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[1]Furkan Kartal and [2*]Uğur Özveren
[1] T.C. Marmara University, Engineering Faculty, Chemical Engineering Department, Aydinevler, Maltepe, Istanbul, 34854, Turkey
[2] T.C. Marmara University, Engineering Faculty, Chemical Engineering Department, Aydinevler, Maltepe, Istanbul, 34854, Turkey

*ugur.ozveren@marmara.edu.tr

Abstract
Although the Aspen Plus process simulator is widely used to model biomass gasification processes, to our best knowledge, no study has yet been reported for the cattle manure downdraft gasification process. This study presents downdraft gasification characteristics of the cattle manure by performing sensitivity analysis in the Aspen Plus process simulator. Effects of gasifier temperature (between 600-1000 °C) and steam/biomass ratio (between 0.5-2.0) on syngas composition and syngas lower heating value (LHV) were discussed. Sensitivity analysis results indicated the higher ratios of steam/biomass and gasifier temperature of 750 °C are the optimum conditions to produce H_2-rich syngas (more than 50% on dry basis). On the other hand, high gasification temperatures and low steam/biomass ratios should be preferred in order to obtain syngas with high calorific value.

Keywords: Cattle manure, Downdraft gasifier, Steam gasification, Aspen Plus, Thermodynamic analysis

I. Introduction
Energy consumption has risen substantially as a result of the continual advancement of socioeconomic development and the fast growth of the world population. Unfortunately, non-renewable fossil fuels such as coal, oil, and natural gas account for more than 84% of the world's total energy requirements (Sawatdeenarunat, Surendra et al. 2015). Thus, many international organizations have concluded that using modern technology to find new alternative energy sources is one of the best solutions to tackle the world's energy crises and environmental risks. Biomass gasification is an effective approach for converting waste to fuels while also conserving fossil fuels. The gasification process also resulted in a reduction in carbon dioxide emissions, allowing for long-term waste disposal. Meanwhile, syngas can be utilized as a source of raw materials for the manufacture of raw chemicals.
Turkey has a population of around 82 million people, with an average age of 32 years, as of 2018 (Melikoglu and Menekse 2020). As a consequence, millions of animals are confined for breeding purposes. Each day, these animals create a huge amount of manure. In June 2020, Turkey's entire cattle population was reported to be 18.4 million, resulting in an annual output of almost 180 million tons of wet cattle manure (Yilmaz, Lauwers et al. 2019). In general, animal manure is stockpiled for fertilizer application at or near animal husbandries. Nonetheless, storing animal manure in unmanaged settings emits greenhouse gases and causes odor and hygienic issues. Because of its abundant availability, cheap cost, and high concentration of lignocellulosic and mineral components, animal manure is a significant biomass resource (Naik, Goud et al. 2010). In addition, animal manure is a type of biomass. Therefore, it can be processed to create value-added products.
Feedstock, gasifier operating conditions, design factors, and the gasifier agent can all impact the quality of syngas. Depending on the targeted syngas composition, quality, and operation cost, the gasification agent utilized in the process can vary. Steam is preferable over other gasifying agents for providing H_2-rich and high-quality syngas (Nipattummakul, Ahmed et al. 2010). Another parameter that affects the gasification performance is the type of gasifier. A concurrently flow of biomass and gasification agent through the product gas defines downdraft fixed-bed gasifiers. Because of its easy handling and low tar concentration in the syngas, a downdraft gasifier is preferred. Moreover, a downdraft gasifier is a viable choice for small-scale heating and power generation, making it a suitable option for biomass gasification (Fazil, Kumar et al. 2021).
Mathematical models provide the benefit of avoiding expensive experimental expenses and allowing for the analysis of several process activities without requiring a significant amount of time or money. In addition, a powerful simulation program known as Aspen Plus has been widely used to examine the process performance and simulate the gasification process. Aspen Plus has a large database of thermodynamics models and compounds, as well as the ability to add various process configurations that regulate the process optimization of varied operational situations. Its properties database toolset can handle solid materials (such as biomass) and their physical properties data (Vikram, Rosha et al. 2021). However, to our best knowledge, examination of the cattle manure steam gasification process in a downdraft gasifier using the Aspen Plus simulator has not been reported. In this study, cattle manure sample is used as fuel in the newly developed downdraft gasifier model and then sensitivity analysis is performed and the effects of gasifier temperature and steam/biomass ratio on syngas composition and lower calorific value (LHV) is discussed.

II. Methodology
The physicochemical characteristics of the cattle manure sample used in this study are listed in Table 1.

