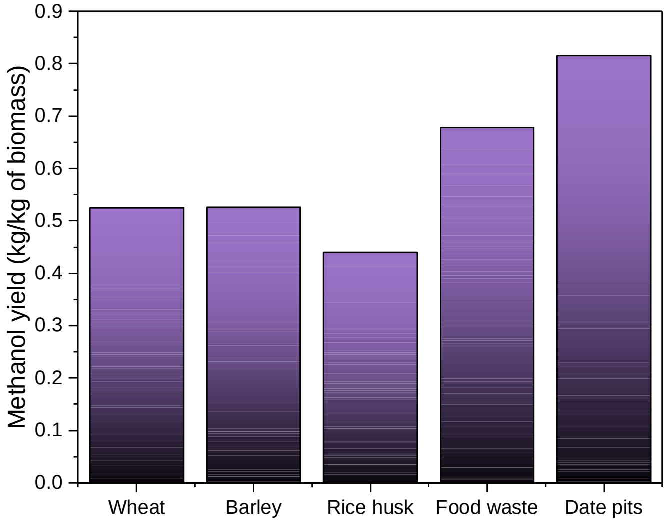

Fig. 4 *Methanol yield using various biomass feedstocks*

4. CONCLUSIONS

In this study, an attempt was made to produce methanol from various biomass feedstocks. First, hydrogen-rich syngas was generated using biomass feedstocks with steam as the gasification medium. After post-treatment, the syngas was used to produce methanol through the hydrogenation of CO_2 and CO present in the syngas. Among all the feedstocks, date pits yielded the highest amounts of hydrogen (52.52%) and carbon monoxide (34.29%) at a gasification temperature of 800°C and a steam-to-biomass ratio of 0.5. The study revealed that the methanol yield from date pits was the highest (0.82 kg/kg of biomass), followed by food waste (0.68 kg/kg of biomass), barley (0.526 kg/kg of biomass), wheat (0.52 kg/kg of biomass), and rice husk (0.44 kg/kg of biomass).

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