Tab. 1: Proximate and ultimate analysis results (dry basis, wt%) of the cattle manure sample (Sweeten, Korenberg et al. 1986).

Sample	Moisture	Volatile Matter	Fixed Carbon	Ash	C	H	N	O	S

Cattle manure	*13.88*	*70.27*	*13.86*	*15.87*	*45.39*	*5.35*	*0.96*	*30.98*	*0.29*

In this study, the Gibbs free energy minimization technique was applied, and in order to determine the thermodynamic properties of the syngas, the Soave-Redlich-Kwong equation of state was chosen. The flowsheet diagram of the entrained bed gasifier model is given in Fig. 1.

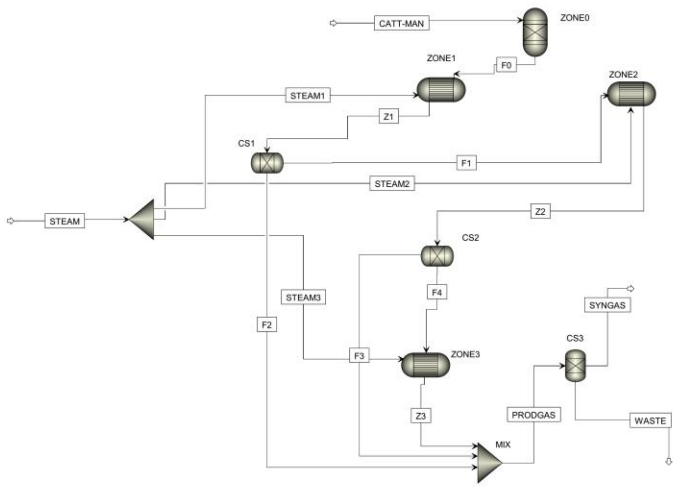

Fig. 1: Aspen HYSYS flowsheet diagram of the entrained bed gasifier model.

The downdraft gasifier model is comprised of three Gibbs reactor (ZONE1, ZONE2 and ZONE3), three component splitters (CS1, CS2 and CS3), one yield reactor (ZONE0). All three Gibbs reactors operate at a different temperature, which is a manifestation of the thermal gradient within the reactor. The yield reactor, on the other hand, decomposes non-conventional solid fuel into conventional components. Component splitter blocks also provide different directions to specific components in order to obtain data compatible with experimental results. The gasification agent "STEAM" and the fuel stream "CATT-MAN" are the input material streams. "CATT-MAN" stream contains proximate and ultimate analysis data. Furthermore, the steam is separated into reactors with different quantities in order to simulate different thermochemical activities.

III. Results and discussions

Temperature is one of the most notable elements for a gasifier since it has such a large impact on the equilibrium state of processes. According to the Le Chatelier principle, higher temperatures shift chemical equilibrium to the side of reactants in exothermic reactions and to the side of products in endothermic processes. Fig. 2 shows the effect of gasifier temperature on syngas composition and LHV.

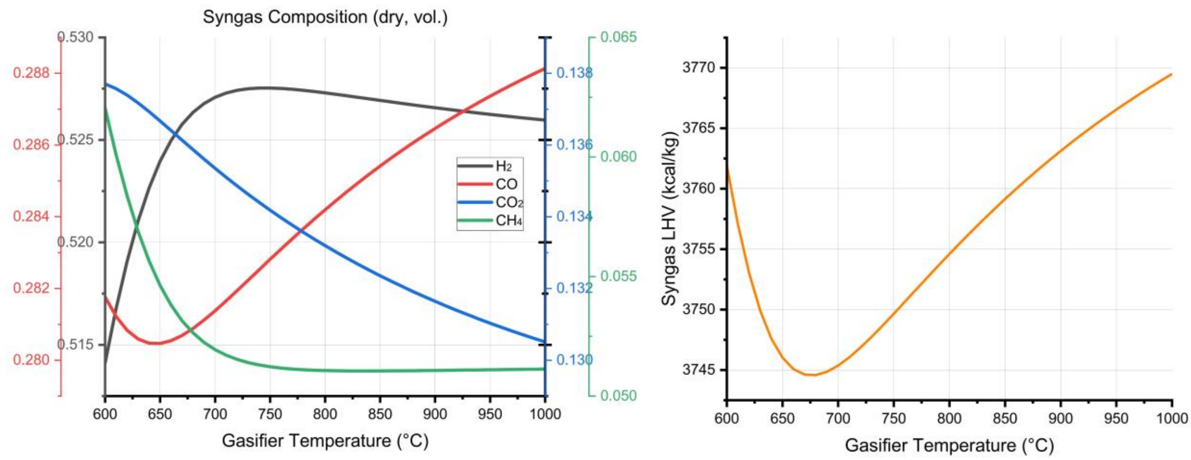

Fig. 2: The effect of gasification temperature on syngas composition and LHV.

High temperatures in the gasifier raise the concentration of H_2 (from 51.41% to 52.59%) and CO (from 28.17% to 28.81%) while lowering the concentration of CO_2 (from 13.77% to 13.05%) and CH_4 (from 6.2% to 5.1%). This can be explained by the endothermic Boudouard, water-gas and steam-methane reforming reactions. Also, the temperature at which the H_2 concentration peaks has been observed to be 750 °C. The LHV of the syngas increases with increasing gasifier temperature (from 3761 kcal/kg to 3769 kcal/kg). However, syngas LHV reaches its minimum value at 680°C and then rises again. With this profile, it is quite similar to the CO concentration. Therefore, it can be said that CO is the most effective component on syngas LHV.

The ratio of steam entering the reactor to biomass fed to the reactor is known as the steam/biomass ratio. One of the critical criteria, in addition to finding the appropriate gasifying temperature, is determining the steam/biomass ratio. Fig. 3 demonstrates the change of syngas content and LHV depending on the steam/biomass ratio.

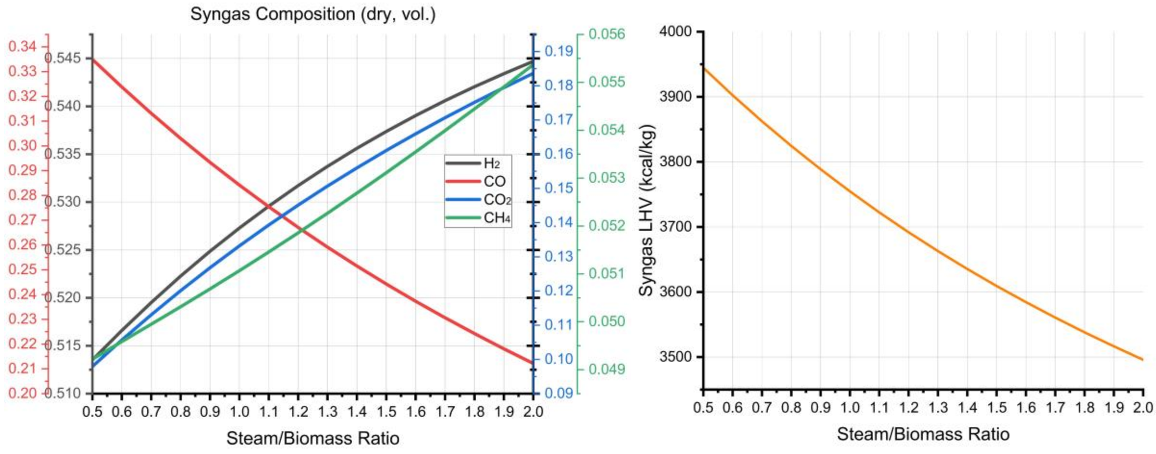

Fig. 3: The effect of steam/biomass ratio on syngas composition and LHV.

Due to heterogeneous char-steam gasification processes, the fraction of H_2 (from 51.35% to 54.47%) gas in the synthesis gas increases as the steam/biomass ratio increases. Furthermore, when the concentration of H_2O rises, the water-gas shift reaction shifts to the products side, resulting in a greater percentage of H_2 and CO_2 (from 9.79% to 18.36%). On the other hand, continuous H_2 production also increases CH_4 (from 4.9% to 5.5%) production by heterogeneous methane formation reactions. The LHV of the syngas decreases (from 3944 kcal/kg to 3495 kcal/kg) as the steam flow increases. Due to the continuous decrease in the CO concentration (from 33.49% to 21.22%) and increase in CO_2 fraction, a dramatic decrease was observed for the syngas LHV.

IV. Conclusions

In this paper, a downdraft gasifier model has been developed, and thermodynamic analysis has been performed for different operating conditions. Thus, different sensitivity analyses were performed to identify the optimum gasifier temperature and steam/biomass ratio in order to obtain optimum syngas composition and LHV. The results demonstrated that the lower steam/biomass ratios provided a high-quality syngas with lower concentrations of H_2. Moreover, it was observed that the optimum gasifier temperature was around 750 °C for the highest yield of H_2. However, the gasifier operated at higher temperatures continously increased the LHV of the syngas. As a result, cattle manure is the waste that can be used in the production of H_2-rich syngas with volume of more than 50% on dry basis.

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